Effects of Distribution Planning Systems on the Cost of Delivery in Unique Make-to-Order Manufacturing

Presented by

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I Abstract

This thesis investigates the effects of simulation through the use of a distribution planning system (DPS) on distribution costs in the setting of unique make-to-order manufacturers (UMTO). In doing so, the German kitchen furniture industry (GKFI) serves as an example and supplier of primary data. On the basis of a detailed market analysis this thesis will demonstrate that this industry, which mostly works with its own vehicles for transport, is in urgent need of innovative logistics strategies. Within the scope of an investigation into the current practical and theoretical use of DPS, it will become apparent that most known DPS are based on the application of given or set delivery tour constraints. Those constraints are often not questioned in practice and in theory nor even attempted to be omitted, but are accepted in day-to-day operation.

This paper applies a different approach. In the context of this research, a practically applied DPS is used supportively for the removal of time window constraints (TWC) in UMTO delivery. The same DPS is used in *ceteris paribus* condition for the re-routing of deliveries and hereby supports the findings regarding the costliness of TWC. From this experiment emerges an overall cost saving of 50.9% and a 43.5% reduction of kilometres travelled. The applied experimental research methodology and the significance of the resulting savings deliver the opportunity to analyse the removal of delivery time window restrictions as one of many constraints in distribution logistics. The economic results of this thesis may become the basis of discussion for further research based on the applied methodology. From a practical point of view, the contributions to new knowledge are the cost savings versus the change of demand for the setting of TWC between the receiver of goods and the UMTO supplier. On the side of theoretical knowledge, this thesis contributes to filling the gap on the production – distribution problem from a UMTO perspective. Further contributions to knowledge are delivered through the experimental methodology with the application of a DPS for research in logistics simulation.

II Table of Contents

III List of Figures

IV List of Tables

Preface

For more than 50 years, researchers from all over the world have researched the vehicle routing problem (VRP). With the availability of computers the complexity of research increased in this area to more than 20,000 research publications until today, thus developing a multitude of continual simulation-based approaches. Simultaneously, research attended to the existence of TWC for delivery in route planning and the effects thereof. Here, too, the majority of tests based upon various presentations of a problem go back to the 1960's. With the linkage of these two values, that is of route planning and the constraints arising from time windows in delivery, many new problems appeared which to this day are often and sometimes divisively discussed in research. Lately, the generic and meta-heuristic procedures and their algorithms have emerged as being particularly efficient processes which provide opportunities for new knowledge in this field of research.

The special demands made by producers in UMTO manufacturing often necessitate route planning for deliveries to clients which is as meticulous as it is complex. Time windows play a highly important role in those delivery processes as they can have a far-reaching influence on delivery costs. Meta-heuristic simulation processes based upon theoretical changes to these time windows may considerably reduce the costs for UMTO manufacturers.

This thesis focuses on this problem and, in doing so, contributes new knowledge by bringing about a reduction in the constraint effect of time windows based upon a succession of theoretical simulation processes, thus proving the effect on delivery costs for UMTO manufacturers. All associated results and solutions introduced to academics and practitioners alike highlight new aspects of scenarios in distribution planning and of cost management in delivery, especially using the example of companies in UMTO manufacturing.

V Acknowledgement

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Without the understanding and support of my family, I would never have been able to write this thesis. Your sympathy and appreciation of my efforts, your indulgence for the countless days I have been away from our home because of this work means more to me than words can possibly express.

To my wife Heike and my daughter Katrin:

I dedicate this work to you!

VI Author’s Declaration

The attached material is submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Management Research in the University of Glasgow, and accords with the University Regulations on plagiarism as detailed in the Programme Handbook and University Calendar.

I declare that this document embodies the results of my own work and that it has been composed by myself. Following normal academic conventions, I have made due acknowledgement of the work of others.

The thesis is less than 90,000 words in length, exclusive of Tables, Figures, bibliographies and appendices, and complies with the stipulations set out for the degree of Doctor of Philosophy by the University of Glasgow and the Faculty of Law, Business and Social Sciences.

Signed

Date 12th of April 2010

VII Definitions

Unique-, Make-to-Order-Manufacturing:

> *"A UMTO company manufactures a wide variety of products in relatively low volumes. Products are always manufactured based on customer design and specification. Therefore, the production can only be started after the customer places an order, as instruction from the customer is required. Even where the company specializes in a type of product, the volumes are low at the component production stage as the product size and material specifications tend to vary enormously."* (Hendry, 1998, p. 146)

The Travelling Salesman Problem in Vehicle Routing with Time Windows:

> *"In the TSP we are given a complete graph on a set V of vertices and a travel time t_{ij} for each edge (Fu, 2002) ϵ V x V. A solution to the TSP is a route, i.e. a cycle which visits vertex exactly once. The objective is to find a route minimizing the sum of travel times of the edges contained in it. Let N=I V I indicate the vertices. We assume that a given vertex, say vertex = 0, will serve as the first and last vertex of any route (the depot in vehicle routing and scheduling problem) and that the matrix (t_{ij}) is symmetric and satisfies the triangle inequality." (Savelsbergh, 1992b, p. 146)*

Logistics:

> *"Logistics are the concepts of leadership for the development, the steering and the realisation of effective and efficient flows of objects (materials, information, monetarisms, persons) in interdisciplinary corporate and external value chains". (Göpfert, 2000, p.54)*

Supply Chain Management:

> *A supply chain is a set of interconnecting and interdependent organisational groupings - connected through from raw materials to final consumer, and back again - responsible for transforming resources and transacting agreements. It does this in order to satisfy an ultimate customer demand so that all in the chain receive acceptable rewards. (Macbeth, at ZMK, 2005, Zurich)*

Heuristic

> *(Greek) heuriskein = finding, discovering; the science from the methodological finding of solutions with the help of experience, (Duden – das Fremdwörterlexikon, 9th Edition, Vol. 5, Mannheim)*

VIII Abbreviations

$\forall$	for all
$\in$	element of
AD	set of all available drivers
add	actual date of delivery
APS	Advanced Planning Systems
atd	actual time of delivery
atw	actually used time window
C	cost
c	cost parameter
cap	volume oriented capacity restriction
CKD	Completely Knocked-Down Devices
CPFR	Collaborative Planning, Forecasting & Replenishment
CTSEPL	Competitive, Technological, Social, Economic, Political and Legal
cust	customer
CUST	set of all customers
CVRPTW	Capacitated Vehicle Routing Problem with Time Windows
DAY	set of days
dc	driver count (number of drivers)
DIN	Deutsche Industrie Normen (German Industrial Standards)
dist	distance traveled
DIY	Do-it-yourself
DOE	Design of Experiments
dow	day of week
DOW	set of days of week

DPS	Distribution Planning Systems
driv	driver
DRIV	set of all drivers
DRP	Distribution Requirement Planning
dt	daily travel time
DVRP	Dynamic Vehicle Routing Problem
EbIT	Earnings before Interest and Taxes
ERP	Enterprise Resource Planning
etd	earliest time of delivery
FCL	Full Container Load
GKFI	German Kitchen Furniture Industry
GPS	Global Positioning Systems
GVRP	Generic Vehicle Routing Problem
h^{load}	unloading time
h^{travel}	travel time
h^{wait}	waiting time
ISO	International Organisation for Standardisation
IT	Information Technology
JIT	Just-in-Time
KPI	Key Performance Indicator
Kt	Kilo Tons
l	loading time parameter
LCL	Less Container Load
ltd	latest time of delivery
MIP	Manufacturing Information Planning
MRP	Materials Requirement Planning
MTO	Make-to-Order

nad	number of available drivers
nd	number of deliveries
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Mono-Nitrogen Oxides
OTD	set of offered time windows
pdd	proposed day of delivery
PPS	Production Planning Systems
ptd	proposed time of delivery
RFID	Radio Frequency Identification
S	speed average
SCC	Supply Chain Council
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SO_2	Sulphur Dioxide
SPR	Stochastic Planning with Resources
SRP	Stochastic Resource Planning
TOC	Theory of Constraints
TQM	Total Quality Management
TSP	The Travelling Salesman Problem
tw	time window
TWC	Time Window Constraints
ud	units delivered
ULD	Unit Load Device
UMTO	Unique-Make-to-Order
vd	volume delivered
VEH	set of all available vehicles
veh	vehicle

vo	volume ordered
VPN	Virtual Private Network
VRP	Vehicle Resource Planning
VRPSD	Vehicle Resource Planning under Stochastic Demands
VRPTW	Vehicle Resource Planning under TWC
wh	working hours
WS	set of possible weeks of shipment
ws	week of shipment

1 Introduction

Logistics – and the physical distribution of goods to consignees as a special interest of Operations Management - have experienced numerous innovations in the past. Many of these innovations have been driven by the so-called 'customer orientation' with its focus on tailored servicing of customers' needs. For this purpose computerized DPS have been developed since the sixties. These DPS use scheduling and routing algorithms (Pachnicke, 2007) to meet customer requirements within their objective of optimising the cost of distribution (or inbound) logistics. Even now there are many research projects and publications on further optimising such algorithms and the cost of transportation. For this research the focus is on studies that deal with Vehicle Routing Problems with Stochastic Demands (VRPSD) which are usually modelled as Stochastic Programs with Resource (SPR). Many of them deal with different meta-heuristics, Simulated Annealing (SA), Threshold Accepting (TA) and Tabu Search (TS) for solutions. (Teng et al., 2003) Whilst many studies focus on the reduction of computational time as measure of the efficiency of the solution process, others deal with the optimisation of vehicle routing and the cost connected herewith. (Fleischmann, 2008, Roehner, 1996, Weisbrodt and Kessel, 2001)

UMTO incorporate a high customer orientation and focus on the needs of their clients. They manufacture goods that meet the specialised and individual requirements of a single client that may never suit any other clients. Consequently, their corporate strategy reflects the highest possible customer orientation. (Tempelmeier, 2003) This orientation may, in some cases, be spread through their entire organisation and consequently along their entire supply and value chain. Their Supply Chain Management (SCM) includes distribution logistics that demonstrate some of the highest operational orientation on customer demands. These customer demands are often directly connected to the nature of goods loaded for transportation in distribution logistics. Transportation from the manufacturing site of a UMTO to its clients is often a niche in transportation management as it may require special equipment and handling operations. In many cases the transportation of UMTO products and its planning dominate the production planning. This is a circumstance that makes the operations management of a UMTO so challenging and interesting.

Delivery cost for a UMTO as for any other manufacturer or retail firm is an important part of a firm's costing. (Roehner, 1996) The modes of transportation used are driven by economic and operational requirements. (Pfohl, 2004a) Additionally, they often underlie 'customer demands' that may have a variety of reasons. Whatever reasons these may be, the policy of the right product, at the right place, at the right time and in the right quality often dominates the economic aspects in today's distribution logistics. (Shapiro, 2006)

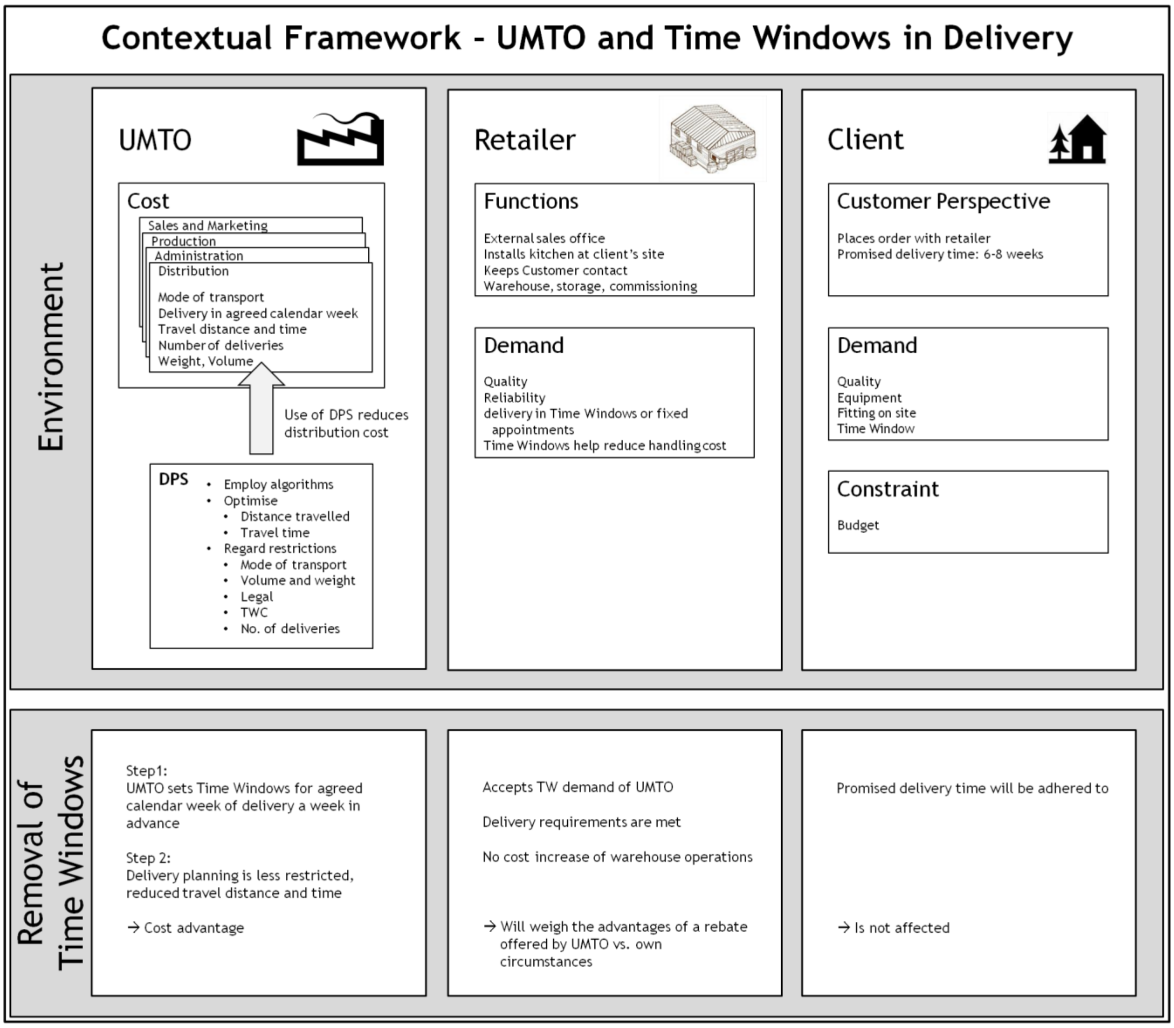

Figure 1: Contextual Framework - UMTO and Time Windows in Delivery

Alternatives to meet the customer orientation by adhering to the constraints of the right product, at the right place, at the right time and in the right quality create different cost in distribution logistics that will be looked at in this thesis. Particularly, it is the question of the right time of delivery that this work will examine by researching the cost of delivery and here, in particular, the effects that time windows for delivery set by the consignees have for UMTO. By doing this, practical established definitions of cost will be used and a focus on the solution process through the relaxation of constraints will be undertaken through the simulation of the *X* – *Y* model referring to Poe et al. (1994). Once these costs of TWC have been identified, the question arises, whether these costs can be reduced without compromising the service quality perceived by the customer.

UMTO with real delivery data from numerous GKFI manufacturers will be used to generate an initial cost base. The re-routing of deliveries with reduced TWC will form an optimal cost from the manufacturer's perspective. In the process of doing so, the customers' demands of the right product, at the right place, at the right time and in the right quality are still being met.

This thesis will demonstrate for the UMTO industry that the cost arising from TWC may be up to 50% of the entire cost of distribution. This high percentage cost may become a driver for the discussion how to shift the TWC demand from the customer to the manufacturer. The incentive for this discussion is the reduction of TWC in favor of UMTO against cost advantages for the consignees of deliveries. Through such a demand shifting, this thesis will show that resulting from a very competitive market, both, the clients and the manufacturers, can have a mutually beneficial operational and economic basis for such a change. This is the major contribution of this thesis to research and practice.

1.1 Research Overview

In order to understand the complex interactions in a UMTO environment, this section of the introduction will deal with general UMTO problems and describe them using the example of the GKFI. It will show that the market and all its stakeholders influence the value chain of UMTO strongly and extensively. This will be made especially clear through the competitive structures of this market which will emphasise the importance of distribution costs even more. The following detailed analysis is based upon economic parameters of this industry and the supply chain in the GKFI. This has partly a historical background, evident through the chain of evolutionary business development from after World War 2 until after the unification of Germany. Out of this illustration from the past emerges the picture of necessary changes for the future. This thesis wishes to make its own contribution towards innovative solutions for this industry. This includes in particular the issues within the settings of a production industry which has grown completely out of formerly family-owned businesses in the post-war era. It evolved into industrial enterprises with clients, complex distribution and transportation, new systems of delivery planning and associated costs. These issues will be dealt with in detail later to establish a comprehensive basis for the analysis.

The GKFI were chosen bearing in mind that they demonstrate all the classical characteristics of a UMTO. In addition, this industry is profoundly interested in new solutions regarding delivery cost. In the recent past, it has suffered from a massive domestic sales and profit decline revealing how important – if not essential for survival - the role that delivery costs play measured against turnover and overall profitability. The literature review investigates if, and in which form respectively, research has been concerned with the specifics of UMTO and their delivery costs. Within this context, general planning systems and cost optimisation for delivery of many products are also analysed. After all, this analysis also concentrates on the general DPS characteristics and developments as well as on the meaning of delivery costs in logistics and SCM.

Collection of primary data created the basis for an experiment to ascertain potential DPS effects in a meta-heuristic simulation procedure. This established the core for the actual hypothesis of this thesis, namely that cost reductions from omitting TWC may enable UMTO manufacturers to motivate their clients to accept these changes. Even though this experiment was carried out with the aid of several hypothetical assumptions and purely theoretical constraints, it still showed that the independent variables had in part an extraordinary effect on the resulting delivery cost. Following this, the results were examined using traditional analysis methods in order to provide evidence of the significance of the independent variables on delivery costs.

Moreover, this research is concerned with transferring information of achieved results to the chosen industry on the basis of supposition. In doing so, the author tried to anticipate the achieved results from this experiment in form of an application model. In this thesis, the model as the research process and the actual cost function with its underlying cost parameters has a clear interdependency. The appendix of this work presents additional analyses of environmental effects to demonstrate that operational changes do have environmental implications. In the past, these environmental and economic interactions were often not directly associated with one another. If, however, one takes into consideration the global framework conditions which emerged at the end of the year 2008, then both the approaches to economy and ecology in SCM and especially in logistics move closer together. Here, one must ask why that is so and how many other global developments will affect the cost of distribution for UMTO in the future. In order to explore this question further, the last section of this thesis's appendix closes with an investigation into the effects which analyses and conclusions may have using the UMTO experimental example. That these effects may also have environmental consequences we have known at least since the existence of global trade with national emission allowances, different charges for starting and loading rights for aircraft, taxation for private and company vehicles in accordance with CO_2 emissions and much more on macro as well as on micro-economic basis. (See Chapter 7 Supporting Environmental Considerations)

The following figure expands on the structural research overview of this thesis. As can be seen, this thesis is grouped into five main sections. The practical background for this thesis is added by the theoretical background and supplies information on the GKFI as a typical UMTO. The research question links directly with the theoretical background and is supported by the literature research that identifies the gaps, which this work attempts to close. The methodological framework of this thesis is also supported by the preceding literature review and identifies another gap in knowledge through the structural and methodological application of simulation systems in logistics.

Structural Research Overview

Chapter 1	Chapter 2	Chapter 3	Chapter 4 + 5	Chapter 6 + 7
Practical Background	**Research Question**	**Literature Review**	**Methodology**	**Analysis and Conclusions**
Stakeholders	Definitions	Distribution Planning	Research Framework	Data Analysis
Manufacturers	UMTO Delivery	Time Windows	Experimental Design	Verification
Clients	Time Window Constraints	UMTO	Data Input	Operational Implications
History	Focussing	Simulation Techniques	Model Definition	Theoretical Implications
Importance	The Cost Problem	Experimental Research	Cost Function	Sensitivity
			Cost Parameters	

Figure 2: Structural Research Overview

One of the core elements of this research is the definition of the cost function and its application in the simulation system. Here, this application supports the model definition. The analysis and the conclusions are strongly supported by numerous verification and validation processes to support the reliability of the experimental design of this work.

1.2 Theoretical Background

This section of the introduction chapter will provide the theoretical background on three major subjects related to this thesis. Further details arising here will be also discussed and described in Chapter 3 of this thesis:

a. distribution planning systems and their use in theoretical analysis;
b. unique-make-to-order manufacturing and its requirements from distribution planning and
c. the importance of distribution cost.

Research in the field of vehicle routing started as early as 1959 with the truck dispatching problem posed by Dantzig and Ramser (1959a). The result of their findings said: *"No practical applications of the method have been made as yet."* (p.90) Since the publication of their work in 1959, further research on the VRP has increased dramatically. Golden et al., (2008, p. VI) report that, in 2008, *"...a Google-Scholar search of the words vehicle routing problem yields more than 21,700 entries."* This shows that in the past 50 years this problem has continuously gained interest for researchers all over the world. Further research expanded on the vehicle routing problem with time windows (VRPTW). Here, Toth and Vigo, (1987) summarized their findings as: *"a collection of exactly K simple circuits with minimum cost, and such that:*

a. *each circuit visits the depot vertex;*
b. *each customer vertex is visited by exactly one circuit;*
c. *the sum of the demands of the vertices visited by a circuit does not exceed the vehicle capacity, C; and*
d. *for each customer, i; the service starts within the time window* $[a_1, b_1]$ *and the vehicle stops* s_1 *time instants."(* p.2)

From those findings and based on the above definition, a large variety of heuristic algorithms for the VRPTW have been developed over the years. (Gendreau et al., 2007 pp. 143-144) They state and summarize them as follows:

a. *ant colony optimization,*
b. *genetic algorithms,*
c. *greedy randomized adaptive search procedure,*
d. *simulated annealing,*
e. *tabu search,*
f. *variable neighbourhood search and*
g. *others*

All of the above techniques represent either a single or a combined metaheuristic methodology to 'further optimise' the VRPTW for capacitated vehicles starting from a central depot, serving a number of clients with soft or hard time windows and returning to the central depot with or without backhauls.

From this derives the theoretical background of DPS, as they are referred to in this research.

From this definition it becomes obvious that UMTO production has a high customer orientation in terms of product selection, product design and also in the delivery of the products to customers. Chung-Hsieng (2000, p.181) explains why the application of such in a make-to-order environment is of high importance:

> *[…] "it facilitates the creation of production jobs with varying routeings and material requirements. A job-oriented finite capacity scheduling system is used to effectively accommodate specific needs of individual customer orders. It allows for realistic setting of delivery dates and negotiation of order changes."*

The specific needs of such customer orders and the allowance for the realistic setting of delivery dates is what is referred to in this thesis as time window constraints. Concluding from this introduction section on the theoretical background of UMTO, one may say that a UMTO manufacturer sets his production planning towards the agreed delivery date with the retailer as one of the many important setting in make-to-order manufacturing. (Vidal and Goetschalckx, 1997)

Toth and Vigo, (2002) report on significant cost savings of 5% to 20% through the help of modern DPS. From this, the question arises, if such savings are really significant and valid at all? This thesis will argue these questions and show evidence that cost savings in transportation are indeed of a high significance, provided that the model underlying the investigation or analysis leading to such evidence fulfils the *ceteris paribus* condition. (Roehner, 1996) Here lies a major and most important criterion of validity of this thesis in terms of its theoretical background and the practical application of the chosen model in this analysis. – The data simulation experiment with a DPS in this thesis fulfils the condition of *ceteris paribus* at all times.

> *"The benefits and cost arising from transport are very complex and therewith fascinating economic aspects. The demand for transport is usually a 'derived demand' serving to satisfy spatial mismatches*

> *between demand and supply on a variety of markets.*" (Lakshmanan et al., 2001, p. 141)
>
> *"Costs and benefits of the transport arise both through the supply and existence of infrastructure, and through its usage. Although it is evident that these two elements are closely connected, the distinction is important as it may have important consequences for the specification of policies."* (Lakshmanan et al., 2001, p. 143)

The theoretical background of this introduction chapter may be concluded as follows: the use of DPS to investigate the important cost of distribution transport for UMTO under the simulated conditions of omitted TWC and adhering to the *ceteris paribus* condition in re-routing is a valid contribution to knowledge.

1.3 Practical Background

This thesis focuses on custom built kitchen manufacturers which face a declining and competitive business environment, characterised by the high individualism of the customers in addition to the high value and the high fragility of each item which is manufactured and delivered. (Berry et al., 1995) This section will focus on the nature of the industry and its particular logistics requirements with regard to their developments and their possible future trends. Both, trends in this industry and the trends and strategies in general logistics show that the cost of delivery is a vital and crucial element of cost management that deserves this intensive research approach. (also see: Appendix 8.5IX.A Trends and Strategies in Logistics and SCM)

UMTO in the GKFI face unique and sometimes very complex and often expensive logistics structures for the distribution of their goods. In general the cost of distributing goods within Europe is rising. (Straube and Pfohl, 2008) While the overall structures of transport are being synchronized by systems of forwarding companies, unique or niche transportation facilities, as required by the manufacturers of custom built kitchens, are becoming rare and expensive. For years, manufacturers in the GKFI have faced a severely declining domestic market (See: Table 57: Orders received: Kitchen Furniture Industry). The structure of their market compels them to be highly competitive, including the delivery to their customers. Therefore the cost of delivery becomes a crucial factor of their operations management.

1.3.1 The Manufacturing Industry

The chosen example of the German kitchen manufacturing industry has undergone many changes in the past years. In order to demonstrate these changes and the resulting importance of such for this research, a detailed analysis of this industry is attached in Appendix 8.5IX.B.i The Furniture Industry. There, the historical development of this industry and its structure is described. From this it becomes obvious that the GKFI is in a declining domestic market. With this understanding, it is necessary to look at the clients of those UMTO.

1.3.2 The Consumer Market

Every industry is affected through its clients' behaviour one way or another. This again is determined by the general and overall political and economic climate within social groups and the local environment of commercial and sociological parameters. (Churchill and Iacobucci, 2004, Kerlinger Fred and Lee, 2000) Social groups with a higher income spend more on furniture and interiors than lower income groups, as shown in the following table. However, it is interesting that middle income groups spend most: they spend an average of 2.6% of their monthly income, which is the same as those on the lower income brackets. Rating this result, this means that top income households which spend between 2.3% and 2.1% of their monthly income, spend this on higher quality and higher value for a longer product lifetime. (Reinbender, 2008) Households in the middle income bracket seem to change their interior decoration more often and seem to favour more fashionable styles.

Table 1: Private Household Expenditure for Furniture and Carpets

Private Household Expenditure for Furniture and Carpets

Based upon monthly net income per Household

Monthly net Income per Household from ...up to below ... Euro	Furniture and Interiors		Carpets and other Floorings	
	per Household and Month in Euro	in % of the net Income per Household	per Household and Month in Euro	in % of the net Income per Household
below 900	9	1.3	1	0.1
900- 1,250	13	1.2	3	0.3
1,250- 1,500	18	1.3	3	0.2
1,500- 2,000	27	1.5	4	0.2
2,000- 2,500	45	2	7	0.3
2,500- 3,500	59	1.9	8	0.3
3,500- 5,000	82	1.9	10	0.2
5,000- 17,500	119	1.7	12	0.2

Source: Federal Bureau of Statistics, Result of a random Income and Expenditure Sampling, 2003.

The total amount of spending for furniture in Germany has decreased by 28% between 1995 and 2002. This is a clear indication for reduced consumer behaviour in a satisfied or declining domestic market. Again, one may argue that this is a post-reactive situation from German unification when there was a massive demand by East Germans who entered a unified market which had been inaccessible to them before 1989. It is evident that the German manufacturing industry now has to serve a total geographical market with reduced concentration of clients in sub-geographical regions. As a result, manufacturers still must send delivery vehicles to those regions, but serve fewer clients by region. What does this imply?

It implies that vehicles sent out for delivery, with an estimated full load of goods need to serve larger delivery areas and/or more areas all at once. This again results in higher kilometrage and consequently longer journeys per vehicle. Finally, this means that the cost of delivery per unit sold is increasing.

Table 2: Total Amount of Private Households Furniture Purchases

Total Amount of Private Households Furniture Purchases

in Recommended Retail Prices

Year	Total expenditure of all German Households		of which for: Furniture, Interiors, Carpets and others			Furniture*)		
	Bill. €	2000 = 100	Bill. €	2000 = 100	%**)	Bill. €	2000 = 100	%**)
1999	1,113.8	96.9	38.10	98.7	3.4	33.0	98.8	2.8
2000	1,149.7	100.0	38.60	100.0	3.3	33.4	100.0	2.8
2001	1,194.0	103.9	38.40	99.5	3.2	33.3	99.7	2.6
2002	1,198.1	104.2	35.70	92.5	3.0	31.0	93.1	2.4
2003	1,214.7	105.7	34.90	90.4	2.9	29.4	88.0	2.3
2004	1,239.4	107.3	35.5	92	2.9	28.9	86.5	2.2
2005	1,260.0	109.6	35.3	91.5	2.8	27	80.8	2.1
2006	1,291.1	112.3	36.4	94.3	2.8	27.8	83.2	2.2

*) The Federal Bureau of Statistics: As of 1998 no further data available, shares are assumed by Fed. B.of.S.

**) Share of total expenditure.

Source: Federal Bureau of Statistics, Fachserie 18, Reihe 1.2; EHI; own Calculations

Here are a few examples on a delivery from Bielefeld to the Stuttgart area:

Example 1:

One truck load of 60 m^3 with a schedule of 10 clients to be served in an area that is within an average range of 500 km from the manufacturer's plant. The vehicle is equipped with 2 drivers and scheduled to serve 5 clients per day while the long haul from the manufacturer's plant to the destined area and the return journey is undertaken during night time. The estimated cost of this delivery is Euro 1,500.00 in total, equalling an average cost of Euro 750.00 per day.

The cost is Euro 150.00 per client delivery or Euro 25.00 per m^3.

Example 2:

The same vehicle serves 7 clients with the same load:

The cost for each delivery is Euro 214.00 per client or Euro 25.00 per m^3

Example 3:

The same vehicle serves 10 clients with 43 m^3 and the same mileage:

The cost for each delivery is Euro 150.00 per client or Euro 35.00 per m^3

Based upon the above example and the changing parameters of furniture spending one may rightly assume that the number of clients per geographic area has decreased. The purchases in terms of volume per order remain unchanged due to the fact that usually a kitchen is bought with average proportions of 6 m^3 per order. Consequently, manufacturers would combine this delivery with orders for delivery to another area. By doing this, the vehicle will use up more time and/or more kilometrage. Consequently, this could result in another day needed for delivery.

1.3.3 The Retail Market

The GKFI sell their products exclusively to retailers. While general furniture stores, DIY markets, furniture cash and carry markets and kitchen markets consist mainly of large chains of companies with several branches, the specialised kitchen retailers are mostly family-run and operate from mostly one location only.

Table 3: Retail Market Share for Kitchen Furniture (2002)

Market Share Split in % of the Retail (Distribution Channels) for Kitchen Market Furniture in 2002

General Furniture Stores	50.90%
Specialised Kitchen Retailers (Shops)	31.25%
Furniture Cash & Carry	6.59%
Kitchen Markets	5.94%
Technical / Sanitary Retailers	2.19%
D-I-Y - Markets	1.23%
Mail Order Companies	1.20%
Building Companies	0.43%
Factory Outlets (Direct Sales)	0.27%

Source: AMK-Statistik "Sales Channels of the Kitchen Furniture Industry", Data Basis: 26 Manufacturers with 1,872 Billion Euro Inland-Sales

General furniture stores and specialised kitchen retailers have a combined market share of 82%. Their logistic requirements are as different as can be. General furniture stores are located mostly on the outskirts of cities and have large warehouses with ramps and good handling facilities for the loading and unloading process. They have their own staff with well organised goods-receiving structures.

The majority of specialized kitchen retail companies are family-run: the owner acts as the general and sales manager while other family members and some staff assemble and install the kitchen on site at the final customers. The majority of these companies are located in cities with showrooms facing pedestrian walkways to maximize marketing exposure. Due to their location, they have little space for storage. Consequently, their logistic requirements, for delivery with large vehicles are characterised by punctuality, and in particular, by the assisting, unloading and handling support of the drivers. Due to the fact and tradition that in those businesses employees are mostly at the assembly sites during day, the drivers become handling assistants (warehouse staff) upon delivery and need to fulfil the task of warehouse handling with the utmost care and confidence.

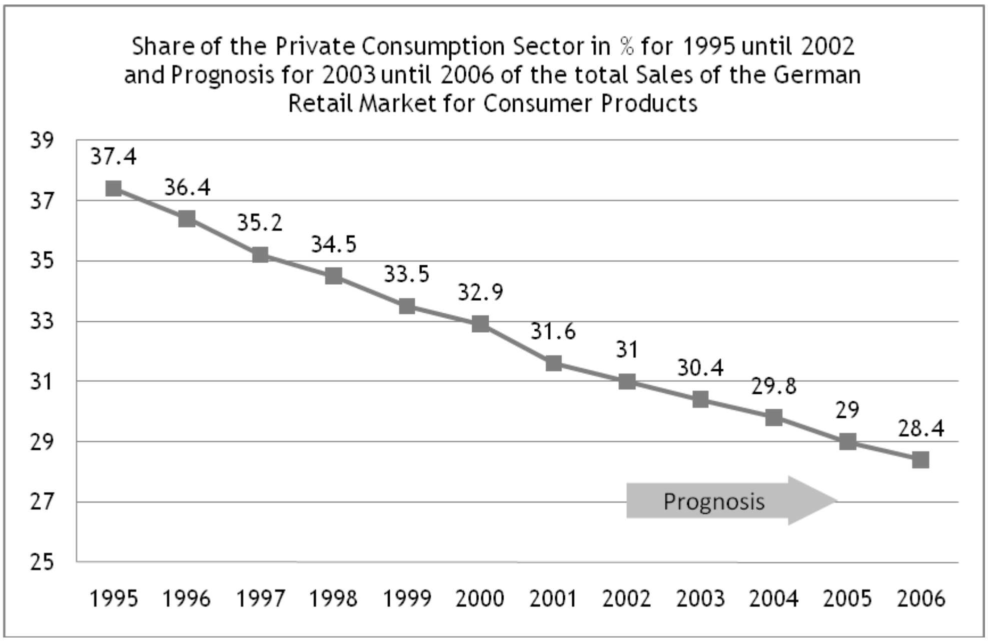

Figure 3: Share of the Private Consumption Sector for Consumer Products

Source: ifo-Branchen-Dialog (2003)

The DIY markets, mail order companies and furniture cash and carry markets very often specialise in lower price categories. These sectors are often of the type where furniture is delivered in flat-pack condition to the retailer and then to the final customer. In recent years, this low price category has considerably increased its market share which surely must be one of the causes of reduced sales and expenditure in this industry (The Ikea-Effect).

From the above Figure 3: Share of the Private Consumption Sector for Consumer Products, it seems that private household-spending has not yet fallen to its lowest level and further decline is likely. Another important and common structure in this retail market for kitchen furniture is the buying process itself. The entire retail industry is controlled by a number of co-operatives who consolidate their buying interests with the manufacturing industry in favour of the retailers. Besides the negotiations of buying terms, they also operate all financial settlements and determine logistic quality assurance and standards. The retailers' market interests are protected and controlled by these co-operatives. The top five co-operatives control a market share of 39% while the top 6-10 have a market share of 19%. Together, they control a share of 58% while the remaining co-operatives have a share of 42%.

Figure 4: Market Share of the German Furniture Co-operatives in 2003

Source: Federal Bureau of Statistics (2004)

The conclusion of this introduction to the retail market is that it consists of two major kinds of clients: general furniture stores and specialised kitchen retailers. All kitchen retail firms are organised in buying and shared interest co-operatives. The top 10 co-operatives hold a market share of 58%.

1.3.4 Delivery and Transportation

Kitchen furniture built in accordance with the client's specifications, in a traditional UMTO way, is not stored at the manufacturer's site. Consequently, this furniture is manufactured, packed and loaded directly onto the delivering vehicle or transportation unit. Deliveries and transportation are grouped into geographical regions to optimise the vehicle routing in terms of cost, time and customer requirements. This section concentrates on the logistics and in particular the operational and handling aspects to support the complex understanding of quality assurance and cost consciousness in the GKFI delivery. The standard of transport and delivery is high, not only because of the fragility of the furniture, but also because of client demands that must be satisfied. It does not allow consolidation of shipments and ordinary groupage transportation services. All vehicles must be air-suspended and all items are loaded and unloaded manually. Use of hooks, forklifts or other handling machinery is not permitted in this industry.

For built-up kitchen furniture minimal packaging is used. The units are protected against damage with simple cardboard, blankets and bubble wrap. The vehicles are loaded by optimising space and stowage. Since the furniture is already assembled, there are no restrictions other than those with regards to utilisation of space on the vehicles and sequence of unloading.

Road transportation is planned in accordance with a geo-time scheme where client orders from a particular region for a certain time are collected, processed, manufactured and then loaded for transport. Transport is planned as a sequence of stops or deliveries as with the travelling salesman problem (TSP) with an optimisation on the total travel distance of the vehicles' journey and in meeting the particular individual requirements of the clients. These requirements may include so called fixed or hard time windows. This means that a delivery is requested by the consignee to take place on a fixed particular day and time within a calendar week. In comparison to a normal or soft time window, a fixed delivery time does not allow any deviation. Soft time windows allow a certain time span on a particular day in a calendar week. The major problem for optimising each vehicle's routing is the planning and scheduling of all production-related aspects in the manufacturing plant subject to consideration of customer restrictions for subsequent delivery.

Traditionally, GKFI use their own vehicles for transport and delivery rather than contracting commercial carriers. This is an issue of quality assurance rather than cost and provides an extended service to the clients. However, this practice also has a negative side: in the past, the cost became almost intolerable, due to low vehicle utilization and GKFI labour union contracts. Almost fully loaded vehicles on the outgoing route always return to the manufacturer's site empty. Since not all vehicles are loaded to full capacity because of the geo-time structure of orders, measured over the whole journey, the utilization rate can fall to less than 40%.

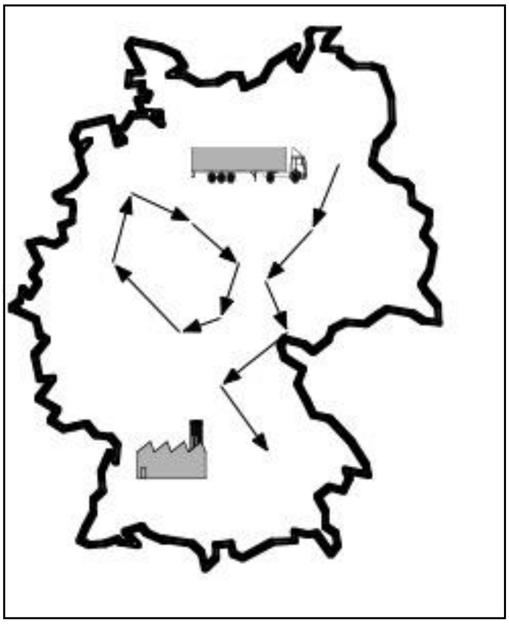

Figure 5: Round-Trip vs. One-Way-Trip

The above figure demonstrates a simple example of a round-trip routing with a company-owned vehicle and a one-way trip of a contracted vehicle. The round-trip vehicle (in this case a company-owned vehicle) has little or no chance of acquiring return loads (McKinnon and Ge, 2006) other than rejects or damaged goods from the clients, to whom it had previously delivered. The contracted vehicle (in this case on the one-way trip) terminates its journey at an indefinite location and continues further services for another client closest to the point where it ended its last route.

The increasing cost pressure and, in particular, the declining national market has forced manufacturers to review this policy. Their use of own vehicles and driving staff is getting gradually outsourced or terminated by natural retirement and vehicles' life cycles. External services began to be implemented more and more and this has yet another effect on cost reduction. The labour union tariff for transport companies and their employees is approximately 35 - 40% lower than the tariff in the furniture manufacturing industry. Finally, the difference in the utilisation of a vehicle in two or three shift engagements has lower cost per kilometre than for company-owned vehicles which can only be used on 1 shift per day because of legal restriction of maximum driving hours per day and staff availability.

Therefore, cost and quality of delivery in transport are major issues and can be seen as key success factors for the GKFI. As a manufacturer has few advantages in costs when he uses his own vehicles, the advantage gained is the quality of service. On the other hand, an external service provider has a large cost advantage (McKinnon, 1994, McKinnon, 1999b), but needs to prove quality standards prior to his engagement.

1.3.5 Operational Utilisation Structures of DPS in UMTO

DPS generally focus on the optimisation of the following measures:

- *Maximum utilisation of transport vehicles, reduction of waiting times, elimination of empty rides.*
- *Reduction of driving distances, shorter connections between loading and unloading stops, reduction of fuel consumption and general cost of maintenance.*
- *Reduction of staff cost and optimisation of co-driver times.*
- *Relief of administrative workforce for vehicle utilisation.*
- *Improvement of customer service through quality in transport and in-time arrival.*
- *Systematic observance of legal restrictions*

Adapted from: (Ziegler and Binder, 1988, pp. 36-45)

These measures are also applying in the production planning in case of UMTO in the GKFI. Consequently, any system for distribution planning needs to have a dual or a hybrid approach, with combined production-distribution planning. In recent years simulation based approaches have been developed to solve this integrated planning problem. (Balsliemke, 2004) These approaches however, can handle the TSP and the VRPTW only to a limited extent. The introduction of graphical user interfaces in the early 1990s improved the overall planning process for the user. Details of developments and the particular requirements of UMTO and especially those of the kitchen manufacturing industry are reviewed in the literature review section of this thesis. (See Section: 3.3 Distribution Planning for UMTO)

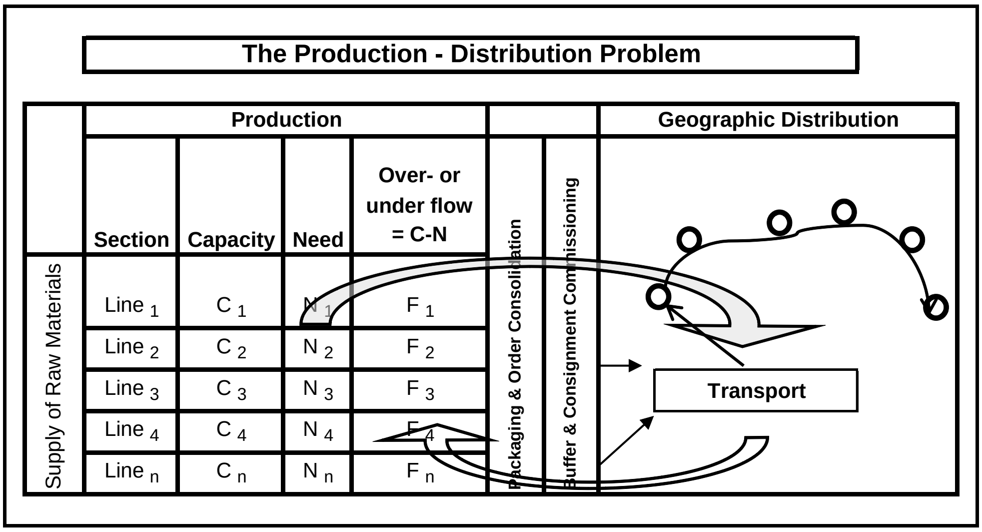

Figure 6: The Production – Distribution Problem

The above Figure 6: The Production – Distribution Problem shows the general procedure where distribution dominates the production planning process, indicated by the arrows in vice-versa relationship. The specifics of consignment production in this case is that an entire kitchen is produced in one production period, i.e. one day, no interim storage is available and all items of the client order need to be collected from the manufacturing site and prepared for delivery. This research assumes that there can always be a shortage or a part missing in the delivery. Consequently, it also assumes that all parts and products are not always manufactured in one manufacturing period. Over- or underflows of production capacity of one production period and relating to one or more lines or shops of production are also considered. This explanation is important to this research as it emphasises the link between production and distribution planning processes in this industry. It is also important to explain the small shipments experienced in the later data sampling.

The conclusion of this section is that any distribution planning system for UMTO in the GKFI needs to have a hybrid production-distribution planning approach. This is often based on stochastic simulation models for the steering of a multi-period, multi-product and geo-time client restriction-planning platform. This requirement is incorporated in the chosen model of this thesis. Based on this, the literature research of this thesis concentrates on research works that incorporate all these factors:

- Production Planning
- Distribution Planning

Hybrid approach to: Production-Distribution Planning

- Consignment Production Scheme
- UMTO Production and its Distribution Logistics

… with a special or major focus on the effects of the cost of delivery.

Another complex requirement is added by the fact that orders, once they are received at the manufacturers, may vary, change or alter up to the actual manufacturing period or even the manufacturing day itself. Consequently the order processing based on simulation for both the production and the distribution are to be highly flexible (See Figure 6: The Production – Distribution Problem), but they always need to consider the originally promised time of delivery within one and the same calendar week. This requirement has also been incorporated in the model of this thesis. This section of Chapter 1 aimed to explain the flexibility requirements of the GKFI in some detail and to contribute towards the understanding that UMTO requirements in the GKFI do indeed require hybrid production-distribution-planning-systems.

1.4 Importance and Attractiveness

The previous sections of this chapter have described the complex environment of the GKFI. Not only is this industry in a highly competitive market, but also the importance of cost orientation in general and, in particular, the cost of distribution is obvious.

The use of DPS for transportation planning has brought much evidence for cost savings in the delivery of goods from the manufacturers to their clients. Many research publications and practical applications have given proof of this statement. (Toth and Vigo, 2002) The chosen model of this thesis applies to this, but extends the application of DPS on the effects of distribution cost of UMTO by theoretically reducing TWC and simulating an almost TWC-free delivery situation. The difference of cost between those two situations will be analysed in such a way to question, whether the savings resulting from this hypothetical approach will be sufficient enough to discuss a practical application of this model. In this context the importance and attractiveness of this thesis lies in the simulated (soft-) TWC-free delivery situation of a UMTO, what cost savings this might bring to light and how this simulated situation might be practically applied. In other words, the theoretical removal of TWC could lead to an economic result that may then lead to the process of discussing the right of demand on TWC between supplier and consignee. From practical experience, this discussion is located in an almost taboo area of corporate marketing strategies and customer orientation. Customer demands such as TWC once being noted and put into the general client data file are rarely questioned or even changed. This thesis theoretically omits existing TWC and shows what implications they have on the cost of delivery. In this context it is important to note however, that the model used in this thesis does not just reduce cost by omitting TWC, but it maintains the levels of quality in delivery between the UMTO and its clients. This is an important and attractive contribution towards any following discussion on practical implication.

2 Research Question

This thesis's research question relates to the field of operations management and more precisely distribution logistics for UMTO. Among the different complex logistics problems which are subject to research, distribution logistics is among the oldest and its history goes back several centuries. Its roots lie in military applications. (Jomini, 1881) Within the past fifty years, simulation based research approaches have been applied in the field of distribution logistics. (Dantzig and Ramser, 1959) One of their main targets was the reduction of travel time and cost. Such cost reduction from using simulations may result from different causes. The majority of the research on this topic focuses on cost reductions in the framework of the TSP. In order to achieve a significant cost reduction, one approach is the improvement of the heuristics used for solving the TSP under the given constraints. This thesis focuses on the effect which a removal of one constraint has on delivery cost and discusses the viability of its removal. The constraint of interest is set by time windows for delivery.

2.1 Definition of the Research Question

The research question of this thesis is the following:

Does the reduction of TWC in UMTO delivery lead to sufficient cost reductions for clients to be motivated to leave the determination of delivery times to the supplier?

This research examines deliveries that have time windows and evaluate those in terms of their cost effects. Once the costs have been identified, the drivers for such cost will be investigated in terms of how they influence the cost as independent variables and with what significance they do that. This creates the basis of discussion on the cost of TWC in UMTO delivery. The entire simulation process of cost identification with and without time windows will be undertaken with the help of a DPS. The reason for this decision to use a DPS lies in the fact that after the reduction of the existing soft TWC the deliveries that were undertaken in routes need to be planned (or theoretically executed) again. This sort of re-routing will bring the cost of delivery to a theoretical state, where no more soft time windows exist and the routing of all deliveries is undertaken in a simulated optimised form from the point of view of the UMTO. This situation is described hereinafter as the change of demand on the creation of TWC in the favour of the UMTO.

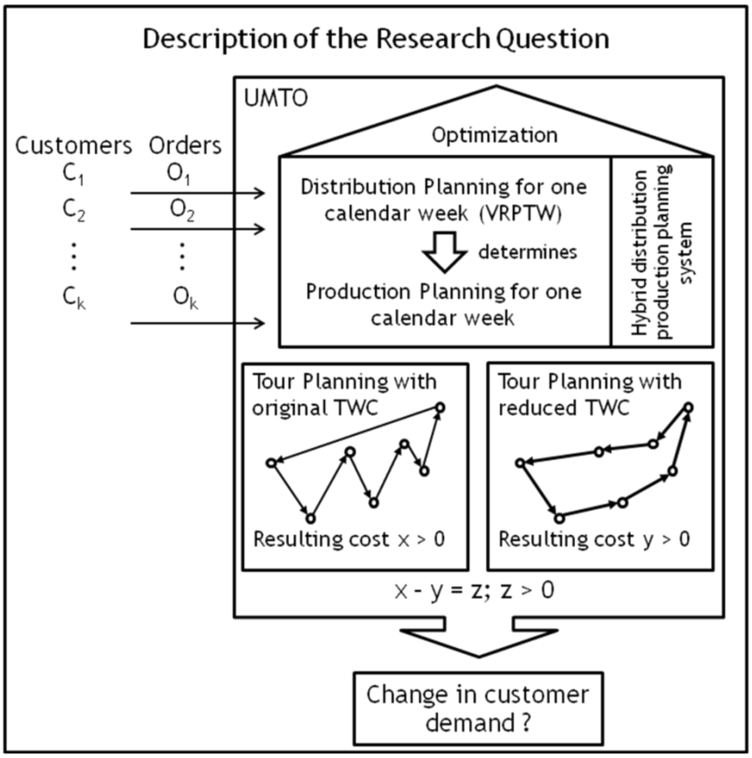

Figure 7: Description of the Research Question

Regarding the second part of this research question, the discussion on how such a change can be evaluated and implemented will follow. This discussion and the questions arising there from are based on the theoretical assumption that the savings in cost from the reduction of TWC in the previous step are indeed achievable and of a high significance. The question if such a hypothesis is achievable in total or only in part thereof will be discussed and tested in a separate sensitivity analysis. Continuing the thought of achievability of a large reduction of TWC in a fixed set of routings, the arguments will be directed towards an economic discussion of total landed cost at the client. At this point it will become obvious and transparent that the sampling from the GKFI may indeed be very open for such a discussion, as they are in a very competitive market that needs new solutions for general cost reductions.

Looking at the research question in a circular way, the first part will look at the theoretical reduction of an operational logistics constraint from which result economic advantages that are being discussed on an economic basis. This discussion will also be viewed from an environmental point of view. This green approach is an additional or supportive argument for the entire cost discussion. It is included in this work in Chapter 7 Supporting Environmental Considerations with the sole intention to highlight its justified meaning and importance. It does not (yet) directly contribute to the answering of the research question. However, under the light of strongly predictable direct CO_2 emission taxation these environmental effects will definitely gain economic worldwide value. Consequently environmental (side) aspects of this research question are economic aspects.

Summarising the definition of the research question of this thesis it can be said that if the reduction of TWC in the delivery of UMTO can reduce the cost to such an extent that both, the client and the supplier of goods, identify significant and mutually beneficial economic advantages, can the determination of ‘client demands’ on TWC be shifted to ‘supplier demands’?

2.2 Definition of UMTO Delivery with Time Windows

The definition of a UMTO delivery with time windows can be adapted from Ho et al., (2001), pp. 432-434 as follows:

> *The VRP with time windows has both an earliest release time and a latest time for delivery. A VRPTW consists of a set of consumers that are to be serviced by a set of vehicles with limited capacity while minimizing the cost of service to the customers. The cost of service is measured by the number of vehicles required to service all customers and the total distance travelled by the vehicles. Each customer has a time window, comprising of an earliest release time, after which the customer will accept service and a latest time, after*

which service to the customer is considered tardy. A service time is also associated with each customer for the servicing vehicle. The objectives and constraints of the UMTO delivery with time windows can be defined as follows:

Objectives:

- *The total number of vehicles, K, to be used for servicing the customers should be minimised.*
- *The total distance travelled by the K vehicles for servicing the N customers should be minimised.*
- *The total travel time of K vehicles for servicing the N customers should be minimised, where travel time of the vehicle is the sum of the total distance travelled by the vehicle and the service time incurred by each of the customers.*
- *The total waiting time of K vehicles for servicing the N customers should be minimised.*

Constraints:

- *All the N customers should be serviced with each individual customer being serviced by only one vehicle.*
- *The vehicles servicing the customers should not exceed their individual capacity Q.*
- *The vehicle serving each of the customers in its route must reach the customers before its latest delivery time. If the vehicle reaches the customer before the earliest time, then the vehicle will have to wait.*
- *The vehicles servicing the customers should not exceed their travel time.*

From this explanation, quoted from (Ho et al., 2001) it becomes obvious that the optimal UMTO deliveries are based upon the Vehicle Routing Problem with Time Windows (VRPTW). In the context of this thesis it becomes clear that the reduction of cost is the highest priority (Fisher, 1994, Potvin and Bengio, 1996, Potvin et al., 1996, Savelsbergh, 1992a), whilst the time window constraints do in fact cause additional cost.

2.3 Narrowing the Focus of the Research Problem

There is the possibility of a large number of constraints that can influence route planning. These constraints may be of an external nature, such as political, legal or natural constraints. Internal constraints may be caused by the type of vehicle or number of drivers or time windows for delivery. (Cordeau et al., 2002a) This thesis focuses on internal restrictions only. As shown in the following table, on those of the time windows for delivery a UMTO has more possibilities of influence than on others. This is referred to as 'convertibility' in the following.

Table 4: Convertibility of Route Planning Constraints

Convertibility of Route Planning Constraints					
Constraints	Convertibility				
	-- = very low	- = low	0 = neutral	+ = good	++ = very high
Road Net	--				
Speed Limit		-			
N° of Drivers				+	
Type of Vehicle				+	
TWC					++
Week of Delivery		-			
Max. Driving Time	--				
Weather	--				
Traffic Congestions			0		
Customs Procedures		-			

(Adapted from Cordeau et al, 2002)

The reason for the choice of TWC as the focal point is explained with their importance and, in particular, with their impact on cost concerns (Ho et al., 2001) and the high degree of their convertibility. Section 3.2.1 Classification of TWC in VRP provides significant and sustained support to this focus. Another major reason for the choice of TWC is because they can be demanded by both the supplier and the consignee. However, both have different interest in the setting of TWC.

In the following, a research oriented narrowing of the focus on the TWC is described and demonstrated with the following figure. The vehicle routing problem contains numerous possibilities of research. Time windows can be determined as soft time windows (S-TW) or as hard time windows (H-TW). (Ho et al., 2001) This thesis will focus at the effects of S-TW. – The VRPTW with S-TW has been researched with two major distinguishing constraints, namely those with capacitated vehicles (CV) and uncapacitated vehicles (UCV). Both constraints lead to cost reductions (Ralphs et al., 2003), but with highly different results.

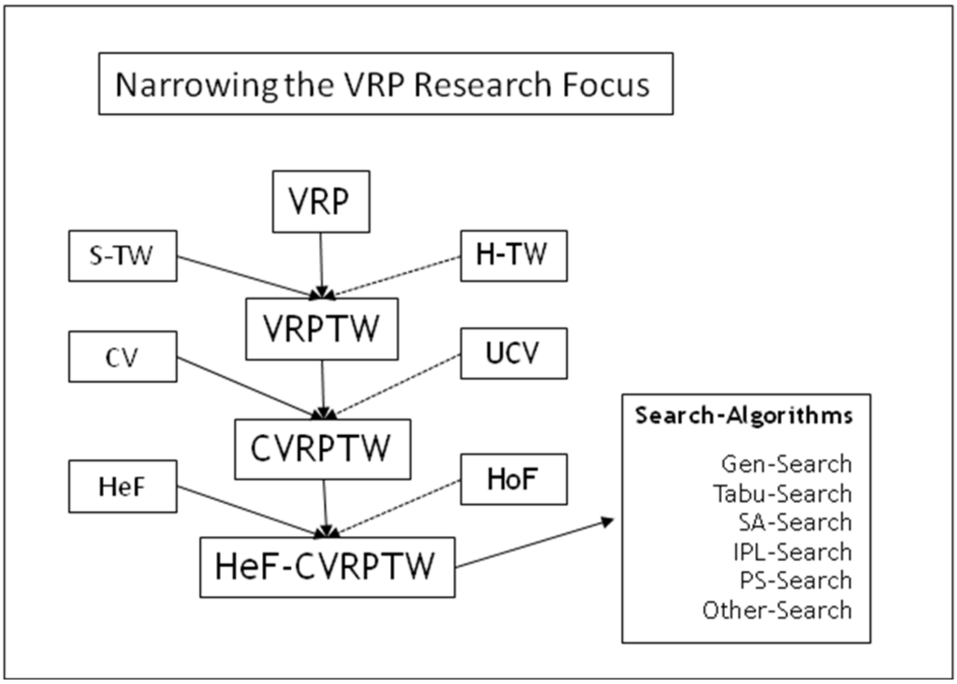

Figure 8: Narrowing of the Research Focus

The next step in narrowing the research focus is undertaken by distinguishing the fleet of vehicles that is referred to in this thesis. Here, the decision was made to use a heterogeneous fleet (HeF) instead of a homogeneous fleet (HoF) of vehicles. The reason for this decision lies in the flexibility that is connected to a heterogeneous fleet in terms of the vehicles' fill-rate as loading capacity. Another reason for this decision is that the sample companies for this research have used heterogeneous vehicles.

Finally, when looking at the HeF-CVRPTW, one can use numerous search algorithms that have a large variety of objectives. This thesis will examine them, discuss them and draw conclusions about their feasibility for this research. However, generic algorithms have different objectives, when used in DPS. Those different objectives are paired with the constraints listed as above. (See Figure 8: Narrowing of the Research Focus) When looking at cost, these constraints become important and have an influence on the results of research. The majority of other researchers concentrate on this, when taking the described approach.

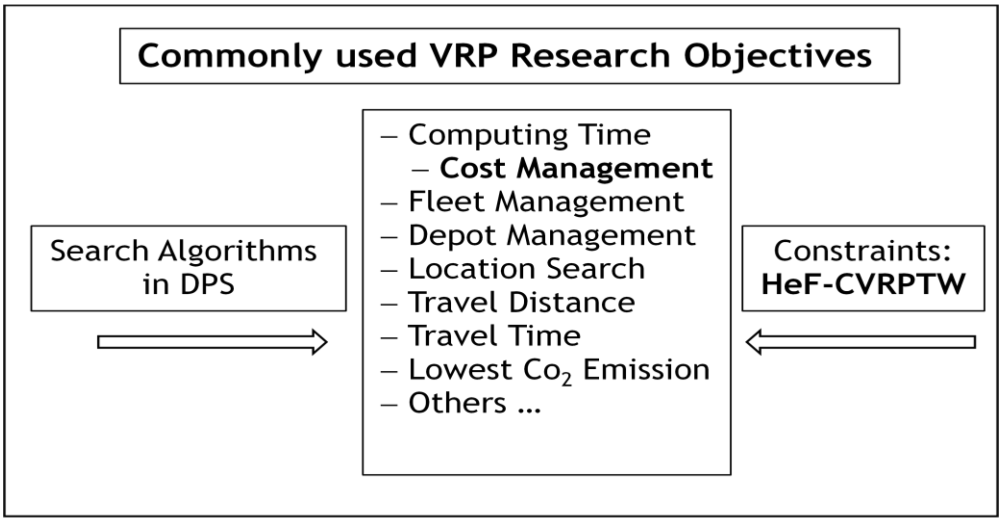

Figure 9: Commonly used VRP Research Objectives

A large number of researches use different algorithms to achieve their different VRP research objectives under set constraints. (See Figure 9: Commonly used VRP Research Objectives) This thesis will take a different approach, by looking at the constraints first and then looking at their cost with the help of a DPS, including numerous search algorithms. (See Figure 10: Objective of this Research)

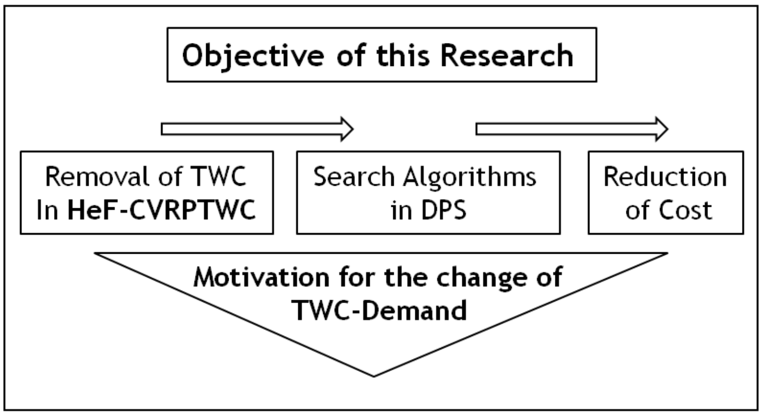

Figure 10: Objective of this Research

This thesis uses a different approach from that demonstrated in Figure 9: Commonly used VRP Research Objectives as applied in most of the existing research (also see: Table 8: : Overview & Classification of Publications on the VRPTW) and applies an approach as demonstrated in Figure 10: Objective of this Research. The objective of cost reduction is familiar or even the same as in other research approaches. But, the use of realistic data from UMTO and then omitting the TWC with a following cost analysis through the re-routing in a commonly used DPS narrows the focus of this research extensively. Very little research has attended to this approach and, in particular, in respect to the research question of this thesis, whereby the cost savings are looked at as a motivation to change the demand for TWC between the UMTO and the clients.

2.4 Generalisability of the Research Question

Now that the narrowing of this research focus has been defined, there is the inevitable question what actual effects this approach might have? In this first step, it is not a question of practicality or application of the results, but of a general methodological approach. This is because the DPS planning constraints emerge mainly from practical experience, such as in a political environment, business economics (especially marketing) and cost orientations. These restrictions are incorporated by the developers and operators of DPS where the systems are often equipped with different methods to handle those restrictions and consequently optimise route characteristics differently. (See: Chapter 3)

The methodological question is then whether, prior to the addition of such system based design parameters, their effects should not better be calculated in the preliminary stages by means of experimental case studies in the simulation process, and then to decide according to the individual reasonableness (that could be in each case the most diverse criteria such as cost etc.) if and how these parameters should be prioritised. Here the majority of systems follow the target to reduce cost. (Quak and De Koster, 2007)

Once these issues have been dealt with, the question, on the inductive behaviour of such a methodological approach follows. This, in turn, makes it necessary, if not crucial to widen or expand the focus of this thesis again. This wider focus on an inductive base may have many aspects. This thesis concentrates on two major priority expansions.

The first one is a purely cost-related analysis. Here, the differences of results from the initial cost condition are compared with the experimental end state. Of particular importance in this focus is the change in the independent variables.

The second focus, in this case best regarded as a supportive focus, is the impact of environmental factors. They are considered in this model only to the extent, to which they are cost related. Such a cost relation is for example the portion of tax on diesel and pollution dependent road toll. Due to their growing recognition, they are dealt with in an own chapter. (See: Chapter 7 Supporting Environmental Considerations)

The generalisability of this research question naturally has to relate to the original population from which the data was sampled, the GKFI. (Frese and Noetel, 1992) By doing so, the two focuses will be applied, analysed and discussed separately. The generalisability however, will need to be based on some further assumptions, such as the answers arising from the research question, if the hypothesis of significant cost savings will be confirmed. Here, a strong correlation to the importance of the cost of delivery will be drawn (See Section: 2.7.2 Delivery Cost as a Share in Total Cost) and the following section of this chapter.

2.5 Importance of the Cost Problem in Distribution for UMTO

The formulation of the actual problem to be investigated has its origins in several, partly consecutive, sources or causes:

1. DPS are subject to strategic and tactical planning parameters. (Lambert, 1978, Waller, 1983) Thus, the framework for route optimisation is determined prior to implementation.

2. These strategic objectives will be mostly complemented with operational additions, such as legal constraints, vehicle capacities and others. (Pfohl, 2004a)

3. Both approaches to parameterisation of the distribution context include a number of different methodological approaches. The target is to find a solution arising from both containing the strategically desirable and the operationally feasible solution. (Collins and Whybark, 1985)

4. In addition for UMTO, the planning arising from the distribution must be coordinated with the production planning, signalling an abundance of approaches and solutions. (Berry et al., 2004)

From the above mentioned influential causes, the cost of distribution for UMTO is influenced from strategic and operational constraints. Both of them are put together in a mix that is added into the parameters that come from production planning. Finally, all the requirements and constraints from distribution planning parameters 1 to 4 in Figure 11: The UMTO Distribution Cost Problem determines the distribution cost for UMTO. Through these descriptions and the subsequent prioritisation of distribution planning it becomes clear that the importance of the cost problem is based upon systematic and chronological consecutive conditions. This description may, in its practical application, differ in many cases. This short excursion and explanation on how distribution cost may arise for UMTO demonstrates that the consistence of distribution cost is very complex. The following Table 5: Set Cost Parameters is an indication on how such cost can arise when the route planning for distribution is influenced by the choice of travel on motorways, country roads and town or city roads as well as by the choice of the length of a journey and by an operational driving decision.

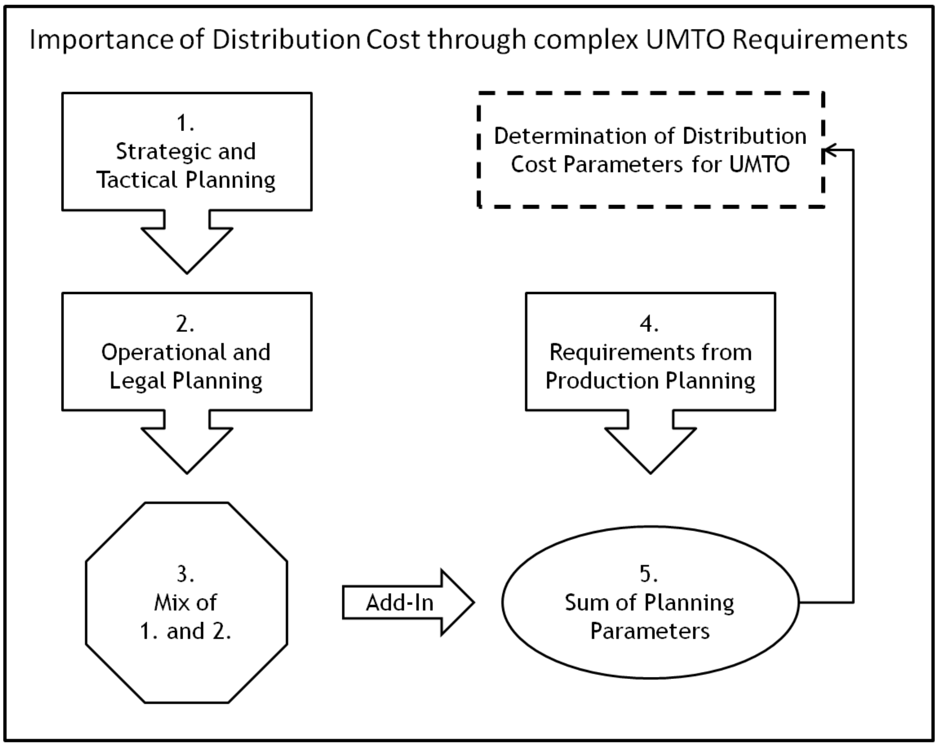

Figure 11: The UMTO Distribution Cost Problem

Table 5: Set Cost Parameters

Set Cost Parameters

Cost Parameter	1 Driver		2 Drivers	
	1 Day Tour	2 Day Tour	1 Day Tour	2 Day Tour
Motorway *	0.79 €	0.87 €	0.63 €	0.53 €
Country Road *	1.02 €	1.13 €	0.82 €	0.68 €
Town / City Road *	1.46 €	1.61 €	1.17 €	0.98 €
Client Stop **	45.00 €	45.00 €	45.00 €	45.00 €

* cost per km excl. Toll

** cost per stop

The above cost parameters are only a small variety of influential factors towards costing structures in the general cost problem of distribution. The following constraints were taken from practical experience into the calculation of the parameters after having been agreed upon with the data and with the DPS suppliers:

- Average speed
  - on motorways: 65 km per hour
  - on country roads: 50 km per hour
  - on city / town roads: 35 km per hour
- daily cost per vehicle
  - 450 € including one driver
  - 615 € including two drivers
- maximum daily travel time
  - 8.8 hours for one driver
  - 17.2 hours for two drivers

(Further details on this are at: 4.2 Definition of the Cost Function) The above demonstrates a highly complex setting of legal and practical influential factors on the cost of distribution. This is why the cost problem in distribution in UMTO is so important and this comes mainly from the influence of production planning that is set up in a geo-time production allocation per calendar week. In other production structures e.g. a serial production the influence of distribution planning over production does not take such a dominant place. There, the planning parameters are strictly on a production optimization a priori to a distribution planning.

2.6 Reflections on the Formulated Cost Problem

The issue of the research question’s importance and the associated methodological approaches throughout this work is, from the author's perspective an important contribution towards a better understanding what effect TWC have on UMTO distribution cost. This thesis endeavours and sets itself the goal to make a contribution to new problem solving approaches and raise awareness about cost and logistics in general for UMTO. Although this is an ambitious target, so often the past has shown that especially in management, research innovations have often only experienced acceptance when the economic or the political pressure had already reached highest levels. (Straube and Pfohl, 2008) Evidence of this is provided in Section 7.2 Pre-Requisites for Environmental Considerations.

Many companies have become highly customer focused in their logistics enabling consignees to track the processing of materials from the initial production stages right up to the ultimate delivery, and they quite rightly demand a quick and trouble-free delivery. This entails specifications provided by the customer to be adhered to by the supplier and which modern DPS will take into account for transport implementation. That this, however, leads to half-empty transport vehicles and in some instances completely empty returns is of no or little interest to the customers. Likewise, the consumers of so-called overnight orders are not concerned at all about the impact their actions or expectations have on the environment. Hence the theory employed in this thesis for the simulation of omitted TWC in UMTO distribution is surely legitimate, and it can make a lasting contribution to new distribution strategies without the customer orientation, transport terms or transport quality having to suffer.

2.7 Cost of Delivery for UMTO

The introduction to the cost of delivery is crucial to this research to achieve a broader understanding for the importance of this research. (See Table 5: Set Cost Parameters) The cost of delivery from distribution planning systems in the business of UMTO is one of the key variables. (See Section: 8.4.4 Summary of Implications) (Bachmann and Langevin, 2009) Transportation of assembled furniture of high value with low, but sufficient packaging standards and high fragility does not suit standard grouping or standard consolidated road transport. It requires specialised transportation, which is found in niche segments of the transportation industry. The following introduction gives an overview of these requirements and the existing operations procedures in this industry from a cost-sensitive point of view. In this context, it is important to note that all manufacturers in the custom-built kitchen furniture industry deliver their goods to their clients on a 'freight charges prepaid' or 'free domicile' basis. This means, that the shipper or consignor of the goods pays for transportation to his client. With regard to national or international road freight requirements, this applies to the majority of deliveries. (Balsliemke, 2004) In the case of international export consignments by air or by sea, the terms and conditions of delivery may vary.

2.7.1 Identifying Cost Parameters

The cost of delivery is an expandable expression: it may include or exclude a number of operational as well as financial aspects. Therefore, the cost of delivery requires a distinguishing and categorizing of these aspects for this research.

When one examines the flow of goods from a SCM point of view, delivery starts with the goods ready for shipping or transportation. In most cases, this includes the loading and stowing of the goods onto the transportation or delivery medium. The reason for this distinction is that the GKFI experiences a high number of (false) damages sustained during transportation e.g., poor loading and inadequate packaging. In addition, a high number of customers claim transportation damage which, in fact, is not a damage incurred during transportation and handling by the transport companies but the result of poor handling by the kitchen installers. Therefore, by identifying the delivery terminology from the ramp of the manufacturer to the ramp of the consignee the separation of responsibilities becomes more evident and controllable.

Following on from the before mentioned, the distinguishing of services rendered could be undertaken as follows:

- Acceptance of packed and loaded goods from manufacturer
  - Quantity and exterior quality control
  - Consignment commissioning
  - Loading and stowing on to vehicle
- Road transport to consignee
- Unloading, quantity and exterior quality control, handling and bringing into warehouse or shop of consignee

Administrative work such as transport documentation, transport planning, technical preparation and services for transport (at or for the vehicle) can be separate costs but still relate to the cost of transport. They are treated as a part of the fixed cost of the total cost. Looking at the cost of delivery in general, another clear distinction must be made. The question of whether to use own or external vehicles has a major impact on the cost of delivery. In the context of this thesis and its research question, no difference is made between the utilization of external or own vehicles in the first step. This relates to the research question, as the data received from the sample companies did not contain any information as to whether, the tours contained therein, were undertaken with external or own vehicles. The question whether own or external vehicles are used will surely effect the result for an individual UMTO. However, for this research this distinction does have much influence as the analysis is based on cost calculated as a function of total distance travelled, runtime and number of deliveries. Concluding this section on the identification of the cost parameters for the answering of this research question, the following is stated:

1. Transport of the loaded goods from the ramp of the manufacturer to the clients;

2. Return of the vehicle to the site of the manufacturer after visiting the last client;

3. Unloading of the vehicle with consignments for each client at his site;

The cost of the vehicle and the staffing with drivers, as well as all underlying cost parameters is described in detail in Section 4.2 Definition of the Cost Function. This section in the chapter of the research question served to identify the focusing of this thesis and deliver a further contribution towards the understanding of the complexity on the cost of delivery for the GKFI in a UMTO environment.

2.7.2 Delivery Cost as a Share in Total Cost

When delivery costs are described, the share of cost must be examined. How much does the delivery to the clients cost? What share are the delivery costs in proportion to the total cost of a product? – This way of measuring cost, allows firms from an industry to be compared with each other and to identify the actual cost of delivery. (Roehner, 1996) It also serves the purpose to prepare ground for the later discussion of the generalisability of the research findings.

The GKFI had an average delivery cost of 7.5% of the sales value in 2005. (Reinbender, 2008) This applies to the entire range of all kitchen brands, types of kitchen and makes in this industry. Flat-packed kitchens, where clients assemble their own furniture, have lower transport costs due to using less volume on vehicles. This reduced cost is more than offset by the total cost for delivery measured on sales values, due to the lower values of the goods transported. Flat pack goods have the lowest relative delivery cost in the industry. The following Table 6: Examples on the Cost of Delivery (%) of total Cost gives three examples of assembled kitchen deliveries in different value classifications. The average volume of an assembled kitchen is about 6 m^3 in total space, including packaging. (Reinbender, 2008)

The assembled upper class kitchen delivery averages a share of 2.7 % delivery cost / value (Reinbender, 2008), owing to the high value of the product, which may be as much as € 15,000 or even more. Consequently, the share of delivery cost decreases.

The middle class value kitchen delivery cost / value rate, with an average value of Euro 5,000 comes to an average cost of 5.4%. Here, the cost of delivery increases due to the lower value.

The lower class value kitchen delivery cost / value rate, with an average value of Euro 2,500 comes to an average cost of 10.8%. Here, the cost of delivery is the highest due to the lowest value.

Table 6: Examples on the Cost of Delivery (%) of total Cost

Examples on the Cost of Delivery (%) of total Cost	
Example A: Built-up furniture of lower value classification	
Total cubage of the shipment in m³	6
Total value of the shipment in Euro	2,500
Average cost of delivery in Germany in Euro per m³	45
Total cost of delivery in Euro	270
Share of the cost of delivery on Sales Value in %	**10.80%**
Example B: Built-up furniture of middle value classification	
Total cubage of the shipment in m³	6
Total value of the shipment in Euro	5,000
Average cost of delivery in Germany in Euro per m³	45
Total cost of delivery in Euro	270
Share of the cost of delivery on Sales Value in %	**5.40%**
Example C: Built-up furniture of upper value classification	
Total cubage of the shipment in m³	6
Total value of the shipment in Euro	10,000
Average cost of delivery in Germany in Euro per m³	45
Total cost of delivery in Euro	270
Share of the cost of delivery on Sales Value in %	**2.70%**

From the above, it is concluded that the importance and relevance of the cost of delivery differs, based on the value of a kitchen being delivered. Consequently, the attractiveness for the use of DPS to reduce cost of delivery depends on the share of such cost, measured on the sales value per kitchen. The verification of the cost of delivery per m^3 is explained in Section 4.2 Definition of the Cost Function. The conclusion in the context of this research question arises from the correlation of the cost for distribution and transport in comparison to the total amount of sales in the GKFI. Here, an analysis of this correlation gains a very significant importance. This is where the answer to this research question will be focused.

2.8 Summary and Conclusions

Distribution costs for UMTO have a high importance on the total cost of a UMTO and therefore warrant a detailed analysis that is dealt with in this thesis. This research will contribute towards those findings by showing how much influence TWC have on the cost of distribution as one of many constraints in UMTO delivery. By doing so, it will be discussed, if the determination of TWC can be shifted from the receiver of goods towards the manufacturer.

The experimental multiple simulation processes will provide evidence that this approach can be the trigger for other possible logistics procedures, thus emphasising a sustainable reuse of the methodologies used here. A partial confirmation of this statement is provided by other publications (Yang et al., 2006, Pachnicke, 2007) establishing that simulation in management research is very much underexposed or represented only marginally. Other works state a good and comparable result in their research on the implementation of TWC by the government for retailer in cities. (Quak and De Koster, 2007) Here, the retailers' sensitivity to reduce TWC is shown through the contribution of various decision parameters. One major reason for the importance of the findings in this thesis is that typical practitioners use DPS with a combination of strategic, tactic and operational planning settings, and seldom apply reverse applications for the investigation of the cost arising from such parameters. This is, where the research question needs to be highlighted in such a way that the change in the right of demand for the choice of TWC depends on how much cost can actually be saved. The latter part of this highlight implies the correlation within the research question in the context of actual cost saving, as a share of total cost, and the attractiveness for the change from a 'customer demand' to a 'supplier demand'. No other studies, to date, have researched this question.

3 Literature Review

This literature review consists of six main sections. It commences with a general focus on the (1) Vehicle Routing Problem (VRP) and the special influence of the (2) Vehicle Routing Problem with Time Windows (VRPTW). Here, a variety of solutions to the problem are looked at to demonstrate historical and current planning approaches. The characteristics of (3) UMTO and their specific requirements from distribution and production planning will be looked at to highlight the specific requirements of this industry in the context of the research objective of this thesis. The importance of (4) simulation techniques in logistics are a major foundation of this thesis. Here, currently used models and their strengths and weaknesses are discussed to identify the borderlines of their application in research. Those borderlines stand in a direct correlation with (5) experimental research in logistics and imply risks, which are discussed and fenced herewith to support the chosen methodology of this thesis. Finally, a review on (6) the coherence between simulation and experimental research will be looked at to further support the importance of this thesis and its contribution to knowledge. The conclusions of this chapter will demonstrate the gaps in literature that this thesis will identify and fill.

3.1 Distribution Planning Approaches

This section of the literature review will deal with developments in various distribution planning approaches for the VRP and the Capacitated Vehicle Routing Problem (CVRP). At the time of writing this thesis, the author found 20,856 publications as a result of searching for the key word “Travelling Salesman Problem and Distribution Planning” on the ISI Web of Knowledge, Emerald Insight and the Elsevier databases. The following sections will deal with the main planning approaches for the solving of the VRP, their historical developments and their key findings.

3.1.1 Historical Development

The historical development of distribution planning is commonly connected with the so-called: "Travelling Salesman Problem." The work of Applegate et al (1998, pp.645-646) states that: *"Given a set of cities along with the cost of travel between each pair of them, the travelling salesman problem, or TSP for short, is to find the cheapest way of visiting all the cities and returning to the starting point"*. The *"way of visiting all the cities, is simply the order in which the cities are visited; the ordering is called a tour or circuit through the cities*". This exercise sounds modest, according to the authors. However, it is:

> *"...in fact one of the most intensely investigated problems in computational mathematics. It has inspired studies by mathematicians, computer scientists, chemists, physicists, psychologists, and a host of non professional researchers. Educators use the TSP to introduce discrete mathematics in elementary, middle, and high schools, as well as in universities and professional schools. The TSP has seen applications in the areas of logistics, genetics, manufacturing, telecommunications, and neuroscience, to name just a few"*

The origination of the assigned name TSP is unknown. Stated to be one of the earliest and most influential of TSP researchers was Merrill Flood of Princeton University and the RAND Corporation. It is reported that Flood revealed that he does not know who first stated the name 'Travelling Salesman Problem' but that developments of this problem began in the 1930s at Princeton University and that it was originally called the '48 States Problem'.

One of the other first recorded references is stated to be (Toth and Vigo, 1987, p. 4) in the work of Julia Robinson, (1951) and that it was *"clear from the writing that she was not introducing the name. All we can conclude is that sometime between the 1930s or 1940s, most likely at Princeton, the TSP took on its name, and mathematicians began to study the problem in earnest."*

It is related that the Commis-Voyaguer1 *"explicitly described the need for good tours"* in the translated version as follows:

> *"Business leads the travelling salesman here and there, and there is not a good tour for all occurring cases; but through an expedient choice and division of the tour so much time can be won that we feel compelled to give guidelines about this. Everyone should use as much of the advice as he thinks useful for his application. We believe we can ensure as much that it will not be possible to plan the tours through Germany in consideration of the distances and the travelling back and forth, which deserves the traveller's special attention, with more economy. The main thing to remember is always to visit as many localities as possible without having to touch them twice".* (Applegate et al., 1998, p. 647)

This statement is confirmed on numerous occasions in the literature (Cordeau et al., 2002b, Toth and Vigo, 1987, Waller, 1983), especially when the issue of allocating vehicles to the tour is discussed.

It is related that the mode of travel that the travelling salesmen utilized varied in nature and included *"horseback and stagecoach to trains and automobiles".* (Bowersox, 1972, p. 5) In each case of travelling choice *"the planning of routes would often take into consideration factors other than simply the distance between the cities, but devising good TSP tours was a regular practice for the salesman on the road."* (Fleischmann, 1993, p. 32) It is said that when a mathematician is investigating a problem and is seeking ideas or solutions that usually most mathematicians will take a pencil, sketch a few ideas and specifically stated is *"...geometric instances of the TSP, where cities are locations and the travel costs are distances between pairs, are tailor-made for such probing."* (Chandra and Fisher, 1994, p. 505) The ability for visualization of tours and for easy manipulation of them by hand is said to have most *"certainly contributed to the widespread appeal of the problem, making the study of the TSP accessible to anyone with a pencil and clean sheet of paper."* (Applegate et al., 1998, p. 645)

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[1] Geschäften gewiss zu sein—derived from a Commissioner-Voyageur (German Traveling Salesman Handbook, 1832) as cited in Applegate, Bixby, Chvatal and Cook (2007)

The work of Golden et al. (2008) states that in the well-known *"Vehicle Routing Problem (VRP) a set of identical vehicles, based at a central depot is to be optimally routed to supply customers with known demands subject to vehicle capacity constraints...and an important variant of the VRP arises when a fleet of vehicles characterized by different capacities and costs is available for distribution activities. The problem is known as the "Mixed Fleet VRP, or as the Heterogeneous Fleet VRP."* (Golden et al., 2008, p. 12) The VRP is stated as one of the *"most studied combinatorial optimization problems and is concerned with the optimal design of routes to be used by a fleet of vehicles to serve a set of customers."* (Golden et al., 2008, p. 5)

First proposed by Dantzig and Ramser (Dantzig and Ramser, 1959) the subject of VRP has been the focus of many publications, seeking the *"exact and approximate solution of the many variants of this problem including the Capacitated VRP (CVRP), in which a homogenous fleet of vehicles is available and the only constraint is the vehicle capacity or the VRP with Time Windows (VRPTW) where customers may be served within a specified time interval and the schedule of the vehicle trips needs to be determined."* (Golden et al., 2008p. 222) These authors report that more recently greater attention has been given to *"more complex variants of the VRP, sometimes named 'rich' VRPs, those are closer to the practical distribution problems than the VRP models."* These variants are said to be characterized *"...by multiple depots, multiple trips to be performed by the vehicles, multiple vehicle types or other operational issues such as loading constraints."* (Golden et al., 2008, p. 222)

The work of Larsen et al. (2002) states that Psaraftis (Psaraftis, 1995, p. 638) uses the classification as follows of the static routing problem: "*if the output of a certain formulation is a set of pre-planned routes that are not re-optimized and are computed from inputs that do not evolve in real time*". Psaraftis refers to a problem as being dynamic as follows: "*if the output is not a set of routes, but rather a policy that prescribes how the routes should evolve as a function of those inputs that evolve in real-time.*" (Larsen et al., 2002, p. 639)

The Static Vehicle Routing Problem is said to be defined by the following characteristics: (1) *"all information relevant to the planning of the routes is assumed to be known by the planner before the routing process begins; and* (2) *information relevant to the routing does not change after the routes have been constructed."* (Larsen et al., 2002, p. 640) The authors state that the dynamic counter part of the static vehicle problem as just defined can be formulated as follows: (1) "*Not all information relevant to the planning of routes is known by the planner when the routing process begins; and* (2) *information can change after the initial routes have been constructed*." Two types of requests are said to be involved in many DVRP. These are: (1) "*advance requests – also referred to as static customers since these requests are received prior to the process of routing had begun; and* (2) *immediate requests*" – referred to as dynamic customers as these appear in real-time during the route extension. (Larsen et al., 2002, p. 640)

Larsen et al. (2002, p.641) state the *"...the more restricted and complex the routing problem is, the more complicated the insertion of new dynamic customers will be."* The example given is that inserting the new customers in a *"time window constrained routing problem will usually be more difficult than in a non-time constrained problem."* This theory is supported further by Toth et al. (2002) as well as Weiqi and Alidaee (2002) and also by Cordeau et al. (2005).

The work of Rizzoli et al. (2004) states that the VRP is concerned with the transport of objects between the original location of manufacture and customers via a fleet of vehicles. The VRP can be translated to many domains in the world, including delivery of mail, routing of school buses, collection of solid waste, distribution of heating oil, pick-up and delivery of parcel and many other systems of this kind. Solutions to VRP are those which identify the optimal route of delivery to all customers via a fleet of vehicles and involve ensuring service to all customers within the stated constraints of operation and minimization of the cost associated with transportation. (Rizzoli et al., 2004)

Rizzoli et al. (2004, p.124) relate that the formulation of the VRP is a *"mathematical programming problem, defined by objective function, and a set* *of constraints."* Objectives are said to *"measure the fitness of a solution. They can be multiple and often they are also conflicting. The most common objective is the minimization of transportation costs as a function of the travelled distance or of the travel time; fixed costs associated with vehicles and drivers can be considered, and therefore the number of vehicles can also be minimized."* (Rizzoli et al., 2004, p. 125)

According to Rizzoli et al. (2004, pp.119-120) they state that vehicle efficiency is another objective to consider and this is stated to be expressed as *"the percentage of load capacity"* and it is held that the higher the load capacity the better. The objective function is also used in representation of 'soft' constraints described as constraints *"...which can be violated paying a penalty."* Both independent variables and dependent variables are contained within the objective function and under the planner's control the independent variables are stated to be decision variables and the dependent variables are stated to be the *"consequence of the assumed decisions."*

The problem's solution is stated to be given *"by the decision variables returning to the best evaluation of the objective function."* (Rizzoli et al., 2004, p. 124) In the case of VRP, the decisions are those which define how the visits to the customers will be sequenced and specifically through defining a set of routes. In order to discover the values which are to be assigned as decision variables, what is needed, is a model of the vehicle routing system which is a model 'defined by the constraints' that establishes the relationships among independent and dependent variables and sets limits of variables' values. The same accounts for the VRPTW and is supported by numerous other authors. (Potvin et al., 1996, Gendreau et al., 2002, Toth and Vigo, 2002, Bräysy and Gendreau, 2002)

Stated by Rizzoli et al., (2004, p.125) as inclusive in the elements that serve to *"define and constrain the model"* are the elements relating to: "(1) *the road network (which describes the connectivity among customers and depots);* (2) *the vehicles (transporting goods between customers and depots on the road network);* (3) *the customers (placing orders and receiving goods*)." The road network is said by these authors to be presented as a graph in which *"depots and* *customers are placed on nodes and the edges represent the distance, in space and/or time between two nodes."*

Rizzoli et al. (2004) and also Bräysy et al. (2002) state that the road network graph may be obtained from a map that details the distribution area with the depots and customers geo-referenced on it. (See Figure 22: Random Sample of Geographical Routings from Base Data-1) The shortest routes can be discovered through use of standard algorithms in regards to time and distance between all node couples enabling the distance matrix to be constructed. (Bräysy and Gendreau, 2002) Depending on the metric that is adopted, various VRP instances may arise and that a stated example is in relation to travel time and depending on the time of day, which means that the 'Time Dependent VRP' is encountered.

When the various elements of the problem are combined, it is possible to define *"a whole family of different VRPs."* (Rizzoli et al., 2004, p. 122) Some of these are those as follows: (1) Capacitated Vehicle Routing Problem (CVRP); (2) VRP with Time Windows (VRPTW); (3) Time Dependent Variable of VRP with Time Windows (TDVRP); (4) The VRP with Pickup and Delivery (VRPPD); and (5) The Dynamic VRP (DVRP). (Rizzoli et al., 2004, Gendreau et al., 2002, Laporte and Semet, 2002)

Bowersox and Closs (1989) state that there are generally three model categories used in logistics planning which are the following: (1) Analytic; (2) Heuristic; and (3) Simulation. Analytic models are stated to use mathematical models to make identification of the best solution to the problem being analyzed. However, the models that use heuristic or simulation procedures are said to use *"numerical techniques to quantify specific problem solutions."* (Bowersox and Closs, 1989, p. 9) Their statements in this context are supported and expanded by numerous other authors. (Charikar et al., 2001, Cordeau et al., 2002b, Laporte et al., 2000)

The distinctive feature of simulation is said to be the capacity of simulation to *"include stochastic situations. In most logistical planning situations, uncertainty and resulting variance are significant considerations."* The capability of simulation technologies is the incorporation of variance *"across either a dynamic* *or static planning horizon."* (Bowersox and Closs, 1989, pp. 21-22) In other words: *"probability can be introduced into analyses dealing with a specific point in time problem (warehouse location) or across time (inventory/customer service relationships)."* (Bowersox, 2008, p. 18) Uncertainty is effectively dealt with by simulations; therefore, these are used frequently in solving problems in which there are requirements of space and time integration. An example given is that of network inventory. Logistic planning situations are either: (1) structural; or (2) operational. (Bowersox and Closs, 1989)

Structural problems are typically characterized as location of the facility and design of the distribution channel. Typical operational analyses according to Bowersox and Closs (1989, p.135) are: (1) "*integration of customer service*; (2) *inventory*; (3) *transportation and* (4) *production*". Structural analysis involves *"the number of facilities and the channel design relationships facilities and/or channel participants."* Facility analysis has as its focus on the *"geographical location and arrangement of the production, warehouse and to a lesser extent retail stores."* An issue that is *"closely related to the facility structure"* is that of the channel design used in supporting marketing. (Bowersox, 1972, p. 112)

Operational analysis is second in the planning and evaluation categories used in simulation. It is said that operational analysis *"considers spatial product positioning and alternative timing. Operational analysis is typically focused on the integration of raw material and finished goods inventory, service levels, and production planning."* (Bowersox et al., 1993, p. 72) In addition, the authors relate that simulation tools are *"becoming increasingly dynamic to capture the interaction between level of service and potential revenue generation."* (p.72) Due to the fact that there are economies of scale in logistics which are substantial, *"increased demand offers the potential to reduce costs, which in turn, offers potential incentives to increase demand."* (nd) It is necessary to evaluate this cycle in terms of finance to make sufficient strategic marketing plans.

Bowersox et al. (1993) state that revenue elasticity replication in simulation of profit enhancement *"can be achieved by a combination of probabilities and* *dynamics."* (nd) Advanced simulation methodologies are utilized in this case which is fairly complex. An example of this demonstrates the complexities which exist between: (1) *"price, demand, and cost of providing service for a market segment;* (2) *volume shipped and price to ship for a segment; and* (3) *service level offered and segment demand as illustrated by the desire for market presence."* (Bowersox, 2008, p. 18)

In a survey of heuristics for the VRP Laporte et al. (2000, p.287) reports that there have been *"...several families of heuristics proposed for the VRP."* These are classified as: *"(1) classical heuristics (developed between: 1960-1990); and (2) metaheuristics (over the past decade)."* Heuristics that are *"standard construction and improvement procedures"* used currently are classical heuristics characterized by *"relatively limited exploration of the search space"* and the production of *"good quality solution within modest computing times."* Furthermore, these can be *"easily extended to account for the diversity of constraints encountered in real-life contexts"* and are widely used in commercial packages. The priority in metaheuristics is stated to be on conducting a *"deep exploration of the most promising regions of the solution space."* (p.288) The authors relate that combined in these methods are the following elements: "*(1) sophisticated neighbourhood search rules; (2) memory structures; and (3) re-combinations of solutions*."

Summarizing the above brief introduction of some historical developments of the VRP, one can say that a large family or many divergent groups of approaches have emerged over the years. All of them however have a main focus and that is the reduction of cost on the journey to be travelled in general. The further sections of this introduction chapter will focus on some of the family members and show parallels to the model of this thesis, its underlying cost function and the implemented cost parameters.

3.1.2 Tactical and Strategic Planning

A large majority of planning processes and planning approaches in operations management start with the focus on the tactical and strategic side of a problem.

(Krajewski and Ritzman, 2002) Researching those two planning characteristics for the VRP, Rushton et al. (2000) published a work which deals with this phenomenon and also shows parallels to the tactical and strategic decisions that this thesis has chosen. Rushton et al. (2000, p.422) say that the scheduling problems of vehicle routing are *"relatively complicated."* The reasons for this are stated to be firstly: *"the different types of problems that can arise … need to be understood and approached in a different way"* and secondly: *"the many detailed aspects that need to be taken into account and the various methods of algorithms that can be used to produce solutions."* Problems may be of the nature of:

1. Strategic;
2. Tactical or operational;
3. Interactive; and
4. Planning.

Strategic problems are concerned *"with the longer-term aspects of vehicle routing and scheduling, in particular where there is a regular delivery of similar products and quantities to fixed or regular customers."* (Rushton et al., 2000, p. 196) Stated as typical examples are *"most retail delivery operations (such as grocery multiples), bread delivery and beer delivery to 'tied' houses."* (Ralphs et al., 2003, p. 345)

From this view, tactical and strategic planning for distribution sets parameters in advance of a supply chain of an organisation. From this context, all planning and operational activities are related to the placing of the product in the market. The product itself, its price, place and promotion (4P's of marketing) (Borden, 1964) are the criteria of selecting tactics and strategies for distribution planning. (Lambert, 1978) From there, some further fundamental decisions follow on:

- packaging, transport quality and transport security;
- direct or indirect transport (i.e. via hubs or depots for interim storage) to the customer;

- how many, how big and where should depots be located;
- choice of transport mode, frequency, unitisation methods;
- transport effected by own or external vehicles and staff;
- geographic location of customers, regional splits, regional density and order frequency of customers. (adapted from Waller, 1983) (See Figure 14: The 7-S Framework)

Rushton et al. (2000) and Ralphs et al. (2003) both say that the primary factor of importance is that either the demand (quantity) of goods cannot be estimated (random demand) or the location of delivery points varies. It is also possible that both of these incidents simultaneously occur. From this, it is very difficult for delivery schedules in the UMTO environment to be planned on the basis of historical information. Their geo-time structures of distribution vary from week to week. In an annual view however, they may derive certain clusters of distribution structures that allow them to plan on a tactical and strategic basis. The individuality of UMTO weekly delivery schedules requires a high individuality for transport operations, e.g. the choice of transport vehicle, the loading capacities or the actual tour sequence in a region. The requirement for strategic and tactical planning should be that each series of orders (on a weekly and geo-time structured basis) is viewed on historically and actually operated routes and schedules, so they can become more flexible to changing and individualism of demand in the future. (Rushton et al., 2000) The strategic and tactical planning of a distribution framework in a repetitive production-distribution environment on basis of historical data, is however very often common practise and successful. Here, the historical data is used to undertake the planning for forecasting purposes with a fairly high accuracy for future operations. The repetitiveness of such environments allows firms to a large degree, to assume that their operational planning may be adjustable to changes in their tactical and strategic planning for distribution.

Often scheduling of this nature is accomplished by a manual load planner or computer applications which enable ‘live scheduling’. Scheduling is now planned on what is known as an interactive basis. This allows the use of a computer by the scheduler to plan the most effective and efficient routes. This process uses the actual demand data rather than historical demand. As a demand data, Rushton et al. (2000) specify time windows of delivery or simply the latest date and time of delivery. They also refer to the so-called ‘hard time windows’ which specify a particular date and time of delivery. Both kinds of demand in this context show consistent parallels to the approaches in this thesis. Therefore, this method of scheduling is known to be that which uses ‘real-time’ data therefore the result is the formulation of routes that are more accurate. (Toth and Vigo, 2002, Rushton et al., 2000)

Computer based techniques are accredited for touring and scheduling coming into its own as the computer models have the capacity for use in testing or simulations of the change in demand and its effect on vehicle availability and so forth and is known as “what-if planning” (Rushton et al., 2000)

Summarizing the above findings, one of the possible tactical or strategic planning approaches dealing with the VRP and in particular with the VRPTW is the planning on demand. This is what this thesis will refer to.

3.1.3 Heuristic and meta-heuristic Models

Having looked at the tactical and strategic planning approaches for distribution and the VRP or the VRPTW, one needs to look now at the underlying algorithms for such systems. Here, the sum of heuristic and meta-heuristic models for a distribution planning in the context of the VRP is very large. The following will therefore concentrate on a small selection that shows similar approaches to those chosen in the model of this thesis. The work of Badr (2002) states that DVRP can be considered a good example of a distribution context, because of the fact that intelligent manipulation of real-time information can distinguish between one company (or group of companies) and another by superior on-time service or cost. Problems of both generic vehicle routing (GVRP) and dynamic vehicle routing are identical. But *“in GVRP all routing and demand information are certain and known prior to the day of operation, whereas in DVRP part of or all of the necessary information is available only at the day of operation.”* The DVRP significance is stated to be *“crystallized by the variety of environments it* *can model."* (Badr, 2002, p. 712) The mention of this DVRP phenomenon with the exact knowledge on or after the operational occasions (i.e. through the removal of TWC in a simulation model) is what this thesis's model refers to by investigating existing routes after their execution. Even though, the model underlying this thesis does not comply with the original base thoughts of the DVRP.

Gambardella et al. (1999) report that one of the most successful and an exact method for the CVRP is the method known as the: *"…k-tree method"* of Fisher (1994) which succeeded in solving a problem with 71 customers. However, there are smaller instances that have not yet been precisely solved. To treat larger instances, or to compute solutions faster, the use of heuristic methods is described as inevitable. (Gambardella et al., 1999)

DPS are very often based on heuristic and meta-heuristic modelling. The reason for this approach becomes obvious when looking at the following basics of heuristics (Grams, 1994):

Analogy: Are there other problems which are similar, the same or related?

Generalization: Does the problem belong to a group or category of problems?

Specialisation: Can I (pre-) solve the problem, by picking an easy special case?

Variation: Can a different view or definition of the problem ease the solution finding process? Can the problem formulation be altered and ease the process of solution finding?

Reverse Search: Does it help to identify the desired result and move backwards in the process of solution finding? (See Section: 4.1.1 Mapping the Research Design)

Splitting: Can the problem be split in small, solvable parts or sections?

Complete Enumeration: Can a sum of partial solutions comply with a part of the target solution? – Can the total of partial solutions be achieved, that comply target solution? (See Section: 6.3: Sensitivity Analysis)

From this, one may conclude that the heuristic research approach on the problem of DPS has to do with trial and error or the trial itself as a basis of this methodology. In fact, the majority of research publications concentrate on heuristic and meta-heuristic distribution planning, optimisation of vehicle routing and the organisation of optimised distribution of goods. (Pachnicke, 2007) Further trade-offs or cut backs from the general problem formulation of optimised distribution are common practice. The equal basis for all research on this field is: a number of customers are to be serviced from a central depot with vehicles of the same (or different) capacity. Each customer's demand is to be covered by exactly one defined kind of service. (Collins and Whybark, 1985)

If this service has to be provided within a given time window, the research focuses additionally on the VRPTW. The objective is to determine a feasible route schedule of the vehicle which primarily minimises the number of vehicles (primary criterion) and then the total travel distance (secondary criterion). These are the two main criteria of research. (Cordeau et al., 2002a) Most of such researches neglect the fact of production planning and the steering of inventory and multi-line production schemes. Such a focus is the hybrid approach where both sections underlie linear heuristic algorithms. From this focus, the heuristic or meta-heuristic tabu research approach does not fully cover the need of an UMTO with direct distribution. The above primary and secondary objectives meet the criteria of modern DPS but do not cover the simulative approach that is used when conditions of delivery change. Such a change of conditions may apply when customers change time windows, the order itself or for other reasons. They also trade-off the fact, that all vehicles have the same capacity. This is in real operations not always the case and cuts back on a manufacturers flexibility using other types of vehicles, should the ones of the same capacity not (not all, or only a part thereof) be available. (Gehring and Homberger, 1999)

The meta-heuristic approach to the VRP or the VRPTW is also done with a parallel or hybrid condition. (Gehring and Homberger, 1999) There are other approaches for operational optimisation where three types of parallel strategies (Toulouse et al., 1996) are used: parallelism of operations within an iteration of the solution method (Garcia et al., 1994), decomposition of problem domain or search space (Badeau et al., 1997) and multi-search threads with various degrees of synchronisation and cooperation. (Schulze and Fahle, 1999) All of these approaches aim for a minimisation of the vehicles and a minimal travelling distance of the vehicles only. Irrespective of their individual approach or methods, these authors do not or only partially cover the need of UMTO. Their results, however, prove that the minimisation of vehicles and total travelling distance do have positive effects on the cost of distribution and consequently on the economies of scale.

The conclusion of this section is that heuristic and meta-heuristic models with linear algorithms for a DPS reduce the number of vehicles and also reduce the total travelling distance of the fleet. In addition, this may also be applied to routing problems with time windows. (Gehring and Homberger, 1999) The cost savings of this approach is underlined by the research results in using heuristic and meta-heuristic solutions, where existing routes using the savings criterion of minimal number of vehicles and optimised mileage of the travelling vehicle is merged (the meta-heuristic approach) with the gradual assignment of vertices to vehicle routes using an insertion cost. (Laporte et al., 2000) These modern approaches have all been built on the results of classical research on heuristics applying for the VRP. (Clarke and Wright, 1964) A more modern approach has begun with considering a heterogeneous fleet of vehicles which are selected in their capacity according to the delivery restrictions given by the customers. This approach is very interesting in light of the fact that not all vehicles are able to service every type of customer. (Chao et al., 1999)

Typically, there are different categories of vehicles which are allocated to the category of customers to be served. This compatibility relationship for a site-dependent VRP has a strong operational directive and uses a heuristic approach.

3.1.4 Stochastic & Dynamic Simulation based Planning in DPS

Other members of the family of approaches to the VRP are the stochastic and the dynamic simulation based systems. They have gained growing importance in recent research on the VRP due to their retro-active and also their pre-active ability to adapt to changes in route planning. Here, especially, the dynamic approach is gaining more and more attention which is evident from the most recent publications. - Ganesh et al. (2009, p.2) say that stochastic and/or dynamic information in most real life applications *"occurs parallel to the routes being carried out."* Real-life examples of stochastic and/or dynamic routing problems include the distribution of deliveries to private households, the pick-up of courier mail/packages and the dispatching of buses for the transportation of elderly and handicapped people. (Ganesh et al., 2009) It is related that in these specific examples unknown may include:

1. Customer profiles;
2. Time to begin service;
3. Geographic location; and
4. Actual demand and these factors may not be known when planning begins or even at the time service has begun for the customers with advance requests. (pp.2-3)

Ganesh et al. (2009) say that two distinct features result in the planning of routes that are of high quality in this more complex environment. These are:

1. Constant change; and
2. Time horizon.

However their findings were anticipated by Bowersox (1972) in his first findings on dynamic vehicle routing. Probably one of the most important publications in recent years was that of Psaraftis (1995). Here the stochastic and dynamic simulation of the VRP was first added with the VRPTW.

From the findings of Bowersox (1972) VRP with stochastic demands, the so-called 'Vehicle Routing Problem with Stochastic Demands' (VRPSD) was developed. It is usually modelled as a Stochastic Programme with Recourse (SPR). SPR solves the VRP in two stages. In the first stage, a planned or an 'a priori' solution is determined. In the second stage, a recourse or 'corrective action' (p.112) is applied to the first. This is done if the first stage has failed due to a route failure. (Teng et al., 2003) A case of route failure may be the exceeding of the vehicle capacities, or failure to meet client demands in the agreed time of delivery. In addition, the total expected cost is composed of the cost of the first stage solution and the net expected cost of the recourse. Looking at recourse policies (Stewart, 1983), research has produced two policies; the first has produced penalties proportional to the probability of for exceeding capacities and the second uses penalties proportional to the expected demand in excess of the capacities. This model of penalisation is more of a strategic and mathematical function; a better form of recourse seems to be to re-optimise the remaining portion of any route upon each failure. This does, however, not include the possibilities of the already planned route and consequently misses out on opportunities to recover lost resources. (Bowersox, 2008, Weiqi and Alidaee, 2002, Larsen et al., 2002)

In many instances today, research with stochastic simulation and dynamic simulation include the parameters of the TSP and the VRPSD. This also allows including return trips to a route with the formulation of maximal driving times and other legal restrictions. (See Section: 4.2.2 Supporting Cost Parameters) At the start of this research, such field algorithms were described as integer linear stochastic processes. Today, this has progressed to research of chance constrained and under recourse aspects. (Yang et al., 2000) Since most of the research in the past has neglected the cost and all related relevance to this under the aspects of cost, the VRPSD has concentrated on the cost effects and consequently has become more attractive to real life-operation.

Consequently, stochastic demands are increasing in attraction for operational systems for DPS. The stochastic element in a DPS is a difficult part of such a system. Based upon near optimal large size problems, efficient heuristics can solve simple routing tasks. Such simple problems include, for example, capacitated vehicles, vehicles of same or different capacities etc. With the implementation of further requirements such as cost aspects, driving time, customer requirements as major constraints, the VRPSD has proved to be an optimal tool to solve complex routing problems. (Teng et al., 2003)

The simulation of different alternatives or routings includes the better solutions (Badr, 2002) under different aspects. With regards to this work, the cost effects are the major criteria in addition to the shortest travelling distance, the use of a minimal number of vehicles, the use of a maximum share of the vehicle's loading capacity under the constraint of transport quality and security and finally the alternative calculation of external or own vehicles. The latter has proved to be somewhat cost sensitive due to basic algorithms of a DPS facility in planning one-way or round trips. (Psaraftis, 1995) Looking at this stochastic demand, one can realise that the probability of one-way trips with external vehicles appear to be a less cost intensive approach, since the vehicle utilisation from a payload point of view is far more optimised. (Tempelmeier, 2002)

Since the classical VRP research does not cover the total amount of planning parameters in real-life, stochastic and simulation based routing optimisation becomes more frequent in its use. (Larsen et al., 2002) This is due to the ability to manage several demands and constraints in parallel and shortcut computing time to a feasible level. In addition to planning parameters previously mentioned, routing optimisation including the factor of cost, the requirement of an UMTO is that the DPS also dominates sequences, frequency and other parameters of production. (Spencer, 1994) Consequently, production planning parameters must be part of a DPS for a UMTO.

In conclusion, current research on VRP with and without stochastic and dynamic demands is at a very high level (Bowersox, 2008) and covers almost all parameters and en route constraints of distribution planning and routing optimisation. The latest research in this field is mainly based on different stochastic modelling of smaller problems in VRPSD and it confirms the statement that a DPS based on VRPSD has the capability to perform optimised routing with all aspects of modern delivery, but is not yet fully solved. (Bowersox, 2008)

3.1.5 Planning under Certainty and Uncertainty

The distribution planning with DPS can be undertaken with certain degrees of certainty and also with uncertainty. Both parameters are fairly common in distribution planning and hence deserve some mention in the context of this thesis. In both cases, uncertainty is more interesting, as planning with a large degree of certainty simply means being on the safe side. Planning with uncertainty, however, includes 'assumptions' en route that may derive from unclear time windows and other delivery demands. Here, Kleywegt and Shapiro (2003, p.17) have some very interesting and important information on this. They state that those decisions are often made by decision makers: *"in the presence of uncertainty"*. Decision problems are often formulated *"as optimization problems and thus in many situations decision makers wish to solve optimization problems which depend on parameters which are unknown."* Formulation and solution of such type problems are generally very difficult *"both conceptually and numerically."* (Kleywegt and Shapiro, 2003, p. 17)

The conceptual stage of modelling presents difficulty since there are various ways that formalization of the uncertainty can be modelled formally. The attempt in formulating optimization problems is to identify a suitable trade-off between *"the realism of the optimization model, which usually affects the usefulness and quality of the obtained decisions, and the tractability of the problem, so that it could be solved analytically or numerically."* (Kleywegt and Shapiro, 2003, p. 18) The authors state a static optimization problem as follows in relation to operation under uncertainty:

> *"Suppose we want to maximize an objective function $G(x, \omega)$, where x denotes the decision to be made, X denotes the set of all feasible decisions, ω denotes an outcome that is unknown at the time the decision has to be made, and Ω denotes the set of all possible outcomes."* (p.19)

Kleywegt and Shapiro (2003, p.21) state that there are: *"…several approaches for dealing with optimization under uncertainty. Therefore, the situation is such that the decision has to have been made prior to the knowledge of the eventual outcome is known to the decision maker."* This statement can be transferred when looking at the cost of transportation. (Copacino and Lapide, 1984) The treatment of uncertainty is mostly dealt with a sensitivity research analysis. Copacino and Lapide (1984) have done this, to an extent, where the choice of transport mode or the comparison of direct versus indirect delivery via an intermediate storage and further transport was analysed. Their modelling of location analysis has become common practice today but fails operational implementation for UMTO as those firms deliver to their customers mainly directly without intermediate storage. On the other hand, their model could be applied for UMTO in a priori state of distribution planning into geo-structures for a kind of pre-analysis of vehicle capacity usage and pre-decision on the utilisation of the fleet of vehicles to be used. Finally, the status of certain and uncertain planning parameters originates ever so often from a non-homogeneous order receiving in business as it is the case with UMTO in general. This may result in a fluctuating distribution planning and in fluctuating transport requirements which also derive at non-homogeneous fleet of own and/or external vehicles.

3.1.6 Tabu Search and Genetic Search

The tabu search heuristic was first introduced by Fred Glover (1989 and 1990). With every iteration the vicinity of each current solution is explored, and the best solution is selected as the new current solution. However, as opposed to a classical local search technique, the procedure does not stop at the first local optimum when no more improvement is possible. The best solution in the vicinity is selected as the current solution, even if it is worse than the current solution. (Glover, 1989) This approach allows the method to escape from local optima and to explore a larger fraction of the search space. To prevent systems from cycling around without coming to solutions, recently selected solutions are forbidden and inserted into a tabu list. (Bräysy and Gendreau, 2002) From this point of view, it makes no sense to store any of the recent solutions in a system. Rather, for each modification leading to a new solution, the inverse modification is declared tabu, and stored in a tabu list. Finally, a tabu move can be overridden if an overall best solution is produced by doing so. These modifications are defined individually of each DPS system in terms of the links that are removed from the current solution. (Potvin et al., 1996)

Genetic search directly applies the genetic operators to the individuals (solutions), and heuristic information about the problem is used to guide the search. (Glover, 1989) Consequently, genetic systems or parameters in a DPS depart from the theoretically founded practise and simply exploit the general problem solving methodology of genetic algorithms, namely the evolution of a population of solutions and the generation of even better solutions through a recombination of good characteristics of parent solutions. Classical genetic algorithms work on a population of chromosomes that encode the characteristics of the corresponding individuals. Their robustness comes from their ability to evolve good individuals (solutions). In other words, classical genetic algorithms do not decode the chromosomes as individuals in order to guide the search process. (Glover, 1990)

Looking at both methodologies, the finding process for a better solution is based on a non duplicable data base. The fact on non-duplication prevents cycling as an indefinite process. (Potvin and Bengio, 1996) The question which arises is which of the two approaches is more effective and ultimately leads to better results? Besides computational aspects of a DPS, the operational requirements are that sometimes the better solutions are a summary of compromises resulting from the 2-Opt and Or-Opt exchanges. The best computational individual solution is practically not always the best. (Gendreau et al., 2002) Therefore, the alternative of the tabu search and modelling of a DPS appears to be more applicable than the genetic search where chromosomes are on principal not decoded for a repetition and prevention of cycling. – As a result of the above, the critique on both search algorithms becomes obvious by stating that they define optimisation, knowing that there could be better solutions. This, however, would lead to the assumption and generally accepted critique that their optimisation search is questionable.

The above explanations on tabu and genetic search algorithms describe some of the concerns and borderlines for the practical implication of simulation in the context of this research. How these concerns will be dealt with in order to reduce the mentioned risks, can be found in the formulation of the cost function and the underlying cost parameters. (See Section: 4.2 Definition of the Cost Function) Here, numerous tabu settings are mentioned in terms of parameters that may not be exceeded, deviated or refuted.

3.1.7 Simulated Annealing

Simulated annealing (SA) search algorithms are currently some of the most recent and popular algorithms in the VRPTW research with capacitated vehicles. Arbelaitz et al. (2004, p.29) state the VRPTW with a SA approach as follows:

> *"The VRPTW problem, has a vehicle fleet $V = \{v_1, v_2, \ldots, v_n\}$ with limited capacity, $CV = \{cv_1, cv_2, \ldots, cv_n\}$, and with a service time $H = \{h_1, h_2, \ldots, h_n\}$, used to serve some orders of customers $P = \{p_1, p_2, \ldots, p_m\}$ each one of a fixed quantity $CP = \{cp_1, cp_2, \ldots, cp_m\}$ and in a constrained time, Time Window $TW = \{tw_1, tw_2, \ldots, tw_m\}$. A set of routes $R = \{R_1, R_2 \ldots, R_l\}$ where $R_i = (p_k, p_l, \ldots, p_s)$ (one for each vehicle, maximum) minimizing the objective function (the addition of the traveled distance) has to be built".*

Based on this definition, this thesis chose a very similar model orientation. The authors propose: a solution combining metaheuristic techniques with a route building heuristic. To do that, they apply random permutations V P of the set of orders P, and take them as the starting point to build a solution. A solution of the problem depends on every parameter mentioned before: $F\ (V\ P; R_i; CV; H; CP; TW)$. (Arbelaitz et al., 2004) From here this thesis develops a model similar to the one used by these authors by combining the SA metaheuristic technique with the route building heuristic. This combination is the basis for their further application in route building:

"A permutation of the whole set of orders of customers is used as working tool, and, at each moment, the permutation being used to get new ones or to make new searches is called the current permutation vector, VP_c. A new element of the search sequence is get applying the investment operator to VP_c: two orders of the permutation are randomly selected and exchanged. In stage n, when the value of the objective function is smaller for VP_n than for VP_c, VP_n becomes VP_c. When the value of the objective function is higher for VP_n than for VP_c, VP_n is accepted as a new starting point with probability $e^{(-D=T)}$, which depends on the quality of the solution, measured as the difference of the current solution and the best solution found up to the moment D = (cost VP_n-cost VP_c), and the temperature parameter T." (p.28)

From this definition of the SA approach many other approaches such as those of Urban (2006) and Cordeau (2005) have been similarly developed.

In summary, the SA approach to the VRPTW is, by far, the most sophisticated and evolutionary developed heuristic. (Golden et al., 2008) In their book, these authors refer with numerous publications of individual writers to this statement and provide evidence that the SA approach today, reveals the highest performance in terms of cost savings and computing time.

3.1.8 Capacitated Vehicle Routing

Literature on the research of the VRPTW differentiates between 'capacitated' and so-called 'un-capacitated vehicles'. Research with a trend towards 'real' life interpretations often use capacitated vehicle approach to identify parallels to operational functions in practice. The problem of capacitated vehicle routing with time windows is defined as follows:

"Given n objects (loading items, cubage or production units), placed at arbitrary initial locations, the problem of transporting them efficiently to n target locations (customers), with a vehicle that can carry at most k objects at a time, on the shortest route and at the lowest cost by meeting all parameters of the customers delivery." (Charikar et al., 2001, p. 228)

Charikar et al. (2001) have demonstrated a good solution to the stowage and packing problem for capacitated vehicles. They have also differentiated between direct and indirect delivery and therefore an application of their findings would be suitable for the requirements of an UMTO on deliveries with TWC.

In most research papers on the subject of capacitated vehicles, the combinatorial approach of the optimised packing of a vehicle and the TSP optimisation can be found. Here, it is common to assume a homogeneous fleet of vehicles departing from a central depot and serving known customers with known demands. (Ralphs et al., 2003) Some research in this field goes back to 1985. (Haimovich and Rinnooy, 1985) These authors, however, make restrictions, whereby the vehicles can only serve a limited number of customers per route, day or delivery period. This approach applies to this thesis. Their competent assumption on the limited service ability of a vehicle can be transferred to legal driving times, maximum loading capacity and other capacitated parameters relating to the vehicle. (See Section: 4.2.2 Supporting Cost Parameters) The major focus and approach of competent research in this field is always the combinatorial demand of two (or more) parallel planning parameters whereby one is always the TSP.

In conclusion, one can say that the capacitating of vehicles is a widely researched common practice. The individual definition of the capacitated constraints varies from paper to paper. In real-life operations, however, there is mostly a combination or a multiple request of capacitated constraints in conjunction with the TSP. It is the sum and the character of the individual capacities that makes this research focus probably one of the most interesting in the area of VRPTW. For the parameterisation of DPS, it is this definition of capacities and their tuning and setting of limits which provide some of the most relevant success factors for implementing such systematic algorithms in an organisation, such as a UMTO.

3.2 TWC in Distribution Planning

Time windows can be customer's restrictions or boundaries of time when delivery has to be affected at a customer. They can also stand for specific handling requirements at specific times of delivery or any other time related restrictions. The lower margin is the case when a vehicle arrives at a customer's location before the agreed window opens. In this case, the vehicle must wait until the window does open. This time gap is considered as waiting time. The upper margin applies when a vehicle arrives after or at a time when the customer will refuse the delivery on the grounds of being too late.

"In case of hard time windows the late arrival is excluded in the planning processes." (Potvin and Bengio, 1996, p. 166)

Time windows in research are always seen as fixed cornerstones and parameters that are fixed or non changeable. (Fisher, 1994, Potvin and Bengio, 1996, Potvin et al., 1996, Savelsbergh, 1992a) This does not always apply to practical operations. If a lower margin is hit by vehicle, it does not automatically imply that the vehicle will wait and that waiting time is added to the total routing time. The same accounts for the hit of the upper margin. It is not always the case that the delivery will be delayed until the next period of delivery or that it is cancelled. Practical operations, however, require more flexibility of a DPS and especially the expansion of time windows. (Tan et al., 2001) Time window boundaries are, therefore, often amended by operational procedures. (Bent and Van Hentenryck, 2004) Here, and in the case of reaching or even exceeding the boundaries, the entire routing calculation needs to be re-done. (Biethahn et al., 2004) In this context, dynamic DPS with selected meta-or hybrid heuristics in terms of TWC have experienced intensive research, but only very little in the surrounding fields of the UMTO requirements and TWC connected herewith.

In today's world and, in particular, with today's traffic congestions, the re-optimisation of routing on a dynamic basis with stochastic demands is a common procedure. TWC is or are the driving force in co-relation with local temporary traffic conditions for the requirement of a high flexibility of any DPS. (Gietz,

1994) This explains why certainty and uncertainty in a DPS needed separate attention in this paper. (See Section: 3.1.5 Planning under Certainty and Uncertainty) The conclusion of TWC is that they are not always, but in most cases fixed time margins which de-optimise vehicle routing from a time and TSP point of view. Time windows are set but yet partially flexible constraints, time windows are regular and common parametric customer requirements.

Finally, one can say that any VRP or DPS research without time windows is, from an operational point of view, not realistic and deserves no further attention for the objectives in this thesis. The reason for this decision is that in today's world, nearly all logistic functions are undertaken in time windows. This results from the implementation of JiT programmes since the early 1960's. (Gudehus, 2005) Time windows are planning factors for any participant in the supply chain and allow them to plan, coordinate, alter and fix the costing of resources.

However, this raises the question why are time windows set at all by many recipients of goods? – If they are set for the sake of optimisation of their own supply chain organisation, then they are very meaningful and should be met under the suppliers' focus of customer driven supply chain management. (Hines, 2004) In many cases however, they exist from marketing base data management without real supply chain management meanings. In the context of this thesis the only contractually set TWC between the GKFI and its retail clients, is a calendar week after the placement of the order. This, according to Hines (2004) and Spencer (1994) is a typical UMTO production and distribution characteristic.

The model underlying this thesis has been calibrated with uniform average speeds for particular classes of road and thereby takes no account of variable traffic conditions (see 2.5 Importance of the Cost Problem in Distribution for UMTO and Table 5: Set Cost Parameters). That the same routes investigated at different points in time may have different traffic conditions is obvious. For the maintenance of the ceteris paribus condition in this thesis, it is necessary to assume identical traffic conditions through a uniform calibration of the applied DPS for each type of road.

3.2.1 Classification of TWC in VRP

In this section of distribution planning approaches, the classification of TWC in the research field of the VRP requires special attention. It may be argued that ordinary TWC in the VRP can only be marginally compared to those in the context of UMTO. From the previous findings and elaboration on the specifics of a UMTO, we know that the TWC for distribution planning stands in a direct and very strong correlation with the TWC in production planning. In the following, some of the important publications on this problem of the correlation between the TWC of distribution and production are looked at and discussed. By doing so, their findings and those related to this thesis are mentioned for the sake of comparability or non-comparability.

The work of Bramel and Simchi-Levi (1992) reports that the Vehicle Routing Problem with Time Windows (VRPTW) can be stated as follows:

> *"... a set of customers dispersed in a geographical region has to be served by a fleet of vehicles initially located at a given depot. Each customer has a load that must be picked up, and the customer specifies a period of time, called a time window, in which this pick up must occur. The customers are served by vehicles of limited capacity, that is, total load carried by each vehicle can be no more than the vehicle capacity. The objective is to find a set of routes for the vehicles, where each route begins and ends at the depot, serves a subset of the customers without violating the capacity and time window constraints, while minimizing the total length of the routes."* (Bramel and Simchi-Levi, 1996 P. 502)

From this definition it may be derived that the problem solving lies with the construction of shortest possible round-trip routes with capacitated vehicles and within pre-set time windows. Their definition of the problem identifies however the importance of the route duration or the objective of minimal kilometrage to be travelled. In this context Savelsbergh 1992b refers to edge exchange methods. These are a widely discussed approach to the TSP and VRP. The TSP is viewed as a graph, such that cities are presented by the graph's vertices while the graph's edges stand for paths, and a path's distance is presented by the edge's length. The end of edge exchange methods may be the minimization of the distance travelled or the tour duration while remaining a cycle tour visiting all cities. In order to achieve such a solution starting from an initial cycle tour serving all cities, edges are removed and replaced by other edges which were not included in the tour before. The resulting total tour length or duration then is compared to the initial status. In the case of an improvement, the new tour is maintained as starting point for further edge exchanges. Improvements to these methods for the VRP according to Savelsbergh (1992b) are referred to be *efficient implementations of edge exchange methods when the objective is to minimize route duration and the departure time of a vehicle in a depot is not fixed, but has to fall within a time window, as it is the case in many real-life situations*. (Savelsberg, 1992b p.146)

During the past decade, researchers investigating vehicle routing and scheduling have highlighted the use of algorithms for problems. In real life however, the problems have increased in size and constraints of practicality are no longer brushed aside in consideration of the research in this area of study.

One such constraint is said to be *"the specification of time window at customers, i.e., time intervals during which they must be served. These lead to mixed routing and scheduling problems."* (Savelsbergh, 1992, p.146) The introduction of time windows for customers there is said to allow *"the specification of more realistic objective functions, compared to minimizing distance, such as minimizing waiting time, minimizing completion time, and minimizing route duration."* The author also states that edge-exchange improvement methods are that which form both an important as well as a popular class of algorithms in the area of vehicle routing problems. (1992, paraphrased) Previous studies in this area focus on efficient implementations of edge-exchange improvement methods for the vehicle routing problem with time windows. However, Savelsbergh (1992, p.146) says that these studies focus completely on the aspect of feasibility and fail to identify *"profitable exchanges for realistic objective functions."*

Savelsbergh (1992, p.153) states that the "*growing importance of 'side constraints as well as realistic objectives in practical distribution management* *and the need for fast implementation of algorithms in the context of interactive planning systems justify the current research."* More realistic objective functions are critically needed. The model presented by Savelsbergh (1992, p.153) is one in which *"the iterative improvement methods were embedded in a two phase approximation algorithm for the VRPTW."* In his function as one of the pioneers in this area of research the author states: *(1) "the relevant iterative improvement methods are applied to all possible combinations of two routes; and (2) the relevant iterative improvement methods are applied to all separate routes"*. (p.154) From this, however, one could question how many times these iterations have to be undertaken to achieve optimum results, and when is such an optimum achieved to satisfy the research objective of minimizing route duration? In this context and to clarify the term optimization used in this thesis the general question arises, what is the optimum and can it ever be achieved? Here, the author has a clear but short answer in saying: *"as long as feasible and profitable exchanges have been found."* (p.154) Salvesbergh (1992) states that while this method is unsophisticated in the least that it is suitable for the present purposes. Investigation of the varying effect of objective function differences compared were the solutions *"obtained with minimizing route duration as objective to those obtained with minimizing travel time and minimizing completion time."* (p.154) The results are stated to demonstrate clearly, the importance of "*being able to handle different objective functions."* (p.155)

This author would state that efficiency has been assessed through comparison of running times of the implementation which has been proposed *"of iterative improvement techniques with a straightforward implementation of these techniques, i.e. (temporarily) perform an exchange and test its feasibility and profitability, for various types."* (p.153) These findings on times include the generation of the first set of routes; this is said to demonstrate 'the efficiency' of the implementation that is proposed in Savelsbergh's work. The chosen solution is one in which 'profitable' exchanges are identified resulting in computing times increasing when there are time windows present. – From these findings, Savelsbergh (1992) has founded the basis for many more worldwide research publications for CVRPTW. However, Savelsbergh (1992) and almost all other researchers have always investigated this problem under the condition of what Bramel and Simchi-Levi (1992) have described as

> *"…each customer has a load that must be picked up (or delivered), and the customer specifies (or demands) a period of time, called a time window, in which this pick up must occur."* (p.502)

This thesis would question those 'must' 'specification or demand' by the clients and aims to investigate on what could occur, when the 'must' is still being satisfied, but in a different context, by 'specification' of new time windows with the motivation of reduced costs in the delivery of UMTO.

In order to understand the particular problems of a UMTO in the context of the production and distribution problem with TWC the work of Wolsey (2006, p.471) reports a study of *"two lot-sizing problems with time windows."* In each of these cases it is stated that the demand data *"...consists of a set of orders" and those are stated as follows: "...k = 1, . . . , K consisting of a quantity Dk and a time interval [bk, ek] lying within the time horizon [1, n]."* (p.471) The author reports that the production time window*" is the interval during which the order must be produced, while delivery of the order takes place in a period 'ek'.* Here, the author continues by stating that this problem involves consideration of two variants: "*(1) in the first each order is distinct (client-specific) whereas in the second, (2) orders are indistinguishable (non-specific).*"

It is, however, held by (Brahimi et al., 2006 p. 471) that the delivery time window for an order *"is the time interval in which the order must be delivered to the client."* For the problem that it is client-specific with production time windows they say that the approach taken is one in which polynomial time optimization algorithms and also that tight mixed integer programming formulations, possibly with additional variables, are sought. In some cases "*this means that we have a description of the convex hull of feasible solutions.*" (p.472)

Multi-item problems are said to require the use of: (1) column generation, or (2) Lagrangian relaxation approaches in which one requires the optimization algorithms to solve the sub-problems, or one can use a direct mixed integer programming approach and provide an initial Manufacturing Information Planning (MIP) formulation including the tight formulations of the sub-problems. The primary results in the work of Wolsey (2006) are said to be:

1. *The presentation of several mixed integer programming formulations and the relationship between them, including those of Brahimi et al. (2006) and Lee et al. (2002);*
2. *For the production time window problem with constant capacities and Wagner-Whitin costs, WW − CC − TWP, derives a tight O(n2) × O(n2) extended formulation. For the uncapacitated version WW − U − TWP, a tight formulation in the original production is obtained, stock and set-up variables with O(n2) constraints;*
3. *The restricted production time window problem with non-inclusive time windows, or equivalently the production time window problem with indistinguishable orders, is also equivalent to the standard lot-sizing problem with upper bounds on stocks. For the problem with general cost structure, derives an O(n2) DP algorithm and an O(n2) × O(n2) tight extended formulation for the uncapacitated problem LS − U − TWP(I) by using the restricted time window structure;*
4. *On the other hand, for the constant capacity version LS −CC −TWP(I), derives an O(n3) DP algorithm and an O(n3)×O(n3) tight extended formulation by using the stock upper bound viewpoint*. (Wolsey, 2006, p. 472)

Here, Wolsey (2006) is supported by others (Medouni et al., 2006) in the statement that the *O(n2)* DP algorithm and an *O(n2)* × *O(n2)* tight extended formulation reflects on the uncapacitated problem *LS* − *U* − *TWP(I)* under a restricted time window structure.

The explanations above of Wolsey (2006) and Medouni et al. (2006) state that the planning of minimal route duration with minimal kilometrage to be travelled, serving a set of clients in specified time windows with capacitated vehicles under the restrictions of time windows in production capacities is of great complexity. Their classification of the TWC distribution problem in the VRP context for production illustrates the fundamental UMTO problem.

According to the authors mentioned in this section, one may conclude that there are different TWCs in VRP and illustrate those in the following table as a simplified overview.

Table 7: Classification of TWC in VRP

Classification of TWC in VRP			
	Charracteristics		
	Time Window	**Compliance**	**Dominance of Heuristics**
Hard TWC	Fixed date and time of delivery	Recipients' requirements have to be met exactly	Time
Soft TWC-1	Time span for delivery	Simple compliance with recipients' requirement	Time, Distance
Soft TWC-2	Time span for delivery	Compliance with recipients' requirement and parallel optimisation of distribution cost	Time, Distance, Distribution Cost

From the authors' findings one may conclude that such a complexity of problems may only be captured and solved with the use of computerized systems. The corroboration of this is stated in the following section of this chapter. The 'Hard TWC' and the 'Soft TWC-2' as explained in the above table are those that this thesis has implied. This category of soft TWC with the dominant heuristics for time, distance and cost optimization, in this sequence of dominance, is what demonstrates the complexity that the above authors refer to.

3.2.2 Use of complex DPS for VRPTW

The use of DPS to solve the complex VRPTW has numerous origins in literature and in practice. One remarkable work is that of Solomon (1987), who reports the consideration of the design and analysis of algorithms for vehicle routing and scheduling problems with time windows constraints. He presents the development of heuristics and test problem sets and computational experiments with results indicating that "*the insertion heuristic I (1) can be explained with the realization that while routing problems seem to be driven by the assignment-of-customers-to-vehicles component—as indicated by the success of the Fisher and Jaikumar generalized assignment heuristic—the sequencing aspect of the problem seems to drive routing problems dominated by time windows. It is this aspect of the problem that the insertion heuristic II (2) captures so well.*" Based upon Solomon's study the use of the insertion heuristic II is recommended *"to obtain excellent initial VRPTW solutions in a reasonable amount of computing time."* Because of the stable behavior of this heuristic it is held by the author that it will *"perform well on practical problems."* (Solomon, 1987, p. 264)

The work of Desrochers et al. (1992, p. 353) develops a *"new optimization algorithm which uses a column generation approach for a set partitioning formulation for the VRPTW."* Here, results indicate that this algorithm was successful and *"on a variety of practical sized benchmark VRPTW test problems."* The algorithm was said to have *"the capacity to problem-solve on a scale that was six times greater than any other reported algorithm."* Stated as a key element of distributions systems is the *"routing and scheduling of vehicles through a set of customers requiring service."* The authors go on to relate that the VRP involves *"the design of a set of minimum-cost vehicle routes, originating and terminating at a central depot, for a fleet of vehicles that services a set of customers with known demands. Each customer is serviced exactly once and, furthermore, all the customers must be assigned to vehicles without exceeding vehicle capacities."* (Desrochers et al., 1992, p. 256) In the following years, these authors have developed their theories on the above mentioned framework further to the extent of the minimizing of computing time and the findings of new algorithms for the VRPTW with computerized systems. To account on all them would certainly stress the frame of this work, but some remarkable works until today show that the process of the worldwide research on the VRPTW is of high research interest and enjoys a continuous development.

Bramel and Simchi-Levi (1993, p. 501) report the use of a new algorithm that is based on the formulation of the problem *"as a stylized location problem"* and give results which demonstrate that the algorithm is effective *"on a set of standard test problems."* This statement relating to the 'Solomon Benchmark' is still valid and is supported by current research findings.

In this context, the work of Bent and van Hentenryck (2004) is very significant. They propose a two-stage hybrid algorithm for the VRP with the minimization of the vehicle number first in the algorithm through the use of simulated annealing and followed by minimization of travel cost through the use of a large neighborhood search, resulting in relocation of some customers. Experimental results are given to *"demonstrate the effectiveness of the algorithm, which has improved 10 of the 56 best published solutions to the Solomon Benchmarks..."* (Bent and Van Hentenryck, 2004, p. 515) In conclusion, they state that this algorithm is robust in nature.

The work of Wolsey (2006) reports a study of two lot-sizing problems and that each of these have time windows which have been recently proposed. It is stated that for the case of production time windows, both of which the client's specific order is required to have reached the end of production in a specified time period and it is reported by Wolsey that derived is *"tight extended formulations for both the constant capacity and uncapacitated problems to the problem in which the time windows can be ordered by time."* (p.471)

According to Wolsey (2006, p.471) this also demonstrates *"…equivalence to the basic lot-sizing problem with upper bounds on the stocks"*. The result is *"…polynomial time dynamic programming algorithms and tight extended formulation for the uncapacitated and constant capacity problems with general costs."* A similar approach is used to derive tight extended formulation for the problem and uncapacitated problems with 'non-speculative costs' with delivery time windows. (Wolsey, 2006, paraphrased)

Looking at the above as a small selection on the use of DPS to solve the VRPTW in the UMTO environment one can say that the developments of the use of DPS have started from single optimization algorithms to the use of multiple algorithms in horizontal and vertical clusters as combinatorial structures. From those developments focusing on the VRPTW, the use of DPS also involves the problem of supply chain modeling. Terzi and Cavalieri (2002, p.2) show to what extent this is being undertaken with the use of DPS. Their work states that *"modern industrial enterprises operate in a rapidly changing world, stressed by even more global competition, managing world-wide procurement and unforeseeable markets, supervising geographically distributed production plants, striving for the provision of outstanding products and high quality customer service."*

Companies unwilling to adapt to these changes by periodically revising their strategies and modifying processes in the organization are at a critical risk of losing their competitive edge. (Terzi and Cavalieri, 2004, paraphrased) There has been a great deal of emphasis on the last ten years on the needs of organizations to "*smooth their physical boundaries in favor of a more integrated perspective...*" (Terzi and Cavalieri, 2004, p. 3)

Simulations and thus the use of DPS in SCM can be carried out *"according to two structural paradigms"* according to Terzi and Cavalieri (2004 p.3). These two are given as follows: (1) *"using only one simulation model, executed over a single computer (local simulation); or* (2) *implementing more models executed over more calculation processors (computers and/or multi-processors) in a parallel or distributed fashion."*

Terzi and Cavalieri (2004, pp.3-6) report that parallel discrete event simulation is *"concerned with the execution of simulation programs on multi-processor computing platforms, while distribute simulation is concerned with execution of simulations on geographically distributed computers interconnected via network, local or wide."* A distributed execution of a simulation across multiple computers is stated to be for the following primary reasons: (1) to reduce execution of overall simulation time; (2) to reproduce a system's geographic distribution; (3) to integrate different simulation models that already exist and to integrate different simulation tools and languages; and (4) to increase tolerance to simulation failures. (Paraphrased)

Conclusions stated by Terzi and Cavalieri (2004, p.14) include that experiments of the hybrid approach proposed resulted in verification that *"the initial analytic solutions could not be accepted in the real world system having stochastic characteristics, which are not included in the analytic model."* They also conclude that the distribution model primarily impacts on production-distribution plans in the supply chain system proposed in their study.

In summary, the use of DPS as a tool of simulation for the improvements of distribution and production problems is an acceptable and preferable means of research and practical applications.

3.3 Distribution Planning for UMTO

SCM is based on the management of 3 basic sectional flows of goods (Günther and Tempelmeier, 2007), the incoming raw materials; the flow of goods within a production of shop(s); and the distribution of the goods to customers, warehouses or other interim locations. SCM as a new or modern management tool incorporates more than the steering and manipulation of the flow of goods and the attached information systems. It is commonly understood as a pragmatic change process in logistics. SCM is based on 3 pillars:

1. *The integration of all internal and external partners in the value chain through a holistic process – oriented cooperation management with such partners;*
2. *The re-design of core competences and complete process-oriented flow and steering of information, material and finance along the value chain under cost and quality aspects;*

3. *The implementation of modern IT-systems with a bi-functional task: (1) coordination (planning and steering of all processes along the value chain) and (2) communication (reduction of information barriers between internal and external partners along the value chain*). (Kuhn and Hellingrath, 2002, p. 127)

In this context, it becomes obvious that the planning of those processes and all related external and internal communication need a pro-active or an advanced planning tool to improve results and their effectiveness. Some more managerial approaches for the definition of SCM in the context of distribution planning for UMTO define it as the management of "...*upstream and downstream of relationships with suppliers and customers allowing superior customer value to be delivered at a lower total supply chain cost*". (Christopher, 1999 p. 81, Hines, 2004) In this context, Christopher (1999) refers his sights to SCM by adding that supply chains need to be extended beyond a purchasing and logistics organisation, as supplier's supplier and their suppliers should be included. Here, Christopher (1996) contributes further by stating that such a chain of supplier's supplier is not necessarily a linear structure as a chain of links, but much more a complex network of hierarchies, grouped in tiers and organisational interdependencies. Those networks with their infrastructure need to create high functionalities in order to provide each single customer along the chain with high quality in delivery. For this purpose, SCM often refers to partnerships and alliances. Here, Christopher (1999) refers to those as strategic and operational necessities. A closer definition in the context of UMTO and their distribution planning problem adds to the before mentioned statements that a major contribution to the successful integration of SCM is made upon the application of JiT (Just-in-Time) structures, through fast reactions in delivery, when a demand is known and goods are not produced for stock. (Harrison and van Hoek, 2005) These authors hereby add to the above mentioned definitions and requirements from SCM for UMTO by additionally focusing at the factor of time consciousness in distribution and by also adding a focus on the overall reduction of inventory all along the chains.

On the side of a distribution focus of the SCM requirements from a retail point of view, SCM for UMTO needs to achieve high levels of fulfilment, meeting as unique supply chain requirements as their product is in itself. (Stock and Lambert, 2001) Here UMTO need to support their customer's policies in service and supply through measurable benefits from economies of purchase. According to Stock and Lambert (2001) UMTO have to meet the changing demands arising from market conditions, e.g. manage traffic conditions in delivery, disruptions from delivery planning or actual transport, and achieve lowest total logistics cost by balancing trade-offs to deliver the agreed level of customer service, such as TWC. From those statements Stock and Lambert (2001) confirm the entire organisational focusing of the distribution planning for UMTO in the context of research in this thesis.

Many research projects on SCM have derived from earlier developments in logistics research. There, the focus was mainly on the flow and the development of the goods in the physical movement process of raw materials from suppliers up to the delivery to the final customer. (Gudehus, 2005) With the introduction of SCM, external partners were included in the value chain which resulted in the need to change processes and communication through a re-design of the entire value chain (Kuhn and Hellingrath, 2002) The target of this inclusion was the reduction of stocks and consequently the reduction of binding capital and all other resources connected herewith. (Stadtler, 2005) Reduction was not only the main purpose. The developments in the automotive industry from 'Just-in-Time' to 'Just-in-Sequence' and other value chain oriented optimisations made it necessary to include external and internal partners more and more, to achieve a smoother flow of goods and information. This change of paradigms in the client-supplier relationship requires a completely new kind of co-operation that is mainly based upon a bi-directional transparency. This transparency brings to light both partners' planning of material and resources requirement and supply planning.

Here it becomes obvious that the planning tools to steer such information and physical flow are indeed critical success factors. APS soon achieved the role of the 'enabler' (Kuhn and Hellingrath, 2002) along the newly re-designed value chain in the industry. With the emerging importance of APS becoming apparent, the research community began to structure such planning systems. The reason for this development stemmed from an operational tendency, where different software companies began to launch their products for these tasks.

Besides different applications and fields of implementation of APS, most did have some programmes and planning tools in common. (Rohde et al., 2000) What is advanced planning and how is it structured? In general, the answer to this question is similar to most other planning methodologies, i.e. financial planning. The process of planning is tri-fold and sub-sectioned into:

1. Long-term planning: at this first level, strategic decisions are made on a corporate level to create the so called prerequisites or general parameters of an enterprise or its subsidiary. These decisions are of a design and political nature. They have long-term effects that are to be implemented over many years.
2. Mid-term planning: This level is characterised by first operational decisions within the scope of the strategic and long-term planning above. This stage is usually affected in project groups that work over a period of 12 - 24 months. Here, internal and external partners get involved and implemented to ensure the flow orientation of SCM and the required transparency between partners.
3. Short-term planning: This level is characterised by immediate action and promptness of implementation. It has a high degree of operational and controlling steps in action. Traditionally, the horizon of activity is from a daily request to such of the mid-term planning level. (Fleischmann et al., 2008)

The entire planning process consists of:

- recognition and analysis of a decision problem
- definition of objectives and organisational targets
- forecasting of future developments and possible solutions
- identification and evaluation of a diversity of feasible activities (solutions), and finally
- selection of positive and feasible solutions (adapted from: Domschke and Scholl, 2000, p. 131)

In addition to the above recommended planning steps, it might be advantageous to include the techniques of scenarios as a fourth step. This might help to overcome difficulties, in particular when it comes to the feasibility and compatibility of IT-systems of different organisations. The above long-, mid- and short-term plannings have a number of sections and interim steps. Existing works on these steps brings to light an almost repetitive sequence that differs only in terms of its applications and the fields of implementation in SCM. The following figure shows a semi detailed structure of APS (Fleischmann, 2008, Rohde et al., 2000) which will differ, of course, for the purposes of UMTO and their requirements. Such difference will be researched in more detail, when looking at the next two sections of distribution planning and production planning.

The major difference of this cross function is that the entire sequence of procurement, production, distribution and sales only partially fits onto the requirements of a UMTO. The process of advanced planning of a UMTO starts with the sales aspect related parameters. Here, at this point, the present standing of the research in APS and SCM does not cover this pillar of the UMTO specifics. (Stadtler, 2005) It is commonly assumed that the planning process starts with the procurement related aspects. (Fleischmann et al., 2008)

This statement is in general correct and also fits partially on to the requirements of a UMTO manufacturer for his production, but as the UMTO does his advanced planning on a geo-time related framework, there the advanced planning process and matrix in SCM starts with the sales related data and is followed by the planned or anticipated distribution planning. (Erengüc et al., 1999) From this step onwards, the procurement and production related planning process follows. Consequently the matrix of modules of SCM should look as follows:

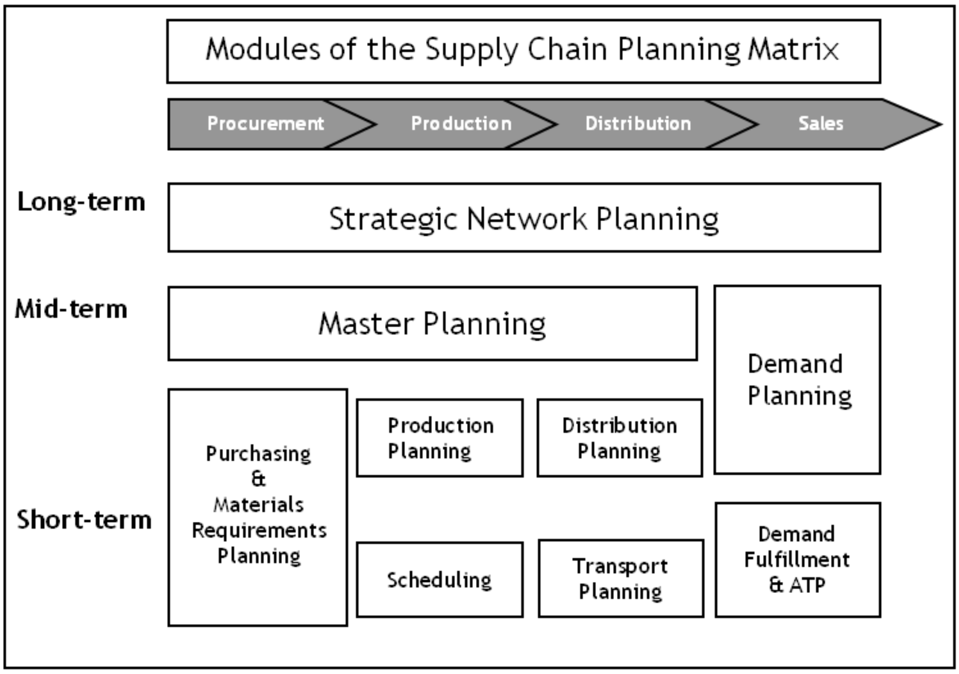

Figure 12: Modules of the Supply Chain Planning Matrix

Source: (Rohde et al., 2000)

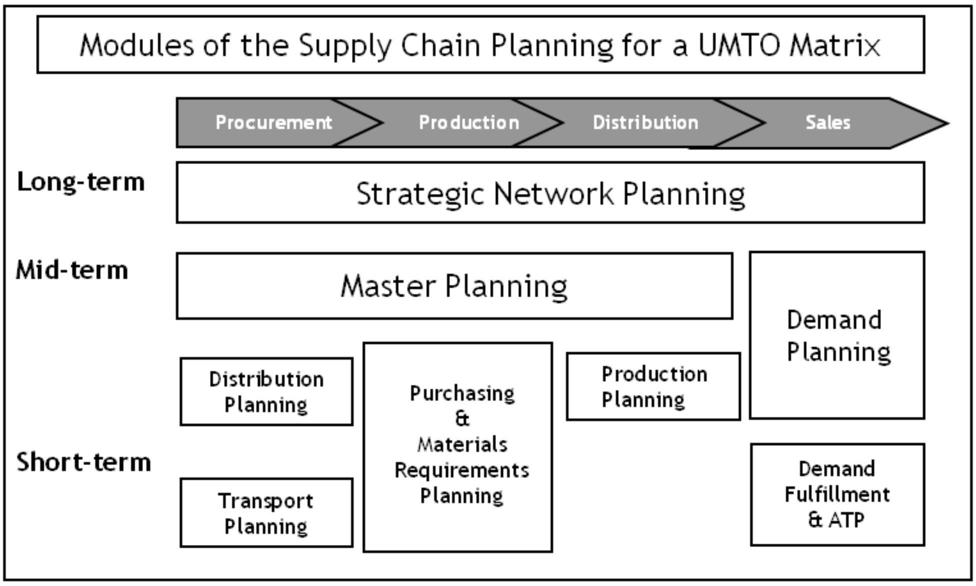

Figure 13: Modules of the Supply Chain Planning for a UMTO Matrix

Adapted from (Rohde et al., 2000)

Referring to previous reflections in this thesis and the introduction to the hybrid approach of production-distribution planning (See Section: 3.1.2 Tactical and Strategic Planning) the above figure demonstrates the basic thoughts of this hybrid approach.

Concluding from the above, current research on APS in SCM focuses on the general needs of production firms which produce their goods to a buffer and which hold stock at a warehouse. This research, however, relates to manufacturers who produce their goods not for a buffer and do not stock at a warehouse. In addition this research looks at the organisational condition, where distribution planning is dominating production planning. This is where this thesis intends to fill an important gap in literature by contributing to the specific requirements of the UMTO industry. The known production planning and scheduling and the following distribution and transport planning of the common APS requires that production planning comes first and is then followed by distribution planning. The opposite is the case for UMTO and the kitchen furniture industry. Section 3.3.1 SCM in Production and Distribution focuses on that specific research problem of distribution and production planning in the context of this thesis and evaluates present research findings.

3.3.1 SCM in Production and Distribution

SCM contains all activities of the corporate internal and external material and information flow in order to achieve a high efficiency in delivery to the client. (Lummus and Vokurka, 1999) This process includes the movements of inbound, internal production orientated flows and outbound movements. The chain of process or the chain of supply from one step to another is the flow of materials and information logistics or, also called, SCM. (Günther and Tempelmeier, 2007) This is why this section is of importance to this thesis and deserves a detailed explanation with a special focus on the implementation methodologies for UMTO firms. Corporate frameworks are designed under a number of aspects and factors of influence. One of the possible descriptions is shown in Figure 14: The 7-S Framework. From this, it is not only corporate strategy that is the dominant determinant, but also strategy in general plays a major role in the corporate environment and particularly in the manufacturing field. (Hill, 1994) Consequently, SCM is a holistic chain of processes that is often formed or designed by the corporate framework. The receiving of a purchase order from a customer initialises the sequence of the course of action in order processing for UMTO. This sequence then continues with the production of the order and terminates with the delivery of the goods or services, and finally with the receipt of the payment.

Corporate strategies determine in which segment an enterprise aims to achieve product-market-competitive advantages. According to Porter (1980) there were three drivers for competitive advantage: cost leadership, diversification and focusing. Today those three have experienced further additions with: flexibility, quality, information and others to cope with the increased requirements from customer driven and customer focused SCM. (Hines, 2004)

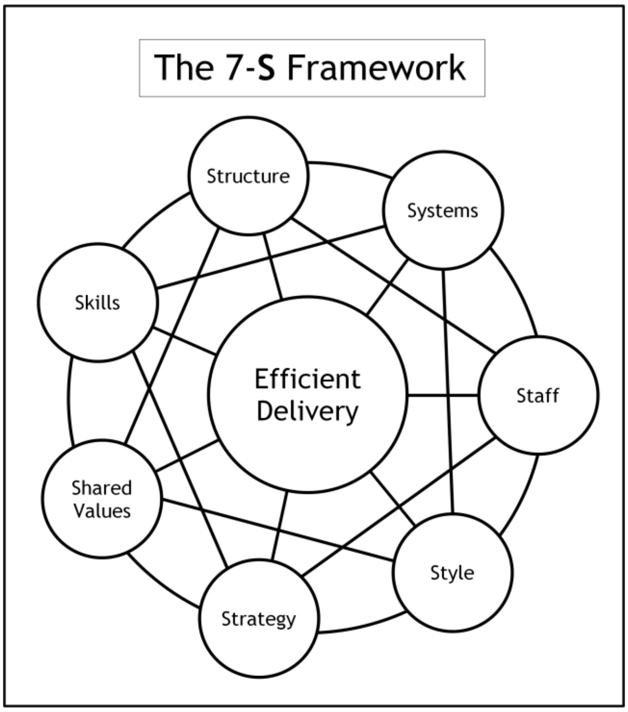

Figure 14: The 7-S Framework

Source: McKinsey & Comp. / Univ. Cologne (2000)

Hines (2004) notes, that organisation sometimes try to implement combinations of strategies, which often leads to difficulties and failure. SCM in production and distribution is often determined by the overall corporate strategies implied or vice versa. (Lummus and Vokurka, 1999) The implementation of corporate strategies has a close co-relationship to the 7-S-Model developed. (Waterman et al., 1980) It is not only a co-relationship of each fragment of the 7-S Framework but also the symbiosis that makes an efficient delivery of the products or the services to the customer. Waterman et al. (1980) speak about a powerful and complex framework that forces organisations to concentrate on interactions and fit. All the variables of this model are re-aligned when a redirection of an organisation is aimed for. However, the same complexity of energy is required when one is looking at the SCM of a company and in particular when focussing at production and distribution systems. The authors reveal with this model that it is the process-orientated symbiosis of all 7-S modules which result in an efficient delivery. Even though the efficiency in delivery from a strategic viewpoint is understood, this model of a framework clearly shows the process orientation of organisations in general. This result can be adapted to the entire SCM in logistics.

The applied corporate strategy of a company and the interaction of the 7-S Framework determine the flow of materials and information as shown in Figure 14: The 7-S Framework above. Looking at the trends and strategies in logistics at a later part of this thesis, some directions on general strategic directions indicate that cost leadership and quality are the main focus on any logistic issue. Next to this statement, innovation in information and communication systems, have recently increasingly become the critical success factor for leadership in logistics. (Lummus and Vokurka, 1999)

The interim conclusion of this view on SCM and distribution is that the entire flow of materials and information is the result of a corporate framework between suppliers in buying and procurement, production and the clients with their demands and their supply through distribution as figured above. Here, McKinsey & Comp in association with the University of Cologne have developed a relatively new view of the core competences of the value chain management or logistics.

Besides the traditional functions of storage, warehousing and transportation, the inbound side of the material flow includes functions of formerly buying orientated processes. These processes of order cycle monitoring, as well as the choice of the development and surveillance of suppliers represent an innovative approach with possible adaptabilities for UMTO.

Practical developments in SCM (Faigle and Schrader, 2000) are production steering and planning with the functions of production sequence planning and capacity management in production. This trend underlines the focus of this thesis, namely that the logistics function of distribution planning with information systems on demand and sales can be used to achieve economic advantage in the cost of distribution. The positioning of distribution planning for UMTO prior to the process of production planning itself is the major differentiating criterion in this context.

The modern or expanded definition of logistics as SCM has experienced numerous developments. No wonder that its terminology defines different points of view on the same subject. (Stadler and Kilger, 2004) From every point of view however, the supply chain from the supplier to customer via the production is subject to control, steering and synchronization by IT-based systems. (Lummus and Vokurka, 1999) The degree of implementation of such systems is as different as the 7-S framework of every company. It is this variety of implementation degree and the basis in which system (i.e. Enterprise Resource Programme – Systems, corporate organisational structure etc.) SCM is located that creates the challenges (and sometimes the problems) when different participants along the value chain intend to co-operate via their own systems. One of the major trends and strategies in SCM for production and distribution is the standardization of communication and terms. (Stadler and Kilger, 2004) Terms in this context are stated to be interfaces of communication between organisations and systems.

It is that interdependence in the demand of participants to one another and the application of the individual systems that require companies to harmonise, synchronise and standardise the chain of processes. The target of the Supply Chain Council in the USA (SCC) is the development of an ‘ideal model’ of the supply chain. For this purpose, SCC has created the model ‘Supply Chain Operations Reference’ (SCOR). It is a process-orientated reference model which is being continuously developed, based on the input of all members of the SCC and their experiences and their research results in SCM. The SCOR model has three major application areas:

- The measuring and comparing of the performance of supply chains
- The creation of integrated supply chains beyond the existing chain of logistic partners
- Research on the feasibility of the implementation of software in the supply chain, as well as its functionality.

The main idea is that every production and logistics framework is characterised by four basic processes of (1) planning, (2) buying, (3) production and (4) distribution as shown below. Lately (5) reverse logistics were added.

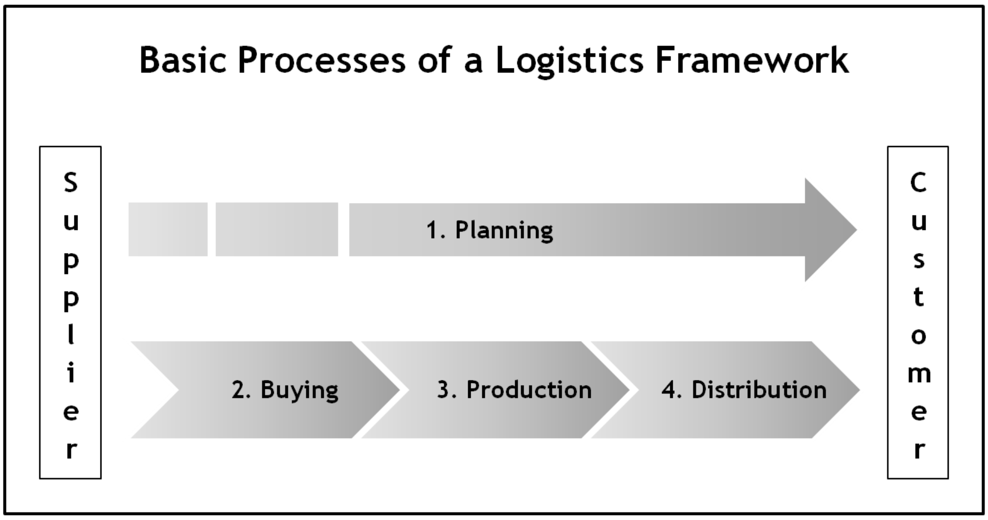

Figure 15: Basic Processes of a Logistics Framework

From the above mentioned, the more general view on SCM discussed here and the relation towards production and distribution planning, the following specifics apply to UMTO. Many publications in research focus on the SCM as a flow oriented process along the value chain. Only a small number of research studies have been performed on different types of production, i.e. UMTO. Therefore, it is important that a structure of the characteristics of UMTO is described to identify that many SCM definitions and structures do not apply or have other implications for UMTO.

Prior to the structure building process, the core parameters of the UMTO are outlined as follows:

1. The production is dominated by geo-time distribution factors.
2. Geo-time distribution factors are the result of the customer behaviour, i.e. their amount of goods purchased, physical location, delivery and service requirements. (Tempelmeier, 2003)
3. Production-distribution requirements are planned with a dual or hybrid application.
4. Production consists of several production units within one plant, all inter-dependent on each other to produce a complete consignment of the different product types in a repetitive environment. (Kolisch, 2001)
5. Production is planned in period sequences of one working day in the framework of a calendar week. Should the capacity of a shop or a line in production run into over- or under-capacities, then the production period can be extended to the next or prior period. This type of planning is called a *‘big bucket’* operation. The following Figure illustrates this type of process in detail. (Stadler and Kilger, 2004)
6. Production is mainly based on the sum of individual single orders of customers.
7. The time (period) when production is to be scheduled is determined by the delivery requirements and the location of the client (geo-time). (Kolisch, 2001)

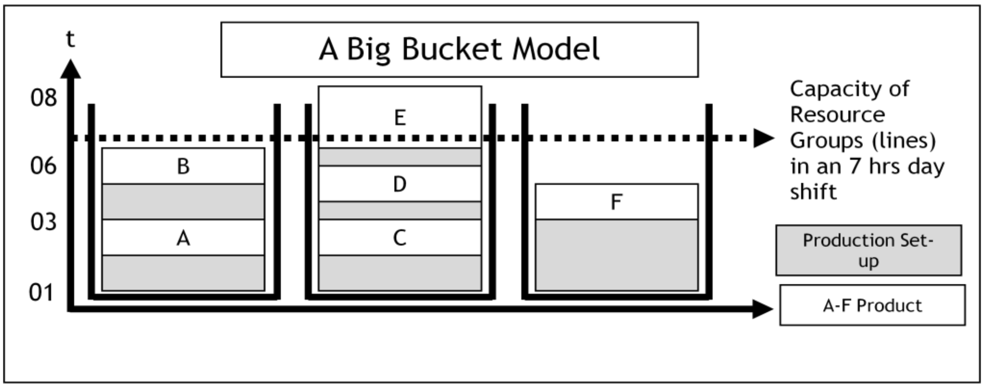

Figure 16: A Big Bucket Model

An adapted model of the Gant-chart and a changed model of Stadler and Kilger, 2004

This bucket model according to Stadler and Kilger (2004) shows an example where the production line C-D-E is exceeding the shift capacity. The production lines F and A-B are under capacity. Consequently, this model demonstrates a possibility to shift capacities from over- to under capacitated production lines. This however implies the compatibility of production lines and staff abilities. In most common practice this shifting is applied for the workers only.

Following these prerequisites and the parameters of UMTO, SCM in production and distribution narrows the view in the following literature review of this chapter. These limits are determined by the strategic positioning of each individual operation or firm. It is their organisational philosophy that sets the prerequisites onto suppliers, production, distribution and their clients. Depending on the product itself, the product positioning in the market and the client behaviour, the organisational behaviour becomes a strategic issue. Consequently the SCM of an organisation is a strategic matter. (Morgan and Monczka, 2003)

3.3.2 Approaches for UMTO

The above section of this chapter has given a broader overview of the Production and Distribution Planning in SCM. In the following, this approach is refined with specific findings in this area of research on approaches for UMTO. Here the work of Chandra and Fisher (1994) report a computational study which investigated the value of coordinating production and distribution planning. The authors consider a plant with various product productions over time and in which is maintained an inventory of finished goods. Parallels to this work and the findings are supported in other works. (Erengüc et al., 1999, Lee and Kim, 2002, Weihrauch and Keller, 2001) Product distribution takes place through a fleet of trucks to various retail outlets at which the demand for each product *"is known for every period of a planning horizon."* (Chandra and Fisher, 1994, p. 503) They state that the majority of consumer products flow through *"a pipeline that begins with production at a plan, followed by transportation to a retail outlet for consumer purchase, perhaps passing through a distribution centre on the way."* Their work thus deals with some of the UMTO specifics focused on in this thesis, but differs in terms of the possibility of using a distribution centre. (Kolisch, 2001, Balsliemke, 2004) Chandra and Fisher (1994) describe the characteristics of the production-distribution planning problem in such detail that their approach to the relationship between production-planning and distribution-planning comes very near to those referred to in this thesis. Yet, they do not consider or elaborate on the fact that distribution planning could, or as it is the case with UMTO in this thesis, should overwrite production planning.

It is stated by Chandra and Fisher (1994, p.504) to be increasingly clear *"that companies will need to make the necessary organizational changes that will facilitate coordination of these operational functions and develop an ability to make more complex decisions within this structure."* Chandra and Fisher (1994, p.505) state that Silver et al. (1988) and Cohen and Lee (1988) *"studied integrated production/distribution systems under stochastic demand"* and that Silver et al. (1998) *"developed an analytical model of a simple three node system (factory, finished goods stockpile and single retailer) and examined the properties of the cost functions arising from this model for a single product case."* However, it is related that this model does not make consideration for costs or issues that are related to the transportation of goods from the stockpile to the retailer. Chandra and Fisher (1994, p.505) state that their work makes comparison of two approaches to management of this operation: *"one in which* *the production scheduling and vehicle routing problems are solved separately and another in which they are coordinated within a single model."* In this instance their latter approach towards the timing horizons of production planning is very similar to that chosen in this thesis arising from the use of the GKFI. (See Figure 40: Production and Delivery-Data Allocation for UMTO) The authors state that the comparison is made:

> *"...for a number of different values of the basic model parameters, which include the length of the planning horizon, the number of products and retail outlets, and the cost of setups, inventory holding and vehicle travel. The reduction in total operating cost from coordination ranged from 3% to 20%. The value of coordination increases as the length of the planning horizon, the number of products and retail outlets, and vehicle capacity increases, as production capacity becomes less binding, and as distribution costs increase relative to production costs."* (p.515)

Chandra and Fisher (1994, p.516) conclude that their study has shown that *"under the right conditions, the value of coordination production and distribution can be extremely high. The analysis further provides the capacity to make the decisions that are more complex that are required under coordination."* At present, the majority of companies are characterized by both the organization and incentive structure design lacking the capacity to support coordination of production and distribution and therefore, the efforts for improvement are focused on these two functions. These efforts are said to be *"reaching the point of diminishing returns"* which results in that the right time must be taken by the organisation to make the right necessary changes needed to achieve production and distribution coordination.

With this article (Chandra and Fisher, 1994) the authors describe a very similar model of the production-distribution planning problem to that one used in this thesis. However, their focus differs mainly by starting with a set plan for the production that is then transferred to the distribution planning. This thesis takes a different approach, but the authors show how complex the implication from the two planning horizons can be.

The work of Park et al. (1999, p.586) states that: *"the problem of setting realizable delivery dates in UMTO manufacturing has received considerable attention in the literature, but most works took a lower level approach. In other words, most research involving adequate delivery dates determination has been concerned primarily with the effect of various delivery date assignment methods on the relative performance of some dispatching rules."* These authors differentiate the determination of delivery times and therefore the distribution planning as follows:

> 1. *Exogenous (external)—the customer determines the delivery date which is usually random in nature and subject to negotiation before acceptance by the company.*
> 2. *Endogenous (internal)—the company establishes the delivery date which is an accurate estimate of the expected throughput time for the accepted customer order. (p.587)*

However, Park et al. (1999, p.587) also state the gap that this work will fill: *"In general, research on delivery date determination has been rather narrowly focused"*. In this context, they refer to the earlier works at a higher level of other authors (Hendry and Kingsman, 1991, Hendry and Kingsman, 1993) by saying: *"The higher level approach is more appropriate, integrating the marketing and production planning functions at an earlier customer enquiry stage. The implications for production and production planning of any potential customer order are considered formally at the customer enquiry stage before the customer order is taken on."* (Park et al., 1999, p. 585) – This differs from the approach this thesis has taken. The GKFI approach differs by setting the delivery time for each order to a specific calendar week 6 to 8 weeks in advance. From this point of view, it can be referred to the above mentioned endogenous approach. Two weeks prior to the scheduled production week follows a production confirmation statement by the UMTO, after which no more changes may be accepted to the placed order. On Thursdays of the proceeding week of production, the GKFI plan their production according to the planned distribution upon previously set TWC per calendar week. Those TWC are exogenous determinants according to the above authors. It can be concluded that the GKFI's two-step process for setting delivery times represents an approach in-between purely exogenous and purely endogenous TWC.

This thesis contributes to knowledge not only by examining the described two-step determination of TWC but also by questioning the exogenous TWC. In literature the exogenous TWC so far have been treated as strict rules and their removal has not been considered. An implicit assumption of those works is that the TWC are really necessary for the consignee. This thesis argues that in the GKFI exogenously set TWC can be replaced with endogenous TWC resulting in mutually beneficial cost savings.

3.3.3 UMTO Distribution Planning under TWC

The above section of distribution planning approaches in the field of UMTO has provided information of the complexities involved for this industry. It has also identified first gaps in existing research. However, the distribution planning for UMTO itself needs further information beyond the delivery date allocation in the context of this thesis, namely for the requirements resulting from specific time windows of delivery. Here, the planning processes which are focused at the exogenous time windows set by the clients require the production and distribution planning to be set in such conditions that specific time frames at specific dates are being met. The complexity of the planning processes involved for a UMTO will therefore increase in comparison to those described in the previous section of this chapter.

Certainty of product definition, accuracy of time window estimates in production and for delivery itself, prerequisite supply inventory availability, and stability of supporting production and supply networks taken together are the constraints that define time windows optimization for make-to-order manufacturing. The work of Wolsey (2006, p.471) points out that *"for this problem, two variants are considered: in the first each order is distinct (client specific), whereas the second orders are indistinguishable (non-specific)."* When a product definition is tightly defined through the make-to-order process, supply chains are more agile and able to react. (Guiffrida et al., 2008) Wolsey (2006, p.472) state and others confirm (Guiffrida et al., 2008) that "*to the extent there is indistinguishability in product definition there are corresponding stresses on the supply chain, with delivery lead time being the most at risk.*"

Intermediating the level of product certainty versus ambiguity, supply chain prerequisites by most often built make-to-order product configurations, and lead times of suppliers for aberrant or unpredictable product orders are measured in delivery performance and equated to costs. *"Cost-based performance metrics that take into account excess inventory levels, penalties for late deliveries, and the relative performance of serially based make-to-order supply chains versus those that are more network-based leads to a series of assumptions regarding modelling improvement deliveries."* (Guiffrida et al., 2008, p. 149) The series of assumptions for the model Guiffrida et al. (2008) present align with the concepts of other authors (ElHafsi, 2000, Wolsey, 2006) in that the assumption is made of a unitary or even distribution of delivery timeframes. Arguably, supply chains do not have this level of consistent, unitary and predictable performance, as the studies of lead time and price quotation in congested manufacturing systems completed by Hadas et al. (2009, pp.356-357) illustrate from their empirical analysis.

Make-to-order manufacturing scheduling for time window constraints in delivery then is not as predictable as models suggest. Alleviating variation in performance through unitary-based (production-) models (Guiffrida et al., 2008) is only possible with *"convex transportation networks"* as defined by Wolsey (2006, p.473). With this expression of *'convex transportation networks'*, the author refers to a firm's strong customer orientation in contrast to a firm's internal orientation towards production problems. Those networks are used to distribute risk in a UMTO organisational network. On this basis, dynamic lot sizing, warehouse optimization and theory of constraints modelling as defined by Jaruphongsa et al. (2004, p.169) attempt to resolve reduction in delivery variance that the model and cost-based metrics of Guiffrida et al. (2008, p.148) attempt to resolve. Yet none of these seek to model external demand as that implied by the clients of UMTO in setting TWC for delivery. The attempts of Wolsey (2006, p.479) to define *"optimization algorithms for indistinguishable orders, non-inclusive time windows or stock upper bounds"* eventually deliver an algorithm that optimizes to a *"specific theories of constraint matrix"* (p.484) which holds constant supply chain variability and lot sizes. In fact *"…it would have been better to have included convex transportation networks"* (p.473) and a corollary for just-in-time inventory management and constraints-based inventory optimization for make-to-order manufacturing. (Hadas et al., 2009)

“Product definition ambiguity, manufacturing scheduling variations, supply chain incremental costs due to lack of accuracy in the form of rush charges and inventory management costs and the latency of serial versus network-based supply chains for make-to-order manufacturing define the models used for cost based metrics according to benchmarking analysis.” (Guiffrida et al., 2008, p. 149) Make-to-order manufacturing’s profitability needs to be defined more thoroughly as a metric, with Guiffrida et al. (2008, p.149) *“having set the foundation for this analysis.”* Theories of constraint applied to the wide variation in product certainty versus ambiguity, presence or absence of serially based versus convex network-based supply networks, stock upper bounds and the often-used assumption of uni-modal production costs all need greater clarification in the form of cost and time-based metrics. Included in these metrics must be a demand component, which is ironically absent from models seeking to optimize UMTO manufacturing workflows. The exception is the *“models of price quotation”* as defined by ElHafsi (2000, p.357) and defining cost constraints of delivery variance. (Jaruphongsa et al., 2004) Applying the Theory of Constraints (TOC), linear programming and pricing models to optimizing time windows for UMTO requires integration to financial systems and balanced scorecards so the insights gained can be used to ensure a manufacturer can benefit from this analysis. (Jaruphongsa et al., 2004) With greater integration in financial systems the uni-mode pricing models and unitary or simple distribution of supply chain reaction times will eventually reflect the unique characteristics of a given manufacturers’ supplier base. Quantifying the reduction in time window scheduling errors can also serve as a means to validate and fine-tune model assumptions. (Guiffrida et al., 2008)

In summary, one may say that the production-distribution planning approach for the UMTO industries towards TWC oriented client delivery demands is a highly complex construct along the entire supply chain. Guiffrida et al. (2008) as well as ElHafsi (2000) have shown that this is often a cost based decision model, whereas others (Jaruphongsa et al., 2004, Wolsey, 2006) direct their models more towards meeting the production requirements from delivery demands such as TWC in the supply chain. Yet, none of these works consider the overwrite position of distribution planning to production planning.

3.4 Simulation Techniques in Logistics

This section of Chapter 3 will examine the use of simulation techniques in (1) experimental research designs and (2) as decision support models for research in logistics and SCM. Both approaches serve to explain and support the chosen methodology in this thesis and strengthen the applied simulation technique.

The key factor for success in business in today's global market is the management of the entire supply chain. It is held that in today's *"World-class organizations...that non-integrated manufacturing processes, non-integrated distribution processes and poor relationships with suppliers and customers"* are not enough for the success of these organizations as they have come to *"realize the impact of an organization's plan on the other areas of the supply chain."* (Chang and Makatsoris, 2001, p. 24) According to those authors supply chain functionalities include those stated as follows:

1. Demand planning;
2. Master planning
3. Procurement
4. Transportation; and
5. Manufacturing. (p.25)

The following illustration is a diagram of an example supply chain simulation model which has been adapted from the work of Chang and Makatsoris (2001):

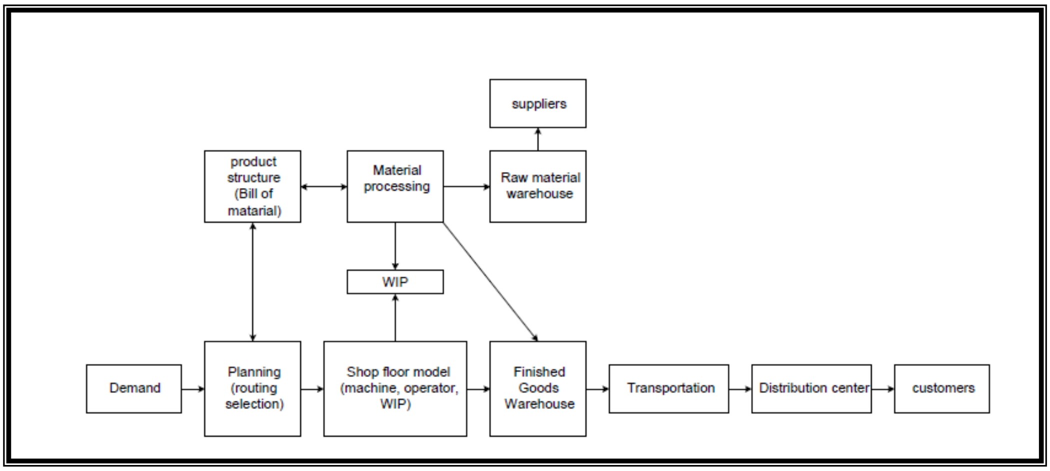

Figure 17: Diagram of Supply Chain Simulation Model

Source: (Chang and Makatsoris, 2001)

Stated as example data requirements are those listed as follows:

1. Manufacturing process and time information;
2. Inventory control policies information
3. Procurement and logistics information
4. Demand information; and
5. Policies and strategies information (Chang and Makatsoris, 2001)

The report of Chang and Makatsoris (2001, pp.24-25) concludes by stating that meeting the customer demand for *"guaranteed delivery of high quality and low cost with minimal lead time is the objective of supply chain management."* If this objective is to be achieved, then companies must have a *"better visibility into the entire supply chain of their own as well as those of their suppliers and customers."* This requires agility to adjust and reformulate plans and to do so in real time, to meet the unplanned moments in the supply chain production process. It is related that these needs are that which have driven the *"application of discrete event simulation for analyzing entire supply chain process".* Supply chain management that is efficient can be realized through considering carefully information related to *"capacity and material information."* (p.25) The basis for such efficiencies includes:

1. The company' corporate structure;
2. The relationships with suppliers;
3. The abilities to communicate via systems, and
4. The organisational flexibility for the adaptation of new structures.

The work of Umeda and Zhang (2006, p.155) proposes a simulation system that is designed for the purpose of supply chain management of operations and that the *"most remarkable characteristic of the simulation"* is the representation of business process activities in supply chain management. Included in these activities are such as:

1. Demand predictions;
2. Manufacturing planning;
3. Material purchasing;
4. Manufacturing and transportation ordering; and
5. Product shipping. (adapted from: Umeda and Zhang, 2006)

From those business process activities, this thesis refers to the shipping or the distribution and transportation ordering or planning. Umeda and Zhang (2006) demonstrate typical forms of simulation and supply chain systems including those which are:

1. Centre-controlled ordering systems;
2. Vendor reorder-point systems; and
3. Pull-operational systems.

These simulations systems are then compared in terms of the performance of the supply chain. Two goals in the supply chain operation are: (1) synchronization; and (2) either inside the enterprise or beyond the enterprise's boundaries on production and logistics issues. It is stated that the robust chain makes unavoidable, a requirement of data exchange on a frequent basis and *"among inner-company processes and outside supplier's processes according to the business process behaviors."* (Umeda and Zhang, 2006, p. 156) The scope of the supply chain oriented simulation is stated in the work of Umeda and Zhang (2006) to require:

1. Material management activities in individual processes (manufacturing, receipt, shipping, storage, handling, inspection; and transportation);
2. Order processing activities in individual processes, such as purchasing (and replenishment), operations, shipment and transportation. The process of sending and receiving between suppliers must be explicitly expressed;
3. Information processing activities which combine material management activities with ordering (and in distributing) activities.

It is necessary to understand that the activities of order processing and information processing *"are tightly coupled with the material management activities in suppliers, main product factories and distributors."* (p.157) Here, these authors give two important findings that are closely related to the works in this thesis:

1. The use of supply chain simulation requires a strict process orientation of materials handling and order processing with a link to transport and shipping, and
2. The synchronization with the clients or recipients of the goods to be sold.

In this instance, the statements of Umeda and Zhang (2006) support the findings of this thesis in sections 1.3.4 Delivery and Transportation and 3.2.2 Use of complex DPS for VRPTW.

There are said to be three problems on simulation modeling that the supply chain must overcome and these are:

1. How business processes in each chain member company should be represented in simulation models;
2. How process synchronization and data exchange transactions among the chain member companies should be represented in simulation models; and
3. How the communication mechanisms between information-flow and material-flow should be represented in simulation models. (adapted from: Umeda and Zhang, 2006)

Those problems have been dealt with in this thesis (See Sections: 1.1 Research Overview, 1.3.4, Delivery and Transportation and 3.3.2 Approaches for UMTO) and explained in detail with their reference to the UMTO business environment.

The following Figure 18: Operational Model of Supply Chain System is an extract of an illustration of the Supply Chain. Here again, the parallels to this thesis are demonstrated when looking at the 'Pull operational Model'. The customers demand on the distribution planning of the manufacturer can be compared with explanations made for the specifics of UMTO and their production-distribution planning requirements. (See Sections: 1.3.4 Delivery and Transportation and 3.3 Distribution Planning for UMTO)

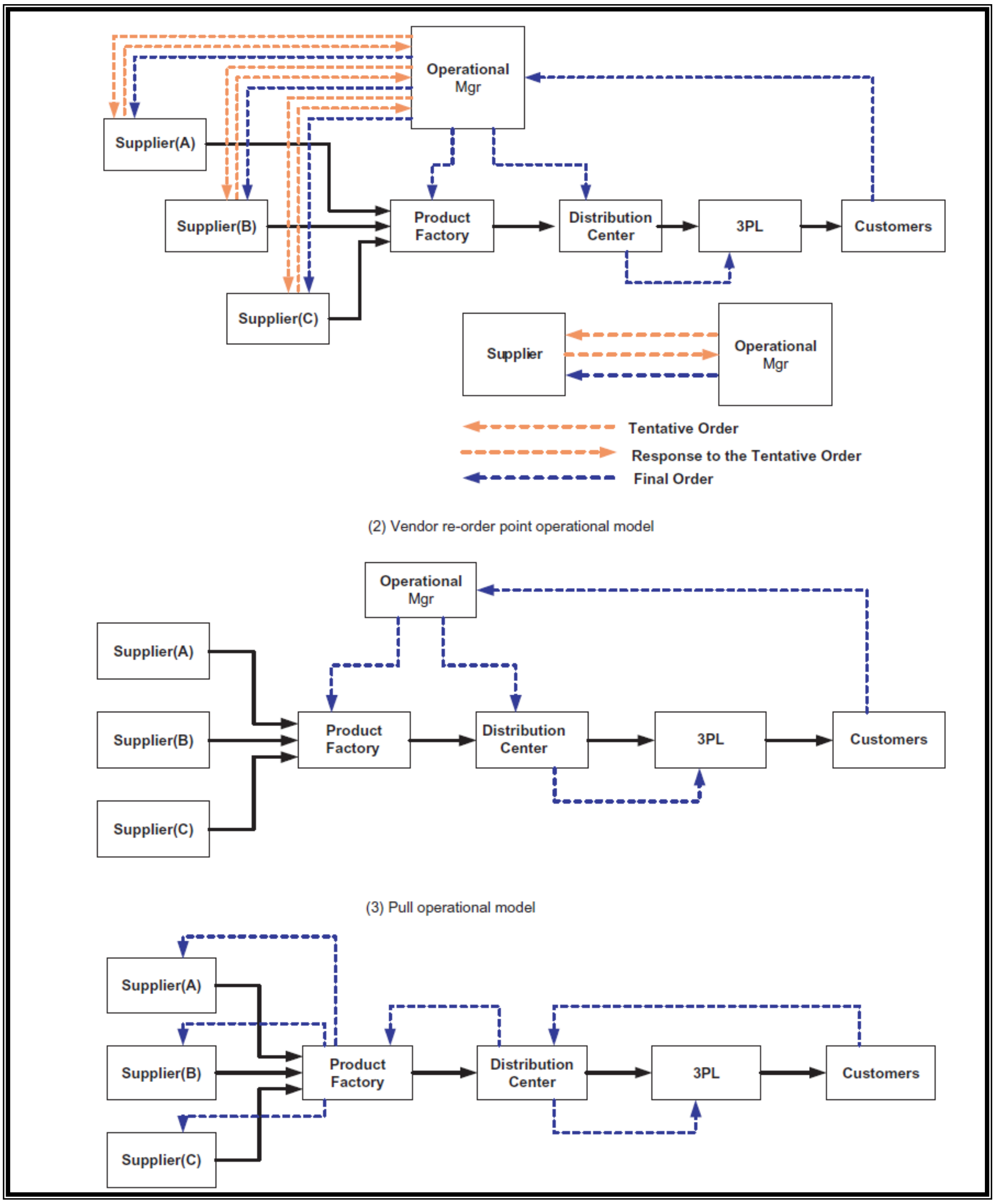

Figure 18: Operational Model of Supply Chain System

Source: Umeda and Zhang (2006)

Umeda and Zhang (2006) conclude by stating that their work demonstrates that simulation models may be specified for discrete manufacturing supply chain systems and demonstrate a proposed model composed of supplier member models. This bears comparison with this thesis, where the combined production and delivery situation is in the forefront.

Bienstock (1996, p.44) states that *"logistics research contains numerous applications of a computer simulation modeling of logistics/distribution systems."* According to her, logistics/distribution systems are stated to:

1. involve networks of 'fixed facilities and connecting linkages';
2. are characterized by complex and stochastic interrelationships among system components; and
3. generate data that are relatively quantifiable.

These are said to be the reason why these systems *"lend themselves to investigation using simulation methodology."* Simulation offers an alternative *"for understanding these systems, since experimenting with the actual systems would be too costly."* (p.45) Furthermore, simulation is stated to facilitate the *"examination of dynamic processes or systems over time by allowing the compression of real time."* (p.44) Bienstock (1996) says that the methods for adjusting the sample size 'n' in simulation studies are as follows:

1. Simulation runs for each experimental condition (each cell) may be replicated 'n' times;
2. Observation of 'n' subintervals of the simulation of an experimental condition may be increased by decreasing the length of the subintervals; or
3. The simulation of an experimental condition may be continued for a longer period of time, thereby increasing the number of subintervals (i.e. the sample size).

The technique described by Bienstock (1996, p.46) is one that

> *"...enables a logistics researcher to determine the number of replications necessary to achieve a relative degree of precision. A relative precision goal for a logistics/distribution experiment ensures a reasonable degree of precision within the context of the system being investigated. Use of this technique will provide a researcher with the number of replications which will yield the degree of precision necessary for drawing conclusions about the behavior of the system under the various experimental conditions."*

This technique is said to be appropriate for *"simulation modeling that employs successive independent replications of simulation runs; it is not appropriate for determination of achieved relative precision on subintervals of a single simulation run"*. (Bienstock, 1996, p. 46) The author hereby confirms the applied simulation application in this thesis.

3.4.1 Appraisal of existing Simulation Models

The work of Rosenfield et al. (1985) is a good base to appraise the early stages of existing simulation models in logistics. They say that the planning for the configuration of *"large, complex distribution systems for optimal balance of cost and service can be best accomplished through use of sophisticated computerized models. The use of such models of all types has gained attention in the solution of large scale logistics problems." (*p.110) One such model was a large-scale logistics planning and optimization model, introduced in the early 1970's for a major food company. (Geoffrion et al., 1978) Important contributions for the development of simulation in logistics in this time were developed (Bowersox, 1972, Klingman et al., 1974). Both were mathematical approaches for logistics planning and optimization models. Other models have focused on simulation of the wide range of *"costs and activities in the logistics system."* (Rosenfield et al., 1985, p. 91)

Rosenfield et al. (1985, p.92) state that the various approaches of computerized and manual evaluations are inclusive of those:

1. Manual evaluation of alternatives;
2. What-If simulation modeling;
3. Optimization modeling; and
4. Heuristic modeling.

It is related that in problems that are 'small-scale' or in which the number of shipment alternatives is limited, the analysis can be performed *"manually and alternative scenarios can be explicitly evaluated."* (p.91) The manual approach is stated to have been used *“historically”* although *“the power and availability of computers have made other approaches more desirable.”* (Rosenfield et al., 1985, p.91)

What-If simulation modeling is one of the two most widely used approaches. The other is optimization modeling. Rosenfield et al. (1985, p.89) state that ‘What-If’ simulation modeling’ *“generally connotes scenario evaluation, while optimization involves a determination of the optimal or best solution.”* A third stated approach by these authors is that of ‘heuristic modeling’ which is defined as a *“trial and error process to reduce the multitude of possible problem solutions to a small, manageable number of feasible solutions.”* (p.90) The heuristic approach is one that is based most often upon *“a criterion which managers seek to optimize. Hence heuristic modeling in this case is really a form of optimization modeling.”* (p.90) ‘The What-If approach’ is stated to be feasible only when there are a limited number of alternatives for consideration. It is also related that the optimization approach is generally necessary when there are *“significant (typically resource allocation) constraints in the logistics system activities.”* (p.92) ‘What-If simulation’ is stated to be *“cumbersome to apply*” when “*systems alternatives are restricted, the complexities of considering many policy variables*” exists. (p.92) ‘What-If simulation’ is preferred when the company is unable to *“undertake a sweeping revision of their logistics system”* since the cost *“in terms of investment and organizational description is often too great.”* (p.93) Therefore, if the company desires to know the effects of a change to only one or just a few variables the ‘What-If’ simulation is very useful.

Advantages to the ‘What-If’ approach are said to be:

1. this simulation model permits more exact representations of the process being modeled;
2. this simulation offers more flexibility;
3. this type of direct calculation can enhance management understanding. (p94)

Rosenfield et al. (1985, p.91) state that the optimization approach and the 'What-If' simulation modeling are "*not necessarily mutually exclusive, and indeed, often overlap.*" They also report that three separate sets of computer programs used in the model reported in their work were those of:

1. Base-data management programs;
2. Freight and lead time analysis models; and
3. The 'What-If' scenario evaluator. (p.89)

The base-data management programs have processed and converted the data into files. These programs then converted the supply/demand data into a set of demands by product class broken down by combination of origin node and destination node. (Rosenfield et al., 1985)

(Note: In this thesis it was decided to call the actual base data of this thesis also base data- # in a numeric sequence of the individual steps of data handling and data simulation.)

A detailed account of the number of parts each supplier shipped and for each model year was contained in the corporate data base including information of the piece weight, dollar value, quantity of each part, assigned shipping class, and destination. Large amounts of freight cost and lead time data were processed by freight and lead time analysis models into functional regression relationships between costs and lead times distances, weights per shipment and other factors. (Rosenfield et al., 1985) System mileages were determined *"on the basis of the latitude and longitude specifications for each of the nodes."* (pp.92)

The use of arbitrary locations was important in the model. The key part of the software was the 'what-if' simulator based on the supply/demand data which made a determination of the overall system costs. (Rosenfield et al., 1985)

The what-if scenario evaluator of the Rosenfield et al. (1985) experiment was designed to determine total system costs given:

1. The supply/demand matrix as a function of the origin/destination pair and part class; and
2. The specific scenario. (p.91)

Rosenfield et al. (1985) state that they created a module that:

1. Recalculated all system mileages;
2. Recomputed all freight rates and lead times;
3. Updated arc costs to reflect modifications; and updated all paths to reflect new arcs. (p.97)

Therefore, the arcs and paths were *"identified in the same way, all paths and arcs were modified."* (p.97) The model is reported to have been implemented *"...in two separate sets of runs."* The appropriate broad alternatives and specific candidate scenarios were identified, but only following much analysis and scenario evaluation. The majority of the lead times underwent regression calculation and the majority of the freight rates on arcs that originated at the suppliers were based on formulas for calculation as well. The primary strategic question was related to the issue of the facility and the actual freight rates were utilized for *"all of the paths in the system in the second set of runs."* (p.97)

Rosenfield et al. (1985, p.104) report that in the runs, and where *"specific freight rates were used to verify the final decisions, shipment sizes were calculated and used to determine the appropriate input freight rate over a selection of weight breaks."* The savings that were identified in this model were consisted of freight and transit inventory savings arising from reduced distances, consolidation of loads and, for a portion of material, elimination of a transit leg." It is stated that the model *"was able to determine the complex effects of these changes."* (p.106) From this it can be stated, that their model was very close to the chosen model of this thesis, whereby the routes containing individual shipments to clients will be dissolved and TWC will be omitted. Then, shipments will be re-directed to routes and those routes will be re-calculated with the same cost parameters, as the previous base data has been cost calculated before. This process and that of Rosenfield et al, from 1985 is being re-stated to perform the requirements for the simulation of base data on cost savings in a model from later authors. (Kern, 1991) and (Gietz, 1994)

Several conclusions concerning the use of logistics planning models in the area of corporate decision-making arise from these studies. Firstly, one factor for successful implementation of any model type is a *“flexible, understandable and clear model.”* Rosenfield et al. (1985, p.116) say that the *“explicit calculation of transit and inventory costs, the clear reporting and tracing of all costs, and the ability of managers to sit at a terminal, specify an alternative and evaluate the impacts of that choice contributed to decisive decision-making and subsequent rapid implementation.”*

According to Rosenfield et al. (1985), Kern (1991) and Gietz (1994) the incorporation of features of ‘clarity and understandability’ increased the chances for success in simulation experiments. Benefits of using computer planning models are benefits which are due to savings realized from alternative configurations. It is stated however, that the catalyst for selecting such alternatives is the model itself as (sometimes) a particular change or customization in the logistics system is needed. A model that is clear and that is easily understood will assist in gaining the agreement of all in implementing the changes that are needed to gain reliable results. The design should be comprehensive so as to enable the organizational parts to participate in its development and additionally this type of design *“gains credence for model accuracy and importance.”* (Rosenfield et al., 1985, pp. 116-117)

In conclusion, similar or comparable systems have been in operation since the 1980’s and have been since refined. However, all or most of these models contain the improvement of individual shipments through the simulation of new paths algorithms. There is little consideration, when tour restrictions, such as TWC are omitted with the help of those systems and individual shipments or client deliveries are re-consolidated into new tours afterwards. Considering this and also adhering to all previously applied tour planning parameters, new tours are being simulated. This is a gap which other publications have not yet filled.

3.4.2 Application of Simulation in Decision Support Models

When looking at the use of simulation in logistics and in SCM, one needs to first look at the organisational requirements that arise from SCM as a horizontal and process oriented holistic approach. Here, the work of Chang and Makatsoris (2001) reviews today's market and relates that it is 'highly competitive' and an environment in which manufacturers face the challenge of reducing manufacturing cycle time, delivery lead-time and inventory reduction. These planning frameworks include the areas of: (1) demand planning; (2) master planning; (3) procurement; (4) transportation; and (5) manufacturing. Expected benefits of SCM are stated to include: (1) material is coordinated better and no utilization loss occurs due to lack of needed materials. This is referred to as 'throughput improvements.' (2) Reduction of cycle time by examining constraints and alternate methods or processes in the supply chain, ultimately reducing the time to cycle. (3) Reduction of the costs of inventory through 'demand and supply visibility' which effectively lowers the requirement of holding inventory at high levels especially in the environment of uncertainty. (4) Capacity to know when to purchase material upon the bases of demands of customers, including capacity to produce and purchase other materials needed to produce. (5) Reduction of the cost of transportation through the optimisation of logistics and vehicle utilisation. (6) Increase of sales with 'real time visibility' across the supply chain (alternate routings, alternate capacity) enables to increase order fill rate. (7) Analysis of the SCM can help to predict propagation of disturbance to downstream. (8) Responsiveness for the ability to react upon increased customer demands resulting in the understanding or the gaining of the capability to deliver to the customer, based on availability of materials, capacity and logistics. (adapted from Chang and Makatsoris, 2001, pp. 25-27) - With the above, the complexity for the application of simulation in logistics and in SCM becomes obvious, as fragmented approaches would always interfere with the holistic SCM set-up. For logistics, simulation could indeed be a less interfering tool to look at probabilistic situations.

Cohen and Lee (1988, p.216) report a *"comprehensive model framework for linking decisions and performance throughout the material-production-*

distribution supply chain." They relate that the threat of foreign competition has resulted in many U.S. firms re-evaluating their strategies in basic manufacturing *"in order to regain a position of competitive advantage."* Reported by these authors is the development of a *"model structure that can be used to predict"* the firm's performance in regards to:

1. Total cost of the products;
2. The level of service(s) provided to the customers; and
3. The responsiveness and flexibility of the production/distribution system.

The analysis they conduct is one that *"takes into account the nature of the products produced, the process technologies used to manufacture the products, the structure of the facility network used to manage the flow of materials and the competitive environment in which the firm operates."* The problem which is of interest is measuring the tradeoffs of production/distribution systems cost, service, and flexibility for various management strategies for materials under alternative conditions relating to the environment and structure of the corporation. Specifically considered in the methodology of Cohen and Lee (1988, p. 216) are the relationships that exist between *"production and distribution control policies"* and more specifically those *"affecting inventory control, plant production mix and production scheduling."*

Cohen and Lee (1988, pp.216-217) state that material flow in the production/distribution system is managed *"…by a variety of mechanisms. The inputs to each factory consist of materials and intermediate products which can be sourced from different vendors or other manufacturing facilities belonging to the firm."* Such input flows as these are manag*ed "by the firm's material requirement inventory control system."* The material flow in the factory is affected by the layout of the plant, routing of products, lot size production and schedules for manufacturing. The outputs of finished goods can be stockpiled and then can be shipped directly to appropriate locations within the distribution network. The authors also aim to introduce a *"model framework and an analytic* *procedure for evaluating the performance attributes of the class of production/distribution systems."* (p.220)

The expressed stated is to accurately predict the affect on performance of manufacturing and material strategies in the form of alternative methods. Questions addressed include these:

1. How can production and distribution control policies be coordinated to achieve synergies in performance?
2. How do service level requirements for material input, work-in-process and finished goods availability affect costs, lead times and flexibility? (adapted from: Cohen and Lee, 1988)

From those two main questions, the relationship to the research question of this thesis becomes obvious. The authors have addressed the general production-distribution problem and examined the requirements resulting from costs and lead times in distribution. They have thus formed their research model similar to Rosenfield et al. (1985), and later confirmed by Kern (1991) and Gietz (1994). The demand requirements in finished goods in the material billing consideration involves a great deal of uncertainty in both the production and distribution areas of the manufacturing process since *"material requirements are not deterministic."* (Cohen and Lee, 1988, p. 217)

Their model further *"takes into account the cost of material inventory (setup and holding) and the cost of delay in order to determine the delay impacts of material shortages on production processing."* (p.218) These are used for the purpose of: (1) determining ordering policies for materials required at each plan which results (2) in service/availability levels (fill rates, stock-out frequencies) for each of the raw materials used in the production lead-times of the product since (3) material shortage can lead to delays in production

Cohen and Lee (1988) base these relationships according to earlier works presented. (Karmarkar and Kekre, 1985, Karmarkar et al., 1985, Karmarkar and Kekre, 1987). By doing so, their illustration displays the 'parallel line multistage production process' as presented in the work of Cohen and Lee (1987, pp.218-

219) and is one in which *“instead of optimizing the whole system”* proposed is a *“decomposition approach so that each sub-model is optimized, subject to some service target defined for that sub-model.”* The ‘local’ service targets will also serve as linkages between the various sub-models. As the distribution sub-model is formulated by Cohen et al. (1988, p.219) as: *“a standard fixed cost, it is used to represent the cost of ordering and shipping items from one restocking location to another,”* their model largely differs from the chosen model of this thesis. However, their model description for analyzing theoretical solutions on the production-distribution problem closely approaches the parameters of the UMTO requirements to which this thesis refers to. They therefore represent a fair sensitivity of the other alternatives which lay between the research focus of this thesis and other existing modules.

3.4.3 Sensitivity Considerations

The work of Park (2005) states that optimization of production and distribution systems have been the focus of many firms although this approach tends to limit increases in profit. Therefore, the analyses of the two systems at the same time have become increasingly important and offer a good opportunity to serve as a fair example of sensitivity to other possible solutions in this thesis. A new approach has been recently identified in analyzing supply chains and that this new approach is one that has as its basis the *“...integration of different functions (e.g. purchasing, production, distribution and storage) in the supply chain into a single optimization model.”* (Park, 2005, p. 1205) This approach is one in which decision variables are simultaneously optimized for different functions that were optimized sequentially traditionally. The last decade has seen a great deal of research conducted in the area of partial integration of the supply chain functions since these are difficult to integrate. Park (2005, p.1206) reports *that “the analysis of the linkages between production and distribution has received less attention than other partial integrations.”* In addition he states that in a production system characterized by customers being scattered assignment of plants to customers for distribution determines the performance of distribution. Integration of these two functions may lead to a: *“…substantial* *saving in global costs and to an improvement in relevant service by exploiting scale economies of production and transportation, balancing production lots and vehicle loads, and reducing total inventory and stock-out"* (p.1206) Here, Park (2005) has identified the gap that this research is filling in the area of research on the production – distribution problem for UMTO.

Park (2005, pp.1205-1206) also reports the consideration of a *"production and distribution planning problem to maximize the total net profit in a multi-plant, multi-retailer, multi-item and multi-period logistic environment"* and proposes *"the optimization models and a heuristic solution for both integrated and decoupled planning."* The primary purpose is the investigation of the *"effectiveness of the integrated approach over the decoupled one through an extensive computations study using the proposed heuristic for the production and distribution planning problem which is not treated explicitly in previous research."*

Conclusions stated by Park (2005) with regards to the effectiveness of integrated analysis for a production and distribution planning problem (in a multi-plant, multi-retailer, multi-item and multi-period logistic environment by use of a mixed-integer model and a heuristic for problem-solving) include that the computational resulting on small-sized problems appears to indicate that the heuristic *"performed well in terms of both optimality approximation and computation time."* (p.1222)

Park (2005, pp.1222-1223) supports the focus of this thesis by stating that there is a need for future research and particularly on the *"tentative production and distribution planning phase, is required to reduce further the error rate of the heuristic to the optimal solution. Computational results using the heuristic showed that the integrated planning approach produced more net profit and higher customer service than the decoupled one did in all of three sized problems, with an average 4.1% increase in total net profit and 2.1% increase in demand fill rate."*

Park (2005, p.1221) also reports that the sensitivity analysis on the problem input parameters was conducted for the purpose of gaining an *"in-depth* *knowledge about the effectiveness of the integrated planning approach using the heuristic"* and that the results of the analysis appear to indicate that *"the value of integrated planning was especially high in an environment of sufficiently large production capacity, high fixed cost per vehicle, small vehicle capacity, and high unit stock-out cost."* Park concludes that a company *"...in order to implement the integrated planning approach properly...must involve all major planning operations in model construction and data processing"*. (p.1219)

From his results one may state that the current findings from research of the distribution-production problem using simulation techniques, has many more alternatives open for further research. One of them is filled by this thesis. Park's statements are confirmed in past publications on this topic. (Marucheck and McClelland, 1986, Lee and Kim, 2002, Cohen and Lee, 1988, Chung-Hsing, 2000)

3.5 Experimental Research

As some parts of this work may be categorised as experimental research, using simulation in logistics to investigate the solution of the research question, this section deserves particular attention. - The research process in experimental research is stated to be of the nature that utilizes scientific techniques in the investigation of phenomenon and a research process which is focused on acquisition of new knowledge about the phenomenon. (Plutchik, 1983) Therefore, the experimental method in research is stated to require the basis of *"observable, empirical and measurable evidence, to be termed scientific"* and it also must *"follow some principles of reasoning."* (Gill and Johnson, 2002, pp. 50-51) These principles are described in the following and guided by some cross references to substantiate their validity for this thesis.

3.5.1 Experimental Research in Logistics

Robert et al. (2005, p.186) say that as the logistics discipline has evolved there has been a call generated for logistics research to become:

> *"...more rigorous with respect to theory development and practitioner application. We see several different responses to this challenge. First, the increased use of SEM as well as simulation would seem to reflect a research purpose driven to discover and explain causality. In the specific instance of SEM, its increased usage may also be evidence of researchers who have already looked at an issue with "proven" techniques but now becomes aware of a new technique which may provide them with additional insight into a situation - and thus they are likely to try and utilize that technique."*

These authors also report of recent research publications that *"case based research can be as useful and rigorous as other research methods."* (p.185) As a result, the authors support the research framework of this thesis and lay the ground for the simulations undertaken to be useful and rigorous. Logistics problems, are said by (Robert et al., 2005, p. 187) to be:

> *"...often ill-structured, even messy, real-world problems. Logistics uses multi-disciplinary and cross-functional approaches. In order to provide value to industry, education in the classroom and in the discipline of logistics as a whole, logistics researchers must gain extreme relevance by understanding what is going on within and between organizations."*

Logistics research will accrue benefits by the researcher investing time observing and communicating with professionals performing logistics in action. (Robert et al., 2005) From this, it may be assumed that the experimental and quasi experimental research approach in Logistics is appropriate and a common practice.

3.5.2 Risks in Experimental Design

The risks in this experimental design stem from three critical points according to Gill and Johnson (2002, pp.47-50):

1. Possible factors for modifying the basic data and data cleansing as well as the final data selection;

2. Possible factors and changes of parameters in the simulation process and evaluation criteria;
3. Volatility of the results based on procedures and structural interdependences.

With this, it becomes clear that the experimental research design and the use of simulation needs exhaustive validity checks and detailed descriptions on how the basic data is being cleansed for further use in the experiment. This thesis addresses those risks in detail in its Sections 5.2.1 Data Cleansing and Selection Parameters until 5.2.7 Data Collection Strategy.

As the risk of possible changes of the parameters in the simulation and evaluation of the results is another pitfall according to Gill and Johnson (2002), this thesis has taken very careful precautions to reduce this risk to a minimum by describing the actual use of the simulation system as the experiment in Section 5.1.4 System Use and Operational Specifications in detail. The demonstration of the experimental processes in an explanatory example (See Section: 5.1.5 Explanatory Example of the Data Simulation Process) and the maintaining of equal parameters in a *'ceteris paribus'* manner was of the highest importance. This most important precaution is explained in detail in Section 4.2 Definition of the Cost Function in this thesis.

3.5.3 Sampling and Pilot Studies in Experimental Research

The researcher deciding on experimentation firstly identifies and then operationalises the research problem in order to define how to measure it. The test results will depend on the exact measurements that the researcher chooses. Through definition of the problem, the researcher is able to formulate a research hypothesis. It is reported that an 'ad hoc analysis' is an additional type of hypothesis and is added to the results of an experiment in order to explain contrary evidence. (Plutchik, 1983) Construction of the experiments involves several aspects of planning and it is of the utmost importance to plan ahead to ensure that the experiment is properly conducted, that the results are an actual reflection of the real world and that this is accomplished through the best method possible. This is yet another important parameter this thesis adheres to in Section: 5.2.3 Research Process Validation. (Congdon and Dunham, 1999)

<u>Sampling</u>

Sampling is an important aspect of the experimental research design and must be correctly initiated because where there is more than just one condition in the experiment, one group is used as a *“control group whereas the others are tested under the experimental conditions.”* (Gill and Johnson, 2002, p. 48) Group samples can be determined in several ways including:

1. Randomization;
2. Quasi randomization; and
3. Pairing (Yang et al., 2006)

The author of this thesis has chosen the first of the above three options for the explanatory description of the sampling process in the multi-staged simulation. The third option of pairing samples will be applied, when the control groups are selected and established for the experiment. (See Section: 4.4.1 Data Sampling) These sampling methods are stated to be the most common among sampling methods which are used. When an experiment is constructed, the researcher often needs to adjust the sample size to reduce the changes of random sampling errors. (Yang et al., 2006) This may, in some instances, also be applied by cleansing data samples from non-research relevant data. (See Section: 5.2 Data Collection and Processing) Here, factors that impact the research design chosen include those such as time, money, ethics and measurements problems. The design of the experiment is critical for the validity of the results. (Banks, 1998) The following typical designs in experiments are adopted from Bryman and Bell (2003) and from Easterby-Smith et al. (2002) and include:

Pre-test: for the purpose of checking as to whether the groups are different prior to the experiment and to sometimes influence the effect.

1. Post-test: Measurement of the effect(s).

2. Control Group: Control groups are designed to measure research bias and measurement effects, such as the Hawthorne Effect. A control group is a group which does not receive the same manipulation. Experiments frequently have 2 conditions, but rarely more than 3 conditions at the same time.
3. Solomon Four-Group Design: With two control groups and two experimental groups, to test both the effect and the effect of a pre-test.
4. Double-Blind Experiment: Neither the researcher, nor the participants know which the control group is. The results can be affected if the researcher or participants know this.
5. Using Bayesian Probability: This method uses Bayesian probability to 'interact' with participants. It can be used for settings where there are many variables which are hard to isolate. The researcher starts with a set of initial beliefs, and tries to adjust them to how participants have responded.

This, again, is another stage where it can be confirmed that this thesis has adhered to those scientific rules by the model descriptions made in Section: 4.1 Research Framework.

Pilot Study

A pilot study may be conducted prior to the actual experiment which serves to ensure that the experiments measure what it is intended to measure. The pilot study assists in identifying minor errors that have the potential to ruin the experiment. When the experiment involves human beings *"a common strategy is to first have a pilot study with someone involved in the research, but not too closely, and then arrange a pilot with a person who resembles the subject(s). Those two different pilots are likely to give the researcher good information about any problems in the experiment."* (Bryman and Bell, 2003, p. 249)

3.6 Coherence between Simulation and Experimental Research

Now the different planning approaches, the role of TWC in this process and the complex requirements from the UMTO point of view have been reviewed, it is important to scrutinise the coherences between simulation and experimental research design. This is of particular interest in the context of this thesis as the use of simulation techniques and the chosen experimental design show correlations

Kleijnen et al. (2005) say that DOE or 'Design of Experiments' has a history that is not only rich but that has many

> *"…theoretical developments and practical applications in a variety of fields. Success stories abound in agriculture, clinical trials, industrial product design, and many other areas. Yet, despite the impact DOE has had on other fields and the wealth of experimental designs that appear in the literature, we feel DOE is not used as widely or effectively in the practice of simulation as it should be."* (p262)

It is additionally stated in the work of Kleijnen et al. (2005, p.263) that simulation has, with computer technology advances, lost some of the *"constraints that characterize real-world experiments."* This may result in opportunities and challenges. The use of simulation in an experiment is stated to have three primary goals:

1. Developing a basic understanding of a particular simulation model or system;
2. Finding robust decisions or policies; and
3. Comparing the merits of various decisions or policies. (Kleijnen et al., 2005, p. 265)

Other works state that in complex system design, *"computer experiments are frequently the only practical approach to obtaining a solution. Typically, a simulation model of system performance is constructed based on knowledge of how the system operates."* In the event that measure of performance is not a straightforward calculation then the sampling via computer experiments *"may be employed to estimate the measure."* In the event that the simulation model is *"computationally expensive, then the optimization may instead rely on a metamodel."* (Chen et al., 2006, p. 273)

The authors also say that there are two primary tasks in meta-modelling: (1) select a set of sample points in the design parameter space (i.e., an experimental design); and (2) fit statistical model(s) to the sample points. Methods for the first task may be used to conduct sampling in general. (Paraphrased) It is also stated by these authors that in real world experiments, *"only a small number of factors are typically varied"* because it is not practical or possible to *"attempt to control more than…10 factors; many published experiments deal with fewer than 5."* Choice of performance measures is addressed and it is stated that some problems make a requirement of *"only relative answers…conversely, some problems require absolute answers."* (p.269)

The DOE framework is said to be restrictive to use in that it suggests that *"the appropriate goal of the study should be examining the expected value of a single performance measure." "Terminating simulations run until a specific event has occurred; steady state simulations are stated to have no natural point of termination"*, resulting in continuous generation of data for analysis. The simulation type has a great bearing on the design and analysis for the terminating simulation it might be necessary to *"…censor results if we are simulating rare events…"* (Chen et al., 2006, pp. 269-270) Thus the authors overwrite the correlation of experimental research with the use of simulation and build a coherence that this thesis wishes to underline.

Chen et al. (2006, p.270) additionally state that the initial conditions for 'steady-state simulations…are *"often chosen for convenience rather than relevance."* The example given is that a simulation of a computer network may begin with *"…all servers and relay nodes operational and no demands on the system. Here, the simulation output of the warm-up period biases the estimated response. The length of the warm-up period affects the total time required for experimentation."* The authors also say that analysts have a large control over many things during the course of a simulation study. Among the major sections over which analysts have such a control during simulation are: the maximum run time for terminating simulations; the setting of system-parameters and others such as data-input batch sizes or data-input framework.

The choice of the number of data-input batches and batch sizes is an important topic of research in itself, and an implicit assumption in many simulation-analysis techniques. (Chen et al., 2006) Next addressed are the criteria for evaluating designs. The design is stated to be that which determines the *"standard errors for the estimated metamodel parameters."* (p.273) The following is given as an example:

> *"A-optimality means that the sum of these standard errors is minimal. D-optimality considers the whole covariance matrix of the estimated parameters (not only the main diagonal) and means that the determinant of this matrix is minimal. G-optimality considers the mean squared error of the output predicted through the metamodel."* (p.274)

These criteria are said to be and to have been *"used to evaluate designs proposed for analyzing simulation experiments…."* (p.274) However, it is also said to be unfortunate that these criteria 'require strong a-priori assumptions' on the meta-models to be a fit to the data and the nature of the expected response. "*These assumptions are usually violated in simulation."* The designs should be *"easy to construct if they are to be used in practice."* (p.274)

Chen et al. (2006, p.285) state that all simulation practitioners should view DOE *"as an integral part of any simulation study, while researchers should move beyond viewing the setting merely as an application area for traditional DOE methods."* The authors advocate thinking first of all about three potential goals of a simulation experiment including:

1. Understanding a system (and its application);
2. Finding robust solutions to serve the research objective; and
3. Comparing two or more systems.

The contention stated is that these goals are "*…often more appropriate than those typically used, namely, testing hypotheses about factor effects, seeking an optimal policy, or making predictions about performance.*" (Chen et al., 2006, p. 287) – To Summarize, these authors have demonstrated that experimental research does indeed have a fair coherence to those designs using simulation. This became especially clear in their remarks on the analysts having high control over many things during the course of a simulation study. It is this level of control that underlines the coherences to the experimental research design, where the validity and reliability testing in the positivistic approach are inevitable research design parameters. (Easterby-Smith et al., 2002)

3.7 Summary and Conclusion

Current literature on the UMTO production and distribution planning approach dominated by TWC with all the complex facets of meeting the clients' demands in delivery reveals that it should deserve more attention. The previous section of this chapter has identified numerous heuristic and meta-heuristic planning approaches for the CVRPTWC, many of them may be applied in full and some of them as a sub-set for this thesis and for the answering of the research question of this thesis. As explained, sometimes only a combination of some sub-sets or full applications of the mentioned distribution planning approaches will lead to sufficient results, when considering specific cost functions that arise from the requirements of a UMTO. That this will be the case will be shown in Section 4.2 Definition of the Cost Function. – One of the important findings from this literature research is however, that the importance and the role that TWC play in the production and distribution planning of a UMTO is certainly not yet researched sufficiently. This becomes evident, as much of the literature either looks at (1) the cost balance between production or distribution planning advantages; or (2) partially neglects the particular requirements in the UMTO industry, and (3) do not consider soft TWC as changeable (or even questionable) client demands under the construct of a promised week of delivery. These are the three contributions, which this thesis provides by bringing forward those possibilities in the UMTO industry. With the latter of those three as an experiment in simulating new tours of delivery, the existing literature has opened another gap that this thesis has identified. The fact that experimental research uses simulation as a tool, particularly in SCM and in logistics, was demonstrated to be a valid choice for this thesis.

4 Methodology

The following chapter will describe the chosen methodology of this thesis in the context of the research question. By doing so, this chapter will examine the research framework and identify how the chosen methodology supports the answering of the research question. One of its major contributions will be the formulation of the cost function and the supporting cost parameters. From the author's perspective, this is the basis of the entire methodological approach of this thesis. Hence, it will be described in detail.

The choice of the simulation model narrows the methodological approach to that of an experimental design in a positivistic research philosophy. This statement will be checked against existing literature from Section 3.5 Experimental Research and validated with the findings from Section 3.4 Simulation Techniques in Logistics.

The section of data input configuration would normally appear in the next chapter of data collection. In this case, however, as it is a part of the methodological foundation for the actual experiment with simulation, it is captured in this chapter of methodological descriptions for this thesis and therewith applies the statements of Robert et al. (2005).

4.1 Research Framework

This section will describe the research framework in which this thesis was undertaken. It will demonstrate and outline the design of the simulation experiment used and discuss the taxonomic approach of this work.

4.1.1 Mapping the Research Design

In Section 3.5 Experimental Research some references were made towards the use of simulation in logistics and their validity in operations management. From some of the cited references the following appears to be appropriate for the design and methodology used in this thesis:

> *Experimental research involves the definition of a theoretical hypothesis; the selection of samples of individuals from known populations; the allocation of samples to different experimental conditions; the introduction of planned change on one or more variables; and measurement on a small number of variables and control over other variables.* (Saunders et al., 2007, p. 597)

At this point, one has to look at this definition and compare it with this thesis's methodological approach. With the definition of the hypothesis that the removal of TWC in the delivery of UMTO will reduce the cost to such an extent that the receiver of goods might leave the demand of TWC to the manufacturer and in return achieve a lower buying price, the chosen methodology follows the above definition. The second prove is the collection of samples for this study from known populations and their allocations to different experimental conditions. Here, collection from real delivery notes in terms of consolidated tours of UMTO in the GKFI has applied the above definition's precondition in full. The introduction of a planned change on one or more variables and the measurement of such in their control over other variables represent the core of the actual experiment with the help of a DPS. In this context, the original data collected from the manufacturers was manipulated by the removal of the TWC; the restructuring of the delivery routes under the maintaining condition of the delivery within the promised calendar week and measured again.

Experimental research design and the applied methods however distinguish between laboratory experiment and field experiment. While true field experimental designs are rare in business and management research, (Bryman and Bell, 2003) laboratory and computerised experimental design has lately gained more and more attention. (Gill and Johnson, 2002) Here, "*…the dependent variable is measured before and after the experimental manipulation, so that a before-and-after analysis can be conducted.*" (Bryman and Bell, 2003, p. 40) Looking at the research process and the methodology with that (See Figure 2: Structural Research Overview) one may raise the questions towards the actually undertaken manipulation of the samples or the data. Here manipulation means: *"…the intervening in a situation to determine which of two or more things happens to subjects"* (Bryman and Bell, 2003, p. 40) under investigation. In order to keep control over the actual manipulation or intervention process, researchers establish two groups of data: the control group and the experimental group. (Saunders et al., 2007) In some instances, one may establish intermediate groups between the two groups to achieve the final experimental group to be investigated. Irrespective however, if there are intermediate groups or not, experimental simulation needs to adhere to the 'ceteris paribus' clause of applying simulation conditions of repeatable and re-measurable facilities. (Kleijnen et al., 2005)

This research, therefore has applied an experimental methodology for the answering of its research question. However, one may ask, if other methodologies could have achieved the same or similar results? The following methodological survey will try to answer this question and investigate what are the major confirmations or refutations why they were or were not inappropriate in the context of this thesis. 'The Research Onion' by Saunders et al. (2007) serves as guidance through this process.

4.1.2 Experimental Research Design

The cornerstones of experimental research design are described and discussed in many publications. Some examples that describe this design and simultaneously support the particular variant that this thesis has chosen by using simulation are now given.

The experimental design process includes the following:

1. Research Question
2. Design of Experiment
3. Data Collection
4. Data Analysis
5. Conclusions (Easterby-Smith et al., 2002)

From this framework definition, the authors pre-define a sequence of processes that show logic towards revealing the results and commenting on them in a conclusion. However, the step (2) of experimental design or process planning may in some instances include the steps (3+4) as its core element when simulation is the core of the experiment. (Fu, 2002) Here, the author describes examples of experimental design (pp.194-198) in simulation with the actual data collection and data analysis as the core of the chosen simulation model. The author considers thereby that the combination of the steps (3+4) can contain the actual simulation model as the experimental design.

Definition of Experimental Research:

> *"Experimental research is generally used in the sciences including sociology, psychology, biology, chemistry and other areas of science. Experimental research is a systematic and scientific approach to research in which the researcher manipulates one or more variables, and controls and measures any change in other variables."* (Gill and Johnson, 2002, pp. 47-48)

Experimental research is used when a time priority exists in a causal relationship and one in which the cause precedes the effect and when there is a consistency in a causal relationship meaning that a cause will always result in the same effect and finally where the magnitude of the correlation is great. (Eisenhardt, 1989)

Experimental research has a broad range of definitions applied to its description. However, in the strictest sense, experimental research is what is termed a 'true experiment' and is an experiment "*where the researcher manipulates one variable, and control/randomizes the rest of the variables.*" (Grams, 1994, p.2) Experimental research has a control group; the subjects are selected through a random process and are randomly assigned between the groups of the study with the researcher testing only one effect at a time. (Pfohl, 2004b)

It is also widely defined as a 'quasi experiment' where the researcher actively influences something to observe the consequences. Most experiments tend to fall between the strict and the wide definition. A rule of thumb is that physical sciences, such as physics, chemistry and geology tend to define experiments more narrowly than social sciences, such as sociology and psychology, which conduct experiments closer to the wider definition. (Adapted from Easterby-Smith et al., 2002)

Research Planning and Operation

Congdon and Dunham (1999, p.64) state that a research plan consists of two general areas:

1. Research concepts and context; and
2. Research logistics

Success or failure is often determined by how well the research is planned and *"how well the steps in the plan are integrated."* (Congdon and Dunham, 1999, p.64) It is important that data sheets are designed for the purpose of collecting data and to minimize mistakes and omissions in the data collection process. Computer programs should ideally be used in managing data.

The work of Robert et al (2005, p.185) states that the research design is the *"overall configuration of a piece of research, the research design provides the opportunity for 'building, revising and choreographing the overall research study."* The authors also state that researchers *"…increasingly face the practical challenges, for example, of achieving acceptable sample size and corresponding response rate. They must also determine the level of control that is plausible and optimal when utilizing individual or organizational behaviours. Research design also drives the choices of methodology and methods."*

Robert et al. (2005) relate in addition that choosing the research methodology appropriate for a study is affected by several factors which include the following:

1. The format of the research questions including “what”, “how”, “who”, “why” each of which requires different research designs to adequately answer them;
2. The nature of the phenomenon under study, i.e., contemporary or historical issues;
3. The extent of control required over behavioural events in the research context (Yin 1994; as cited in Robert, 2005, p.187); and
4. The researcher's philosophical stance, i.e., his/her understanding of the nature of social reality and how knowledge of that reality can be gained.(Robert et al., 2005, p. 11, Plutchik, 1983)

Robert et al. (2005, p.187) say that qualitative research methods *“primarily create meanings and explanations to research phenomena”* and include data collection methods such as:

1. Observation;
2. Fieldwork including interviews and questionnaires, diary methods, documents and texts, case studies; and
3. The researcher’s impressions and reactions to observed phenomena. Quantitative research methods serve to make provision of a broad range of situations as well as being fast and economic.

Commonly utilized quantitative research methods include those of:

1. Laboratory experiments;
2. Formal methods; and
3. Numerical methods and techniques. (Robert et al., 2005, pp. 188-189)

They also say (p.185) that an analysis in logistics simulation as an experiment often identifies a number of interesting trends and trends that are potentially important in logistics research. They relate this to the use of survey methods in logistics where in the past "*a considerable proportion of the survey-based method of data collection has been analyzed with structural equation modelling (SEM).*" They also noted the trends towards "*greater application of case methods.*"

4.1.3 Simulation in the Environment of Positivistic Research

The use of a simulation system in an experiment does not automatically identify a research approach as a purely positivist one. It is more a question, if the applied experimental approach can be described as a form of detached or involved one. (Easterby-Smith et al., 2002) These authors distinguish the methodological approach for a research design in three main kinds of validity to support chosen designs:

1. The accuracy of instruments to measure reality;
2. The capability to eliminate bias and the effect of extraneous variables; and
3. The definition of domains for generalisation of the results. (p.53)

From a positivist viewpoint, the questions of validity must be answered, if the measures of the chosen research design correspond closely to reality. In terms of reliability, the questions must be answered, if the chosen research methods yield the same results on other occasions. Finally, the positivist approach must stand the question, to what extent the study confirms or contradicts findings in the same filed. (Easterby-Smith et al., 2002)

In order to support what has been already mentioned, this thesis describes the applied instruments in detail in Section: 5.2.2 Validity and Reliability of the Screening. It demonstrates the numerous measures that were undertaken to identify its validity. The reliability in terms of the yielding of same or similar results also on other occasions is described in Section: 5.2.3 Research Process Validation of this thesis. – When looking at the generalisability of the chosen positivist approach, it becomes a little more complex in terms of a possible generalisability of the results to other research. However, when looking at similar research experiments (Quak and De Koster, 2007) one will find that this thesis does indeed have a large degree of generalization to its own or a comparable population. This becomes particularly aware, when looking at the 'What-if' question that simulation often deals with. (Rosenfield et al., 1985) Here, it becomes evident that using the same simulation and the same experimental design as in this thesis, but however, adopting different situations in simulation with the same cost function may contribute towards the generalisability of this thesis.

One may ask why the chosen research design could not have taken a social constructionist approach. In social constructionism the explanations attached to the research design are to increase a general understanding of the situation, whilst using a simulation in a positivist experimental research design rather aims to demonstrate the causality of different situations. The chosen research approach of this thesis, progresses through the definition of hypotheses and deductions towards answering the research question. The most important distinguishing and reason why this research does not apply a social constructionist approach is that it should incorporate stakeholder interests as a concept and this was unnecessary for this research. This thesis's concept is clearly defined and measurable and focuses on reduced units of base data in the simplest terms. Finally, the distinguishing between the two different philosophies becomes obvious when looking at the sampling processes attached there with and the generalisation of the results. The positivistic approach of this thesis incorporated a random (or stratified random) selection of large numbers, while the social constructionism framework would rather focus at a selection of small numbers of cases for very specific reasons and research targets. The generalisation of the results from this thesis will be discussed from a statistical point of view, thus supporting the positivistic framework against that of the social constructionism, where the generalisation of results is limited to theoretical abstractions. (Gill and Johnson, 2002)

Moreover, the concepts and constructs deriving from this research design have a large degree of relevance to other settings using a simulation approach. (Easterby-Smith et al., 2002) – Deriving from this, one might conclude that the chosen research design and its methodology could also be referred to as a case study design. (Yin, 2004) However it is the construct of base data management according to Rosenfield et al. (1985) that dominated the classification of this research design by assigning the raw data gained not fully at random but by a controlled group of data. (Easterby-Smith et al., 2002) By doing this, the grouping of the collected data also differentiates this approach from the quasi-experimental research design, as that it *"…makes use of multiple measures over time in order to reduce the effects of control and experimental groups not being fully matched."* (Easterby-Smith et al., 2002, p. 48)

Finally, one could also argue that the chosen research design of using simulation in an experimental approach would come close to that of 'fieldwork' and hence become an ethnographical research design. This may be refuted, as this approach includes the researcher himself being part of the study groups (Easterby-Smith et al., 2002), which is clearly not the case in this thesis.

Summarising some of the above epistemological and ontological thoughts on the chosen experimental methodology, one can say, that the experimental research design of this thesis with its adaptive and positivistic nature has an 'applied research' character through its cost-benefit analysis.

4.1.4 Combining Qualitative and Quantitative Research

Prior to looking at the research oriented combinations of qualitative and quantitative methodologies in research, one has to look at the three main issues addressed in this thesis:

1. The use of simulation in an experimental research design for logistics is often structured in such a way, that new, better or optimised situations are simulated by intervention or manipulation and are investigated. In this context, the large majority of research projects that investigate new optimisation algorithms for the TSP also belong. – This thesis however does not fully apply such a methodology. It looks at a given situation that arises from

practical implications and so far undisputed constraints, such as the TWC. By doing this, one has to look at similar approaches from a qualitative point of view and try to identify parallels between other work and that of this thesis. This is where the qualitative approach in this thesis finds its place of critical reasoning towards other research.

2. From a quantitative point of view, the thesis answers its research question through an empirical investigation by comparing the control group of data against the experimental group of data. This comparison is undertaken after the manipulation of the controlled group into a new simulated situation.
3. After the execution of the quantitative analysis, the thesis refers back to the origins of data and implies its qualitative findings together with the quantitative. By doing this, the author discusses the possibilities of his hypothesis's application or implementation possibilities within the same population, thus allowing the generalisability. (Bienstock, 1996)

From these three methodological issues, it becomes evident that a combination of qualitative and quantitative approaches in the context of this thesis deserves more explanation. Prior to doing this, the arguments against such a combinatorial methodology of embedded or paradigm arguments are defined as follows:

1. The embedded methods argument states: …*that the idea that research methods carry epistemological commitments; and*
2. The paradigm methods argument states: …*that the idea that qualitative and quantitative research methods are separate paradigms*. (Bryman and Bell, 2003, p. 480)

There are certainly many more such statements and definitions (Yang et al., 2006, Saunders et al., 2007) which provide similar arguments. However, the basic discussion on the combined qualitative and quantitative approach has two versions of debate:

1. The epistemological version: *"…sees quantitative and qualitative research as grounded in incompatible epistemological and ontological principles".*
2. The technical version: *"…gives greater prominence to the strength of data collection and data analysis techniques with which qualitative and quantitative research are each associated and sees these as capable and fused.* (Bryman and Bell, 2003, p. 481)

From these two versions, one may derive that there is a recognition that qualitative and quantitative research are each connected with distinctive epistemological and ontological assumptions, but the connections are not viewed as fixed and ineluctable. (Bryman and Bell, 2003) From this point of view, one may conclude that the technical version views both methodological strategies and approaches as compatible, both feasible and desirable. (Bryman, 2006)

The classification of combined or multi-stage approaches to the problem of qualitative or quantitative research can be stated as follows: (Hammersley, 1996 p. 161)

- *'Triangulation'* uses quantitative research to corroborate qualitative research findings or vice versa.
- *'Facilitation'* arises when research strategy is employed in order to aid research using the other research strategy.
- *'Complementary'* occurs when the two research strategies are employed in order that different aspects of an investigation can be dovetailed.

From this, the applied methodological strategy of this thesis, using qualitative findings to state the innovative character of this thesis and to support them with a quantitative analysis may be concluded as acceptable.

4.1.5 Combining Inductive and deductive Methodologies

A brief explanation of the two strategies is now given. It is then argued why both of them have been applied in this thesis. Since neither is considered better than the other, the decision to choose one is irrelevant. A combination of both may be applicable. (Saunders et al., 2007)

Deduction processes explain the causal relationship between variables. These processes control to allow the testing of the hypothesis, which underlies a strictly structured methodology (i.e. a Cost Function and Cost Parameters in a Simulation Experiment under the ceteris paribus clause) to facilitate replication. (Saunders et al., 2007) Another important characteristic of methodological deduction approach is that the applied *"…concepts need to be operationalised in a way that enables facts to be measured quantitatively"*. (Saunders et al., 2007, p. 118) In doing that, often the principle of reductionism is being followed. Finally, a deductive methodological approach to research includes the important criterion of generalisation about statistically found regularities. By doing this, one may apply discussions about the cause-effect link or the transferability of the findings to other or associated fields of research. (Saunders et al., 2007)

Induction strategy as a methodological approach to research focuses strongly on the choice of small samples and qualitative research. Here a clear distinction between verification and falsification *"…on how much data one obtains in support of a scientific theory it is not possible to reach a conclusive proof of the truth of that law."* (Easterby-Smith et al., 2002, p. 51) From this statement according to Popper (1956), one of the inductive strategies is not the confirmation of evidence but largely the refutation of such.

Now, when one looks at the combination of both approaches one may conclude that there are rigid divisions between deduction and induction. This is not the case. (Creswell, 1994, Saunders et al., 2007, Hanson et al., 2005) According to Creswell (1994); it depends strongly on the nature of the research topic and a close understanding of the research context. It permits a more flexible structure and even changes in the research progress. With generalisation a lesser concern, the inductive methodology or strategy is based on a realisation that the researcher is often a part of the research process and it is often described as protracted. (Saunders et al., 2007)

Now looking at the chosen methodology of this thesis, one can say that a deductive methodological approach was adopted more than an inductive approach. Explaining the causal relationship between the variables that influence the cost of delivery for UMTO, the operationalisation of the undertaken simulation and, finally, the strictly structured methodology for the testing of the hypothesis characterise the main methodology of this thesis. – This inductive methodological approach relates more to the literature research of this work. Here, a refuting approach was often chosen to identify the gaps between the existing literature and the thesis's findings.

4.1.6 Parameters of Validity Substantiation

One of the most important criteria in experimental research design methodology is the validity, the reliability and the replicability of measurement issues. A major reason for this importance lies in the fact that experimental research allows the researcher to 'manipulate' processes, data, and individual circumstances of his research. Consequently, the replicability is a foremost important criterion of experimental research that requires the substantiation through the validation of all single steps in experimental research. (Bryman and Bell, 2003) However, the criteria of reliability, validity and replicability have not experienced a fully satisfactory and consistent definition in literature on research methodologies in the past. (Denscombe, 2002)

> *"When one looks at the discussion of reliability and validity one finds not a clear set of definitions but a confusing diversity of ideas. There are substantial divergences among authors' definitions, and there is even some overlap between definitions of the two concepts."* (Hammersley, 1987, p. 73)

Taken from the above, one may define validity and reliability as follows:

"Validity concerns the accuracy of questions asked, the data collected and the explanations offered. Generally, it relates to the data and the analysis used in the research".

"Reliability relates to the methods of data collection and the concern that they should be consistent and not distort the findings. Generally, it entails an evaluation of the methods and techniques used to collect the data." (Denscombe, 2002, p. 100)

From these two definitions, one may assume that they apply particularly and are especially important to an experimental research design. In relation with the use of computerised simulation systems, the validity previously mentioned and reliability gain yet another important status, whereby the systems setting for the data input and the calculation of data require a high transparency of those processes. This is why this thesis has followed Denscombe (2002) and entered a very detailed data input description. (See 5.2 Data Collection and Processing) At this point, yet another requirement from Denscombe (2002) and Bryman and Bell (2003) will be met by showing how numerous validity and reliability checks will be undertaken during the simulation experiment, to ensure the transparency of processes undertaken so they may be replicated. (See 5.2.2 Validity and Reliability of the Screening and also 5.2.3 Research Process Validation) Here, the data collection process is described in extensive detail, in order to substantiate the knowledge about the data collected, its origin and also how the initial raw data will be prepared for the experiment. (See 5.2.1 Data Cleansing and Selection Parameters) The latter was highly important to the experiment, as, at this stage, a manipulation of the gathered data will be undertaken in the cleansing of the data for the preparation of the actual data input.

In adherence to a fully applied replicability of the undertaken experiment, the simulation systems' specifications will be described together with the systems selection process. (See 5.1.4 System Use and Operational Specifications and 5.1.3 System Selection Process) Both these sections of Chapter 5, describe in detail the individual steps of the experiment chosen by the author. Hence, they warrant the chosen methodology of this experiment and the actual data collection and its analysis.

In terms of applying a high degree of transparency of the entire methodological approach of the experiment, the detailed explanation of the cost functions and all underlying cost parameters will be added to satisfy the replicability of this work. (See 4.2 Definition of the Cost Function and 4.2.2 Supporting Cost Parameters) However, some self-critique is justifiable at this stage and deserves some reflection. These reflections are based on the fact that this thesis will use a computerised simulation system for the re-routing of vehicles from originally given tours. By doing so, the originally supplied tours contained individual deliveries; these tours will be de-consolidated and then re-consolidated by the formation of new routes. In this process, the previously existing TWC are omitted. With this removal of TWC, the de-consolidation and the re-consolidation of the tours with a DPS are a fact of manipulation in the sense of how Denscombe (2002) and Bryman and Bell (2003) describe it. Referring to the statement of Hammersley (1987, p.73), as stated in the beginning of this section; this was endeavoured to be refuted by adhering to the guidance of Denscombe (2002) and Bryman and Bell (2003).

4.1.7 Practical and Phenomenological Research Initiations

This section of the methodological conceptions will describe how business and phenomenological oriented initiatives led towards this research and have actively influenced this work. To start with, one has to survey some practical business routines about the use of DPS in general in the field of UMTO. Here, DPS are often used to plan distribution in a pre-active approach for a routine production based on exogenous determinations. Details of this are explained in Section 1.3 Practical Background and in the Appendix. The business research initiation of this thesis has a methodological background whereby the real existence of TWC in their practical sense is hardly ever questioned. This means that routes in the CVRPTW are planned as described in Figure 40 Production and Delivery-Data Allocation for UMTO. Once those routes are executed, and the goods are delivered with the vehicle returning to its depot, these routes are seldom questioned anymore. The questions why were they there, how much did they cost and what could one have done to avoid them, is not practised in the real world. This was a major innovation by raising the question, why are these UMTO businesses doing what they are doing. A practical background also gave rise to thoughts on the promised week of delivery, which in practice is actually narrowed to a particular day and time. On the other hand, the receiving stores run warehouse operation hours and days that are often highly flexible and could accept a change of soft TWC.

Some phenomenological initiations for this research have a more philosophical background on this problem, raising the question of how practitioners make sense by doing, what they are doing and how from a point of view from this thesis, one could 'bracket out' some preconceptions on this problem. (Bryman and Bell, 2003) If TWC really cause such cost as this thesis will try to ascertain, then why are they not being questioned to a much higher degree? Immediately, experts in SCM and logistics might raise the question about the cost for the receivers of goods, if the demand of the TWC lies in the hands of the suppliers. The phenomenological approach would be to 'bracket' this 'out' for the time being, until, one has answered the first question about the results arising from the total removal of TWC.

Another important phenomenological innovation in this thesis stems from the fact that most research on the CVRPTW accepts the TWC for 'being given'. The previous chapter Literature Research has shown this in numerous cited references. A search for the refutation of this was not found in more than 500 publications during this research. Consequently, it may be questioned, why people do what they do, and why they do not even partially question the CVRPTW. Why does research always accept the TWC in the CVRP? From a phenomenological point of view, this question may be justified to such an extent that the 'bracketing out' of conflicting interests is neglected for a time being. However, from a business point of view, this could raise some serious questions. A compromise for the two contradicting points of view may lie in a more sensitive approach to this problem. Here, the methodological solution or partial contribution towards these phenomena will be stated in Section: 6.3: Sensitivity Analysis.

In order to substantiate the before mentioned statement of given or generally accepted TWC in the VRPTW, the following table will demonstrate what different foci those publications have and how they can be classified.

Table 8: Overview & Classification of Publications on the VRPTW

Main Themes	Main Focus	TWC Acceptance
A. VRPTW in general	1. New Search Algorithms	yes
	2. Comparisons of Search Algorithms	yes
	3. Parallel Applications	yes
	4. Minimising Distance & Route Duration	yes
	5. Pick-up & Delivery Problem	yes
	6. Scheduling Problems	yes
B. VRPTW & soft TWC	1. New Search Algorithms	yes
	2. Minimising Distance & Route Duration	yes
	3. Parallel Applications	yes
	4. Pick-up & Delivery	yes

The first classification is on the research of the VRPTW in general. From the large number of publications, the majority focus on the development of new search algorithms. Here, in the search for new improving algorithms and also in the focus of comparing different algorithmic approaches, can be found the majority of publications. When looking at them in some detail and over the past two decades from today, one finds a number of leading researchers in this field. (Desrochers et al., 1992, Bräysy and Gendreau, 2002, Cordeau et al., 2002b, Cordeau et al., 2005, Laporte and Semet, 2002, Potvin and Bengio, 1996, Toth and Vigo, 2002) Without prioritising any of them, they all have contributed towards the rapid development of the problem solving process. However, all of them have accepted the existence of TWC in their work and did not consider or compare existing TWC with any kind of relaxation of such. Their focus is on the creation of new search algorithms to improve the optimisation of the problem. The parallel application of different search algorithms and the combination of the general search with that of pick-up and delivery has recently developed to a new and most interesting field of research, particularly from a real-life perspective. Here, some authors have developed new insights into this problem and its increased complexity over the general research on the VRPTW. (Urban, 2006, Vural, 2003) Their contribution to new knowledge was highlighted by solving the very complex problems arising from the combination of the VRPTW with new and additional constraints en route through the pick-up and delivery phenomenon. The application of hybrid or parallel search algorithms was introduced by some authors (Bent and Van Hentenryck, 2004, Gehring and Homberger, 1999, Ho et al., 2001) in the attempt to achieve even better solutions for the entire problem of the VRPTW. Another section of the VRPTW is that which focuses on the pure minimisation of route duration and total distance to be travelled. Some of the researchers see this as the core of research in the field of VRPTW, as it is closely connected to the original TSP. Here, one may state that research in this specialised field is, until today, still dominated by some pioneers in this research. (Savelsbergh, 1992b, Cordeau et al., 2002a, Tempelmeier, 2002, Solomon, 1987, Urban, 2006) Another category of research in the field of the VRPTW is that of scheduling. Here, the authors report on the problem of scheduling of vehicles, the scheduling of vehicle lot-sizes and also the scheduling of production lot-sizes in the context of the VRPTW. (Solomon, 1987, Fleischmann and Meyr, 1997, Clarke and Wright, 1964, Qureshi et al., 2009, Silver et al., 1998, Charikar et al., 2001, Bachmann and Langevin, 2009) The scheduling problem as an additional constraint to those arising from the general VRPTW is of a very high complexity, as it requires the partially additional, hybrid or parallel adaption of system overlapping algorithms with partially contrary objectives of optimisation.

The second classification of the VRPTW is more specific and also more focused than the first. It focuses on this problem in connection with soft TWC only. This means that any hard TWC are excluded or at least neglected. The soft TWC phenomenon in most of those publications is described as a time corridor of earliest vehicle arrival and latest vehicle departure. What however, if the arrival time of the vehicle meets the permitted arrival time of the given TWC, but the unloading process exceeds the TWC due the load size? In other words, the unloading time required of the given load also has to match the set time corridor. This phenomenon is dealt with in the focus of ‘pick-up & delivery’.

Research focus on the general improvement of algorithms for the reduction of computing time and the reduction of total distance travelled are the majority in this field. Here, many researchers apply similar or related approaches as other researchers do for the general VRPTW. (Badeau et al., 1997, Qureshi et al., 2009, Figliozzi, 2009, Fu et al., 2008) However, as stated before in this section, none of the authors actually questions the TWC and looks at them as a removable constraint. All their valuable work concentrates at the optimization of routes, distances, cost and other variables, but does not look at the opportunity of investigating their results against the removal of such soft TWC as a major constraint.

When looking at the VRPTW with soft time windows, one also finds numerous publications that focus on the application of more than just one set or one single classification of algorithms and do apply them in a parallel or hybrid approach. Here some authors (Tavakolimoghadam et al., 2006, Calvete et al., 2007) solve this problem with a multiple and or parallel use of different search algorithms.

Finally this section of the VRPTW also has a specialised focus on the soft TWC issue and combines such with the additional problem arising from the pick-up and delivery constraint. This increased complexity of a multiple task during route duration is probably one of the most challenging. The latter is supported by the goal of route optimization with set soft TWC for both activities. Here the current research definitely does not consider any removal of the TWC constraints nor does it consider any relaxation of such. (Ai-min et al., 2009, Hsu, 2008)

Taken from the above table and its explanations thereafter, one may conclude that all of them focus their research objective on a route optimization, including constraints such as the TWC. An analysis including the relaxation or removal of such TWC constraints against original states of TWC constrained route operation could not be found in this thesis' entire Literature Research.

4.2 Definition of the Cost Function

In this section, the cost function as well as the objective function for the tour planning and the distribution simulation will be presented. By doing so, a closer look will be taken at the factors influencing delivery cost in the first section. The underlying cost parameters as an important input to the cost function will be defined in the second section. Further, the cost function will be stated in (1) a detailed and (2) in a simplified form. The objective function to achieve the answering of the research question with all its constraints will be presented as a cost minimization function in distribution and tour planning.

4.2.1 Influences on Delivery Cost

Since the kitchen manufacturers plan their deliveries in accordance with their production schedules on a weekly basis, an approach to optimizing delivery cost is optimizing such for every single calendar week. Prior to the presentation of the detailed cost function some of its elements are introduced in the following.

The week of shipment in the following will be referred to as ws.

$$ws \in WS; \qquad WS = \{1, \ldots, 52\}$$

The customers are referred to as

$$cust \in CUST; \; CUST = \{1, \ldots, k\}$$

The orders a customer makes and the UMTO confirms for delivery in a certain calendar week are vo_{wscust} for the volume ordered and vd_{wscust} for the volume delivered. Serving the complete order of each customer requires compliance with the following constraint:

$$vo_{wscust} = vd_{wscust} \qquad \forall\, ws \in WS \quad and \quad \forall\, cust \in CUST$$

The same condition could be formulated for the weight ordered / delivered and the units ordered / delivered, too. However, since customized kitchen furniture is a voluminous good, the relevant restriction regarding transport matters is the volume. Hence, the volume restriction dominates the others and is the only one that needs adherence. In order to later calculate a loading time depending on the number of units delivered for each stop at a customer's site it is referred to them as ud_{wscust}. Each delivery represents a stop.

For serving the customers, a restricted number of vehicles are available.

$$veh \in VEH; \quad VEH = \{1, \ldots, i\}$$

These i vehicles have constrained loading capacity cap_{veh}. For the same argument as above, capacity is viewed as a volume restriction not as a weight restriction. A further constraint to the use of vehicles is that drivers operate under legal rules concerning the maximum daily travelling time. A vehicle can be staffed with either one or two drivers and each driver's daily travel time is constrained to be 8.8 hours or less. We define the number of drivers a vehicle is staffed with in one week as dc_{wsveh}. For a vehicle's daily travel time dt_{wsveh} this means:

$$dt_{wsveh} \leq y$$

with

$$y = 8.8 \text{ when } dc_{wsveh} = 1 \quad \text{and} \quad y = 17.6 \text{ when } dc_{wsveh} = 2; \quad \forall\, dc_{wsveh} \in \{1;2\}$$

Staffing of vehicles each week is restricted by the number of available drivers nad_{ws}. The set of all drivers is referred to as $DRIV$.

$$driv \in DRIV; \qquad DRIV = \{1, \ldots, d\}.$$

The set of drivers who are available in one week is AD_{ws}. For a certain day the set of available drivers is given as AD_{wsdow}. Where the day of the week is referred to as dow.

$$AD_{wsdow} \subseteq AD_{ws}$$

$$dow \in DOW;\ DOW = \{1,\ldots,7\}$$

The hours a driver works on a certain day in one week are $wh_{wsdowdriv}$. A driver is available when his aggregated working time over the last 28 days is 160 hours or less.

$$ad_{wsdow} \in AD_{wsdow};$$

$$\forall\, ad_{wsdow} \left| \sum_{dow=1}^{dow} wh_{ws-4dowdriv} + \sum_{ws=ws-3}^{ws-1} \sum_{dow=1}^{7} wh_{wsdowdriv} + \sum_{dow=1}^{dow-1} wh_{wsdowdriv} \leq 160 \text{ hours and } AD_{ws} = \{1,\ldots,nad_{ws}\} \right.$$

AD_{ws} is a subset of the set of all drivers $DRIV$.

$$AD_{ws} \subseteq DRIV$$

A further restriction related to operating hours is given by the weekly working hours. Working hours are from Sunday 10pm until Saturday 10pm.

For economic reasons, a vehicle can - within its capacity restriction - load goods for more than just one customer and serve these customers consecutively, without an intermediate stop at the home depot, in a tour. One customer's order shall be delivered by only one vehicle whenever this is possible. A second stop is only allowed in the case that vo_{wscust} exceeds a vehicle's capacity. In the case that a customer has made multiple orders for delivery in one and the same calendar week, these orders shall be consolidated to a minimum number of deliveries. We define the number of deliveries a customer receives in one calendar week as nd_{wscust} and formulate the constraint.

$$nd = \min nd \quad with\, nd \in \mathbb{N}$$

Here it is important to note that the requirement of complete delivery has been formulated already above.

One week's total travelling time h_{ws}^{travel} results from the heuristics used to solve the optimization problem. Its calculation is based on the distance travelled on different types of roads (motorway, country and city) and the assumed corresponding average travelling speed.

$dist_{ws}^{motorway}, dist_{ws}^{country}$ and $dist_{ws}^{city}$ stand for the distances in kilometers travelled on the different types of roads in one week. $S^{motorway}, S^{country}$ and S^{city} give the corresponding speed averages in kph.

$$h_{ws}^{travel} = \frac{dist_{ws}^{motorway}}{S^{motorway}} + \frac{dist_{ws}^{country}}{S^{country}} + \frac{dist_{ws}^{city}}{S^{city}}$$

The total distance traveled in one week $Dist_{ws}$ is the sum of the distances travelled on the different types of roads.

$$Dist_{ws} = dist_{ws}^{motorway} + dist_{ws}^{country} + dist_{ws}^{city}$$

A further time component is the time needed in one week for unloading at the customers' sites h_{ws}^{load}. It depends on the number of units delivered and a time parameter l.

$$h_{ws}^{load} = \sum_{cust=1}^{k} (1 - f_{wscust}) * (ud_{wscust} * l) + \sum_{cust=1}^{k} f_{wscust} * (100 \min + (ud_{wscust} - 10) * l)$$

with $\quad l = 10 \min \quad$ and $\quad f_{wscust} = 0 \quad \forall\, ud_{wscust} \leq 10$

and $\quad l = 5 \min \quad$ and $\quad f_{wscust} = 1 \quad \forall\, ud_{wscust} > 10$

After dealing with unloading time, loading time has to be mentioned, too. Loading time is assumed to be dependent on the number of units loaded. This number does not depend on how the delivery of the goods is planned. Thus cost for loading the vehicles in the depot is not taken into consideration here.

Waiting time h_{ws}^{wait} occurs when a vehicle arrives at a customer's site before the agreed time window opens. The planned unloading time is restricted by the TWC which is the focal point of this thesis. A customer's TWC basically is given by an earliest time of delivery etd_{cust} and a latest time of delivery ltd_{cust}. For each customer these can vary infinitely for each week day. Furthermore, a customer may offer more than one time window a day. Customers are allowed to offer no time window at all for one or more week days. This reflects the case that they do not accept deliveries on certain days. Thus, we extend the basic version to:

$etd_{custdaytw}$ and $ltd_{custdaytw}$

with $day \in DAY \quad DAY = \{mon, tue, wed, thu, fri, sat, sun\}$

and $tw \in \mathrm{N}$

We define the set of time windows offered by one customer as OTD_{cust} and the time window in which delivery takes place as $atw_{wscustdaytw}$ which is further specified by an actual time of delivery atd_{wscust} and actual date of delivery add_{wscust}. Additionally we have to take into account that the UMTO proposes its customers a delivery date pdd_{wscust} and a time of delivery on that date ptd_{wscust}. The following constraints need to be complied with:

$$pdd_{wscust} = add_{wscust}$$

$$ptd_{wscust} = atd_{wscust}$$

$$etd_{custdaytw} \leq atd_{wscust} \leq ltd_{custdaytw}$$

$$atw_{wscustdaytw} \in OTD_{cust}$$

A week's aggregated waiting time is the sum of waiting time from all single deliveries in this week h_{wscust}^{wait} which result from the heuristics for tour planning.

$$h_{ws}^{wait} = \sum_{cust=1}^{k} h_{wscust}^{wait}$$

Before summarizing the before mentioned relations between delivery cost and the factors influencing it in one cost function the next section will introduce cost parameters which for this research have been set once and maintained at the same level throughout the whole of it. Since cost determination for the different sets of bases data will be done in accordance with the presented cost function and these underlying cost parameters it will be possible to compare the sets of base data ceteris paribus.

4.2.2 Supporting Cost Parameters

The cost of one week's deliveries $C_{ws}^{delivery}$ in this thesis is viewed as the aggregate of time depending cost C_{ws}^{time} and distance induced cost $C_{ws}^{distance}$. Its basic form is:

$$C_{ws}^{delivery} = C_{ws}^{time} + C_{ws}^{distance}$$

The first component C_{ws}^{time} derives from multiplication of the following factors: First, the sum of hourly cost per vehicle $c^{vehicle}$ and hourly cost per driver c^{driver} secondly the sum of travelling time h_{ws}^{travel}, unloading time h_{ws}^{load} and waiting time h_{ws}^{wait}.

$$C_{ws}^{time} = \left(c^{vehicle} + c^{driver}\right) * \left(h_{ws}^{travel} + h_{ws}^{load} + h_{ws}^{wait}\right)$$

The distance component $C_{ws}^{distance}$ is the product of $Dist_{ws}$ and a cost parameter $c^{distance}$ that reflects variable cost related to the vehicle.

$$C_{ws}^{distance} = Dist_{ws} * c^{distance}$$

In the following a closer look will be taken at the cost parameters $c^{vehicle}$, c^{driver} and $c^{distance}$. They will be reasoned on the level of annual cost per vehicle. Since the parameters as presented here present relative values they can easily be applied to more than one vehicle.

$c^{vehicle}$ describes vehicle cost per minute. The cost component covers all fixed cost related to a vehicle. These are depreciation, financing, maintenance and insurance. Annual depreciation and financing are calculated based on Dekra statistics (German expert commission on commercial vehicle fleet Management, 2002) about the average acquisition cost per vehicle, the amortisation period, the residual value at the end of the amortisation period and the imputed interest rate. The mentioned statistics are given in the table below. All of which have been derived from Dekra, based on market prices in the years 2000 until today.

Depreciation is assumed to be accomplished on a linear basis while the financing cost is calculated with the approximate formula.

annual depreciation: $€110{,}000 * (1 - 12\%) / 8 = €12{,}100$

annual financing cost: $€110{,}000 / 2 * 6\% = €\ 3{,}300$

Additionally, maintenance costs are considered with an annual total of € 16,000. These include tyres, repairs, insurance, lubricants and check-ups. Total average vehicle cost thus sum up to € 31,400. The time component of $c^{vehicle}$ represents the sum of all minutes an average vehicle is used within one average year. Minutes of usage are those a vehicle is operating on tours. Therefore, driving time, breaks and unloading time are included while loading time and time a vehicle is left in the depot are not included. The usage factor is set at 53%. This signifies that on average, a vehicle is on tour 89 hours per week in relation to 168 hours which a week has in total. The 89 hours include driving times as well as unloading times and breaks. The sum of hours a vehicle is used per year results as 4,642.8. It can be concluded:

$$c^{vehicle} = \frac{€\,31{,}400}{4{,}642.8\,\text{hours}} = 6.6\,\frac{€}{\text{hour}}$$

Table 9: Derivation of Cost Parameters - underlying assumptions

Derivation of Cost Parameters
underlying assumptions

assumption	value	entity
acquisition cost per vehicle	110,000	Euro
residual value at end of useful life	12	%
amortisation period	8	years
imputed anual interest rate	6	%
annual maintenance cost per vehicle	16,000	Euro
usage factor	53	%
number of drivers per vehicle	2	drivers
average monthly cost per driver	2,900	Euro
Fuel price	0.6	Euro per litre
average fuel consumption	17.4	litres per 100 kilometers

The second time dependent parameter is c^{driver}. It is calculated as the annual cost for staffing a vehicle with drivers divided by the annual minutes of usage. The ladder has been presented above. The annual cost for drivers per vehicle is calculated based on Dekra statistics from the years 2000 until 2008 about cost per driver and drivers needed to staff a vehicle. The monthly cost per driver in Germany is approximately € 2,900 including payments to the driver as well as the cost of social security. Out of 252 working days per year, an average driver is considered operational and due to illness and holidays, 210 days only. Having each vehicle staffed with one driver on each working day thus requires for hiring 1.2 drivers. The vehicles of the UMTO analysed in this thesis operate with two drivers. Hence 2.4 drivers have to be paid for each vehicle. Annual driver cost per vehicle results as € 83,520. Summarised this means:

$$c^{driver} = \frac{€\,83{,}520}{4{,}642.8\,\text{hours}} = 18\,\frac{€}{\text{hour}}$$

The third parameter $c^{distance}$ reflects the dependence of cost on kilometrage. Its entity is € per kilometre and it is calculated as the proportion between cost for fuel and kilometres travelled. Cost for fuel is the price per litre of fuel multiplied with the consumption in litres. Statements regarding these values have been given in the table above. A fuel price of € 0.6 per litre reflects the net price (excluding v.a.t.) for fuel in the year 2000 reduced for a reasonable volume discount of 3%. The consumption of 17.4 litres per 100 kilometres accounts for the comparatively light shipments and the partial usage of small vehicles. The fuel cost per kilometre $c^{distance}$ results as follows:

$$c^{distance} = 0.6 \frac{€}{litre} * \frac{17.4 \text{litres}}{100 \text{kilometres}} * 100 = 0.1 \frac{€}{kilometre}$$

The cost parameters $c^{vehicle}$ and c^{driver} represent certain costs related to vehicles and staffing of these which are fixed cost. Their value does not change weekly. Here, with an assumed utilization rate which stays fixed for the evaluation of all three base data it is possible to implement them as a linear influence on the time dependent cost. The logical influence of a removal of TWC on the utilization rate is that it will increase, since less waiting time at customers' sites and lower kilometrage mean higher utilization in the sense of being able to serve more customers with the same number of vehicles and drivers. This increased utilization rate would induce lower values for the cost parameters $c^{vehicle}$ and c^{driver}. Since these parameters remain the same throughout the research, cost calculated for Base Data-2 and Base Data-3 will be in fact lower than calculated based on these fixed parameters. However, when interpreting the significant cost reductions which will appear in the analysis section, it has to be taken into consideration that this effect is not yet included. Though, it has to be noted that for the short term, the underlying costs are fixed and a lower utilization may mean understating real cost because the parameters ignore over-capacities which will be eliminated for the mid and long term.

The above cost parameters were implemented in a ceteris paribus framework for all experimental steps of data simulation in this thesis and were implemented into the used DPS. They have to be set before the Cost Function presented in the next section can be solved.

4.2.3 Cost Function and Objective Function

Now that the factors influencing distribution cost have been identified and the underlying cost parameters have been defined, the cost function and based thereon, the objective function can be formulated. At the beginning of the previous section a simplified version has already been given.

$$C_{ws}^{delivery} = C_{ws}^{time} + C_{ws}^{distance}$$

Its components have been defined as follows:

$$C_{ws}^{time} = \left(c^{vehicle} + c^{driver}\right) * \left(h_{ws}^{travel} + h_{ws}^{load} + h_{ws}^{wait}\right)$$

and

$$C_{ws}^{distance} = Dist_{ws} * c^{distance}$$

Put together the cost function can be given in a more detailed form:

$$C_{ws}^{delivery} = \left(c^{vehicle} + c^{driver}\right) * \left(h_{ws}^{travel} + h_{ws}^{load} + h_{ws}^{wait}\right) + Dist_{ws} * c^{distance}$$

It can be further detailed with the information given in Section 4.2.1 Influences on Delivery Cost:

$$C_{ws}^{delivery} = \left(c^{vehicle} + c^{driver}\right)$$

$$* \left(\begin{aligned} &\frac{dist_{ws}^{motorway}}{S^{motorway}} + \frac{dist_{ws}^{country}}{S^{country}} + \frac{dist_{ws}^{city}}{S^{city}} + \sum_{cust=1}^{k} (1 - f_{wscust}) * \left(ud_{wscust} * l\right) + \sum_{cust=1}^{k} f_{wscust} * (100 \min + (ud_{wscust} - 10) * l) \\ &+ \sum_{cust=1}^{k} h_{wscust}^{wait} \end{aligned} \right)$$
$$+ c^{distance} * \left(dist_{ws}^{motorway} + dist_{ws}^{country} + dist_{ws}^{city}\right)$$

In this model $c^{vehicle}, c^{driver}, c^{distance}, S^{motorway}, S^{country}$ and S^{city} are pre-set parameters while f_{wscust} is a binary variable depending on the units delivered and the parameter l gives the time needed for unloading one unit in dependency on the number of units delivered. The variables influencing cost are distance, time and units delivered. Hence the summarized cost function for one week's deliveries can be given as:

$$C_{ws}^{delivery} = F\left(dist_{ws}, h_{ws}, ud_{ws}\right).$$

And even more generalized the cost function is:

$$C^{delivery} = F(dist, h, ud).$$

The objective in tour planning as viewed in this thesis is cost minimization. The objective function is:

$$\min C^{delivery} = F(dist, h, ud)$$

subject to:

Defined weeks of delivery:

$$ws \in WS; \qquad WS = \{1, \ldots, 52\}$$

Defined number of customers:

$$cust \in CUST;\ CUST = \{1,\ldots,k\}$$

Completion of all client orders:

$$vo_{wscust} = vd_{wscust} \qquad \forall\, ws \in WS \quad and \quad \forall\, cust \in CUST$$

Limited number of vehicles:

$$veh \in VEH; \quad VEH = \{1,\ldots,i\}$$

Legal restriction to drivers' daily travel time:

$$dt_{wsveh} \le y$$

with

$$y = 8.8\, when\ dc_{wsveh} = 1 \quad and \quad y = 17.6\, when\, dc_{wsveh} = 2; \quad \forall\, dc_{wsveh} \in \{1;2\}$$

Limited number of drivers:

$$driv \in DRIV; \qquad DRIV = \{1,\ldots,d\}$$

Limitation to availability of drivers:

$$AD_{wsdow} \subseteq AD_{ws}$$

$$dow \in DOW;\ DOW = \{1,\ldots,7\}$$

$$ad_{wsdow} \in AD_{wsdow};$$

$$\forall\, ad_{wsdow} \left| \sum_{dow=1}^{dow} wh_{ws-4dowdriv} + \sum_{ws=ws-3}^{ws-1} \sum_{dow=1}^{7} wh_{wsdowdriv} + \sum_{dow=1}^{dow-1} wh_{wsdowdriv} \le 160\ hours\, and\, AD_{ws} = \{1,\ldots,nad_{ws}\} \right.$$

$AD_{ws} \subseteq DRIV$

Requirement of serving customers with as few deliveries as possible:

$nd = \min nd \quad with\, nd \in \mathrm{N}$

TWC and accordance to proposed delivery times and dates:

$etd_{custdaytw}$ and $ltd_{custdaytw}$

with $\quad day \in DAY \quad DAY = \{mon, tue, wed, thu, fri, sat, sun\}$

and $\quad tw \in \mathrm{N}$

$pdd_{wscust} = add_{wscust}$

$ptd_{wscust} = atd_{wscust}$

$etd_{custdaytw} \leq atd_{wscust} \leq ltd_{custdaytw}$

$atw_{wscustdaytw} \in OTD_{cust}$

Obviously, the TWC have an indirect influence on cost. They are a limitation to the number of possible solutions of the tour planning process and thereby influence time and distance. In this thesis's simulation process, the cost is first calculated according to the above function and parameters for an original situation with TWC. In a first step the TWC are loosened and distribution is re-planned under the constraint of keeping existing tours together and to change only the order of serving clients within these tours. The resulting travel time and distance are used as an input to the above cost function and delivery cost is calculated comparable to the cost in the original situation. Secondly, distribution is re-planned with omitted soft TWC only, maintaining the hard TWC, allowing for re-combination of tours within one and the same calendar week. Once again, the resulting travel time and distance are used as an input to the cost function. As a result cost can be compared for three different stages of optimization. The next section of this chapter will give more information about the simulation process and the final definition of the applied model from above findings.

4.3 Choice of the Simulation Model

The choice of the simulation model for this thesis can be compared to that stated on the work of Poe et al. (1994, p.904). Here the authors define their model as: *"Measuring the Difference (X – Y) of Simulated Distributions."* It is this measurement of *X* – *Y* of simulated distributions that are compared and applied to the methodological approach of this thesis. Bryman and Bell (2007, p.40) describe the *X* – *Y* comparison in their findings on the experimental research design as the *"comparison of the experimental or treatment group against the control group"* and by doing so, they describe the basis for experimental manipulation of the independent variable. It is this manipulation of the independent variable(s), which forms the basis for the choice of the simulation model. If the *X* – *Y* comparison needs to achieve a real dichotomous comparison through the approximation of simulated distributions as reported by Poe et al. (1994) is questionable. This thesis has refuted such a dichotomous comparison and has chosen a continuum of comparison on the X – Y phenomenon.

Rosenfield et al. (1985, p.90) in their work distinguish four different models of simulation:

1. Manual evaluation of alternatives;
2. What-if simulation modelling;
3. Optimisation modelling; and
4. Heuristic modelling.

The authors state that the "*…heuristic modelling approach is really a form of optimising modelling*", as the intentions of the heuristics are the optimisation of specific criteria. This statement was confirmed several times in Section 3.1.3

Heuristic and meta-heuristic Models of this thesis. Further, the authors describe the optimisation modelling as *“optimisation involves a determination of the optimal or best solution.”* (p.90) As these authors *“categorise procedures as either optimisation or simulation”* in their work as a result of previous research, they refer this to the *“availability of a limited number of alternatives.”* (p.91) Another reason for the previously distinguished categorisation comes from the necessity in situations for the use of optimisation modelling, *“…where there are significant constraints in the logistics system activities.”* (p.91) Rosenfield et al. (1985, p.91) have developed the ‘What-if’ simulation modelling by combing *“optimisation with a heuristic fashion.”*

It is this optimisation with heuristics, which has formed the simulation modelling of the chosen methodological approach in this thesis. The underlying bases of this model have been described in Section: 3.1 Distribution Planning Approaches of this thesis in detail.

4.3.1 Structural and Methodological Approach

The structural and methodological approaches in this thesis cover a variety of research design alternatives. They are described and discussed in the sections of this chapter. In this section however, the design or the main frame that will eventually lead to the answering of this research question will be discussed and reasoned. The objective of this research question is to find out, if the removal of TWC will lead to such cost reductions that the receiver of deliveries from a UMTO might leave the demand on TWC to his supplier. Consequently, once the optimisation with a simulated situation of omitted TWC is analysed, the answering of the research question requires a final finding. Assuming the case that the removal of TWC would result in significant cost savings, and this affirming the first part of the research question, would the consignees be prepared to allow a change of TWC demand? In order to answer such a question one would in other research structures try to answer this question with the findings from a questionnaire. This way, one would achieve a representative and qualified final research objective, provided it takes place in the same population as the data origin to maintain the generalisability. If the questioned population would then act as they have answered in a questionnaire, remains unanswered but ambiguous.

The structural and methodological approach in this thesis has chosen another alternative by continuing to apply the philosophy arising from Section 4.1.7 Practical and Phenomenological Research Initiations and hereby practising a consistent research philosophy. By doing so, the implied structural and methodological approach will be demonstrated, through analysing the entire market situation that the population of sample companies belongs to. Here, it is shown that the GKFI is indeed in a highly competitive market with a shrinking number of manufacturers, reduced national revenue and an increasing international market. (See Table 59: Index of Gross Production for Kitchen Furniture) The analysis of the GKFI market is therefore attached in the Appendix of this thesis. (See Appendix: 8.5IX.B.i The Furniture Industry)

Other supporting elements of the research philosophy and the answering of the research question in a consistent structural and methodological way, lie in the environmental effects that the first part of the research question may imply. In other words, if the cost reductions are significant and hereby the travel distances are reduced, then this will automatically imply reduced environmental effects. In view of the high probability of taxation of such environmental constraints, the change of TWC demand in favour of the supplier may gain additional attractiveness. Details of this assumption and possible consequences will be discussed in the Chapter 7 Supporting Environmental Considerations. Through this additional motivation factor and through the expected economic savings, assumptions on the changeability of the TWC demands will be made.

However it will not be mere assumption, but hard facts of economic discussions which may raise even new discussions. Such new discussions would be the practicality of any possible solution coming from the results of this research.

4.3.2 Logistics Optimisation through Simulation

Simulation has become a routine practice in many business areas in the past years. The use of simulation software for the practical optimization of processes and cost as a routine tool of analysis and restructuring is however associated with numerous questions. Here, Fu (2002, p.192) states:

> *"… there is a disconnect between research in simulation optimization – which has addressed the stochastic nature of discrete-event simulation by concentrating on theoretical results of convergence and specialized algorithms that are mathematically elegant – and the recent software developments, which implement very general algorithms adopted from techniques in the deterministic optimization metaheuristic literature (e.g. genetic algorithms, tabu search, artificial neural networks)."*

With this statement one of the very important characteristics applying to this thesis and its applied methodology comes to light and this becomes even more relevant through: *"the recent integration of optimization techniques into simulation practice, specifically into simulation software, has become nearly ubiquitous, as most discrete-event simulation packages now include some form of 'optimisation' routine."* (Fu, 2002, p.192) With this in mind, the general question on the use of simulation practice with a commercial software tool in a scientific work raises questions. Here however, one needs to rationalize and distinguish two different points of views: (1) the optimisation of given (theoretical) data with the application of 'mathematically elegant' algorithms in a simulation software system and (2) the optimisation of given (real) data with the application of practically applicable (or appropriate) algorithms in a simulation software. From the perspective of this thesis, the second alternative has sufficiently satisfied the objectives of this research. Knowing that there is a multitude of concerns on this decision as mentioned by many authors i.e. (Fu, 2002), (Umeda and Zhang, 2006, Kleijnen et al., 2005); (Biethahn et al., 2004, Banks, 1998). The author of this thesis has himself undertaken a small experiment to understand the implications of different search algorithms in practical DPS. Choosing a random location within a country and choosing a random destination with a minimum distance of 500 kilometres, a random selection of three automobile car manufacturer's navigation systems calculated the travel distance and travel time with equal travelling parameters, resulting in 2,48% and 2,23% deviance to the best solution. With this small and insignificant experiment, the understanding of the application of different vehicle routing optimisation algorithms became understandable and added to the mathematical concerns of the chosen methodology in this thesis. The questions from using simulation systems for the optimisation of logistics routing gain even more concern from a statement of Fu (2002, p.192): *"the goal… to seek improved settings of user-selected system parameters with respect to the performance measure(s) of interest, but contrary to the use of mathematical programming software packages, the user has no way of knowing if an optimum has actually been reached"*. The latter would have happened to the author of this thesis, sitting in only one of the three motorcars, using the navigation system.

To conclude the general, but highly important, concerns on the use of simulation for the optimisation in logistics, one may state that optimisation can only be described as a 'good' solution, knowing that there might be other even better solutions. Being aware of this, the entire methodological approach and design of this thesis is based upon the 'trust' that the practical system applied in this thesis delivers a 'good solution' for this research objective. In this context, however it is very important to mention that the use of the system applied contained practicable route parameters only. (See Section: 4.2.2 Supporting Cost Parameters) This decision limiting the optimisation results was undertaken to contribute knowledge to practitioners rather than to theorists.

4.3.3 Summary of the applied Simulation Model

In previous chapters, it has been already described that in this research three different solutions to the same distribution panning problem are compared on the level of distribution cost. This section will embed the approach as it has been described before into the chosen simulation model.

The simulation starts with an original situation where soft time windows are adhered to during tour planning. The resulting set of data is Base Data-1. This Base Data-1 represents the control group as described by Bryman and Bell

(2007). The distribution cost calculated for this set of data based on the cost parameters introduced above, represents the X as described by Poe et al. (1994). Using the same references, the second set of data (Base Data-2) represents a treatment group with distribution cost Y_1. It is the result of a re-planning within existing tours after the removal of soft time windows. Finally, Base Data-3 which results from complete re-planning after removal of all soft time windows is a further treatment group. Distribution cost calculated for the resulting data is referred to as Y_2.

Comparability between X, Y_1, and Y_2 is given since these cost have been calculated, based on the same cost parameters. Regarding the constraints some remarks must be stated. There is a common or shared set of constraints which all three tour planning approaches are subject to. These constraints have been given in Section 4.2.3 Cost Function and Objective Function. From the original state to the final state, restrictions are loosened in two steps. In addition to the common constraints, the control group and the first treatment group are subject to further constraints, stemming from the original data. These are the soft time windows, tour composition and delivery order within tours for the control group and tour composition for the first treatment group. The soft time window constraint is not surprising. It is the subject of this thesis and its variation is simulated here. Setting the other two constraints is necessary because otherwise Base Data-1 and 2 would not be possible with their results of a tour planning process with the objective of minimal cost. This is because Base Data-1 was composed from various sets of data supplied by different kitchen manufacturers (See Section: 5.2.2 Validity and Reliability of the Screening) and did not result from a single tour planning process. Base Data-2 is the result of re-planning the delivery order within the tours maintaining the tour composition from Base Data-1. Hence, composition of tours is an additional constraint for the first treatment group. In Figure 19: Overview of the Simulation Process, the simulation process and its elements are shown. Besides the described loosening of constraints the corresponding sets of data were maintained. The resulting distribution cost and the conducted cost comparisons are presented for each of the described steps of simulation.

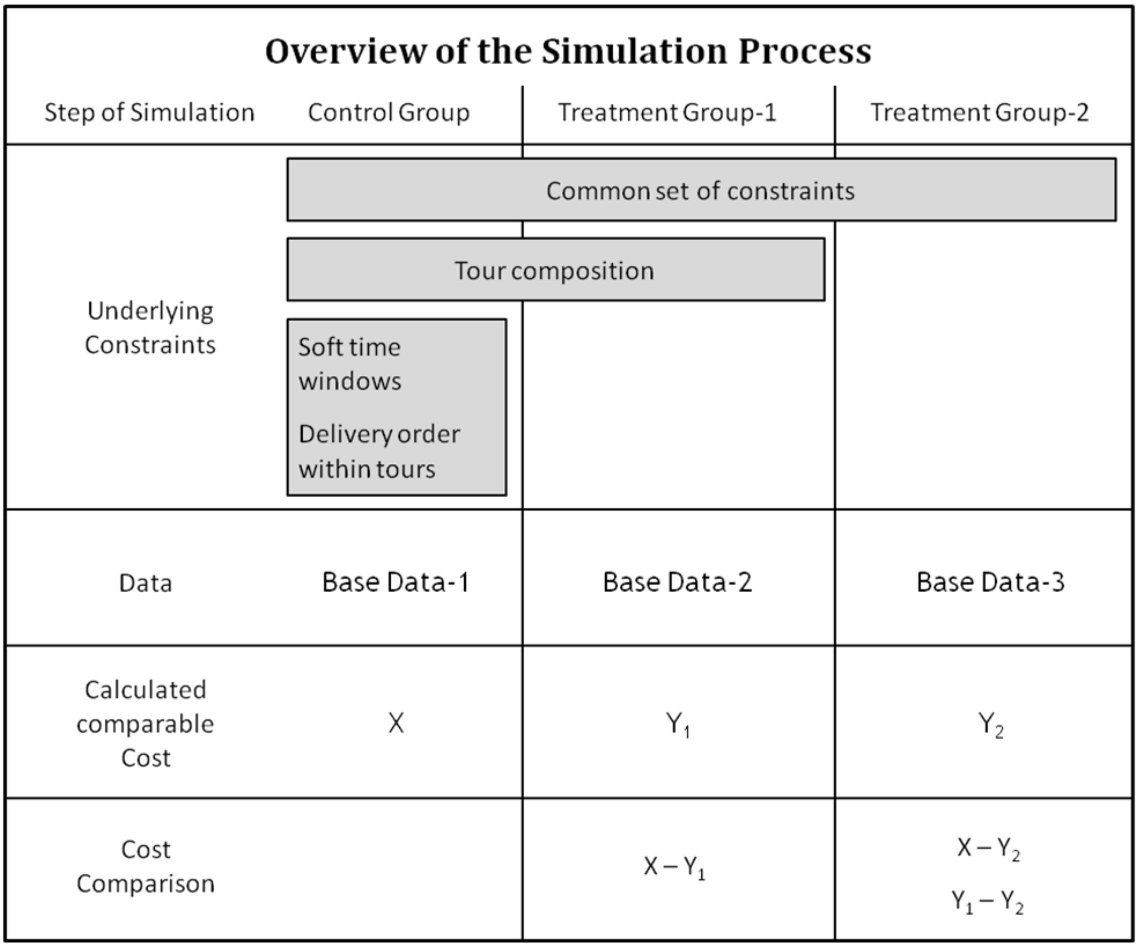

Figure 19: Overview of the Simulation Process

4.4 Sampling and Data Input Configurations

Data sampling is one of the important processes in research design and is divided into numerous techniques. The following section will highlight those techniques and reason the choice for this thesis in its methodological approach. The subsequent configuration of data input and the data collection process itself are eminently important foundations in experimental research methodologies. (Bienstock, 1996) That some of the configurations bring to light advantages and disadvantages, will be discussed and evaluated in the following sections.

4.4.1 Data Sampling

The methodologies for data sampling demonstrate a large variety of research possibilities. Saunders et al. (2007, p.207) state two distinguished groups of sampling techniques: (1) the probability and (2) the non-probability technique. *"With probability samples the chance, or probability, of each case being selected from the population is known and is usually equal for all cases."* From this derives that it is possible to answer research questions and to achieve research objectives that require estimating statistically the characteristics of the population of the sample. *"Consequently, probability sampling is often associated with survey and experimental research strategies."*

As for non-probability sampling *"…the probability of each being selected from the total population is not known and it is impossible to answer research questions or to address objectives that require … to make statistical inferences about the characteristics of the population", (Saunders et al., 2007, p. 207),* this approach was not pursued in this research methodology.

According to Saunders et al. (2007, p.208) the probability sampling, or as it is called sometimes: the 'representative sampling', is often divided into four stages:

1. The identification of a suitable sampling frame based on the research question or objectives;
2. The decision on a suitable sample size;
3. The selection of most appropriate sampling technique;
4. The representation of the population by the sample.

In the following, these four stages are described, compared or cross-referenced to the techniques of this thesis.

<u>Identification of the right sample frame:</u>

The identification of the right or appropriate sample frame comes from implications for the generalisability. However, this requires to be unbiased, current and accurate and generalisations may only be drawn from the chosen population. (Bryman, 2006)

In the context of this thesis and in investigation of UMTO, the GKFI was chosen as a sampling frame to demonstrate particularly the specifics of the make-to-order problem. Here, with this demonstration of the distribution and production planning problem (See Section: 1.3 Practical Background) and the theoretical findings (See Section: 3.3 Distribution Planning for UMTO) for the right sampling frame was identified and described in large detail.

Decision on the right sample size:

As it is often impossible, or impractical, to collect data from the entire population, it is necessary to focus on a practical and manoeuvrable sample size. (Saunders et al., 2007) However, what size sample will allow the generalisation about the population from the data collected and how this generalisation can be verified? In order to answer these questions, one has to compromise on the following milestones on suitable sample sizes:

1. The gaining of confidence and certainty that the characteristics of the data collected will represent the characteristics of the total population;
2. The toleration of the margins of error for the estimations made from the sample; and
3. The appropriation for the adequate data handling and data manoeuvrability in respect of the categorisation and subdivision of data for statistical purposes. (Saunders et al., 2007)

As the GKFI is like many other UMTO industries and is affected by seasonal fluctuations and individual economic fluctuations or fluctuations unknown to the author, a reduction of chosen GKFI sample frame was undertaken as described in Section 5.2.4 Data Request, Origin and Delivery. By doing so, the confidence that the characteristics of the data collected was maintained, but the sample size reduced by a twelfth to ensure the handling and the manoeuvrability of the data amount. This reduction of the sample size also contained a tolerable margin of errors.

Finally, the planned data simulation with a DPS required specific data handling and categorisation for the subdivision of data for the objective of this analysis. In order to pre-streamline this requirement, the data-input format was created as described in Section 5.2.5. Data Input Format.

Selecting the most appropriate sampling technique (and data collection format):

Sampling techniques can differ from type to type and are often differentiated as follows. Here those techniques need to satisfy the researcher in answering his research question and his research objectives through:

1. Simple random sampling;
2. Systematic sampling;
3. Clustered sampling;
4. Multi-stage sampling (Saunders et al., 2007) and
5. Stratified random sampling (Easterby-Smith, 2002)

The following statements will describe those techniques and reason the chosen methodology of data sampling in this thesis.

The random sampling process is like closing one's eyes and pointing at a number of potential sample companies that might or might not supply you with data. This process could be repeated until such time that sufficient confidence on the representative structure of the data gathered could be achieved. Still, the data contents could deviate from what was required and expected, hence this technique was not followed for this thesis. The objectives of the research questions might have failed to be achieved by this methodology, and a systematic, clustered and multi stage approach appeared to be more promising.

The systematic approach involved a systematic request to potential sample companies in the market (who were unaware of their implications on the research question and its objectives for this thesis) about certain preliminary conditions of UMTO characteristics in the GKFI and whether they could provide operational data. (See Section: 5.2.7. Data Collection Strategy). The sample was subdivided into cluster groupings in the sampling frame and each identified with a unique number (or alphabetical letter). The selection of the new sample was then undertaken at random. However, the author followed this technique in a slightly different way. In addition the entire sample was put in an alphanumerical order of sample companies and then the data was used in fractions of a monthly alphanumerical selection. This approach defines the stratified random sampling method by creating a homogenous strata group by taking a simple random sample within each stratum. (Easterby-Smith, 2002)

<u>Is the sample representative of the population?</u>

The question whether a population sample is representative or not is often answered by comparing that sample with other samples of the same population. Another method complies with a percentage rule and states the sample size in comparison with the entire population. Here the status of being representative is sometimes rather subjective and opens margins of errors that require in-depth discussions. (Bienstock, 1996) On other occasions, the representative status of the sample is argued with the sample size and the limitations of data or sample handling (or as called in this context: manoeuvrability). In this case, the sample size is limited to a system's capacity and the researcher's ability to handle the sample. If this, however, clarifies the sample's representative status may be questioned. Bienstock (1996, p.44) in her work identifies three methods for adjusting the sample size, n, in simulation studies:

1. *"simulation runs for each experimental condition (each cell) may be replicated n times;*
2. *Observation of n subintervals of the simulation of an experimental condition may be increased by decreasing the length of the subintervals; or*

3. *The simulation of an experimental condition may be continued for a longer period of time, thereby increasing the number of subintervals (i.e. the sample size)"*

From this, the author states: *"…in logistics research using simulation methodology, sample means for a response variable of interest are obtained so that population values for the response may be estimated."*

By identifying the entire GKFI population in this thesis (See Table 56: The German Furniture Industry in 2005 by Sections) and the reduced sample size in Table 58 Kitchen Furniture Production, this thesis has followed this author's theoretical sample selection and identification recommendation. With regards to this sample achieving a representative status, a simple answer may be given in this context referring again to Bienstock (1996). In 2006, the GKFI numbered 96 manufacturers. (Reinbender, 2008) This thesis has identified and used 12 of them as a sample of 13% from the entire GKFI population. That this can be called a representative sample may be assumed for the purpose and objective of this thesis. Whether the sample however is of a quality that deserves the same statement, is another aspect altogether. Here, the sampling in this thesis identifies four groups of different price levels: (1) three sample companies in the lower price category, (2) four sample companies in the middle price category, (3) three sample companies in the upper price category, and (4) two sample companies in the exclusive top price category. With this spread over all price categories in the GKFI the quality of sampling assures a fair coverage of the market and a representative sampling quality.

4.5 Analysis

The analysis of quantitative data in business research is a common practise to communicate the key findings. Ways to demonstrate such findings are manifold and need to serve the purpose of answering the research question and meeting the objectives of such. (Saunders et al., 2007) In the following, a number of quantitative research methodologies are mentioned, described and reasoned for their use to the methodologies chosen in this thesis.

4.5.1 Application of Descriptive Statistics

For the purpose of applying descriptive data Saunders et al. (2007, p.420) state in their work: *"…once data have been entered and checked for errors, you are ready to start your analysis."* By doing this, the researcher has to keep his research question and research objectives in mind in order to focus the analysis accordingly. Here in this process, an exploratory data analysis *"…allows more flexibility to introduce previously unplanned analyses to respond to new findings."* (p.420) From this 'allowance' it may be derived that the new findings might not have been anticipated at the beginning of a research process but will develop importance during the research process towards an unexpected contribution answering the research question. From this, an exploratory methodological approach gives opportunity to widen the research findings and also contribute towards a possible generalisability.

Since there is large number of diverse presentations of descriptive analysis results, some important ones and related to this thesis are worthy to mention:

Presentation of specific values:

One of the easiest ways to summarize data *"…for individual variables so that specific values can read is the use of tables."* (Saunders et al., 2007, p. 423) Such tables for descriptive data summarise the number of cases or frequencies for each category. In research with data simulation, these categories may be different stages of the simulation for one and the same set of data under simulated, differing situations. (Banks, 1998) In order to answer the research question from such tables resulting from large numbers of values, it may be recommended to group the data into categories. In this context the tables should concentrate on those findings that are of importance for the answering of the research question.

This thesis has applied these recommendations and has described the formation of tables and their containing results in Section 6.1 Descriptive Base Data Analysis. Here, the important variables to answering the research question are shown and it is also demonstrated how they have developed in the process of the three-staged simulation. Finally, they are compared with one another to describe the relevant findings of the simulation experiment. By doing this, the research question will be answered to the satisfaction of the author of this thesis. This answered the basic questions that originated from Chapter 2 Research Question and the detailed parameters of this research in Sections 4.2 Definition of the Cost Function and 4.2.2 Supporting Cost Parameters; through the subsequent removal of TWC.

4.5.2 Other Multivariate Analyses

One may question if additional analyses will contribute in answering the research question. Strictly speaking from a future perspective, this cannot be answered satisfactorily. However, those additional analyses might bring to light some new findings, which were unforeseen. One of those perspectives is the answering of the question as to how the significance of different independent variables develops during the process of the simulation. In the context of the VRPTW of this thesis, this question has been dealt with. (See Section: 3.2.1 Classification of TWC in VRP) Here, the developments of significance of the variables: kilometrage, number of client stops, volume and units on the cost of delivery is of minor interest to be investigated. – In order to do this, a number of multivariate analyses would be applicable to be undertaken, discussed and interpreted.

From expecting the descriptive analyses to be rather simple, the same might apply to the multivariate analyses. This means that those analyses would also be undertaken in a fairly simple methodology. They could focus on the determination of simple causalities.

The Methodology of a simple Regression Analysis:

The methodology of a simple regression analysis is a section of multivariate statistics. In this, the measuring of single-sighted models and numbers is the focus. For this methodology, the following pre-conditions are important: the simple regression analysis (1) requires an objective and logic reasoning and (2) does not replace a causality analysis. With the help of a simple regression analysis one is only able to (3) reveal causalities and add or confirm such. (Eckstein, 2000)

Causalities in the Context of this Research Analysis:

(1) The process of producing Base Data-2 from Base Data-1 contains the optimisation of existing tours without TWC and without changing the actual tour itself. By doing this, the utilization of the vehicles is expected to increase, waiting times at client stops are expected to decrease or remain unchanged, and the total kilometrage is expected to decrease and thus it might have a reduced influence on the total cost of delivery.

(2) The process of producing Base Data-3 from Base Data-2 contains the optimisation within new tours and without TWC, but within one and the same calendar week. Here, it may be expected that the utilisation of vehicles will be even higher than in the process of optimisation previously mentioned. It is also expected that waiting times at client stops are reduced further, thus the influence of the number of units might increase. The major expectation will be the strong and significant reduction of kilometrage and thus this influence will be reduced further.

The Methodology of a simple Correlation Analysis

The methodology of a simple correlation analysis contains the generalization of the *t*-test for two independent random samples. This methodology is applied in social sciences and business research, where the investigation focuses on the homogeneity of such samples. The target of this methodology is to find out if such homogeneity of average values shows consistency or not. This methodology is also called the ANOVA-Test (*AN*alysis *O*f *VA*riance). (Eckstein, 2000)

To focus on the research question of this thesis, one may ask what contribution towards its answer those multivariate analyses will bring. This question is indeed a valid one and deserves some comment at this stage. Yes, the contribution of the above multivariate methodologies to the research objectives in this thesis is questionable and doubtful. According to Poe et al. (1994), Kleijnen et al. (2005) and Biethahn et al. (2004) however, they do represent a major function within the application of a simulation. (See Section: 3.4.2 Application of Simulation in Decision Support Models) In the context of this research question, it must be stated that their results are not expected to support a better understanding of the impacts from the removal of TWC on the cost of distribution. However, it might be expected that those methodologies of analysis may bring to light some 'side-effects' of new knowledge. What-if, the simulation experiment of omitting the TWC from the given deliveries in tours will bring alight a significant reduction of some of the independent variables such as the kilometers, how does their influence on the cost of delivery develop? And does a possible consolidation of deliveries within one tour through the removal of TWC have a significant influence on the cost of delivery? The answers to these questions will contribute no new knowledge to the answering of this research question, and they may be of little interest to the real world of practical tour planning with DPS. For this reason, it was decided not to add a multivariate methodology of analysis to the analysis of this thesis.

4.6 Critical Reflections on the chosen Methodological Approach

The above mentioned methodological approaches open space for a possible critique and therefore require some critical reflections. Those critical reflections have their roots in the general choice of experimental research design and the use of simulation. Here, one of the most critical reflections on the chosen methodological approaches can be found in the work of Bienstock (1996, pp.44-45). The author states:

> *Should the number of replications be increased until statistically significant results have been obtained, i.e. until an absolute level of precision is attained? Whilst this may be relatively easy to accomplish, …, the external validity of experimental results thus obtained may be questionable."*

To avoid this serious critique to a large extent, one may satisfy this concern by the guidance of 'practical' degree of precision and sampling sizes, through the magnitude of the population mean(s) that is (are) being estimated. (Bienstock, 1996, Fu, 2002) From an experimental point of view for achieving the objectives of the research question in this thesis, one may say that the use of a commonly available DPS for the simulation of commercial vehicle routes is the methodology that has satisfied this research. The mathematical insignificance remains undoubted, although in real life, the possible influences of vehicle routing through daily congested traffic constraints en route may be much higher.

Another critical reflection on the chosen methodology is the actual data collection and data preparation for the input process to the DPS. Here, the data request to the sample companies and the format of data transfer with the data cleansing is a very critical process. This process is accompanied with numerous imponderables of technical data handling that may lead to a loss of data quality and consequently raises doubts in the validity of data sampling. This thesis has chosen multiple sequences of technical checks to minimize such a loss and described them in large detail. (See Section: 5.2.3 Research Process Validation)

The applied cost function with its underlying cost parameters also contributes towards possible criticism or weaknesses on the methodology of this thesis. One of the examples for this concern is the actual cost of the vehicles and their fuel consumption in this experiment. Here, the imponderables are manifold in terms that a comparable vehicle price may alter up to 20% and more, depending on the technical specifications and the choice of the manufacturer. That the used calculation for the fuel consumption may alter up to 15-25% is common knowledge, because of individual driver behaviour. Every owner of a vehicle may have a different experience.

Finally, another critical reflection on the chosen methodological approach may arise from the phenomenological concerns and from a research philosophy point of view. Here, when looking at the removal of TWC, a major critique may come up from the point of view of intentionally ‘opposing a client demand’. Such a contradiction of commonly accepted logistics and marketing oriented constraints appears to be irrational. This is however, where the phenomenological and philosophical approach of this methodology has its foundations. By questioning commonly tolerated logistics constraints such as TWC, this thesis's analysis will show that despite their removal one can still meet client demands. Moreover, by doing so, one enters discussion on the cost savings versus the right of demand on the determination of time windows in UMTO delivery.

5 Research Process

The previous two chapters have identified, described, reasoned and discussed a variety of methodological approaches and designs. They have also argued why some of these are applicable and others are not, or, are less applicable, for this thesis. In other words, the 'What' and 'Why' possibilities were evaluated to achieve the objectives of this research.

This chapter describes 'How' the research process has to be carried out in order to fulfil the methodological requirements defined and to achieve the research objectives. From the research question in the context of the applied proceeding, it may be expected that savings will be achieved through the removal of TWC. The question is now, will they be sufficient enough to enter a discussion on the demand of TWC for the UMTO delivery planning. The description of the research process for this thesis will deliver information how to answer this question by using existing constrained routes. The existing routes then will be re-created and re-calculated without TWC. The detailed description of how this process was created is defined in Section 5.1.1 Research Process Definition. In order to undertake this research, a computerised system was applied to support this analysis with the tools of a routing simulation and to reduce calculation times.

The system requirements to operate the simulation were not available in existing or readily configured DPS set-ups. But they were created by using commonly available DPS in a different methodology of use, as specified below. Therefore, the definition of the process, for creating a simulated and economically improved delivery structure of tours without TWC, and the decision to use a commonly available DPS, ultimately belong together in defining the following research process.

The data collection and all processing are described in Section 5.2 Data Collection and Processing of this chapter. In order to answer the research question it was decided to use raw tour and delivery data from the GKFI. This decision is reasoned with the fact that the tours contained therein have in fact taken place. They therefore are of high practical relevance when it comes to answering the research question.

5.1 Definition of the Research Process and DPS Selection

The following definition of the research process and the DPS selection are vital operations in this experimental research design. Vital, as the system specifications had to meet the research objectives, by delivering a high data security. That this requirement is of high relevance in experimental simulation is referred to in Section 3.4.2 Application of Simulation in Decision Support Models. Another criterion of data reliability and process validation is referred to in Section 3.5.2 Risks in Experimental Design. Both concerns arising there from are dealt with in the following sections of this chapter to reduce the commonly accepted weaknesses of experimental research and the use of simulation in it.

5.1.1 Research Process Definition

The following two figures define the actual research process. This serves the purpose of an introduction from an experimental point of view and to demonstrate the complexity contained therein. The proceeding itself is defined in the context of this thesis as the process of data gathering, data cleansing, data simulation and data analysis.

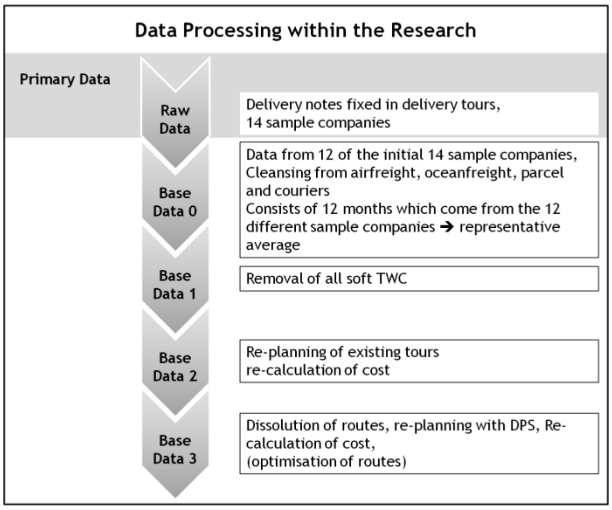

Figure 20: Data Processing within the Research

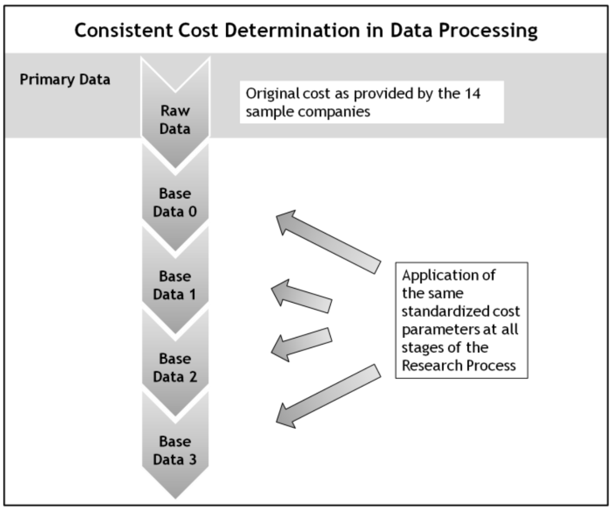

Figure 21: Consistent Cost Determination in Data Processing

Time Windows

When looking at time windows in route planning, one must differentiate such in various clusters. Normally a customer has a time window, comprising of an earliest release time, after which the customer will accept service and a latest time, after which service to the customer is considered tardy. (Ho et al., 2001) In the context of this thesis, such a time window is a ‘soft window’, as it defines a time span ‘from’ – ‘until’. The constraint here is that those windows are normally set from the consignees in accordance with their warehouse receiving hours. In some instances it may also be set, when the warehouse is only a shed or a garage and staff will be directed to receive the goods particularly for a specific delivery.

Fixed Delivery Times

In general fixed delivery times are ‘hard time windows’, except, they have a rather small window for delivery. They are used, when a delivery may not be early or tardy at all and definitely needs to meet time slots for other works attached to the receiving of the goods. Those hard time windows are often applied, when the delivery of kitchen furniture has to match the delivery of electrical appliances or other criteria. They are also used, when roads need to be secured for large trucks admittance for delivery in pedestrian areas etc. Even though from an algorithms point of view for computing such fixed time windows, practical operators of route planning treat them differently. They would plan such a fixed time window with a safe and early arrival of the delivering vehicle rather than an approximate arrival, as they would do for the regular soft time windows.

UMTO

The UMTO manufacturers from the industry taken as an example promise their clients delivery within six to eight weeks after receipt of the client order. Approximately three weeks prior to the end of this period, the UMTO manufacturers confirm the actual week of delivery. (See Figure 40: Production and Delivery-Data Allocation for UMTO) After this confirmation, the client cannot alter the purchase order details anymore. For this thesis’s underlying model, this means that the UMTO manufacturer plans the production from this point of time onwards.

Cost Parameters setting in Route Simulation

The underlying cost parameters of the applied model are described in detail in Section 4.2 Definition of the Cost Function. As shown in Figure 21: Consistent Cost Determination in Data Processing; these cost parameters remain unchanged through all steps in this process of data analysis.

5.1.2 System Requirements

At the start of the system selection and evaluation process, the specifications and performance of the available systems were extracted and listed. From a list of the best criteria, a table showing system requirements & overview was generated. (See Table 11: BSC Systems Performance & Adaptability Results)

These system requirements are performance programmes with which the intended data simulation was planned to be undertaken. All details on this are attached in the Appendix. (See: Appendix 8.5IX.D Supplement Information on CD-Rom)

5.1.3 System Selection Process

A total of twelve possible manufacturers had a suitable DPS but only three would release their systems for this research. Only the Wanko Company would provide free software (available for student research purposes). After careful consideration, a decision was made in favour of Wanko GmbH, as payment for the use of licences might constitute some form of possible manipulation. The following Table 10: Overview of Systems Providers shows a list of all potential suppliers of DPS systems in the German market. (as per 2006) They provide DPS with different product features.

Table 10: Overview of Systems Providers

Overview of Systems Providers

Company	Hybrid	N° of Installations	Place	Software
Cardy	-	n.a.	Mönchengladbach	
Dr. Städtler	X	1,294	Nürnberg	Trampas
LSC	-	412	Hamburg	
Profi. L	-	124	Remscheid	
PTV	X	3,876	Karlsruhe	Intertour
SISA	-	n.a.	Reinach	
Soloplan GmbH	X	887	Kempten	
Transdata	-	291	Bielefeld	
Wanko	X	2,251	Ainring	Pracar 3000
Weber Data Service	-	407	Bielefeld	
GLO	-	917	Steinroth	
GREOO GmbH	-	n.a.	Hamburg	

A comparison table containing individual service packages and programmes was compiled in order to gain a neutral and impartial overview of all the providers' system-oriented performance data.

A separate system requirement table was then established in order to show a comparative achievement potential between providers. Preceding this was a table with all essential performance qualifications, which were evaluated according to the significance of individual criteria. Next, the specifications of system manufacturers were requested and such information was transferred to the tables.

After that, all the system manufacturers were assessed. For this, a simplified model of the classical 'balanced-score-card' (BSC) was designed with particular consideration given to performance and adaptability. The results obtained from the best two providers in this BSC analysis are shown in the following table. The Wanko Company (system provider B) achieved the best results with a marginal lead of 234 points over provider A. As the difference between this maximum result and the lowest score is only 9% it could be assumed that the four systems which allow for the re-planning of all tours would all have been suitable for this research.

Table 11: BSC Systems Performance & Adaptability Results

Balanced Scorecard Systems Performance & Adaptability Results

	System Provider A	System Provider B	Difference B to A	Performance Variance B to A
1. Technical Features	314	329	16	4.76%
2. Interface/ Data Exchange	112	116	4	3.45%
3. Software Features	1.583	1.671	8	5.25%
4. Modules for Administration / Other Program Characteristics	215	337	122	36.2%
5. Service	55	55	-	0%
6. Hardware Pre-Conditions	28	33	5	15.15%
7. Software Pre-Conditions	60	60	-	0%
Summary and Totals	**2.366**	**2.601**	**234**	**9.01%**

The result of the BSC assessment is based upon 35 evaluation and requirement criteria arising from the total of all relevant system descriptions. This determined and finalised the choice of system and selection process. However, the 'unknown' in the system manufacturers' heuristic approaches is the same constant for all manufacturers and, therefore, a comparable feature. The choice between different state-of-the-art algorithms as they are employed in competitive DPS affects the cost of delivery, only to a small degree compared to the variation resulting from a relaxation of TWC. In the literature, the variation caused by the choice of different algorithms for the VRPTW is only of small significance. (Pachnicke, 2007)

5.1.4 System Use and Operational Specifications

The operational specifications of the chosen DPS are summarised for a better understanding of the system requirements. These have been extracted from the product information and combined into a comprehensive set, recognising that not all of the providers of DPS met the required criteria. Nevertheless, the list of operative system specifications constitutes the required features for this thesis regarding data and cost simulation, and the creation of new delivery routes. These specifications and system applications were not available from all system providers; however, the provider chosen from the BSC model was able to fulfil these requirements, in part through system-related plug-ins in standard DPS. A listing of operational specifications for the system use is provided in the attached CD-Rom in the Appendix.

5.1.5 Explanatory Example of the Data Simulation Process

The following example shows all three steps of the simulation process, and serves as procedure verification in the meta-heuristic simulation process. (Kleijnen et al., 2005, Biethahn et al., 2004) This detailed description serves the purpose to repulse the concerns raised in Sections 3.4 Simulation Techniques in Logistics and 3.5 Experimental Research. The values contained therein are a randomly chosen sample and based upon a data selection of days as shown in the table and the later described format template for data input.

Step 1

All values shown in the table contain the initial TWC and come from only one sample company who is located between Osnabrück and Herford, Germany. The first step describes the 'as-is' situation of a total of 17 tours. The following table (shown as monitor print screen) illustrates the respective tour values and their summarised results. On a travel distance covering 12,868 kilometres, 86 clients served and a volume of 571 m^3 transported.

At this point, the simulation system also indicated the respective load of the vehicles as shown in the master data. In the original database, the average utilisation of vehicles (outbound) was just 50%. This load rate referred to the outgoing route and not to the total travel distance. That means that the empty return route was not covered in this capacity enquiry (a point to be noted and one, which will be given particular attention in Chapter 7 of this thesis). Of primary importance are the total costs of Euro 9,920.10 for all the selected tours. The following image shows a monitor print screen from the simulation programme as evidence of data authenticity.

Table 12: Random Sample of Deliveries from Base Data-1

Random Sample of Deliveries from Base Data-1

Tour No.	Units	KG	M³	Clients	Km	Driving Time (net) (Ttl)	Driving Time (Ttl)	Start Date	End Date	Cost	Capacity Usage (%)
102	187	5,977	71.86	11	1,629	26:50:00	11:22	27.11.06	30.11.06	1.336.43	89
101	203	7,193	75.33	8	977	17:37	01:52	28.11.06	29.11.06	949.57	94
202	107	3,612	37.00	8	1,256	22:42	04:05	29.11.06	30.11.06	968.10	99
215	85	2,831	38.11	7	890	13:54	18:21	05.12.06	06.12.06	639.50	42
216	81	2,808	29.51	6	937	14:15	18:21	30.11.06	01.12.06	644.20	32
211	25	910	Dez 61	6	433	07:03	09:28	30.11.06	30.11.06	327.30	14
212	38	1,064	14.91	5	660	10:22	12:56	03.12.06	03.12.06	454.00	16
103	149	4,469	59.66	5	508	08:53	14:47	28.11.06	28.11.06	522.20	74
203	77	2,527	28.52	4	816	12:19	15:47	01.12.06	01.12.06	555.10	77
213	63	2,288	25.00	4	860	13:01	16:04	03.12.06	04.12.06	568.00	27
204	75	2,712	30.73	4	449	07:00	10:25	29.11.06	29.11.06	357.40	83
210	87	2,527	36.89	4	534	09:00	12:46	02.12.06	02.12.06	436.40	40
206	57	1,761	17. Jun	4	275	06:04	08:58	01.12.06	01.12.06	296.50	46
214	51	2,041	20.88	3	875	12:13	14:39	04.12.06	04.12.06	527.00	23
104	62	2,416	23.56	3	681	13:12	15:59	01.12.06	01.12.06	547.60	63
205	43	1,538	16.56	3	205	04:16	06:28	29.11.06	29.11.06	214.50	44
201	88	3,023	33.13	1	883	13:13	16:16	29.11.06	30.11.06	576.30	89
	1,478	**49,697**	**571**	**86**	**12,868**	**Average / Total**				**9,920.10**	**50**

Table 13: Table with 17 Tours from Base Data-1

Tabelle (17 Touren) 35008

Aufträge | Kunde | Läger | Kunden | Touren

Nummer	Einheiten	Gewicht	Volumen	Kunden	Kilometer	Fahrzeit	Dauer (Kosten)	Beginndatum	Endedatum	Kosten	Auslastung (%)
102	187.00	5977.213	71.858	11	1628.700	26:50	35:22	27.11.2006	30.11.2006	1336.43	89
202	107.00	3611.813	36.996	8	1256.200	22:42	28:05	29.11.2006	30.11.2006	968.10	99
101	203.00	7192.983	75.334	8	976.500	17:37	25:52	28.11.2006	29.11.2006	949.57	94
216	81.00	2807.624	29.507	6	937.200	14:15	18:21	30.11.2006	01.12.2006	644.20	32
215	85.00	2830.682	38.109	7	889.500	13:54	18:21	05.12.2006	06.12.2006	639.50	42
201	88.00	3023.297	33.128	1	883.200	13:13	16:16	29.11.2006	30.11.2006	576.30	89
213	63.00	2288.011	25.000	4	860.100	13:01	16:04	03.12.2006	04.12.2006	568.00	27
104	62.00	2416.397	23.558	3	681.400	13:12	15:59	01.12.2006	01.12.2006	547.60	63
203	77.00	2526.963	28.522	4	816.100	12:19	15:47	01.12.2006	01.12.2006	555.10	77
103	149.00	4468.966	59.660	5	508.100	08:53	14:47	28.11.2006	28.11.2006	522.20	74
214	51.00	2041.037	20.880	3	874.900	12:13	14:39	04.12.2006	04.12.2006	527.00	23
212	38.00	1063.619	14.909	5	660.100	10:22	12:56	03.12.2006	03.12.2006	454.00	16
210	87.00	2527.220	36.891	4	533.800	09:00	12:46	02.12.2006	02.12.2006	436.40	40
204	75.00	2712.340	30.734	4	449.000	07:00	10:25	29.11.2006	29.11.2006	357.40	83
211	25.00	909.918	12.610	6	433.000	07:03	9:28	30.11.2006	30.11.2006	327.30	14
206	57.00	1761.347	17.061	4	275.300	06:04	8:58	01.12.2006	01.12.2006	296.50	46
205	43.00	1538.009	16.561	3	204.600	04:16	6:28	29.11.2006	29.11.2006	214.50	44
Anzahl: 17	1478.00	49697.439	571.318	86	12867.700	211:54	280:34			9920.10	50

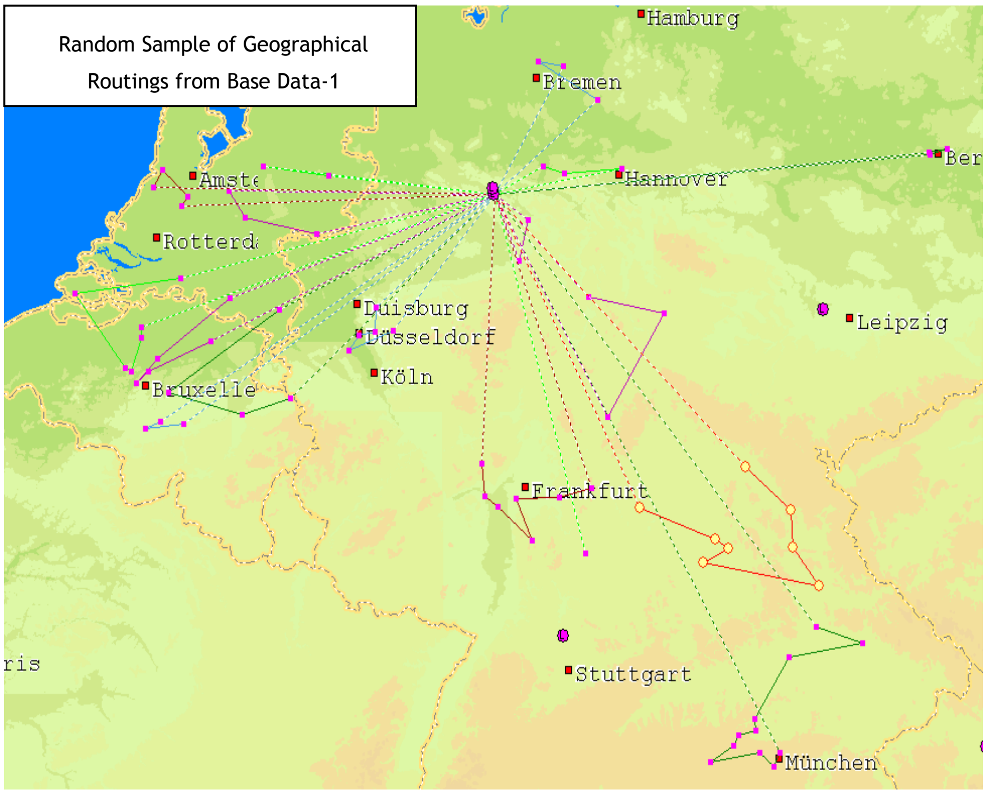

Figure 22: Random Sample of Geographical Routings from Base Data-1

Looking at these above tours and scrutinising the degree of optimisation in context with the existing TWC, one will find that these are absolutely realistic and well-conceived tours. If one examines the above Figure 22: Random Sample of Geographical Routings from Base Data-1, a continuous line identifies distribution tours from the first point of supply to the last point of client delivery. The dashed lines depict the journey from the manufacturer's to the first client or the return journeys from the last client back to the manufacturer’s location.

It would have been interesting to calculate the kilometres of empty backhaul (journey from the last client back to the manufacturer’s location) in relation to the kilometres with loaded vehicles. Nevertheless, yet the system in its present version could not answer this question. However, this will again be important and will be dealt with at a later stage of this thesis. (See Section: 8.4 Implications on Operational Practice) The empty backhaul phenomenon (McKinnon, 1996) is indeed a very costly and highly interesting question, in particular for UMTO using specialized transportation vehicles.

Step 2

Step 2 includes the same manner of representation as in Step 1. The values contained therein all refer to tours from the identical time periods as those in Step 1, but still with the existing time windows and with new routing optimisation.

Table 14: Random Sample of Deliveries from Base Data-2

Random Sample of Deliveries from Base Data-2

Tour No.	Units	KG	M³	Clients	KM	Driving Time (net)	Driving Time(Ttl)	Start Date	End Date	Cost	Capacity Usage (%)
FO0042	86	2,591	35.23	5	554	09:44	14:26	27/11/2006	28/11/2006	488.4	95
FO0043	215	6,498	75.23	13	1,773	09:41	43:41:00	27/11/2006	01/12/2006	1,619.62	94
FO0044	207	7,211	79.54	10	1,662	04:13	37:21:00	27/11/2006	30/11/2006	1,403.79	99
FO0045	206	7,267	79.03	9	904	16:19	25:40:00	27/11/2006	29/11/2006	933.72	98
FO0046	192	6,706	77.13	13	1,044	16:30	26:36:00	29/11/2006	01/12/2006	981.6	96
FO0047	181	6,087	76.78	18	1,297	22:28	33:11:00	27/11/2006	30/11/2006	1,223.84	95
FO0048	182	6,337	72.08	6	764	11:51	19:57	30/11/2006	01/12/2006	733.73	90
FO0049	209	7,001	76.32	14	1,117	19:01	28:53:00	27/11/2006	30/11/2006	1,063.70	95
	1,478	**49,697**	**571**	**88**	**9,115**	**Average / Total**				**8,448.40**	**95**

At first glance this exposes a reduction of the 17 tours in Base Data-1 to an overall remaining 8 tours. In this randomly chosen example it is important to notice that the vehicle capacity utilisation of formerly 50% has now increased to already 95%. Cost thereby has decreased from 9,920.1 Euro to 8,448.4 Euro. The savings amount to 1,471.7 Euro (14.8%). A comparison to the same data in Base Data-1 shows a difference of two more clients that were served in this example. The reason for these additional two clients was that the system had to retain the hard time windows while only the soft time windows were omitted. By doing this, formerly combined deliveries of hard and soft time windows were now split into two deliveries. From a tour optimisation point of view this appears counter-productive. If one considers however, that by splitting a combined delivery in order to meet the hard time windows of the following clients on route, this explains the system's decision to do so, by adhering to the hard time window constraints.

Table 15: Table with 8 Tours from Base Data-2

Tabelle (8 Touren) 35008

Aufträge | Kunde | Läger | Kunden | Touren

Nummer	Einheiten	Gewicht	Volumen	Kunden	Kilometer	Fahrzeit	Dauer (Kosten)	Beginndatum	Endedatum	Kosten	Auslastung (%)
FO0042	86.00	2590.937	35.225	5	554.300	09:44	14:26	27.11.2006	28.11.2006	488.40	95
FO0043	215.00	6498.431	75.226	13	1772.800	33:41	43:41	27.11.2006	01.12.2006	1619.62	94
FO0044	207.00	7210.787	79.542	10	1662.400	28:13	37:21	27.11.2006	30.11.2006	1403.79	99
FO0045	206.00	7267.290	79.026	9	904.400	16:19	25:40	27.11.2006	29.11.2006	933.72	98
FO0046	192.00	6705.538	77.126	13	1044.200	16:30	26:36	29.11.2006	01.12.2006	981.60	96
FO0047	181.00	6086.626	76.777	18	1297.200	22:28	33:11	27.11.2006	30.11.2006	1223.84	95
FO0048	182.00	6337.180	72.079	6	763.500	11:51	19:57	30.11.2006	01.12.2006	733.73	90
FO0049	209.00	7000.650	76.317	14	1116.500	19:01	28:53	27.11.2006	30.11.2006	1063.70	95
Anzahl: 8	1478.00	49697.439	571.318	88	9115.300	157:47	229:45			8448.40	95

The geographical changes occurring in this first optimisation stage can be seen well on the map below. In this step, the system has optimised, in particular the tours around the areas of Bremen, Hanover and Berlin and also improved the tours around Amsterdam and Brussels. In addition, the tours to the south and southeast of Frankfurt have improved considerably.

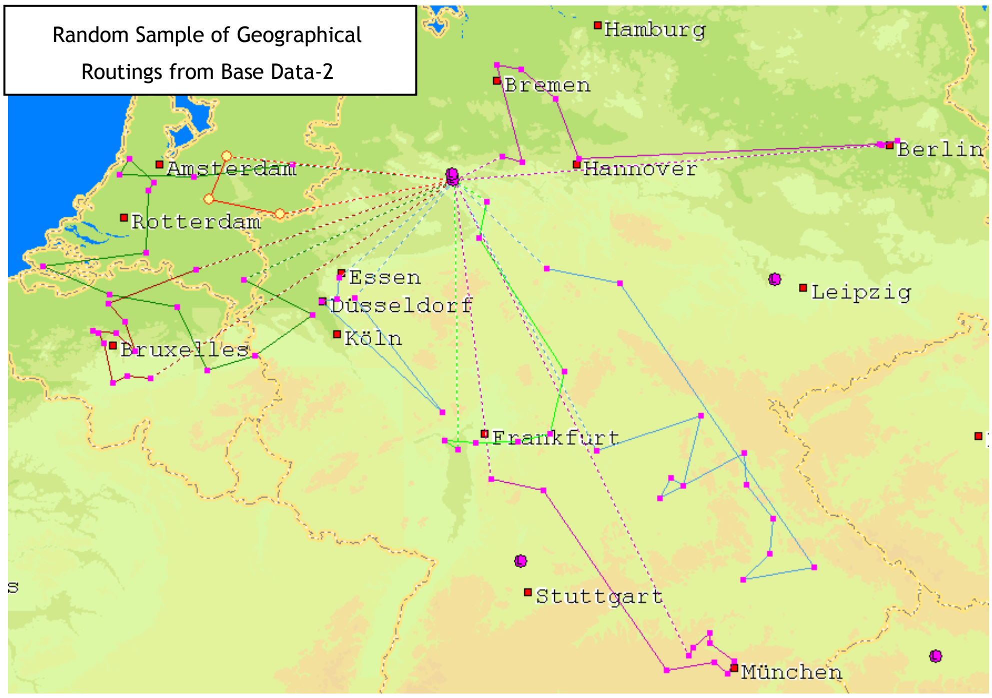

Figure 23: Random Sample of Geographical Routings from Base Data-2

If one now looks at the ratio between the individual empty journeys (dashed line) and the journey with loaded vehicles, it becomes apparent that they have decreased considerably.

Step 3

As in Step 2, the results listed in simulation Step 3 originate in Base Data-1, from the identical initial data of a total of 17 tours in the same time period. This time, however, subsequent to the simulation in Step 2 all existing soft TWC were deleted as a restriction to client deliveries and replaced with values of Monday to Friday, each from 0800 hrs to 1800 hrs. Fixed or hard time windows remained unchanged in this step; they were retained. The same accounts for the agreed calendar week of delivery.

Table 16: Random Sample of Deliveries from Base Data-3

Random Sample of Deliveries from Base Data-3

Tour No.	Units	KG	M^3	Clients	Km	Driving Time (net)	Driving Time(Ttl)	Start Date	End Date	Cost	Capacity Usage (%)
FO0039	205	8,297	76.98	11	1.544	03:46	13:28	27/11/2006	30/11/2006	1,392.16	96
FO0036	203	6,393	77.89	12	1.659	03:29	13:19	27/11/2006	30/11/2006	1,402.34	97
FO0041	172	5,95	72.54	15	1,320	23:06	09:08	28/11/2006	01/12/2006	1,225.24	90
FO0035	150	4,863	55.00	9	1,005	20:11	03:21	28/11/2006	01/12/2006	973.92	91
FO0038	192	6,706	77.13	13	1,044	16:30	02:36	29/11/2006	01/12/2006	981.60	96
FO0037	209	6,733	76.08	6	997	16:54	00:59	27/11/2006	29/11/2006	924.08	95
FO0034	149	4,997	56.22	14	786	13:38	21:27	27/11/2006	28/11/2006	763.56	93
FO0040	198	5,758	79.48	8	679	11:50	21:07	27/11/2006	28/11/2006	759.78	99
	1,478	**49,697**	**571.0**	**88**	**9,032**	**Average / Total**				**8,422.68**	**95%**

In this random sample, the economic values of this simulation process have, in comparison with the previous Step 2, changed only marginally. In order to explore the question for the reasons leading to these circumstances, the tours were examined in the system once again and, indeed, it became apparent that this random sample contained a high number of hard time windows (a total of 8) which were not subject to optimisation by the system.

As the economic values hardly changed in comparison with Step 2, one must assume that the geographical values in this example have not changed much either. The following figure elucidates this in part only as again it shows some substantial changes regarding deliveries for the Bremen, Berlin and Hanover areas. Obviously, these tours were calculated completely afresh when the soft TWC were deleted and which could not have been simulated in this form before.

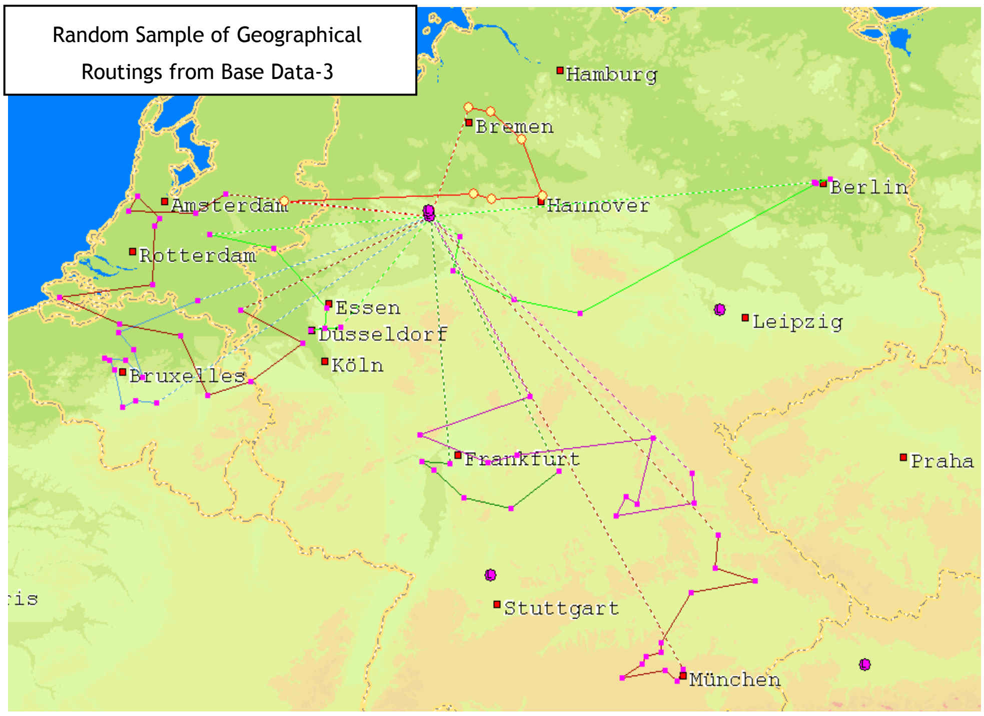

Figure 24: Random Sample of Geographical Routings from Base Data-3

The following table shows the results of the meta-heuristic simulation process by means of a consistently used sample. Even so, the results in this sample do not coincide with the results of the overall evaluation, which would be purely coincidental; the methods used in this approach are demonstrated and, additionally, the sample emphasises the effected changes in the system, particularly with the aid of geographical depictions. The table was created in order to give a better overview of results and evaluations arrived at this random sample:

Table 17: Random Sample Summary Analysis

Random Sample Summary Analysis

	Base Data-1	Base Data-2	Base Data-3	Variance 1-3	in %
Tours	17	8	8	-9	-52.90%
Units	1,478	1,478	1478	0	0.00%
Weight	49,697	49,697	49,697	0	0.00%
Volume	571	571	571	0	0.00%
Clients	88	88	88	0	0.00%
Kilometres	12,868	9,115	9,032	-3,835	-29.80%
Cost €	9,920	8,448	8,422	-1,497	-15.10%
Capacity (%)	50	95	95	45	47.40%

Finally, it must be pointed out that this simulation sample imposes many constraints on vehicles, tour planning, journey time, vehicle standing times, team composition for vehicles (i.e. one or two drivers), route criteria (motorway / country road ratio etc.). These have a high degree of control over the values to be simulated and, therefore, they are of great significance. With all three simulation steps in this approach, the settings for cost calculations in the system were determined once at the beginning and strictly adhered to throughout the entire simulation process. That means that the simulation settings were not changed at any time. Details to this are explained in Section 4.2.2 Supporting Cost Parameters.

5.1.6 Critical Reflections on the Chosen Approach

This section raises the question if the proceeding applied was adapted from the system's structure or, if the system was adjusted to the approach's specifications. In actual fact, it was both. The original structure intended to recalculate existing deliveries in tours with the relaxation of all TWC. By doing so, it was aimed to find out if this would lead to significant cost savings. However, the use of the selected DPS required the creation of the interim step of Base Data-2 findings. Only from this interim step, it was possible to achieve the results of Base Data-3. Therefore, as a critical remark, it may be stated, that the creation of Base Data-2 was a system requirement and not an intended part of the proceeding. The approach itself was originally planned with an immediate transformation of the Base Data-1 into the Base Data-3.

5.2 Data Collection and Processing

The data collection and particularly the data processing are the core element of the research process in this thesis. The reason for this lies in the described data processing procedures (See Figure 20: Data Processing within the Research) as a structural approach of investigation with multiple simulation. This section of Chapter 5 describes this process in detail and in order to comply with one of the important requirements of experimental research (Easterby-Smith et al., 2002). It pays special attention to the validation and verification of the single steps in this process. By doing so in all stringency, (1) the data cleansing and (2) the screening of the data during the process of multiple simulations is a very important part of the experiment undertaken. The extreme importance of these processes was described and reasoned in Section 3.5.2 Risks in Experimental Design and in Section 5.1.1 Research Process Definition.

The structural configurations of the data collection and data purification processes are described in single steps in the following section; an explanatory chart precedes some of the stages. Those structural stages reflect the process of data treatment and the preparation for the data analysis of this thesis. Therefore, the descriptions of the structural configurations may be seen as a part of the proceeding this thesis is based upon as an experimental research design.

The individual steps were consolidated and implemented as follows:

Step 1

Establishing and defining required data using a data acquisition template in Microsoft Access.

Step 2

Potential data providers were chosen using market research, personal contacts with manufacturers and generally available publications regarding the GKFI, like newspapers and magazines.

Step 3

Commentary regarding this research: a confidentiality declaration and application for the use of data was sent to 14 kitchen manufacturers in Germany in various locations to provide anonymous delivery files containing data acquisition templates.

Step 4

Perusal of data received from all 14 data providers, selection of potential data from each sample company selection of 12 sample companies. The 2 rejected data sets predominantly (more than 55% of their own total distribution data) consisted of dispatch information for either transoceanic containers or airfreight unsuitable for this research.

Step 5

The selection of those 12 data providers was carried out according to the following sampling format:

Alphanumerical sorting of 12 data providers:

The month of January was assigned to provider No. 1; February to provider No. 2, March to provider No. 3 and so on. Based on this method, an all-year data record of all providers was set up, thus giving a fairly representative data set. It is representative in the sense of: (1) a broad spectrum of different sample companies who have different customers with different logistic requirements; (2) a fair mixture of product pricing categories; (3) a good mix of accepting hard time delivery windows and (4) a good mix of geographical sales and delivery activities.

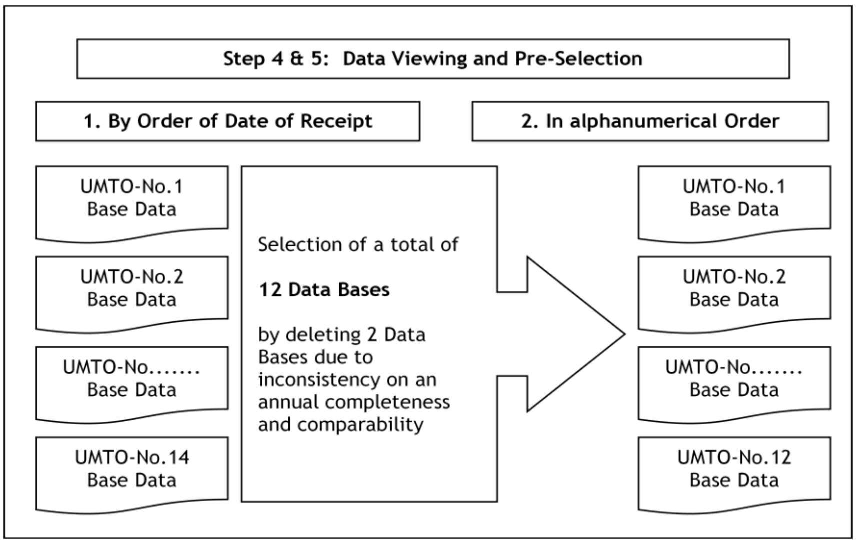

Figure 25: Data Viewing and Pre-Selection

Step 6

The new all-year data derived from the alphanumerically sorted 12 data providers formed a completely new database, which in the following will be referred to as Base Data-0. It contains the distribution data for all of 2006 from 12 kitchen manufacturers. However, a detailed resurvey revealed a number of deliveries, which obviously had not been executed by heavy goods vehicles. e.g.:

- Consignees located in the USA
- Air cargo shipments to the Far East, Hong Kong and Melbourne etc.
- Consignments which evidently had been taken by courier vehicle (ergo, not by lorry).

These consignments were extracted from the MS-Access programme and, therefore, were no longer relevant or of use for further consideration. This was applied to the entire Base Data-0 to ensure that such a stringent process would warrant data validity and reliability.

Step 7

With this step, the information received from Base Data-0 had to be sorted in a chronological sequence for further investigations. This became Base Data -1.

Step 8

This step was one of the most basic in this entire experiment. From the distribution criteria such as consignee's address, weight and m^3 volume of consignment and a summary of individual deliveries arranged, emerged a representative data set for the analysis. The comparable cost of delivery for this data set was calculated based on the cost parameters described in Section: 4.2.2 Supporting Cost Parameters. The costs involved and other variables were consolidated in descriptive Base Data-1 which represents the original research basis and, therefore, the origin from which mathematical comparisons are made to all subsequent Base Data.

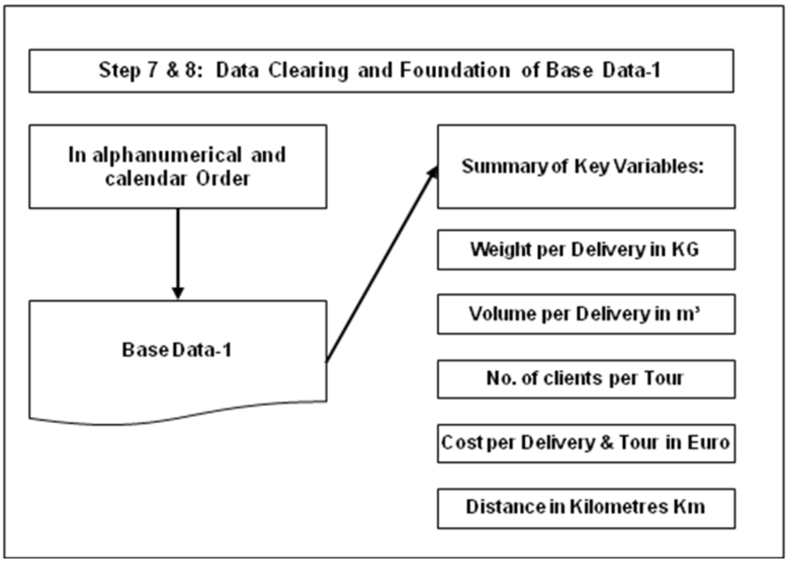

Figure 26: Data Clearing and Foundation of Base Data-1

Step 9

In the preceding data processing steps, no changes were made to the so far treated data other than the already explained deletions. Base Data-1 consisted of a year's actual deliveries from 12 kitchen manufacturers. These deliveries and all associated data such as kilometres, weight, volume, and in particular the number of customers to be supplied was, in this step, compared with the preceding data base and checked for completeness. These checks represent the validity check of the input data process.

Step 10

In this step, all original tours were maintained and manifested with the aid of the simulation system, that is, they were codified. However, the pre-defined soft TWC were relaxed. This means that it was assumed that all those customers could be supplied from Mondays to Fridays and from 8:00 am until 6:00 pm. In other words, there followed a process of simulation (and experiment) that all deliveries could be maintained without the given time restrictions with regards to deliveries inside the customary business hours.

Step 11

With the help of the simulation system and based upon Base Data-1, this step simply contains the summary of economic effects. This is how Base Date-2 came into existence and thus could be compared with the conclusions drawn from Base Data-1. At this juncture, a comment is essential in order to promote the crucial perception of this approach. It must be borne in mind that the difference between Base Data-1 and Base Data-2 (X – Y_1)is such that, although exactly the same tours were maintained, only the soft time windows in Base Data-2 were expanded to the theoretically i.e. practically maximum possible time frame (not the hard time windows). With respect to the essence of this research and the effect of DPS on distribution costs, it means that the consequential economic effects in Base Data-2 are due only to the soft time window removals. This was an important and unavoidable intermediate measure in order to attain the subsequent results. (Bryman and Bell, 2003) In order to answer the research question regarding the actual effects of DPS on distribution costs for UMTO, it took one last step of data simulation by restructuring all the initially maintained tours.

Step 12

This final step - after the preservation of initial tours from Base Data-2 and maximum soft time window removal - deals with the restructuring of tours supported by a DPS and simulation with the given situation, i.e. existing hard TWC for delivery. The necessary measures that had to be taken correspond to those already described for the interim step in creating Base Data-2 and, therefore, need not be repeated again at this stage.

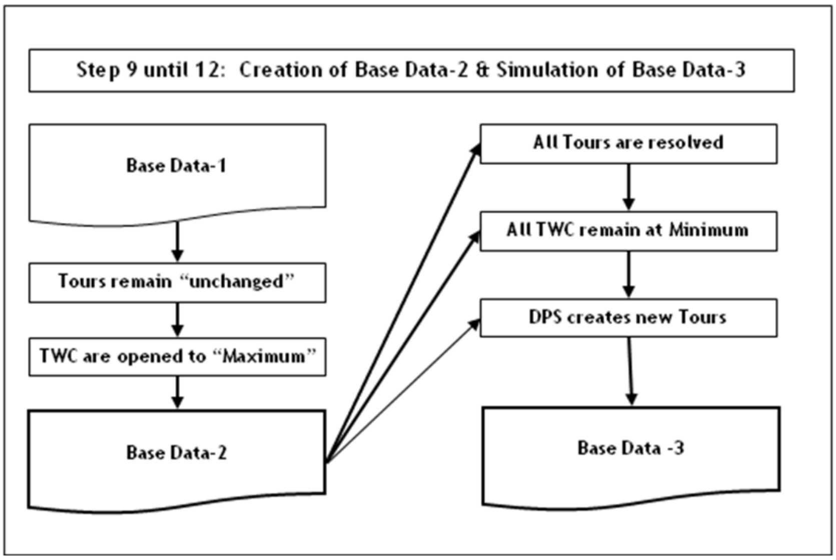

Figure 27: Creation of Base Data-2 and Simulation of Base Data-3

The object of the following proceedings was to dissolve the existing tours in Base Data-2 and to break them up into individual deliveries or shipments. In doing so, strict attention was paid to the fact that the new delivery date given to a customer would still be in the same calendar week as the original. If a different planning method had been employed, the DPS would have produced an unrealistic solution through consolidation of geographically close distribution points that were spread very widely over the whole year. This process of dissolving of all tours in Base Data-2 was done with the help of the simulation system and DPS. With some customers who had been given fixed dates and times (as detailed in the original data), it was assumed that these were irreversible delivery times which had to be taken into consideration during the following optimisation. Therefore, these fixed dates were maintained again.

The subsequent optimisation of all individual deliveries within one calendar week was subject to one more consideration. This was whether planning should also take into consideration 1 – 2 days of the preceding and succeeding weeks respectively. In order to explore this option further, a brief (interim) experiment over a period of 10 calendar weeks was conducted. With this analysis, it became evident that the kitchen furniture manufacturers all plan in a geographical rotation, or a so-called repetitive business environment. This means that suppliers deliver their goods to a specific area (sorted by postal codes and turnover) at regular intervals. Therefore, and in order to arrive at the envisaged optimisation option, it would have been obligatory to widen the approach by far more than just 1 – 2 days before and after that particular calendar week. If one had proceeded along those lines, then one would have essentially contradicted the sample companies' planning claim, and it follows that the GKFI would have had to deal with unintelligible planning parameters. Accordingly, this approach was not pursued any further, as it would have contradicted the ceteris paribus clause of this research.

Next, with the help of DPS individual distributions from the dissolved tours in Base Data-2, the tours were newly optimised based upon the aforementioned processes, meaning that all deliveries (or individual shipments) for one calendar week were consolidated and then re-planned into newly optimised tours.

Thus the results from Base Data-3 were the final objective of the simulation. For this research it sufficed to show a differential between the initial Base Data-1 and the optimised Base Data-3 without TWC in order to determine the significance of cost through the use of a DPS and to answer the research question.

5.2.1 Data Cleansing and Selection Parameters

For the purpose of simulation process validation and data consistency verification undertaken in this thesis, all parameters concerning data cleansing and data selection are listed hereinafter.

All delivery dates of sample companies which did not meet the following criteria or selection parameters where excluded from the respective Base Data and filtered out.

Setting up of Base Data-1 from Base Data-0

- Consignments with less than approx. 0.5 m^3 volume
- Consignments of less than approx. 31 kilograms but with a maximum lashing belt length of 2.1 metres
- Consignments destined for overseas, i.e. outside of European lorry capabilities
- Consignments which have verifiably been transported by courier vehicles

Setting up of Base Data-3 from Base Data-2

- Retention of calendar week for delivery
- Retention of fixed delivery dates (hard TWC)

All delivery data meeting these criteria were retained in the respective Base Data and adopted unaltered. This means for both the aforementioned special cases, that consignments in one calendar week were not transferred to either preceding or succeeding calendar weeks; fixed delivery dates remained in place.

There might well have been another way to determine or assign these processes. However, this selection conforms to the customary practices within the GKFI and the ceteris paribus condition for this research. Therefore, essential preconditions were set for the ease of reference at a later time as well as for the transfer of these research results to answering the research question. The process selection criteria for the setting up of Base Data-1 from Base Data-0 play a rather subordinate role. The processes for the setting up of Base Data-3 from Base Data-2 are of much more importance.

It is most likely that the GKFI will comply with customary practices and thus will adhere to weekly deliveries. This also applies to the retention of fixed delivery dates. Against this backdrop, the latter was chosen as a constraint (See Section: 4.2 Definition of the Cost Function) so that, at a later time, when the results are validated and verified, the margin for error with regards to the transfer of theoretical research results to answering the research question would be kept as narrow as possible. Fixed delivery dates could contain theoretical measures on the part of the consignee, which from the researcher’s perspective might not be instantly recognisable. Therefore, the decision of retention is a criterion which admittedly somewhat limits the options for optimisation as these dates remain unchanged.

5.2.2 Validity and Reliability of the Screening

The value of this experimental research largely depends on the credibility and validity of data and its processing. (Saunders et al., 2007) From this point of view, the analytical methods matter as much as a stringent data processing ensuring no occurring loss of information or unintended manipulation. (Biethahn et al., 2004)

This section conveys an overview of all such mechanisms and screening criteria in the following figures which have been employed during the course of data processing; it aims to ensure the validity and to support the creditability of all processes and approaches applied in order to ascertain these research results. With the intention to present a logical illustration of the screening criteria and mechanisms, it was opted to dispense with a detailed description and to offer a series of graphic representations instead.

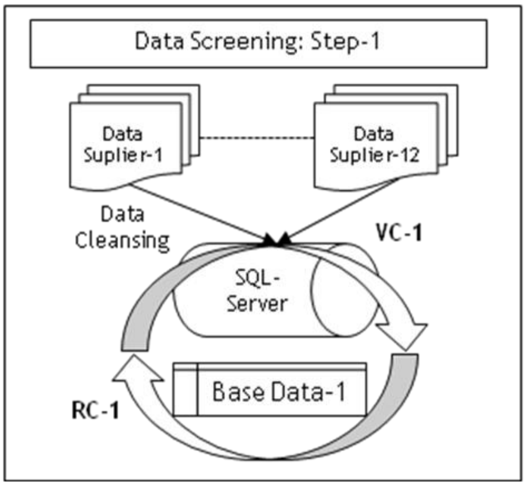

Figure 28: Data Screening Step-1

In this step the screening focused on the Validity Check-1 (VC-1) after the receiving of the data from the sample companies and the Reliability Check (RC-1) after the transformation from the SQL Server into the Base Data-1. Both screening checks were undertaken in order to screen on the completeness of the data, the coherence of data sets as tours and the implications of the data cleansing process.

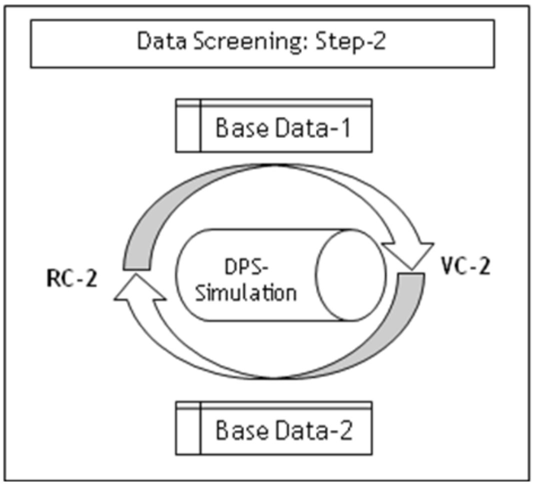

Figure 29: Data Screening Step-2

As this step contained the removal of all TWC on all deliveries from Base Data-1, it became of vital importance to screen the validity of the data in terms of the completeness of this removal. As the second screening of reliability (RC-2), it became important to screen the completeness of all data through a data linkage check between the data from the two different Base Data.

The continuous data and process screening was finally added by yet another double check. Here, the data was extracted from Base Data-2 out of the SQL Server and transferred into the DPS for simulation. Both outgoing and incoming interfaces were secured with screening tests due to the large amount of data in transit. This transit was the main focus of this screening step, as the DPS computing facilities could only handle small portions of data to be simulated at each one time.

The RC-3 concentrated on the originality and completeness of the data sources and also ensured no data was lost in the interface towards the DPS. The VC-3 screening focussed on the adherence to logistics constraints, i.e. for the capacity of the vehicles, the total legal driving time of the drivers and others. Another important reason, (due to computer configurations), for this screening was that such constraints needed to be re-stated in the system for every package of data transferred. The latter was also an important reason why these two screening processes had a vital meaning in this step of data processing and data transfer.

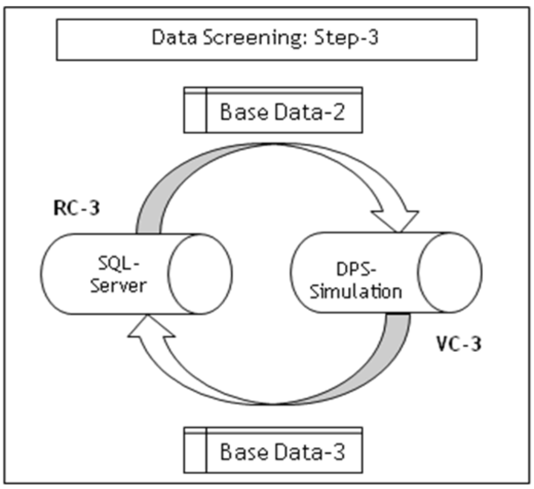

Figure 30: Data Screening Step-3

The above Figure 30 illustrates a forward and rolling over application of a data simulation and data transfer process, and where the screening of validity and reliability was located.

5.2.3 Research Process Validation

This section is dedicated to the validation of the entire processes as opposed to the operational structures, and it is intended to underline the philosophy of the chosen experimental research methodologies. (Biethahn et al., 2004) It describes the process validations from the beginning with Base Data-1 replacing Base Data-0, Base Data-2 replacing Base Data-1 and finally Base Data-3 replacing Base Data-2. In correlation to the graphical description in Section 5.2.1 Data Cleansing and Selection Parameters, this section describes these process validations and all interim steps. In particular, it focuses on the stringent validation during each stage of data development, starting from the data as supplied by the kitchen furniture manufacturers up to the ultimate Base Data-3. That this is an important, if not vital measure in experimental research was described in Section 3.5 Experimental Research. The comprehensiveness of this section serves the purpose to reduce the weaknesses of experimental research using simulation according to some authors mentioned in 3.5.2 Risks in Experimental Design. (Terzi and Cavalieri, 2004, Kleijnen et al., 2005, Fu, 2002)

A special account is given of how this data was edited and, with the assistance of the DPS, subsequently acquired from Base Data-2 and incorporated into Base Data-3. In doing so, non route-relevant distribution data (listing of reassessed delivery data) was discarded utilising route-relevant client orders only. This information also formed the basis of the new Base Data-2; Base Data-2 then incorporated client orders qualified for delivery only. Continuous validation (of information) was of the utmost importance, albeit quite laborious. The modification of Base Data-1 in order to establish Base Data-2 meant a multiple transfer of more than 2.2 million data cells. It was inevitable that transfer errors occurred during this process. In addition, the original data, (supplied by furniture manufacturers), had to be screened several times by linking all available information.

The following illustrates the validation process pertaining to a single data provider, and it is intended to prove continual data validation throughout the entire simulating process. Simulation of data may, among other things, also lead to data changes i.e. mutations, (Fu, 2002) which once a simulation has been concluded, are irreproducible, and therefore, calls into question the validity and accuracy of data processing. (Banks, 1998)

Step 1

The handing over of data on storage medium means transferring individual client orders in a data-input format along with actual routes taken. With this, the new cost calculation was drawn up in line with standard criteria of this thesis (See explanation below and Section: 2.7.1 Identifying Cost Parameters) and the kilometres to be driven.

a. The standard cost calculation was drawn up with due diligence in order to attain the potential comparability of cost parameters and, (Kleijnen et al., 2005) simultaneously, to eliminate the diversities in the sample companies' methods of purchasing freight or producing transport themselves, the latter being the chief argument in favour of validation. (also See Section: 4.2.2 Supporting Cost Parameters)
b. At the same time, the entire original Base Data-0 was filed in a so-called data archive so that in the event of potential loss of data the initial data could to be retrieved in an instant

Step 2

The information gathered from step-1 was then put into a SQL data base. From this SQL data base, the data was transferred in overwrite format to the system of the DPS in order to ensure continued processing of data within a standardised system.

Step 3

On perusal of the existing datasets, initially a total of 14 sample companies, it was noticed that the dataset of 2 suppliers were partially fragmented and included deficient shipment dates as well as client constraints. After consulting with the sample companies, it was decided not to draw on their records any further as a short-term intervening adjustment was clearly unattainable.

Step 4

The next step was to decide which monthly datasets filed during a year per sample company (separated in calendar months) could be utilised for the forthcoming analysis. An alphanumerical selection as described before was undertaken. With this systematic selection process, it was also possible to compensate for and eliminate seasonal fluctuations, in-house deviations and client-orientated differences. In this step of process validation the restrictions of Biethahn et al. (2005) were fully adhered to.

Step 5

In creating Base Data-1, the data linked all the original versions of data supply procedures to these alphanumerically cross-sectioned 12 sample companies. Thereafter, the selection of functional data followed. During this process, all deliveries not suitable for truck transport were deleted as described before.

Step 6

Base Data-1 was the initial basis from which Base Data-2 evolved. The latter was cleared of all TWC, that is the respective restrictions were removed individually and manually for all actual driven routes and their appertaining individual orders. This was achieved by applying the DPS to their programme: Route Restrictions. This particular stage of data processing validation carried the highest risk of data deviating in between Base Data-1 and 2 during the SQL transfer. However, in order to avoid any deviations, i.e. to ensure the 100 percent successful transfer of data, all files were extracted from the system again and transferred to the MS-Access programme. Following this transfer, the Base Data files of all individual client orders and the resultant deliveries were split again into individual calendar months and compared with each other by using MS-Excel linkage command for data rows and columns. During the linkage procedure, both Base Data files were placed next to each other having previously been given a unique identification number (ID). Then both these ID numbers were matched up to each other via a 'result cell' and, if the numbers tallied, the result was marked in green colour. In case of a deviation the result cell was marked in red colour and later corrected in Step 8.

Step 7

The following table is an extract of tour listings from two different Data Bases. Both Data Bases were compared with each other in Microsoft Excel using Excel's linkage command. Tour number 502 which previously served 9 clients now, in its simulated version, serves only 8 clients. The client who was dropped is now included in tour 503. This linkage served the purpose to validate that all clients were being considered, i.e. assigned a delivery. The Linkage Ref. No. 50237830 in this table indicates that both tours refer to each other and that they have the same data origin.

Table 18: Examples of Validation Linkage

Examples of Validation Linkage								
Tour Number	**No of Clients**	**Prod. Date**	**Linkage Ref.**	**Difference**	**Tour Number**	**No of Clients**	**Prod. Date**	**Linkage Ref.**
406	6	12/01/2006	40638729	1.00	406	5	12/01/2006	40638729
410	8	12/01/2006	41038729	0.00	410	8	12/01/2006	41038729
415	3	12/01/2006	41538729	0.00	415	3	12/01/2006	41538729
487	11	12/01/2006	48738729	0.00	487	11	12/01/2006	48738729
495	3	12/01/2006	49538729	0.00	495	3	12/01/2006	49538729
501	18	13/01/2006	50138730	0.00	501	18	13/01/2006	50138730
502	9	13/01/2006	50237830	1.00	502	8	13/01/2006	50237830
503	12	13/01/2006	50338730	-1.00	503	13	13/01/2006	50338730
504	2	13/01/2006	50438730	0.00	504	2	13/01/2006	50438730
505	11	13/01/2006	50538730	1.00	505	10	13/01/2006	50538730

Step 8

This step necessitated an adjustment of the red cells only, during the process of which it became clear that this particular way of data transfer was the most suitable method for validation of both Base Data-1 and 2. Any deviations could be corrected with very little time spent, double entries be spotted straight away and any data transfer errors or loss of data be recovered in an instant. The outcome at this stage was the existence of two identical data compilations (1 and 2), one with and one without TWC.

Step 9

For the validation of the creation of Base Data-3, similar processes of repetitive screening were undertaken. In its preliminary stages, Base Data-3 was based again on Base Data-2. All existing (original) routes which presented the basis of actual costs accounting were cancelled. That meant that once again all routes were reverted back to individual client orders (or individual order deliveries) before they were eventually deleted. Subsequently, individual client orders were stored at interim. Now, the validation focused at the identical contents of both data sets by linking them again with the MS-Office Linkage command. Next, individual client orders were sorted afresh in order of their production date and new routes were structured via the DPS; however, this time without TWC. The new Base Data-3 presented the economic result of theoretically optimised distributions for the chosen GKFI population who deliver to their customers without any TWC. All validation processes so far, revealed a loss and mutation free data handling.

Step 10

Next, as a primary intermediate step of this data analysis, the first economic comparison of results from Base Data-1 began against those of Base Data-2, and then the latter against Base Data-3, whilst at the same time Base Data-1 was compared against Base Data-3. During this process, relativity comparisons were made in order to be able to find a reasonably comprehensible data simulation from within the first results. Therefore, the entire data processing was based on this theory: the inclusion of the initial data supply at random, the data analysis and then the correction of this data to make it comparable and finally rejoin all information by means of data simulations under altered constraints.

Regarding the comparability of cost between the different steps of analysis it is stated herewith that the identical cost parameters and cost functions were applied as reported in Section 4.2 Definition of the Cost Function.

5.2.4 Data Request, Origin and Delivery

All sample companies were treated as being anonymous, in order to be able to make possible comparisons to other research work. This, incidentally, met with the wishes of most sample companies, too. The original data in this research (from Base Data-0) does therefore, not include any of the suppliers' names but merely their postal code of location, although it would still be possible that one could draw some inferences from this as to their identity.

Based on DPS calculation, which compute the distances in between two geographical points by their postal code, it is likely that one could surmise or even assume the names of either originator or addressee. In consultation with the sample companies all the different dispatching locations were consolidated to one theoretical dispatch location. This was an inconsequential manipulation, as all sample companies were located within 64 km of each other. It was agreed with the sample companies that data input formats should also have the authentic recipients name written next to his postal code to allow for potential collaboration regarding tour deliveries within the scope of DPS optimisation namely consolidation per consignee per calendar week per delivery.

Temporal and Effort-Oriented Advantages of Primary Data

It is obvious that the use of primary data, in this case the tour data of selected kitchen manufacturers in Germany, brings with it an enormous saving of time rather than having to generate theoretical data oneself, i.e. to generate it from individual deliveries. A further advantage is that this data, therefore, possesses a high degree of originality. (See Section: 3.5.3 Sampling and Pilot Studies in Experimental Research)

Quality Advantages of Primary Data

The quality of this data is extremely important for the entire research project, especially if one considers that it is data exclusively provided from GKFI, who manufacture assembled kitchen furniture only. The data quality from the primary sources is, therefore, the basis for the attempt to answer the research question. (Kleijnen et al., 2005)

Possibilities for Sub-grouping of primary Data

The use of primary data enables this data to be subdivided into so-called sub-groups of realistically driveable tours (i.e. excluding air- and ocean-freight, courier and parcel shipments). This option was of the particularly important when data was applied because not all data was exploitable for the purpose of a focalised research. (Chang and Makatsoris, 2001) By using primary data, yet another advantage was exploited.

Possibilities for Group-Overlapping Data Analysis with Primary Data

Overlapping of groups also occurred during data analysis, which had an extremely positive effect on the decision in favour of primary data. The data analysis of this thesis revealed that grouping, i.e. the formation of clusters produced quintessential affirmation of the achieved results. (Banks, 1998) This means that group-overlapping analysis corroborated the analyses results obtained from other processes.

Possibilities for Re-Analysing Processes of Primary Data

This last, but very significant, aspect for the use of primary data plays a special role in economic or practical operation viability. It means that in case of re-analysing the data actually used on the basis of other similar industry data, this method could stand up to generalisation towards the chosen population.

(Bryman and Bell, 2003) Next follows an account of the complete data preparation and data gathering process. The formats used are all self-developed within the framework of this research. Behind each step will be the question of what advantages and disadvantages such an approach holds, to stand against the concerns of Section 3.4.2. Application of Simulation in Decision Support Models until 3.5.3 Sampling and Pilot Studies in Experimental Research.

5.2.5 Data Input Format

The collection and the further use of data play an important role in research. Collecting primary data using a structured format is a generally accepted and practised method. (Saunders et al., 2007) This thesis has used such a completely structured format in an electronic template for the sample companies to provide their information. This template contained a predetermined and standardised or identical set of data requests. (See Table 19: Client Data Input Format Client Data Input Format) In the beginning of this process of collecting data, the only social interaction with the sample companies was by telephone conversation for the purpose of being granted the permission to receive such data. Thereafter, all further interaction with the sample companies was on an electronic communication basis. However, this was minimal and negligible, as all sample companies without any fail complied with the template of a fully structured data request. With this process of collecting data, the basis for the sampling was initiated. Saunders et al. (2007, p.317) describe this process however as critical and hereby refer to *"data quality issues"* that have to be concerned with. Here, the authors refer to the reliability of the process of data collection itself and appropriateness of the questioning (or data request templates). These aspects were dealt with in Section 5.2.2 Validity and Reliability of the Screening of this thesis in detail. The methodology of collecting data in this thesis complies with recommended precautions and expertise according to Saunders et al. (2007) and to those of Bryman and Bell (2003).

The structure and entire process of the data creation plays an important role (Rosenfield et al., 1985) in this research in respect of a consistent methodology and research strategy, and it is for this reason that the process is described in detail. Core data requirements did indeed necessitate a completeness of information, thus requiring the following two different data input format set-ups:

Client Data Input Format

The data gathering (or acquisition) format in this research had to contain all geographical location data of clients who receive deliveries from the chosen suppliers. The following table was created as a fixed data gathering and input mask. The mask was created in a bi-directionally transferable MS-Office Excel file.

This structure of data input format has the following advantages:

- Fixed data fields require standardised field contents.
- The definition of an exact field length determines the data input and reduced error rates.
- A pre-determined field characteristic of either: time, words, numeric contents or other described typology of data input and reduced errors rates in the transfer process from data input to data simulation and to data analysis. This format of data input facilitated the process of multiple repetition of data simulation by assigning certain duty format contents to each field.

The disadvantages of this format are:

The transfer into an MS-Office Excel file does not consider the license version of the simulation tool and may lead to complications in their transferability.

Table 19: Client Data Input Format

Client Data Input Format

Data Contents	Field Length	Field Type	Remarks
100	4	A	Data-Set-Fix 0100
37718	17	A	Client ID.-No.
Test Client 1	40	A	Client Name 1
D	3	A	Client Country
38789	5	A	Client Postal Code
St. Leon-Rot	40	A	Client Location-City
High Street 44	40	A	Client Street Address
700	4	TIME	Delivery Time from
1200	4	TIME	Delivery Time until
1	1	Y	Monday
1	1	Y	Tuesday
1	1	Y	Wednesday
1	1	Y	Thursday
1	1	Y	Friday
0	0	N	Saturday
0	0	N	Sunday

0= no delivery on this day 1 = Delivery on this day

Moreover, the major disadvantages of this format are technologically based data transfer resources. Even though these resources may be acquired through equivalent hardware support, the actual action may lead to temporary system shut-down and interruption, if not break-down of data transfer. In general, one can state this format via an MS-Office Excel file is highly fragile in transferability and may cause the total or temporary loss of data, resulting in numerous repetitions of data transfer.

Table 20: Client: Time Window Constraints

Client: Time Window Constraints

									Day for Delivery				
Data Set	ID.-No.	Client ID	Country	Postal Code	Location City	Street Address	Delivery Time From	Delivery Time Until	Mo	Tu	We	Th	Fr
100	37.718	12.345	D	38789	St. Leon-Rot	High Str., 44	700	1200	1	1	0	1	1
100	46.443	12.346	D	46443	Blumberg	Tevestr. 2C	800	1100	1	0	1	0	1

The structure of both above data acquisition formats ensured, however, the highest level of client data information on all existing TWC. Those TWC are the main frame of distribution planning, fixing likely and less likely delivery times by weekdays and time limits. In addition, the allocation of an identification number to each client avoids duplication.

The geographic data gathering (i.e. postal codes) is essential to provide any DPS with client allocation details as well as identification within the routing of a tour delivery. The delivery time from starting point to endpoint, along with the weekdays in this gathering format, are the client's actual TWC with which the DPS in a 'Yes' or 'No' decision format allocates possible deliveries. Such a table shows a data-gathering format in another version as client TWC.

Delivery Data Input Format

The delivery data input template - as a client order input format below - has a similar structure as the above client data format. Field contents and length are purely technical field restrictions to ensure readability. The type of data like numeric, date, time and alphanumeric characteristics are formatting templates.

The following data acquisition table deviates from the above-mentioned in that it does not contain individual delivery orders (as above) but those tours, which have been compiled from the individual orders as mentioned above. In short, it contains the targets given to the sample companies for information about their actual and individual tour data.

The following considerations, regarding advantages and disadvantages of this chosen data input do, of course, present a restriction to the overall data processing. For this reason, this process will be described in detail hereafter. If this is not done, one might soon easily succumb to the arguments of 'unclean data processing' and 'influence of hidden manipulation options'.

The structure of the below data input format has the following advantages:

– each tour has its own number of TWC,

- each tour has a common geographic departure point and a different destination,
- different orders from different clients, or even the same clients to the same geographic destination but resulting from different production cycles are allocated to different tours,
- each tour has an identification number; in it, a number of client orders are combined, and these orders were allocated to the tour according to the TWC and other determination factors (most of them unknown or not identifiable from the data supplied).

Table 21: Client Order Input Format

Client Order Input Format

Field Contents	Field Length	Type of Data	Remarks
0200	4	A	Data-Set-Fix 0200
10000	14	A	Order No.
1	1	A	Assortment: 1,2,…
20443	17	A	Client ID. No.
20050117	8	DATE	Date of Delivery
100	10	N	Weight
100	10	N	Volume
12	10	N	No. Of Items: Pckgs, Boxes,…
30036	5	A	Tour No.
10	30	A	Tour Sequence
200T B0 4/1	10	A	Tour ID No
282	4	A	Tour Distance
0600	30	A	Ariival at Client
0615	30	A	Departure at Client
1	1	N	No. Of Items: Pckgs, Boxes,…
1500	4	TIME	Waiting Time at Client
0330	4	TIME	Tour Start
0915	4	TIME	End of Tour

The disadvantages of this format are:

The total of all tour data includes subcontracted transport to certain service providers whenever tours by a regular furniture delivery truck are not feasible. For example, a load of very small items for 27 clients with a total of 0.001 m^3 is not practical for a delivery by lorry. This is even more evident when the total distance of this tour would come to more than 2.500 kilometres. In that case, it was found the client orders were in fact shipped by ordinary parcel mail and consequently count as “unrealistic” tour data. To conclude, the major disadvantage of this input format is the large number of "unrealistic client orders" included in a tour.

With this in mind, the process of collecting data was ended. It was learnt from this process that the initially collected data in its original version was not yet suitable for the objectives of this research. Another step of data creation became necessary to facilitate a data simulation in a DPS.

5.2.6 Data Purification

In order to distinguish between 'realistic' and 'unrealistic' tour or client data, the 'unrealistic' client order and tour data needed to be extracted by the above mentioned parameters. With the experiences from this previous process the captured data needed to undergo further data preparation to suit the objectives of this research. This process was undertaken as follows:

Table 22: Client Delivery Data Input Format

Client Delivery Data Input Format

Data Set	Order No.	Assort ment 1,2,…	Client Id. No	Data of Delivery	Weight	Volume	No. Of Items Pckgs, Boxes,…	Tour No.	Tour Sequence
0200	10000	2	20443	20050117	100	100	12	30036	10
0200	10001	2	40678	20050117	500	500	9	30040	5
0200	10002	2	39677	20050117	300	300	12	30030	3

Continued/…

Tour ID No	Tour Distance	Arrival at Client	Departure at Client	No. Of Items: Pckgs., Boxes,...	Tour Start	End of Tour	Cost per Client
200TB04/1	282	0600	0615	1	0330	0915	105.00 €
200TB10/1	442	0545	0607	2	0415	0845	212.75 €
200TB12/1	334	0544	0558	1	0515	0620	447.56 €

This structure of data input format has the following advantages:

- each client and client order identification number is immediately recognisable;
- each client order is linked with a tour in the base data, allowing the analysis of variance after the simulation;
- each client order and tour is linked with cost of delivery parameters that will show the variance after the tour data simulation;
- each tour, and consequently each client order from the base data has its own key figure analysis, thus identifying the key variables of this entire research process and analysis in the actual cost per m^3, per actually driven km, per client delivery or order, per tour etc. – In this way, the base data forms the data base for the further data analysis with and without data simulation.

The extraction and subsequent deletion of the so-called unrealistic delivery data immediately identifies the realistic data. This approach does not weaken the validity or the reliability of the data analysis process so far as it retains the possibility to maintain the control mechanisms of ‘original base data’ as the control group and a ‘selected base data’ as a treatment group.

The disadvantages of this format are:

The fact that such a client data input format includes all complete annual deliveries of a manufacturer, irrespective of their actual mode of transportation and consequently their feasibility for a tour truck delivery (and for this research focus) confirms the concerns about this methodology of data collection and modelling according to some other authors. (Poe et al., 1994, Bryman and Bell, 2003) This states one of the accepted weaknesses of this research methodology in this thesis. It was however found to be a tolerable critique due to the numerous data validity and data reliability checks in this experiment as described in Section 5.2.2 Validity and Reliability of the Screening.

Such a methodological and thereby theoretical modelling of the client data input format narrows the possibility to focus on 'realistically' feasible truck deliveries only, within Germany and the neighbouring countries. It required additional cleansing and remodelling. By deleting the 'unrealistic' base data, the question of data validity is certainly a factor that must be dealt with and reasoned in detail. To account on this concern, a very time consuming process of data cleansing was undertaken as described in Section 5.2.1 Data Cleansing and Selection Parameters. More detail on this concern is described in Figure 20: Data Processing within the Research.

5.2.7 Data Collection Strategy

At the end of 2006 the GKFI reported that there were 96 companies (with more than 20 employees) with an average annual turnover of 41.2 million Euros per company. Their export rate was 30.7 %. (Source: Federal Bureau of Statistics; Special Publication No. 4, Series 4.1.1) Since this market structure offers a variety of options for data collection, the strategy of this research opted to present a robust sampling from a population that would allow a valid generalisation. Therefore, it was decided to focus on receiving as much information as possible from all 96 kitchen manufacturers. A total of 23 companies were contacted, 14 of which readily signalled their willingness to supply data in the required format and on the understanding that it would be used for research as described earlier in this chapter.

Another aim of the data collection strategy was to achieve a fair average of manufacturers representing all clusters of product pricing within the GKFI (see Table 6: Examples on the Cost of Delivery (%) of total Cost), thus providing this research with a credible sample. In contrast to a simple random sampling within the GKFI, a stratified random sampling method offered a number of significant advantages to this thesis. Those advantages are (1) avoiding the drawback of non-inclusion of clusters or cluster members, (2) disproportional balance of clusters, (3) increased representativeness for small and heterogeneous samples. (adapted from Easterby-Smith et al., 2002) The latter of those advantages refers to a better comparability of the stratified sampling to the entire population. The high significance of this chosen stratified sampling process is demonstrated by the fact that if one had randomly chosen one single sample from the sample companies, then this would have become a single case study of that particular company. Any non-stratified selection of only some of the sample companies would have created a biased result. This is due to the small number of sample companies and the heterogeneity of the population. Given the small population, the stratified random sampling cannot entirely avoid a bias but it makes sure that all clusters are represented and the margin of error in possible claims is reduced to a minimum.

In other words, if the manufacturers, who were prepared to supply such research data material, were from all levels of selling price and market position, then the conclusions on the effects of DPS on the cost of delivery for the UMTO in this industry would contain a fairly high validity in terms of the application of the simulated data and its generalisability. (See requirements from: Section 2.7.2 Delivery Cost as a Share in Total Cost)

The following 2 tables give an overview of the anonymous sample companies in alphabetical order and their data input. Table 23: Overview of Sample companies' Annual In-Put shows the annual shipping statistics of those suppliers. It is stated later that all of them have different clients, different products, and different strategies on how they perform their vehicle routing. From this, the strategy to present a robust sampling for this research objective may be stated.

Table 23 Overview of Sample companies' Annual In-Put reflects the annual total of each sample company of which one month was selected for the following Table 23 Overview of Sample companies' Monthly In-Put. Looking at the annual average cost of Euro 42.94 per m³, this is derived from all of their deliveries throughout the year. The assumption that this may differ from month to month is obvious. The existing cost structures of all the sample companies may derive from cost calculations per m³, per tour, or any other variable. The actual facts however, were unknown to the author of this thesis. From this, it is important to note that those costs were captured only for the purpose of a later verification of the intended experiment.

Table 23: Overview of Sample companies' Annual In-Put

Overview of Sample Companies' Annual In-Put in Alphabetical Order

Sample Company (Alpha-Sort)	No. of Deliveries	No. of Tours	No. of m³	No. of km	Total Cost in Euro	Total Cost per m³
1	12,537	1,636	57,098	2,428,596	1,933,259 €	33.86 €
2	14,404	2,228	54,425	2,842,586	1,827,962 €	33.59 €
3	14,183	2,072	54,613	2,567,236	1,851,894 €	33.91 €
4	15,198	2,058	52,915	3,273,633	2,243,060 €	42.39 €
5	14,224	2,657	62,782	2,615,047	2,720,429 €	43.33 €
6	14,538	3,183	57,173	4,638,529	3,846,501 €	67.28 €
7	9,525	1,335	27,151	1,834,834	1,614,496 €	59.46 €
8	10,356	1,516	40,755	2,965,591	1,586,899 €	38.94 €
9	8,919	1,242	38,860	2,995,413	1,874,020 €	48.22 €
10	18,129	2,040	51,213	3,360,315	2,320,747 €	45.32 €
11	11,241	2,229	55,454	2,891,681	2,177,823 €	39.27 €
12	7,902	2,483	39,176	1,898,142	1,404,400 €	35.85 €
Total	**151,156**	**24,679**	**591,615**	**34,311,603**	**25,401,490 €**	**42.94 €**

Table 24: Overview of Sample companies’ Monthly In-Put

Overview of Sample Companies' Monthly In-Put in Alphabetical Order						
Sample Company (Alpha-Sort)	No. of Deliveries	No. of Tours	No. of m³	No. of km	Total Cost in Euro	Selected Month
1	957	123	4,021	191,228	146,459 €	January
2	1,108	165	4,219	222,077	138,482 €	February
3	1,178	176	4,708	227,189	159,646 €	March
4	1,256	196	4,992	304,524	203,502 €	April
5	1,377	242	5,227	229,874	162,220 €	May
6	1,142	184	4,235	271,259	176,445 €	June
7	762	87	2,779	196,449	113,537 €	July
8	811	118	4,125	226,381	126,547 €	August
9	1,085	135	4,431	231,306	144,712 €	September
10	1,117	162	4,836	236,143	151,386 €	October
11	1,124	199	5,023	220,739	166,246 €	November
12	901	167	3,822	203,445	106,233 €	December
Total	**12,818**	**1,954**	**52,418**	**2,760,614**	**1,795,415 €**	January

The above tables are meant to show the complexity and divergence of data input and strategy of data collection for this research.

By choosing the above strategy, a sampling of monthly data from different sample companies was affected as described. This decision was based upon the knowledge that different kitchen furniture manufacturers may have different shipment structures in their deliveries and different geographical spreads. The strategy to select firstly the sample companies by their willingness to provide data in the required format and then secondly the completeness of annual data and thirdly by the alphabetical order is the baseline of all further data research in this thesis.

6 Analysis of Results

This chapter describes the simulation with the edited and cleansed data and evaluates its results. The descriptive results illustrate the values before and after the multi-stage simulation.

This chapter provides evidence of the effects that the simulated removal of TWC has on UMTO delivery costs. If, and to what extent, these results may have practical application options will be discussed at a later stage. The investigations in this chapter are concerned first of all with establishing a high optimisation degree to show that DPS, apart from the capability to optimise delivery tours, are also able to create completely computational situations which, in turn, will lead to further discussions and new considerations.

6.1 Descriptive Base Data Analysis

The following descriptive data analysis was undertaken as described in Section 4.3.3: Summary of the applied Simulation Model. In doing so, the following three tables show the descriptive outcome of the simulation. All three tables are in the same format and contain the same key indicators from different perspectives. The perspectives are subdivided in:

1. Analysis per Tour
2. Analysis per Volume in m^3
3. Analysis per Client
4. Analysis per Distance in KM

The summary per table consists of:

1. Number of Clients (for validation purposes only)
2. Number of Tours (for validation purposes only)
3. Total m^3 (for validation purposes only)

4. Total Cost in €
5. Total KM

The choice of the above key indicators has its origin in practical operations. Here, the GKFI measures the performance per tour and the total amount of m^3 per tour, the number of clients served per tour, the total distance in km per tour and the total cost per tour. The same accounts to the other three headings per table. The contents and format of the following three tables was applied in order to return such to the sample companies as a feedback after this research. They do, however, contain relevant information for the objective of this research. These are the total cost per KM, the cost per tour or the total cost per m^3.

The key indicators were used during the analysis process for pure plausibility checks, even though they do not have any linear correlation. However, with the decrease of the number of tours, the increase of distance travelled in KM per tour and the increase in the number of clients per tour must reveal plausibility. With ceteris paribus decreased number of tours the average volume per tour as well as the average number of clients per tour must increase.

6.1.1 Results – Base Data-1

The table below illustrates the consolidated tabular results of all tours in one year. The table is divided in line with observations and costs per tour, per m^3, per client and per kilometre. Its structure is adopted from commonly applied practicality of the GKFI.

Table 25: Original Base Data with TWC

Original Base Data with TWC

Base Data-1 Analysis per Tour			
m^3 per Tour	Clients per Tour	KM per Tour	Ttl Cost per Tour
26.83	6.10	1,413	919
Base Data-1 Analysis per Volume in m^3			
Clients per m^3	Distance per m^3	Tours per m^3	Ttl Cost per m^3
0.164	52.7	0.0373	34.3
Base Data-1 Analysis per Client			
m^3 per Client	Distance per Client (KM)	Tours per Client	Ttl Cost per Client
4.399	231.7	0.16	150.7
Base Data-1 Analysis per Distance in KM			
m^3 per KM	Clients per KM	Tours per KM	Ttl Cost per KM
0.019	0.004	0.0007	0.6504

No. of Clients	11,917
No. of Tours	1,954
Total m^3	52,418
Total Cost €	1,795,415
Total KM	2,760,614

The observation and analysis of the cost related Key Performance Indicators (KPI) is very important. One focal point in this analysis is: how will these KPI change during the course of further data simulation?

Further aspects in this descriptive analysis of base date are the standard deviation analyses and the mean value calculations. With this procedure, in one case the base data was reviewed via the N-valid value with regards to their consistency and completeness (Data Sets Missing) and in the other, the statistical values determined in this table were substantiated. The statistical mean values of all values and standard deviations shown below serve to complement the table above.

Table 26: Description of Base-Data / with TWC

Description of Base Data-1 / with TWC								
	N	Data Sets	Average	Median	Standard	Min.	Max.	Total
	Valid	Missing			Deviation			
Units	1,954	0	71.78	68.50	59.60	0.00	234.00	140,255
Volume in m³	1,954	0	26.83	25.81	22.12	0.00	88.67	52,418
No. of Clients	1,954	0	6.10	5.00	4.44	1.00	25.00	11,917
Kilometres	1,954	0	1,412.80	1,099.20	1,034.74	10.20	4,996.50	2,760,614
Cost in Euro	1,954	0	918.84	740.65	594.17	25.50	3,046.40	1,795,415
Weight	1,954	0	2,502.58	2,349.25	2,054.03	0.00	10,648.86	4,890,046

6.1.2 Results -Base Data-2

The following table 'Original Base Data without TWC' represents Base Data-2 analysis of initial tour data in summary *without* TWC and the table according to the selected variables in relation to the respective cost factors, as in the preceding table.

Table 27: Original Base Data without TWC

Original Base Data without TWC			
Base Data-2 Analysis per Tour			
m³ per Tour	**Clients per Tour**	**KM per Tour**	**Ttl Cost per Tour**
26.83	6.10	1,254	837
Base Data-2 Analysis per Volume in m³			
Clients per m³	**Distance per m³**	**Tours per m³**	**Ttl Cost per m³**
0.227	46.8	0.0373	31.2
Base Data-2 Analysis per Client			
m³ per Client	**Distance per Client (KM)**	**Tours per Client**	**Ttl Cost per Client**
4.399	205.7	0.16	137.2
Base Data-2 Analysis per Distance in KM			
m³ per KM	**Clients per KM**	**Tours per KM**	**Ttl Cost per KM**
0.021	0.005	0.0008	0.6670

No. Clients	**11,917**
No. of Tours	**1954**
Total m³	**52,418**
Total Cost	**1,634,813 €**
Total KM	**2,450,996**

It should be mentioned that the independent variables such as cubic metre per tour etc. have remained almost the same, as the original tours were retained and only the tour order was modified in that succession of deliveries to clients changed through removal of TWC.

It follows from the subsequent comparison of the first two descriptive evaluations that the amount of kilometres was reduced by 11.22% and the total costs decreased by 8.95% through the removal of TWC. What should be mentioned, however, is that through the sole change of order for the deliveries within unchanged tours, a cost reduction of around 8.95% is achievable through the removal of TWC and retention of the so-called fixed delivery windows. This, in today's economic environment, is thought very interesting, yet not significant enough to answer the research question of this thesis.

Table 28: Description of Base Data-2 / without TWC

Description of Base Data-2 / without TWC								
	N	Data Sets	Average	Median	Standard	Min.	Max.	Total
	Valid	Missing			Deviation			
Units	1,954	0	71.78	68.50	59.60	0.00	234.00	140,255
Volume in m³	1,954	0	26.83	25.81	22.12	0.00	88.67	52,418
No. of Clients	1,954	0	6.10	5.00	4.44	1.00	25.00	11,917
Kilometer	1,954	0	1,254.35	1,081.90	775.69	10.20	4,753.80	2,450,996
Cost in Euro	1,954	0	836.65	726.30	472.18	25.50	2,710.80	1,634,813
Weight	1,954	0	2,502.58	2,349.25	2,054.03	0.00	10,648.86	4,890,046

6.1.3 Results - Base Data-3

The results from the final step of simulating the given tours without TWC are the basis to the answer for the research question of this thesis. The result of the base data from the state when it was cleansed until all soft TWC were deleted and all routes where re-structured is shown in the following table.

Table 29: Optimized & Simulated Base Data without TWC

Optimised & Simulated Base Data without TWC

Base Data-3 Analysis per Tour			
m³ per Tour	Clients per Tour	KM per Tour	Ttl Cost per Tour
63.15	14.21	1,878	1,061
Base Data-3 Analysis per Volume in m³			
Clients per m³	Distance per m³	Tours per m³	Ttl Cost per m³
0.225	29.7	0.0158	16.8
Base Data-3 Analysis per Client			
m³ per Client	Distance per Client (KM)	Tours per Client	Ttl Cost per Client
4.443	132.2	0.07	74.6
Base Data-3 Analysis per Distance in KM			
m³ per KM	Clients per KM	Tours per KM	Ttl Cost per KM
0.034	0.008	0.0005	0.5646

No. Clients	**11,917**
No. of Tours	**830**
Total m³	**52,418**
Total Cost €	**880,330**
Total KM	**1,559,107**

This is the descriptive result of the simulation experiment of this thesis, from which all further interpretations and assumptions are concluded. The above Table 29: Optimized & Simulated Base Data without TWC with a total cost of 880,330 € shows a very significant cost saving in comparison to the original cost of 1,795,415 €. The difference is 915,085 € as a result of this entire experiment.

Table 30: Description of Base Data-3 / without TWC Optimised

Description of Base Data-3 / without TWC Optimised

	N	Data Sets	Average	Median	Standard	Min.	Max.	Total
	Valid	Missing			Deviation			
Units	830	0	168.98	165.00	244.09	0.00	4,546.08	140,255
Volume in m³	830	0	63.15	64.64	26.98	0.01	135.85	52,418
No. of Clients	830	0	14.21	14.00	6.21	1.00	38.00	11,797
Kilometre	830	0	1,878.44	1,912.95	695.69	117.60	4,240.60	1,559,107
Cost in Euro	830	0	1,060.64	900.74	437.08	89.69	2,217.60	880,330
Weight	830	0	5,891.62	5,961.38	2,592.65	5.90	14,312.97	4,890,046

Table 30: Description of Base Data-3 / without TWC Optimised delivers the KPI of Base Data-3 in its standard deviation.

6.1.4 Summary and Conclusions

These results prove that the removal of TWC together with re-planning via DPS is able to reduce costs significantly in UMTO distribution logistics. A cost reduction in comparison with the original base data of a total of 50.97% (See Table 31: Sequential Base Data-1 to 3 Comparison) clearly proves a significant cost saving obtained from this experiment.

Table 31: Sequential Base Data-1 to 3 Comparison

Sequential Base Data-1 to 3 Comparison

	Base Data-1	Base Data-2	Base Data-3	Variance1-3	in %
Base Data Totals					
No. Clients	11,917	11,917	11,917	0.00	0.00%
No. of Tours	1954	1954	830	-1,124.00	-57.52%
Total m³	52,418	52,418	52,418	0.20	0.00%
Total Cost	1,795,415	1,634,813	880,330	-915,085	-50.97%
Total KM	2,760,614	2,450,996	1,559,107	-1,201,506	-43.52%
Individual Cost (€)					
per Tour	918.84	836.65	1,060.64	141.80	15.43%
per M³	34.25	31.19	16.79	-17.46	-50.97%
per KM	0.65	0.67	0.56	-0.09	-13.18%
per Client	150.66	137.18	74.62	-76.04	-50.47%

The conclusions from this descriptive analysis are manifold. The most important finding from here is the total cost reduction which provides a definite and positive answer to the research question of this thesis. The simulation in three steps, however, also has other effects. The cost per tour has increased by 15.3% whilst the total number of tours has decreased by 57.2%. The result from here is that the total distance travelled in kilometres per tour has decreased by 53.52%. These results were only possible due to the combination of the removal of TWC and the re-planning of tours. The sole removal of TWC alone did not result in significantly reduced cost. It was the subsequent re-planning of the tours after the TWC-removal which has resulted in the cost savings with such significance that they deliver the positive answer to the research question of this thesis.

6.2 Customer Service Perspective

Until this point a removal of soft TWC and the resulting cost effects have been researched from the manufacturers' perspective only. This section will elaborate how such a removal influences the customers' perspective and what their reactions may be. It will be shown that the cost reduction resulting from optimization without soft TWC is not the only influence on profitability resulting from the alternation. There are also other adverse effects. How the customers' reaction to a shift of demand in setting TWC influences profitability, is reasoned in the following.

The GKFI sells high price products. These high price levels can only be justified by an adequately high quality of the furniture sold and furthermore by accompanying services, which are of interest to the clients. These may include aspects of the order process, the invoicing, the handling or as researched in this thesis, the setting of delivery times. The customers perceive the sum of these accompanying services as the service level.

How the sum of services is perceived, is individual for each client. Each client views the package of accompanying services from his individual perspective. The focus lies on services which are of individual value and importance, while other services may not be perceived at all. However, the latter may be of significant importance for other clients. Regarding the removal of soft TWC, this raises the question, under which conditions a client appreciates soft TWC most and under which conditions they are of minor importance.

Table 32: Degree of Flexibility for Goods Receiving Time Windows

Degree of Flexibility for Goods Receiving Time Windows

Group	Type of Consignee	very low	low	medium	high	very high	service level elasticity of demand
1	Large Regional Depots					X	low
1	Warehouses of large local Stores					X	
1	Medium-sized Retailers with permanently staffed Warehouse				X		
2	Medium-sized Retailers with temporarily staffed Warehouse			X			
2	Small Retailers with temporarily staffed Warehouse		X				
3	Small Retailers with no Warehouse staff	X					
3	Small Retailers with no Warehouse	X					high

In above Table 32: Degree of Flexibility for Goods Receiving Time Windows customers are classified by the type of their warehouse operations. It is assumed that a customer who depends on the setting soft TWC is the least flexible, while a customer who does not receive any extra value from this opportunity, is the most flexible. As indicated in the above table, the highest flexibility with regards to the acceptance of a change in demand for the determination of TWC in GKFI delivery may surely be seen with large regional depots and warehouses of large local stores. For both of them, it can be estimated that their warehouse opening hours and their consequent staffing from Mondays to Fridays 08:00 until 18:00 hours allow a change of demand on TWC. In general, one may conclude that the smaller in logistics operational size and sales turnover a retailer is, the less the flexibility for a change of demand in TWC may be. In some cases the shown flexibility will be less than indicated. Reasons for such a decrease are the following:

- kitchen ordered for installation in a newly built home
- location with legal restrictions regarding heavy vehicle access
- location with difficult traffic conditions during peak hours
- coordination of electrical appliances with furniture delivery

On the very right side of the above table an assumption is sketched how a service level elasticity of demand might develop between these groups. This elasticity reflects the customers' reaction to a variation of the service level. It is defined as the percentage change in demand (client reaction) divided by the percentage variation of service level (supplier action). When calculating such elasticity, it is assumed that only the service level will be varied initially, and that customers only show their reaction in demand. The table supports in estimating the economical importance of the soft TWC for different groups of clients. Group 1 are those customers who operate warehouses which are permanently staffed. They are interested in pre-planning deliveries to their warehouse. For them, pre-announcement of deliveries is important. After the removal of TWC considered in this thesis, deliveries will still be announced and confirmed at least one week in advance. For Group 1 customers, this indicates that they will show only little reaction to the reduced service level. In other terms: before the removal of soft TWC, those firms received a service which did not mean much additional value to them. Their reaction will be comparatively inelastic resulting in only minor changes (reductions) in demand. Group 2 consists of customers who operate only temporarily staffed warehouses. They show interest in pre-planning. Furthermore, some of them are not flexible to receiving deliveries at any time during the day. Consequently, changes in demand from these customers in reaction to the removal of soft TWC will result in a loss of demand, comparatively higher than for Group 1. Service level elasticity of demand for Group 2 customers is higher than for those with permanently staffed warehouses. Group 3 customers operate warehouses without special warehouse staff or no warehouses at all. They are less interested in pre-announcements than in fitting deliveries into their daily schedules between sales, administrative activities and installation works. For them soft TWC may be of high economic interest. Hence, their response to a removal of TWC can be expected to be more elastic than for the first two groups.

Some comments on the measurement of service levels have to be made at this point, before the impact, which the customers' reaction on a variation of service level has on profitability, can be reasoned. The offered service level, as described above, is perceived differently by each customer depending on individual aspects of business operations. The possibility of setting soft TWC is one of many influences on service level. This possibility may be important to some customers and will not interfere with other customers' operations. Thus, it is of positive or no value to the customers and will influence service level positively or not at all. The overall problem lies in the measuring of the service level. Many factors like packaging, handling support, fulfilment rate, error rates, punctuality or invoicing procedures can be identified and the direction of their influence may be possible to reason. Some of them can be measured in percentage rates, while others are of binary character or discrete attributes. This makes the modelling of a service level complex on the customer level and due to the described individual perception, even more so on the aggregate level. Hence, there is no exact measure for the service level incorporated in the above mentioned elasticity. This section's objective is to reason the customers' reaction and the impact that their reaction will have on the profitability of the UMTO. This is reasoned in addition to the significant cost savings, which result from a removal of soft TWC in the experiment of this thesis. From the above, it can be concluded that the direction of the change in demand in response to a variation of soft TWC can be reasoned, even though the service level cannot be determined. Demand is positively correlated with service level while client-set soft TWC have positive influence on service level. Thus, the direction of the response has been reasoned, but the amplitude of such remains unknown. Summarising the before mentioned, the removal of soft TWC will ceteris paribus lead to less demand. The described elasticity is of positive value.

Assuming that the GKFI sell their furniture with a positive profit margin, the reasoned client response will lead to decreased profits. The manufacturers' reactions to this may be reduced prices, other financial compensations or the inclusion of complementary valued services at the existing price. Those possible reactions intend to raise additional demand. Additional services which are possible to offer at no extra cost are not considered here. It is assumed that they had been offered already. Any other additional service will cause extra cost and price reductions will reduce profits. These adverse effects need to be taken into account when discussing how the UMTO profitability will change in reaction to the removal of soft TWC. Since service level is complex to model and to measure, only the direction of the impact can be stated. There are adverse effects on the profitability of a customer, which will at least partially compensate for the achieved cost reduction.

Table 33: Influences on UMTO profitability from TWC removal

Influences on UMTO Profitability from TWC Removal

Effect	Description	Direction
direct effect	cost reduction	+
primary reaction	reduced demand	-
secondary reactions	lower prices additional services raised demand	- - } + +

+ increases profitability, - decreases profitability

The significance of the cost reduction makes a positive overall effect likely. An overview of the described effects and their influence on profitability is given in Table 33: Influences on UMTO profitability from TWC removal. The UMTOs' adjustments on price and service level are concluded as secondary effects together with the raised demand resulting there from. In sum these secondary effects will show positive influence on UMTO profitability. Otherwise those secondary reactions would not be reasonable.

6.3 Sensitivity Analysis

The removal of TWC, as has been shown in this thesis, leads to significantly reduced distribution cost. The simulated removal led to a reduction of distribution cost of 50.97%. This cost reduction is as high that offering a part of this economic advantage to the clients in exchange for the acceptance of the new rules for delivery could facilitate the change. However, this work has only compared two states. On one hand, the TWC set by the clients and on the other hand a situation with totally omitted soft TWC. In order to answer the research question this was sufficient. Further research could focus on the question, how exactly delivery costs react on partial changes of TWC. This thesis's approach only reveals the average gradient between the two levels of TWC restriction. How exactly the cost function would develop with intermediate measures of TWC removal cannot be concluded from this result. Since tour planning becomes far more complex for high levels of TWC restriction, a function similar to the one drawn in Figure 31: Sensitivity Reflections can be assumed. The x-axis shows the degree of TWC-restriction. It is 0% for a situation without any TWC and 100% if every delivery underlies TWC and the time windows are narrow. The y-axis shows cost in percent of cost at 100% TWC restriction. A value of 60% for instance, means that cost at this point ceteris paribus has fallen by 40% compared to the situation of full restriction just by loosening TWC. Incentives which might be necessary to persuade clients into accepting changed time windows are not included in the cost observed here.

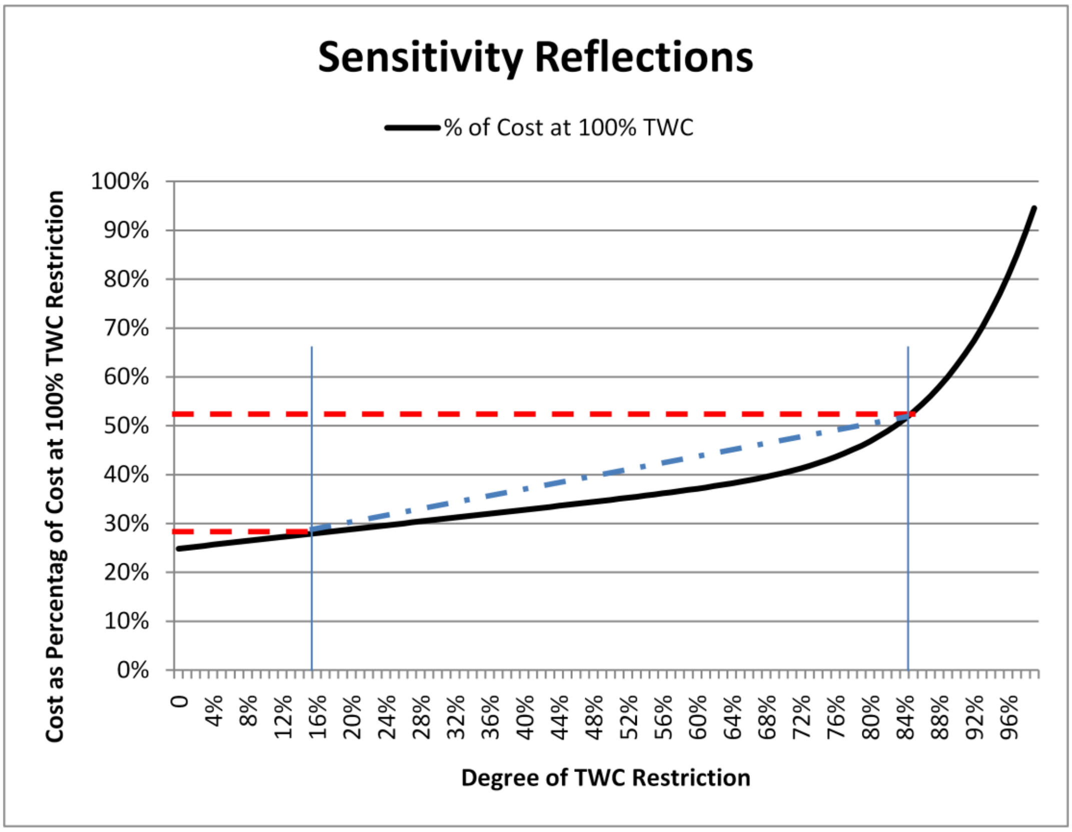

Figure 31: Sensitivity Reflections

In order to understand the assumed dependency, the impact of TWC on tour planning has to be examined. A time window is most restrictive when it is narrow and allows for delivery only in a short span of time. Furthermore, tour planning is more restricted in a situation with time windows set for many deliveries than it is in a situation where only few deliveries underlie TWC. Thus, a degree of 100% TWC restriction reflects a situation where narrow TWC are set for all deliveries. TWC always influence distribution planning. Without TWC, it is not necessary to observe the time of arrival at a client's site. When there are little TWC, it is possible to combine those deliveries which underlie TWC in one tour with others which do not. As a result tours become more costly than the ones planned without the TWC. This is because travelling time and kilometrage when both have been tried to keep as low as possible during planning the tours without TWC, will increase now after re-assembling the tours in a way which was not necessarily considered economic in the situation without TWC. The more clients set TWC, the less possibility for combination with unrestricted deliveries remains. As a result, vehicles wait often because they arrived, or otherwise would arrive, before the assigned time window. Those waiting times further increase cost.

The example in Figure 31: Sensitivity Reflections shows a cost reduction of more than 50% when loosening TWC restriction from 84% to 16%. Taking into account that some clients might require a financial incentive, this is not necessarily the point where the UMTO profits most. The general removal of TWC as analysed in this research does not differentiate between clients who require a small incentive for loosening their TWC, which imposed a strong restriction and those, who are willing to loosen a weak restriction against a large incentive only. Finding the optimal point where delivery cost plus incentives is lowest, requires further research. The exact dependency between TWC and distribution cost has to be clarified and a selection process for time windows worth changing has to be developed.

6.4 Summary and Conclusions of the Data Analysis

Based upon the example of GKFI, one finds that the removal of soft TWC and the restructuring of tours with the help of DPS undoubtedly reduce UMTO costs considerably. The fact that the kilometres to be travelled, the client deliveries and the resulting costs have been attributed the highest effect on total costs is not particularly surprising, but on closer look at the entire analyses procedures, it merits further evaluation and comments.

What emerged from the simulation processes and descriptive analysis as a significant overall result is the clear reduction on costs and heavy drop in total distance travelled. Even though individual routes increased in kilometrage, the total amount of routes was reduced considerably. The change of the latter resulted in the drop of total kilometrage. Therefore, the question is whether this can remain a theoretical assumption or, if it is possible to apply this model in practice? The results in Table 30: Description of Base Data-3 / without TWC Optimised reveal the evidence that the use of a DPS under the theoretical reduction of TWC results in a significant drop of cost (-50.97 %).

The final conclusion from this data analysis chapter is that the achieved cost savings in this experiment do indeed answer the first part of the research question positively. The acquired results warrant the discussion on basis of significant savings. Another contribution to knowledge can be seen in the methodological approach in the experiment and its analysis, whereby existing routes with all their constraints have been exempted from TWC and re-structured. Taking into account that research will reveal ongoing new heuristics for the VRP and for the VRPTW; the open question remains how general constraints in the field of VRP can be avoided.

After the first part of the research question has been answered positively and the hypothesis has been confirmed, the following conclusions will now discuss opportunities and implementation methodologies regarding the second part of the research question.

7 Supporting Environmental Considerations

The supporting environmental considerations deriving from the answering of the research question are described in this chapter. It has been stated, in previous chapters, that they do not have a direct impact or an influence on the results from the analysis of this thesis. However, environmental findings that base upon environmental pollution in terms of CO_2 emissions may be seen of equally important economic significance. This chapter will deal with environmental considerations arising from the experiment of this thesis and discuss them on grounds of most recent research publications. The implied national road toll systems in Germany, the latest theories on the 'Carbon Footprint' subject, current political tax innovation attempts and public concerns of general environmental issues are the basis of this discussion. This chapter will not enter political discussions but will raise thoughts that arise from the experiment in this thesis, according to the results from Chapter 6.1.3 Results - Base Data-3. The reduction in distance travelled in kilometres of 43.52% forms the basis of the following considerations.

7.1 Externalities of Road Transport

An impact on a third party that is not directly involved in the transaction causing the impact is referred to as an externality. In general, there may be positive as well as negative externalities. In the case of road transport, a number of negative externalities can be identified. These are various emissions such as CO_2, NO_x, SO_2, NMVOC, respirable dust and noise as well as land consumption and consumption of other scarce resources, mainly oil. Furthermore, road transport is responsible for accidents and injuries. NMVOC include all volatile carbon hydrides except methane (CH_4) in form of liquid and gaseous carbon hydrides with mostly toxic potential. Their sources are mainly the petroleum industry and chemical solvents. Vehicle engines represent another important source of NMVOC emissions. Examples for NMVOC are Benzene, Ethanol, Acetone or Formaldehyde. The problem of negative externalities is that the price agreed upon between the transaction parties only reflects their cost and preferences while their agreement does not account for the cost and inconvenience experienced by third parties. (Mankiw, 2008) Examples for negative effects from the above externalities are given in Table 34: Road Transport Externalities.

Table 34: Road Transport Externalities

Road Transport Externalities	
Externalities	**Negative Effects**
Emission of	
CO_2	greenhouse gas accelerates global warming
NO_x	direct and indirect cause of health damages, causes acid rain, destroys ozone layer, products of reactions may cause biological mutations
SO_2	causes acid rain, increased clouding causes descreased exposure to sunlight
NMVOC	headaches, tremors, dizziness, chromosomal damages, confusion, unconciousness, DNA strand breaks, various types of cancer, anemia, depression of the immune system, depression of central nervous system
respirable dust	health damages
noise	stress, health damages
Inconveniences	
accidents	injuries, and deaths
traffic conditions	congestions, delays, disturbance
Consumption of	
land	loss of renewable resources, sealing of land with resulting disturbance of waterbalance
oil	loss of fossil resources

As this thesis's objective is not the medical explanation of health issues caused by toxic emissions, Table 34: Road Transport Externalities only states the different externalities' possible causes. However, it has to be mentioned that the demonstrated effects become more likely as an emission's concentration rises.

CO_2 will be the main focus of the following considerations. This is because CO_2 is the only one of the mentioned externalities which is regulated by the Kyoto Protocol and its regulation thus has become a focus of politics across Europe and the entire world. For this thesis it is however important, because one possible way for politicians to influence negative externalities is the introduction of corrective taxes. Possible ways to tax CO_2 emissions in the road transport sector are road tolls depending on the vehicles' emission classifications or taxes per vehicle in accordance to their emission classification. A subsidy for cleaner vehicles would be another alternative. (Mankiw, 2008)

Corrective tax on CO_2 emission, irrespective how exactly it will be arranged, will cause a competitive advantage for those companies which cause less CO_2 emission. Less emission can be achieved either by the use of cleaner vehicles or by the reduction of kilometrage. A way how to achieve the latter has been shown in this thesis.

7.2 Pre-Requisites for Environmental Considerations

This section will introduce statistics from the German Ministry of Transport as pre-requisites to form the basis of the further considerations. Here it will be shown that commercial road traffic is indeed a very significant contribution to environmental pollution and that the CO_2 emissions play an important role in those considerations. It will be further shown that the total kilometrage travelled by commercial vehicles on German roads is one of the significant contributions to the emissions next to the technical specifications of the vehicles. Different perspectives from short and long haul traffic as well as load or weight concerned results will indicate how they have an influence on this subject.

Table 35: Commercial Road Transport in Germany 2007

Commercial Road Transport in Distance Clusters - 2007 (Germany)

	Carriage - in Mln. t				Performance - in Bln. tkm			
Distance in Km	Total	Commercial Transport	In-House Transport	in % of total	Total	Commercial Transport	In-House Transport	in % of total
up tp 50	1,715.5	918.9	796.5		28.0	15.7	12.2	
51 bis 100	390.2	245.5	144.6		28.0	17.7	10.3	
101 bis 150	220.8	153.6	67.2		26.8	18.6	8.1	
1-150	**2,326.4**	**1,318.1**	**1,008.3**	**43%**	**82.7**	**52.0**	**30.7**	**37%**
151 bis 200	145.2	107.3	37.9		24.5	18.0	6.4	
201 bis 250	106.9	85.0	21.9		22.7	18.0	4.7	
251 bis 300	84.6	71.3	13.3		21.9	18.4	3.5	
301 bis 350	67.5	57.8	9.7		20.6	17.5	3.0	
351 bis 400	49.7	43.7	6.0		17.4	15.3	2.1	
401 bis 451	40.7	36.6	4.1		16.1	14.5	1.6	
451 bis 500	34.9	32.0	2.9		15.2	13.9	1.3	
151-500	**529.5**	**433.8**	**95.7**	**18%**	**138.5**	**115.7**	**22.8**	**16%**
501 bis 600	56.4	52.0	4.4		27.8	25.6	2.2	
601 bis 700	34.8	32.6	2.2		19.5	18.2	1.3	
701 bis 800	19.0	17.8	1.2		11.3	10.6	0.8	
801 bis 900	10.0	9.5	0.5		6.2	5.8	0.4	
901 bis 1000	6.2	5.8	0.4		3.7	3.4	0.3	
1001 und meh	17.0	15.9	1.0		10.6	9.7	0.9	
501 plus	**143.3**	**133.5**	**9.7**	**7%**	**79.1**	**73.2**	**5.9**	**7%**
Totals	**2,999.2**	**1,885.4**	**1,113.8**	**37%**	**300.3**	**240.9**	**59.4**	**20%**

1) Commercial road transport vehicles above 6.0 tons total weight

2) Source: German Ministry of Transport, Traffic Data 2008/2009, DVV Media Group, Hamburg

If one looks at the kilometres driven by commercial transport vehicles in Germany as a macro-economic reflection, some important considerations will emerge with regard to the economic statements in the preceding chapters concerned with the implementation considerations. The national average of works own transport amounts to 37%. However, it is noticeable that in closer proximity, that is to say on short haul routes, this share is considerably higher with 43%. This is corroborated by previous statements regarding poor return loads which present a higher cost risk especially on longer distance tours and customer supplies. That makes these transports on their own account a prime challenge for environmental considerations. Table 35: Commercial Road Transport in Germany 2007 above shows three classifications of travelled distances divided into two sections of commercial and in-house transport. This differentiation between in-house transport and commercial transport is undertaken because of the commonly known problems regarding the 'return load factor' and the economic or environmental implications there from. (Gudehus, 2005, McKinnon, 1996) The column in the above table in % of total shows the share of the in-house transport from the total in each distance cluster. Here, it becomes evident that the farther the distances are the fewer shares the in-house transport has in the total distances travelled or loads carried. Reasons for the distinguishing of those two sections will be discussed at a later stage in this section.

What needs to be investigated next is what other challenges from an environmental point of view and how many of them can be associated with this thesis. The following tables and comments are meant to demonstrate the development of environmental measures since 1990, where the concerns for this way of thinking have started not only on a national but also on an international basis.

Table 36: Air Pollution by Type of Emission from 1990-2006 in Germany

Air-Pollution: by Type of Emission [1] from 1990-2006

Emission	Unit	1990	2006	Difference	in %
Co_2	Mln. T.	150	149	1	-0.7%
Dust	kt	62	50	12	-19.4%
No_2	kt	1,141	613	528	-46.3%
So_2	kt	90	1	89	-98.9%
CO	kt	6,527	1,386	5,141	-78.8%

1) = by road traffic only

Source: German Ministry of Transport, 2008, DVV-Media-Group, Hamburg

The above table shows some of the most significant emissions through commercial road transport. Whilst almost all of the relevant harmful emissions have shown a distinct decrease, the CO_2 and fine dust discharge which have hardly changed at all. In line with this observation is the following table which depicts the traffic volume in Germany for almost the same period. From this table, it is apparent that the transport volume in terms of million tons has risen in a comparable period by 23.8%. The symbiosis of both tables leads to the conclusion that, in spite of increased transport volumes, pollutant emission per measuring unit has greatly decreased.

Table 37: Commercial Transport in Germany in Mln. Tons 1990 - 2007

Commercial Transport in Germany in Mln. Tons 1990 - 2007

	Rail	Road [1]	Road [2]	Road [3]	Air [4]	Total
1990	303.7	2,742.9	1,591.4	133.8	1,578.5	8,340.3
2007	361.1	2,999.2	1,113.8	394.7	3,468.8	10,344.6
Difference	57.4	256.3	-477.6	260.9	1,890.3	1,987.3
in %	18.9%	9.3%	-30.0%	195.0%	119.8%	23.8%

1) = by German vehicles
2) = by retail own vehicles or in-house transports
3)= by foreign vehicles
4) = in 1,000 tons

Source: German Ministry of Transport, 2008, DVV-Media-Group, Hamburg

If one then examines how commercial transport has increased mainly due to foreign vehicles, an increase by 195% during the period 1990 – 2007 becomes clearly noticeable. Reflections on a general traffic reduction and the consequences on environmental burden would lead to the conclusion that this would no longer be achievable through national legislation alone – it is a European wide problem.

Another challenge for innovative environmental ideas on the reduction of environmental pollutions, doubtless lies in the vehicles' technical state and the way they are equipped. For the past five years, European statutory provisions have affected many positive trends; however, the increase of transport volume during the period 1990 to 2006-07 has downright nullified the positive trends of technical innovations. A clear attestation to this fact is the prevailing CO_2 burden on our environment. At the same time, pollution through fine dust and organic compounds has dropped enormously. Therefore, that leaves the CO_2 values as the major strain on the environment. Proof of this is provided in the following table.

Table 38: Environmental Pollution in Germany 1990 - 2006

Environmental Pollution in Germany 1990 - 2006

	Unit	1990	2006	Difference	in %
CO_2 Emissions	Mio. t	1,182.53	1,029.14	153.39	-13.0%
All Traffic & Transport	Mio. t	162.46	160.64	1.82	-1.1%
Road Traffic only	Mio. t	150.36	148.88	1.48	-1.0%
Organic Compounds	kt	5,177.44	1,482.59	3,694.85	-71.4%
All Traffic & Transport	kt	1,434.84	143.91	1,290.93	-90.0%
Road Traffic only	kt	1,408.97	133.49	1,275.48	-90.5%
Dust	kt	2,729.91	310.31	2,419.60	-88.6%
All Traffic & Transport	kt	72.04	54.20	17.84	-24.8%
Road Traffic only	kt	61.96	49.94	12.02	-19.4%

1) NMVOC - organic compounds excl. Methane

Source: Ministry of Transport, Verkehr in Zahlen 2008/09, DVV Media group, Hamburg

In summary it can be said, therefore, that the environmental stress caused by traffic – and especially commercial freight traffic – is one of the most challenging issues of our present times.

The acceptance of this challenge is being perceived and handled differently in the different countries of this world. Likewise, political concepts with regards to national agreements and objective targets vary from country to country. It follows then that academic elaborations attempting to answer this challenge must have diverse goals and characteristics. Without wanting to find fault with any of those, it is quite evident that there is a great number of deviating and different representational forms and results within Europe, on a national, political and on an academic research level. For this reason, it was decided not to comment on any of these works.

In the now following observations, it is intended to develop and discuss an approach to conditions on possible environmental considerations of the economic results of this thesis. It lies in the nature of things that such conditions are, to a certain extent, of a purely hypothetical nature. If this were not so, then today the burden on our environment would be much lower already.

A correlation will be made between data from Chapter 6 and data from the above mentioned tables in this section. The latter have identified environmental pollution and data from in-house vehicles as a prerequisite for the further environmental considerations. These considerations will have a similar structure to those in Section 8.4.3 Implementation Scenarios.

The experiment in this thesis has revealed a one-sided result only, by demonstrating the cost savings in favour of the UMTO and to the disadvantage of his clients through a change of set delivery times within one calendar week. That this solution to the problem may only be seen as a purely theoretical one has been discussed in Section 6.2 Customer Service Perspective. From the customer service perspective the removal of TWC in favour of his supplier is a clear reduction in expected service levels. That this reduction of service level is intended to be compensated by a reduction of price or other financial incentives will be discussed in Section 8.4.3 Implementation Scenarios. In case of reductions of service levels one may however expect that some customers will either refuse such or accept them only to certain degree. Reflections on this have been discussed in Section 6.3 Sensitivity Analysis. From this it can be stated that not all clients would agree to the change of demand for TWC, thus leading to a mix of customers per geo-time planning horizon for a UMTO. One solution to answer the question or solve the problem of identifying customers willing to accept the change of demand would be a manual and individual questioning. Here, the financial compensation in favour of the removal of TWC would lead to altered deliveries and altered or only partly repetitive delivery schedules per weekly geo-time delivery. After establishing which customer would accept the TWC removal in return for a financial compensation, those who will refuse such can be identified. From such an intermediate solution against that from this thesis, it may be assumed that the customers with removed TWC will be scheduled for their delivery according to those customers which have not accepted the TWC removal. From this assumption however, it may be assumed further that the reduction of kilometrage and route duration effects will not be the anticipated route and distribution optimization envisaged by a UMTO. Referring however to the highly competitive market situation of the GKFI, the spread of market information on available innovative financial advantages may lead to a certain degree of the ‘Me-too effect’.

Summarizing the possible customer service dimensions one may conclude that the removal of TWC is a solvable task in this industry, provided that the cost arising here from is in no case higher than the financial compensation offered by the UMTO. In this context it may be allowed to refer to a different level of comparability of this problem of customer service dimension from the automotive industry. Here the determination of TWC is in some cases regulated through bi-directional systems interfaces which automatically determine advantages and disadvantages from both sides and find mutually suitable solutions through pre-set algorithms. Those algorithms are based on the bi-lateral cost advantages and disadvantages. However, these decision models always contain a preferential solution in favour of the customer service dimension. In relation to the experiment from this thesis, the total removal of TWC remains a purely theoretical approach. From a practical point of view on this, the customer service dimension always experiences preferential treatment over the optimization interest of a supplier.

In the analysis section a ceteris paribus cost reduction resulting from a complete removal of all soft TWC has been modelled and calculated. A statement regarding the profitability of an implementation needs to take into account the aggregate compensations beside this cost reduction. The balance of these is the resulting change in profitability. From this research it can only be stated that the ceteris paribus variation of TWC leads to a significant cost reduction. The aggregate compensations are not known. Hence, it cannot be concluded how the UMTO’s profitability will change and to what extent the customer service expectations from this can be met.

Set out below and taken from a recent survey are some reflections on environmental awareness of people and managers working in the logistics field. (Straube and Pfohl, 2008) This is to support the hypothesis that, in addition to the economic objectives of logistics and SCM, the environmental importance is hardly of any less importance. Furthermore, the analysis results with regards to the eco-conscious implementation of logistical structures demonstrate that, despite still existing barriers, much progress has already been made for the sake of ‘greener’ logistics. This as well as some other arguments are to furnish evidence that there are sufficient requirements for innovative new concepts, such as those rendered in this thesis.

The following table summarises a 2008 survey by the Bundesvereinigung Logistik e.V. (German Registered Association of Federal Logistics) which shows that environmental changes and their effective range are no longer a fashionable trend, but that they are now a part of a responsible logistic manager’s everyday life. (Straube and Pfohl, 2008)

Table 39: Sustainability of Environmental Implementation in Logistics

Sustainability of Environmental Implementations [1)]

	Sustainable Trend	Fashion Trend
Manufacturing	86%	14%
Retail	95%	5%
Service	91%	9%

1) = in % of all questioned Participants

Source: Bundesvereinigung Logistik e.V., 2008

From this survey, one can identify areas of interest to manufacturing, retail and service industries. Manufacturers will initially be less convinced about the topic of sustainability since these are conveyed to them as additional services predominantly by their customers i.e. retail and service. Retail and service companies however, view sustainability much more strongly, because they also see less risk capital in the future. From that angle, this trend analysis is undoubtedly very interesting and of some significance; nevertheless, the willingness to take risks needs to be interpreted with caution.

The results are also quite different if one takes a look at the ‘driving forces’' in favour of environmental changes in logistics. Here, Government takes the lead, and relevant guidelines are anticipated under its direction which will bring about environmental advantages. At the same time, the companies' own motivation regarding such changes and that of their clients is just as important; however, for them, the issue will unquestionably receive fresh impetus when it comes to the actual changes, as the past has often shown on those occasions of new logistics concepts being introduced.

Table 40: Drivers for Environmental Changes in Logistics

Drivers for Environmental Changes in Logistics [1)]

	Manufacturers	Retail	Service Ind.
Government	71%	48%	66%
Own Motivation	58%	64%	42%
Clients	35%	52%	56%
Employees	13%	14%	11%
OEM	8%	5%	12%
Suppliers	5%	9%	8%

1) = in % of all questioned Participants

Source: Bundesvereinigung Logistik e.V., 2008

The above table is an important documentation of theoretical requirements for the implementation of new environmental aspects in logistics. First of all, it is expected that the government will take the initiative, and that only then will the 'moving forces' act upon their own motivation - and this is where the main problem of companies appears to be, as the following table shows.

Table 41: Missing Tools & Concepts for ‘Green Logistics’

Missing Tools & Concepts for 'Green Logistics' [1]

	Manufacturing	Retail	Service Ind.
Cost & Return Meassurements	61%	45%	47%
Strategic Innovation-Management	46%	33%	51%
Measurement of own Consternation	42%	48%	32%
Measurement of "Carbon Footprint"	35%	39%	33%
Integration of Existing IT	31%	36%	39%
Methodologies & Tools for Implementation	34%	27%	34%
Introduction of CO2 Emission Trade	27%	45%	25%
Standardisation, Certification	13%	30%	18%

1) = in % of all questioned Participants

Source: Bundesvereinigung Logistik e.V., 2008 (adapted)

Operational effectiveness is still hampered by a shortage of suitable tools and lack of concepts, primarily the concepts for the calculation of costs and use. What does become fairly obvious is that the costs in particular can still be looked upon as being a so-called 'black box'. This becomes apparent in various instances, owing to the lack of assessment methods and the absence of green logistics in existing IT systems, such as DPS for UMTO distribution. A substantial factor with regards to absent application procedures and concepts can be found in implementation planning where, to this day, there are still extensive gaps to which, 30% of the investigated companies admitted.

If one, however, looks at the state of implemented environmental measures within the areas of manufacture, industry and retail, it is easily seen from the following table that there is already a variety of initiatives.

Table 42: Implementation of Environmental Measures

Implemented Environmental Measures: Planning & Structures [1]

	yes, highly developed	yes, developed	no, but planned	no & not planned	
Consolidation of Shipments	22%	**61%**	12%	5%	Manufacturing
	33%	**44%**	11%	11%	Retail
Regionalisation of Distribution Structures	6%	**40%**	16%	38%	Manufacturing
	15%	**53%**	3%	26%	Retail
Regionalisation of Procurement Structures	6%	**42%**	15%	36%	Manufacturing
	9%	**41%**	12%	38%	Retail
Consideration of Reverse Logistics	14%	**46%**	21%	18%	Manufacturing
	12%	**42%**	27%	18%	Retail
Plant Localisation	4%	37%	15%	**44%**	Manufacturing
	6%	29%	12%	**53%**	Retail
Horizontal Cooperation with Competitors	5%	16%	25%	**54%**	Manufacturing
	3%	15%	15%	**67%**	Retail
Vertical Cooperation with suppliers & Clients	4%	21%	**72%**	11%	Manufacturing
	5%	18%	**47%**	34%	Retail

1) = in % of all questioned Participants

Source: Bundesvereinigung Logistik e.V., 2008 (adapted)

Both retail and manufacturing have made good progress with the consolidation of consignments. Similar progress has been achieved regarding the regionalisation of distribution structures and procurement. Nowadays, both these developments represent commonly practised structures, and they are closely connected with each other. Yet it should not be forgotten, that at the same time, the regionalisation of depots poses questions for inventory management as this is far more likely to be of less environmental standing in a regional company structure than it might be in a purely centralised organisation. The question about the development of reverse logistics has, without doubt, a strong German character. Here, the implementation of environmental concepts is far above global standards. They offer rather less freedom of development as such actions are usually associated with high investments.

Finally, the horizontal co-operation with competitors and the vertical co-operation with customers or suppliers need to be investigated. To this day, the former has only very little implementation opportunities as many companies trade in a global market, thus making them part of predatory competition. The vertical cooperation types have greater environmental implementation opportunities by far as for years retail business has been the acknowledged front runner in initiating such implementations. Manufacturing industry has been directly responsible for the operational side.

Looking at the above prerequisites for the implementation of experimental results from this thesis, the following can be ascertained:

1. The sustainability and importance of environmental orientated structures and concepts in logistics are no longer a fashionable trend. They are a primary ingredient in organisational strategies.
2. Many companies see the government as the leader of all initiations for innovative environmental structures. Their own motivation takes second place only.
3. The main obstacles in the way of immediate environmental orientation are the lack of measuring instruments for sustainability, calculation of cost-benefit-ratio, integration into existing IT systems and a general methodological approach.

Final considerations in the contents of this subsection are listed in Table 43: Implementation of Planning Tools & Environmental IT. They state the following conclusions:

1. The implementation of general transport is already very popular and advanced in almost a third of the companies investigated. The manufacturing industry has taken on the role of forerunner.
2. The environmental process orientation in logistics is yet underdeveloped. The reason for this is that often there are no KPI and appropriate control measures.
3. The implementation of DPS and general telemetric systems is still very much in its infancy. Only 8% of manufacturers and 3% of retailers operate well developed IT systems.

These findings confirm the significance of this thesis. It is apparent that many companies begin to develop environmental awareness regarding innovative distribution planning only with the imposition of governmental guidelines. Furthermore, it is evident that currently there is not enough knowledge about the field of application for DPS. In order to counteract these shortages, the following examples for the implementation of environmental implementation considerations are intended to make a new contribution and to support new discussions actively.

Table 43: Implementation of Planning Tools & Environmental IT

Implementation of Planning Tools & Environmetal IT [1)]

	yes, highly developed	yes, developed	no, but planned	no & not planned	
Transport Optimisation	26%	**53%**	10%	11%	Manufacturing
	31%	21%	32%	**41%**	Retail
Environmental Process Optimisation	7%	31%	**33%**	**30%**	Manufacturing
	6%	21%	**32%**	**41%**	Retail
Environmental Controlling & KPI's	5%	25%	25%	**45%**	Manufacturing
	3%	9%	36%	**52%**	Retail
Use of DPS, GPS & Simulation Tools	8%	19%	14%	**59%**	Manufacturing
	3%	19%	16%	**63%**	Retail
Carbon Footprint Checks on Process Levels	5%	8%	23%	**65%**	Manufacturing
	3%	25%	6%	**72%**	Retail

1) = in % of all questioned Participants

Source: Bundesvereinigung Logistik e.V., 2008

The above considerations reflect the significance for innovation of environmental considerations in logistics and in SCM. The question on how this relates to the findings of this thesis will be answered in the following subsection. Here the following findings from above will be included to (1) convert the kilometrage savings from the experiment into CO_2 emission reduction results, (2) apply the CO_2 reduction to the overall national in-house transport and (3) indicate the savings resulting to the total national CO_2 output.

7.3 Implications of Environmental Considerations

The prerequisites of environmental considerations from the previous section are derived from thinking about the implications of the economic finding of this thesis. The findings from the preceding subsection have stated that currently there is no coherent approach to the operational reduction of environmental pollution in logistics and in SCM. The latter defends the approach and methodology in the following. With this, the results concerning in-house transports and their characteristics in Germany play a particular role as it still has a share of 37% in overall commercial road freight traffic.

Table 44: Industry Related Co_2 Model Conclusions

Industry Related CO_2 Model Conclusions

	Base Data-1	Base Data-3	Variance 1-3	GKFI Industry	
Base Data Totals				96 Manufaturers	Incl. empty returns
Kilometrage	2,760,614	1,559,107	**-1,201,507**	**-115,344,672**	**-173,017,008**
CO_2 Emission in Tons	2,153	1,216	-937	**-89,969**	**-134,953**

The findings in Section 6.1.3 Results - Base Data-3 and the comparison against the data from Base Data-1 are described in the column of Variance 1-3. It includes the results of simulated data from the experimental approach of this thesis, and column 96 Manufacturers shows the extrapolation from 96 companies taken from the entire GKFI. In column incl. empty returns, the sum of all kitchen furniture manufacturers is multiplied by a factor of 1.5, taking into account empty return journeys. For the calculation of CO_2 emission, the average of CO_2 release per truck of class Euro 3-4 was set at 0.780 kg/km as a very conservative approach.

Deriving from the experimental sample of one GKFI in this thesis, the CO_2 emission was reduced by 937 tons, for the entire GKFI industry with 96 participants this amounts to 89,969 tons and considering the suboptimal usage of vehicle capacity and the empty return loads, the savings amount to 134,953 tons. This is the central message of implied environmental considerations of this subsection.

It is self-evident that there are a number of critical imponderables with this approach. The above example is just one of many considerations about how to consider CO_2 emissions critically and how to apply very basic and simple contemplations on their reduction.

In the following, an explanation of how the results of these considerations could affect the overall CO_2 emissions in Germany is required. This is illustrated by the following (Table 45: : Experimental Repercussions on total CO2 Emissions in Germany). The statistics of the Federal Ministry of Transport have served as key calculation parameters, as listed above.

Even though these calculations and the generalisability of data from the experiment in this thesis are a risky basis for these considerations (Bryman and Bell, 2003), the results of this methodology intend to state a message rather than explicit and generalisable results. At this point it must be reiterated again that there is unquestionably a plethora of other methods for the calculation of CO_2 reduction.

Table 45: Experimental Repercussions on total CO_2 Emissions in Germany

Experimental Repercussions on total CO_2 Emissions in Germany		
2006	CO_2 in Mln. Tons	in % of Germany Total
Co_2 Emission in Germany Total	1029.14	100%
by all Road Traffic	160.64	15.61%
by all Commercial Road Traffic	148.88	14.47%
By Inhouse Transport	55.09	5.35%
Results from this Experiment	**0.135**	**0.013%**
Potentials by In-House Transport	**24.24**	**2.36%**

The above table orientates itself on the total national CO_2 emissions in 2008. The share of the in-house transport is 5.35% and that of the GKFI 0.013%. If the kilometrage savings from the experiment in this thesis was applied to the entire national in-house transport than the potential of 24.24 million tons of CO_2 emission is envisaged. The mere finding that this could reduce the entire national CO_2 output by 2.36% makes this an interesting opportunity. However, such a focus would be questionable due to the absence of data of the Euro emission standards of the vehicles used by the sample companies. Since this vital data was not available, it was not possible to model the above savings in pollutant emissions correctly for the sample. This is why, the experimental repercussions in Table 45: : Experimental Repercussions on total CO2 Emissions in Germany are of purely hypothetical nature, but surely worthwhile further research in this area.

If the parameters of the overall German works traffic were indeed based on the parameters of vehicle assignments in this experiment, then these results would be of high interest. However, the comparison of distances to be travelled from Table 64, Commercial Road Transport in Germany 2007 and Table 40, Description of base data 3 / without TWC Optimised shows that this theory is not fully tenable. On the basis of data used in this experiment, the average route came to 659 kilometres; the statistics of the Federal Office for Transport showed an average route of less than 50 kilometres. This would always make the savings potential of 24.24 million tons CO_2 contestable, and in actual fact, invalid. On the other hand, the potential of 135,000 tons or 0.013% of the overall German CO_2 emission which is the outcome of this experiment is hardly challengeable.

Considering the above findings and knowing that the CO_2 emissions on short haul transport are inevitably higher than they are on the long hauls, the statement of non generalisability of this thesis's results is still upheld, but it raises justified positive concerns on the considerations stated herewith.

7.4 Considerations on other Freight Transport Externalities

When looking at the environmental aspects from the experiment in this thesis, it is not only CO_2 that deserves a specific mention. Other freight transport externalities are stated in Table 34: Road Transport Externalities. In the following, it will be discussed which impact this thesis's results may have on such other freight transport externalities. Here, some of the mentioned road transport externalities from this table deserve more detailed explanations.

At first, the negative effects of NO_x and SO_2 have proven influences on direct and indirect cause of health damages, acid rain, destruction of ozone layer and reactions with them producing substances that may cause biological mutations. As an exemplary description of the before mentioned, the following table aims to demonstrate to what extend those road transport externalities may be reduced on the basis of this thesis's findings.

Table 46: Other Exhaust Pollutants

Other Exhaust Pollutants

2001	NO_x in kt	SO_2 in Tons	NMVOC in kt
Total Emissions in Germany *)	1,541	631,050	1,594
by all Road Traffic *)	742	16,084	256
by all Commercial Road Traffic	334	8,008	62
By In-House Transport	123.6	2,963.0	22.9
Results from this Experiment	**0.3**	**7.3**	**0.1**
Potentials by In-House Transport	**54.4**	**1,303.7**	**10.1**
in % of Total German Emission	**3.5%**	**0.2%**	**0.6%**

*) Source: Federal Bureau of Statistics, Wiesbaden, 2005

Given the total emissions of NO_x, SO_2 and NMVOC as a national total and shares by all road traffic and commercial road traffic, the shares resulting from the in-house transport were calculated on comparable basis to the previous calculations on CO_2 and the economic results in this thesis. From this, the results of this experiment show that the NO_x externalities could be reduced by 0.3 kt, and if they were to be transferred to the entire German in-house transport by 54.4 kt; resulting in a total national NO_x reduction by 3.5% of the total. The total national reduction of SO_2 results in 0.2% and that of NMVOC in 0.6% of the total.

This hypothetical approach may surely be criticized due to the large number of imponderables associated with the in-house road transport. The assumption that a linear reduction of those negative externalities can be achieved by the reduction of kilometrage in this thesis is surely questionable. Even though, the above total national reductions do not state correct, reliable and robust results, they tend to indicate possible directions for reducing such negative externalities from road freight transport.

Similar to the above approach, one may look at the road transport externalities of accidents with injuries and deaths. The following Table 47: : Road Accidents in Germany 2000-2007 provides the statistical overview of road accidents in Germany for that time span with injuries and deaths totals per billion vehicle km. Table 48: Road Transport Externalities - Injuries & Deaths refers to the total kilometrage driven by commercial vehicles exceeding 3.5 tons of total weight for 2007. The share of in-house transport represents 37% of all commercial road transport, statistically affecting a total of 17,900 accidents with injuries and 205 deaths. The result of this experiment in relation to the road transport externalities of accidents with injuries and deaths leads to a reduction of injuries of 43.9 and deaths of 0.5 for the sample companies alone. If one would transfer this result linearly to the entire German volume of in-house transport, then this would result in a reduction of injuries of 7,876 and deaths of 90.3 for 2007.

Table 47: Road Accidents in Germany 2000-2007

Road Accidents in Germany 2000 - 2007

	Accidents with Injuries per Billion Vehicle*1) KM		Accidents Death Total per Billion Vehicle KM	
	All Roads in Total	Motorways only	All Roads in Total	Motorways only
2000	577	126	11	4
2001	550	126	10	4
2002	530	118	10	4
2003	520	107	10	4
2004	487	100	8	3
2005	492	98	8	3
2006	477	93	7	3
2007	485	91	7	3

*1) = all private & commercial Vehicles, incl. Bicycles

Source: Ministry of Transport, 2009 Federal Traffic Statistics, p.167

Table 48: Road Transport Externalities - Injuries & Deaths

Road Transport Externalities - Injuries and Deaths

2007	Injuries in Road Traffic	Deaths in Road Traffic
Total in Germany *)	431,419	4,949
by all Commercial Road Traffic *)	48,379	555
By In-House Transport	17,900	205.3
Results from this Experiment	**43.9**	**0.5**
Potentials by In-House Transport	**7,876.1**	**90.3**
in % of Total	**1.83%**	**1.83%**

*) Source: Ministry of Transport, DVV Media Group, Hamburg, 2009

The above considerations with a linear application of the results from the removal of TWC and the consequent reduction of kilometrage are of purely hypothetical nature. Hypothetical, because this approach assumes that the traffic involvement of in-house transport vehicles is equal to all other traffic participants, at all times and under all conditions. That this is not the case is obvious. Commercial vehicles operate under conditions which are not comparable to those of passenger vehicles at all due to their weight, size, maneuverability, speed, daily operating hours and many others. However, such a linear comparison indicates how realistic possible impacts from those road transport externalities could be viewed. This view however, requires substantial and adequate new research to achieve validity and recognizable substance that the above mentioned can only indicate.

The above road transport externalities do not imply the reduction of distribution cost of a UMTO as a direct result from the removal of TWC. Pollutants and inconveniences do not yet have direct economic consequences as a result of the reduction of kilometrage. However, the reduction of kilometrage brings with it the direct reduction of diesel consumption and thereby contributes to the overall reduction of pollutants and inconveniences. The reduction of total distance travelled results in less traffic participation and consequently this may lead to fewer accidents with injuries and deaths. This thesis has proved that the removal of TWC has resulted in significant cost savings. A robust economic imperative resulting from a reduction of other road transport externalities cannot be measured exactly and scientifically from the experiment in this thesis. Yet, those imperatives are worth further research in this area.

7.5 Conclusions and Summary

The summary and conclusions of this subsection are summarized in the following. Here, besides the findings from the impacts of a possible CO_2 reduction, the thoughts on further impacts from other road transport externalities are concluded.

1. The CO_2 reduction in this experiment is 0.013% of the overall German CO_2 emissions; provided the vehicles in the experiment are in-house vehicles and return back to their depot empty. In this case it was assumed that the vehicle's fill rate was at 80% only. The fill rate of the vehicles in this experiment was below 70%.
2. The CO_2 savings in Germany could be as much as 2.35% if the experimental results were to be transferred to the overall German in-house transport with supplement conditions as above. This result is however a questionable, due to the missing data on Euro emission standards of the trucks used by the sample companies.
3. In the event of an environmental validity of these results, this would be a major contribution for the recognition and implementation of the economic results arrived at in Section 6.1.3 Results - Base Data-3.
4. In the future, the German government is expected to issue statutory provisions for the reduction of CO_2. Corresponding polls

have made it clear that this is most likely achieved with the help of appropriate IT systems, such as those used in this experiment.

5. It was previously stated in this thesis that the environmental findings in this thesis may have economic influence on the results of this thesis. Presuming that the tariffs of the German Road Toll System (Toll Collect) will be increased in the future based upon the CO_2 emission of vehicles, then the environmental findings of this thesis have indeed made a valid contribution to the results from this experiment.
6. Provided that the results from the focus on the other road transport externalities such as NOx, SO2 and NMVOC are indeed applicable to the removal of TWC in this experiment and provide small portions of generalisability, then the approach chosen in this thesis deserves further research to substantiate those findings.
7. The thoughts developed from the findings of applying the reduction of kilometrage to a linear reduction of accidents with injuries and deaths are probably the most worthwhile initiations for further research in this area. It has become obvious that there is a correlation between a reduction of kilometrage and there from a reduction of vehicles on tour and a reduction of accidents. Concluding from this, it may be said that further substantiations of answers to the questions about such a correlation are worthwhile investigating.

Finally, there still remains one crucial point: this concerns the question of the initiation of environmental logistics and SCM structures. Table 40: Drivers for Environmental Changes in Logistics has confirmed that, first of all, it is government which has to meet this challenge. The German Federal Government has already responded to this statement in the private passenger car section, it has established a new law which came into effect on 1 September 2009, stating that from this date, all newly registered cars will no longer be taxed according to engine sizes but depending on their respective CO_2 emissions.

What would happen if an identical procedure would also be applied to all commercial transport vehicles? Would this not bring about a completely new way of thinking in favour of the hypotheses established in this chapter? Would it not be possible to arrange for an environmental charge via adequate telemetric systems such as the German Toll Collect System and thus compel the companies to rethink their actions? That would almost certainly make this thesis’s environmental hypotheses more than a mere theoretical thought. In view of an only theoretical reduction of the overall German CO_2 output by commercial in-house transport to the extent of 2.36%, this might well be a laudable starting point for further discussions and considerations.

8 Conclusions

Prior to discussing the results from this thesis, one must look at the meaningfulness of the transformation of such findings from simulation to their practical applicability, transferability and even their generalisability in knowledge. Here, the concerns of researchers differ to some extent. (Fu, 2002) One major criticism in research using optimisation and simulation systems is quoted as follows:

> *Optimization via simulation adds an additional complication because the performance of a particular design cannot be evaluated exactly, but instead must be estimated. Because we have estimates, it may not be possible to conclusively determine if one design is better than another, frustrating optimization algorithms that try to move in improving directions. In principle, one can eliminate this complication by making so many replications, or such long runs, at each design point that the performance estimate has essentially no variance. In practice, this could mean that very few alternative designs will be explored due to the time required to simulate each one*. (Banks, 1998, pp.3-4)

The results of this analysis however, have brought to light significant findings. Certainly, they could be improved much more by referring to the above quote of Banks (1998). The answer to the research question was satisfied with a total of two phases of simulation application. By doing so, the further assumptions were made and validated on the findings of a so called: ‘optimized’ status, knowing that further optimization could have been undertaken with further data simulation, particularly in Base Data-3. The findings acquired in this thesis have satisfied to the extent that they show practically meaningful solutions to the hypothesis.

From this potential criticism of Banks (1998) derives the general acceptance of critical reasoning for any optimization via simulation. This thesis however, avoids this criticism and refers to optimization not to the extent of merely finding the optimal mathematical solution of the re-routing of vehicles via simulation and the consequent mathematical best solution for the reduction of kilometrage. This thesis’s methodological approach of optimizing delivery vehicles routes after the removal of TWC in a UMTO environment aims to identify possible savings of kilometrage and time as general economic findings in favor of a change from existing exogenous to theoretical endogenous decision parameters in the distribution-production problem with TWC and hereby attempts to stand aside from the critique raised by Banks (1998).

That TWC is or are the driving force in co-relation with local temporary traffic conditions and that TWC as fixed time margins de-optimize vehicle routing from a time, cost and TSP point of view, was stated by Gietz (1994). This author however, did not consider them as being removable and did not simulate their removal, measuring the X – Y of simulated distributions according to Poe (1994). The latter's applied methodology of a *"comparison of the experimental or treatment group against the control group"* is what this thesis has implied by referring to the findings from Gietz (1994) and identified the cost of those (soft) fixed time margins. This leads the introductions in this concluding chapter to a three-folded subdivision of conclusions on (1) the contribution to theoretical knowledge about the application of simulations in an experimental research design for the general VRPTW, (2) the contribution to the existing literature on the VRPTW, the use of simulation in it, the approach of removing TWC and measuring those effects economically as well as referring to them from an environmental point of view and (3) the contribution to knowledge from actual results of the experiment to practical application possibilities. Here, the possible transferability and the generalisability of the results will be discussed and argued critically. By doing this, this concluding chapter will discuss the findings from this thesis by transferring those findings to possible other industries and draw conclusions of how they may be generalised. Through this, it may become evident, that the achieved cost reduction from this thesis's experiment and the parallel environmental aspects may be compressed in an ideological framework for general approaches in the production-distribution problem of the VRPTW and even beyond this. The last sections and their subsections of this concluding chapter will then focus on the practical implications and the general production-distribution practice in the UMTO environment.

8.1 Contribution to theoretical Knowledge

The theory underlying this thesis is that the removal of TWC with the application of DPS in the distribution logistics of UMTO reduces the cost of delivery significantly. That TWC are the driving forces in co-relation with temporary and local traffic conditions for the use of DPS, in order to achieve improved vehicle routing, has been stated by Gietz (1994). Rushton et al. (2000) and Toth and Vigo (2002) refer to TWC as so called hard time windows, which specify a particular latest date and time of delivery, but they do not consider them as removable constraints and do not consider a change of such from the point of view of a manufacturer as endogenous determining factors for the production-distribution problem. These authors see TWC as given and describe them as being cost drivers in distribution. How much cost arises from the existence of TWC, they do not mention in their works. This is where this thesis has contributed to new theoretical knowledge, by simulating their removal and calculating the actual cost of TWC in comparison to their existence from the captured primary data cost calculations. This methodology of calculation of the costliness of TWC in the UMTO environment is a new contribution to knowledge.

From the above one may say that TWC in logistics distribution operations have been generally known as cost drivers from past research. This is why a number of publications concentrate on new search algorithms in the field of VRPTW in the attempt to improve vehicle routing and reduce route duration (Pachnicke, 2007, Cordeau et al., 2002b) Their comparisons of a multitude of new search algorithms state that all attempts to solve this VRPTW accept TWC as being irremovable constraints. This is where this thesis has chosen a different approach and actually demonstrated that by removing TWC, significant cost savings can be achieved in theory. This theoretical contribution to knowledge however, relates to the assumption that a removal of TWC incorporates the general acceptance from the customers. This acceptance is an assumption which relates to the given contractual agreement between the UMTO in the GKFI and their clients that states a single calendar week for delivery. Thus, by adhering to this agreement, the customer requirements and thereby the quality in agreed delivery are being adhered to in the theory of this thesis. However, this is not the case in real practice. The purely theoretical approach chosen in this thesis does not stand up for real life implications. The discussion on this in Section 6.2: Customer Service Perspective shows that the degree of flexibility for the acceptance of a change of demand on the determination of TWC is indeed a questionable imponderable. Those imponderables can be explained from service level elasticity of demand.

Using a simulation based DPS to create an almost TWC free distribution, thereby reducing travelled distance and minimising route duration, is what Poe (1994) has referred to with his findings in measuring the difference (X-Y) of simulated distributions. Here, this thesis has built upon that existing methodological knowledge and has applied it by measuring the difference between Base Data-1 and Base Date-3 through methodologically creating a simulated soft TWC free delivery. Combining this knowledge from Poe (1994) with simulated distributions in logistics and applying it to that of the costliness of TWC in distribution logistics of Gietz (1994) is what demonstrates the core of new knowledge contribution in this thesis from a methodological point of view.

The outlook resulting from the before mentioned combination of Gietz (1994) and Poe (1994) defines this thesis's main contribution to knowledge in this environment of simulation application in distribution logistics. Here, some researchers have already paved this way by stating that the use of simulation in experimental research for the optimisation in SCM related problem solving areas is not yet fully explored. (Terzi and Cavalieri, 2004, Chang and Makatsoris, 2001, Kleijnen et al., 2005) Here, this thesis contributes to new knowledge through the questioning of existing constraints by simulating their removal and identifying the constraints' cost with an evaluation of the possibilities towards their removal to a minimum. The discussion of the influence from the customers' perspective is an additional feature worth further exploration. This thesis employs service level elasticity of demand and price elasticity of demand when reasoning customer reactions. (See Section 6.2 Customer Service Perspective) This is where further research could take place, through an in-depth measuring of the acceptance of the TWC removal from a customer's perspective and draw further analytical conclusions from it. Such analytical conclusions could be based on the results from the experimental route simulation with the removal of TWC which have resulted in more than 50% savings in the cost of distribution. That these cost savings may result in a 3-5% reduction of total production cost or price of goods sold is even more significant. If one would now identify further constraints that de-optimize distribution logistics and commercial transport for distribution (and also for the combined delivery – pick –up problem) and analyse such in a comparative experimental research using simulation, this would contribute to new knowledge in the field of distribution logistics and SCM. Some of those constraints could be the capacity restrictions of vehicles (new technologies for maximum use of vehicle capacity and changed legislations), the removal of hard (or fixed) time windows in delivery, the determination of loading and unloading times during day – peak times, resulting in general traffic participation of commercial vehicles in mostly congested traffic conditions. Such constraints as well as possible others, could be investigated through simulating theoretically optimized conditions for distribution logistics, neglecting the customer constraints in a first stage, but trying to achieve a theoretically best possible result from a transport operator's point of view. By doing this, one could simulate business opportunities that are ideal in terms of transport operation and also in terms of environmental aspects. The simulated scenarios would then most certainly need to be evaluated through risk assessments covering the possible customer constraints and possible other externalities arising there from as the second step. The discussion of the pros and cons of such simulated experiments may certainly lead towards new contributions to knowledge for the sustainability of commercial road transport and new competitive advantages in distribution logistics.

Additional contributions to knowledge from this thesis are the environmental results. Here, with the specific focus on the in-house transport structures, the results from this analysis have indicated that not only a reduction of CO_2 of 135,000 tons resulting from the experiment in this thesis, but also a reduction of NO_x, SO_2 and NMVOC, as some of the other pollutants, are of significance.

Transferring the theoretical implication from this thesis to the other road transport externalities of road accidents with injuries and deaths is another contribution to existing knowledge. Even though the transferability from this thesis's finding of a 44% kilometres reduction of in-house transport from the chosen sample to other industries is questionable, the indications from this may lead to new research with more substantiality that is very much worthwhile. The possible reduction of 0.5 deaths and 43.5 less persons injured through the reduction of 44% less kilometrage from in-house transport in the GKFI sample of this thesis is an indicative opportunity for the attractiveness of research in this field. This opportunity is corroborated by the potential reduction of 17,900 injuries and 205 deaths from road accidents in Germany, 2007. (See: Table 48: Road Transport Externalities - Injuries & Deaths)

8.2 Contribution to Literature

The historical development of research on the TSP has lead to the VRP in general and to the VRPTW with dynamic planning. (Bowersox, 2008) Numerous publications on the VRPTW have been established in the past 30 years, making this field of research one of the most investigated problems in logistics and neighbouring SCM fields. (Table 8: : Overview & Classification of Publications on the VRPTW)

When looking at the existing literature, one finds that the majority of publications focus on the improvements of algorithms for the combinatorial minimisation of route duration and the reduction of distance travelled under given constraints of TWC. (Cordeau et al., 2002a, Toth and Vigo, 2002) These authors deliver overviews on the VRP with time windows which form the basis, where this thesis's contribution to literature relates to. Firstly this thesis does not offer any new algorithms for the VRPTW problem solving, but removes the TWC to an absolute minimum. Secondly, this thesis builds upon the findings from Gietz (1994) and states the exact cost of TWC from the example of UMTO deliveries, applying the X-Y=Z methodology proposed by Poe (1994). It is this 'Z' that is used for the interpretation of the results from this experimental research and its stratified sample, to conclude possible savings in distribution logistics for UMTO and to transfer them to a measurable model of environmental impacts.

Here, the closest findings in the existing literature are that, which have investigated retailers' sensitivity to local sustainability policies. (Quak and De Koster, 2007) Their investigations on such local policies show a similar approach to what this thesis has demonstrated, but no removal of such policies was simulated to the extent that the X-Y=Z result was investigated, measured and lead to conclusions there from.

Summarising from the above, one may say that the contribution to literature from this thesis is of a combinatorial nature. Using simulation with highly developed algorithms for the minimisation of route duration and calculating shortest kilometrage in an experimental research in logistics is a first combinatorial approach. (Terzi and Cavalieri, 2004, Umeda and Zhang, 2006, Kleijnen et al., 2005) By doing this, this thesis has aimed to counter these authors' criticism of the lack of existing research using simulation in experiments. Combining this fairly novel approach with the removal of TWC represents another contribution to existing literature. This combination of two novel contributions was added with the calculation of the X-Y=Z from Base Data-1 to Base Data-3 (Poe et al., 1994, Rosenfield et al., 1985) and led to the analysis of the significance of cost of distribution for UMTO and confirming previous findings (Christopher, 1999, Lakshmanan et al., 2001, Cukrowski and Fischer, 2000) in logistics research. Thus, by identifying the significance of possible savings, confirmed those authors' findings about the importance of research on the cost of distribution.

This thesis has further filled a gap by adding knowledge to the literature with its results from applying DPS in an uncommon methodology and achieving results with great significance for the UMTO and VRPTW community. This contribution may lead to further discussions on comparative analysis of the cost from the removal of TWC from the retailers' side. As this work in all its simulation stages, has maintained the originally promised delivery of the UMTO within a specific calendar week, but has only changed the soft time windows of days and times within the promised calendar week, this thesis's contribution to knowledge may form a new approach to the CVRPTWC and the production – distribution problem according to Park (2005).

A second, but no less important resume on the findings from this thesis as a new contribution to literature, are the transformations from the economic findings to possible environmental aspects. Here, this thesis adds a direct contribution to knowledge for green value chain practises in the furniture industry. (Handfield et al., 1997) The findings from these authors have clearly identified the distribution on furniture manufacturing as an environmentally-friendly practice in their research. In this context, the contribution of this thesis to the existing literature of Handfield et al. (1997) is that the X-Y=Z results were directly transferred to environmental impacts. That is however, a highly questionable approach as was shown in Section 7.5: Conclusions and Summary. Yet, such an application requires more accuracy and a more substantiated approach. However, the chosen approach of embedding a simulation in this thesis's experiment of removing all soft TWC for a sector indicates a possible significant reduction of commercial road traffic in Germany. This is calculated to be 16%. The calculation is based on the observed reduction of in-house transport for the sample companies of 44% and the share of all in-house transport in commercial transport in Germany. Even though the exact size of the calculated reduction may be questionable, it indicates valuable possibilities for future research which have not been given appropriate emphasis before. This represents a contribution to the existing literature in logistics and SCM research.

8.3 Transferability and Generalisability

Prior to looking at the two concepts, one needs to distinguish both from each other. The transferability of findings in the context of this thesis is restricted to transferring the results from this research to other related single industries in the furniture industry or other sectors of other industries i.e. the manufacturing of upholstery, the manufacturing of bedroom furniture or the manufacturing of office furniture. The generalisability however would imply the application of this research to the entire furniture industry or other industries.

Now looking at the transferability of the research results one may indeed draw parallels and conclusions to other related manufacturing in the furniture industry. Here for example, some other furniture manufacturers, as mentioned above, have similar production-distribution methodologies. The upholstery manufacturers for example, mostly are required by their clients to deliver their goods with two drivers, have an indeed comparable structure of clients to that of the GKFI and comparable handling structures of the goods for distribution requirements. This industry of upholstery manufacturing has a total market share measured in sales revenues in the entire German furniture industry of 14% compared to the GKFI with 22%. (Reinbender, 2008) Looking at the production-distribution problem of the entire bedroom furniture industry as another transferable focus for the application of the results from this research, one needs to differentiate such. Here, this business incorporates the manufacturing of mattresses besides the actual wooden products such as beds, cupboards, wardrobes and closets. These products undergo similar distribution conditions to those from the GKFI but are traditionally delivered with only one driver. Hence, the underlying cost function of this thesis would require to be adjusted accordingly, same as some other cost function conditions. Those could well be the actual cost for the delivery vehicle and the fuel consumption, due to heavier loads. In general however, the bedroom industry that represents a total share of 9% of all German furniture sales has comparable structures to the GKFI and therefore might well have acceptable transferability conditions.

If one now looks at the entire German furniture industry, one might tend to generalize the applicability of the solution from the problem of the production distribution from this thesis and the results from the experimental research herein. However this must be refuted from a UMTO perspective. As only a share of 67% of all manufactures in the entire German furniture industry classify for the typology of UMTO, the remainders do not. (Reinbender, 2008) Their distribution logistics methodologies incorporate intermediate storage, consolidation of shipments, non-specialised vehicles. Their production schemes include large shares of serial production and production to stock. In addition, there is no reliable information at this point in time, how much of the sales generated by those 67% are indeed associated with the distribution-production problem underlying this thesis' research question.

What however does speak against a general refutation of the generalisability of this thesis' research results is the VRPTW framework. Here, one may certainly allow further ongoing thoughts then those made above. In order to simplify those assumptions of generalisability and to structure them, the following clusters of perspective can be modelled.

1. The general question must be applied, why exogenous or endogenous TWC in the context of the VRP are set at all?
2. What are the advantages of those TWC?
3. How can a shift of demand on TWC lead to mutually beneficial advantages?
4. And, finally how a compromise of endogenous and exogenous interests could be drawn-up?

The first question clearly relates to the sight of those organisations that set the TWC. Here the dominant interest is the saving of cost and the ease of operational practice, by the exogenous demand of the retailer. Optimising their own SCM by demanding their supplier to adhere to TWC, leaves them in a position with little interest towards how the supplier operates his tours. The latter that is seen as a category of customer service follows this request. This thesis however applies a model of a shift in TWC demand for the benefit of a UMTO and thereby towards an endogenous demand. In both cases, organisations use such right of demand for the optimisation of their own structures. This highlights the advantages of TWC from an endogenous perspective only.

Now follows the perspective of a mutually beneficial TWC determination. Here, a possible solution lies within a compromise between two organisations. However, how could such a compromise be operationalized? On the basis of a UMTO structure that produces its goods for the distribution logistics fulfilment in geo-time structured areas; this could mean that delivery frequencies must alter from traditional behaviour. Such an alteration would imply however, the irregular supply of different geographic areas, resulting in the preferential treatment of areas with high buying power. In contrast, this would mean that areas with low buying power would experience much longer terms of delivery and lower levels of customer service. In terms of a broader view on this question, a compromise for a mutual setting of TWC in modern organisations, may be implied only with the help of cross-border and inter-organisational communication of highly adaptable and flexible systems. (Hines, 2004, Hokey and Wen-Bin 'Vincent, 2008)

Under the above conditions and in the context of this research, further transferability and generalisability may be considered. The general problem of delivery from manufacturers and also from wholesalers to retail may be focused under those conditions. Some research has already looked at related questions to this. (Quak and De Koster, 2007) It is certain however, that the generalisability of the VRPTW problem from a UMTO environment and the solutions presented in this thesis indicate a large degree of applicability to other organisational structures, where TWC in distribution logistics play an important role. A good example where TWC play a highly important role in distribution logistics are some of the German food discounters. Here, those organisations used to have their retail locations in the middle of towns and cities, enjoying high client visiting frequency. However, those locations were unsuitable for the optimisation of logistics operations. As a consequence to this (and other reasons), these firms relocated their retail operation to the outskirts of cities and towns thus enabling themselves to minimise TWC set by local authorities and maximise staff utilisation for unloading of the vehicles during non-peak sales times. This example indicates a certain generalisability of this thesis' research results on the important findings regarding the significance of cost of TWC in distribution logistics.

A final conclusion to the question of a possible transferability and generalisability from the findings of this research deserves a focused look at the geo-time oriented production distribution problem of UMTO. This industry by its own structure may only permit the transfer of this research's results if the UMTO characteristics are being met. The significant savings stated in the experiment of this research however, could initiate discussions on why the determination of TWC actually needs to be endogenous or exogenous at all. Looking at this question, one may say that the final solution is that it will always be one of the two determinants. However, if both organisations, the retailer and the UMTO could find a solution, whereby the optimum time of delivery within one calendar week could be identified respecting both interests, then a generalisation towards the VRPTW from this thesis would be justifiable.

8.4 Implications on Operational Practice

This section intends to convert the knowledge acquired from the previous chapters into a practical implementation, and in particular those from Section 6.1: Descriptive Base Data Analysis. The following table summarizes the results of the simulation based experiment of this thesis. The focus of this thesis and its research question is directed towards cost effects of the distribution for UMTO. This will be dealt with in the following section. However, other important contributions towards further conclusions may be derived from the results and the analyses of this thesis. These are in particular, the customer service dimension with possible adverse effects, how they might be measured and how they might be modeled. Further it needs to be looked at what would motivate the customers of the GKFI to accept the proposed deterioration in service quality and reference is made to the application of service elasticity of demand.

Table 49: Sequential Base Data-1 and 3 Comparison

Sequential Base Data-1 and 3 Comparison

	Base Data-1	Base Data-3	Variance1-3	in %
Base Data Totals				
No. Clients	11,917	11,917	0.00	0.00%
No. of Tours	1,954	830	-1,124.00	-57.52%
Total m³	52,418	52,418	0.20	0.00%
Total Cost	1,795,415	880,330	-915,085	-50.97%
Total KM	2,760,614	1,559,107	-1,201,506	-43.52%
Individual Cost (€)				
per Tour	918.84	1,060.64	141.80	15.43%
per M ³	34.25	16.79	-17.46	-50.97%
per KM	0.65	0.56	-0.09	-13.18%
per Client	150.66	74.62	-76.04	-50.47%

The starting point for further considerations is that above findings will be considered for practical application in the GKFI.

8.4.1 Significance of the Cost Advantage

In the following, the significance of the cost advantage through the application of the findings from this thesis to the original state of delivery in the GKFI as demonstrated in Base Data-1 will be reasoned. This means that the knowledge acquired through the experiment in this thesis is used to answer the second part of the research question. Here, it was asked if the savings through the removal of TWC could motivate the retailers to leave the demand for the determination of TWC to the UMTO. Assuming that UMTO were aware of the significant savings, the question that needs to be answered now, is how the significance of cost savings can be demonstrated.

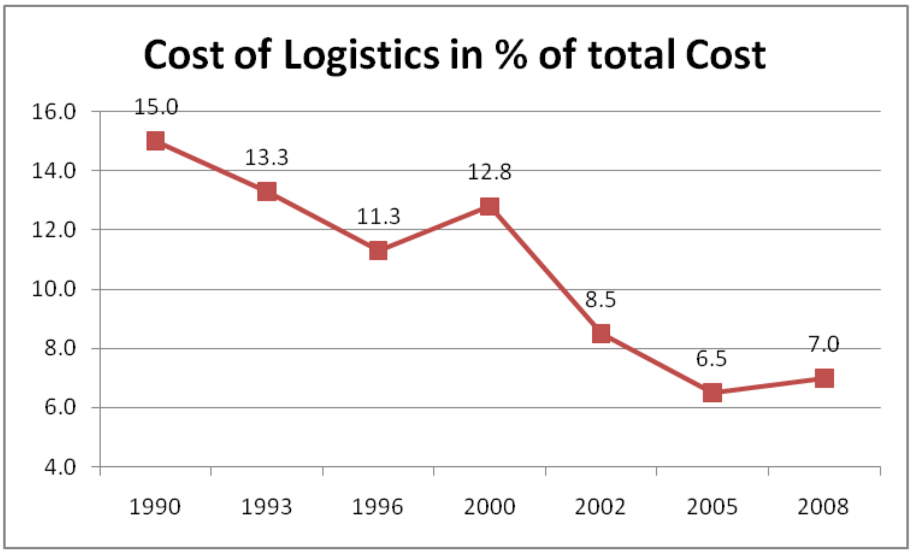

Figure 32: Cost of Logistics in % of total Cost

This section aims to provide evidence for the significance of cost savings for the change of demand of TWC. By doing so their share on the total sales of the manufacturers is chosen as a measure. Figure 32: Cost of Logistics in % of total Cost shows cost of logistics as percentage of total cost for the entire spectrum of the German industry. This serves as the basis for the following reflections. Reinbender (2006, p.63) states that the GKFI for built-up kitchen in 2002 consisted of a total of 115 manufacturing firms with a minimum of twenty employees. Total sales of these manufacturers accounted for 3,478 Million Euros in 2002. This results in an average of 30.24 Million Euros sales turnover per manufacturer. The twelve sample companies in this thesis all employ more than twenty employees. As a representative sample of this industry, they show an average of 1.8 Million Euro as their cost of delivery. This results in a total of 206.47 Million Euro for the 115 kitchen manufacturers with a minimum of twenty employees. Table 50: Industry Related Model Conclusions (1) gives the percentage of cost of delivery on total sales for these groups.

Table 50: Industry Related Model Conclusions (1)

Industry Related Model Conclusions (1)

		Sales Mln € p.a.	Annual Cost of Deliveries Mln €	Share
Average for Population of the Experiment	Base Data-1	30.24	1.80	5.94%
	Base Data-3		0.88	2.91%
	Difference	**0.00**	**0.92**	**3.03%**
Total for 115 Manufacturers	Base Data-1	3478.00	206.47	5.94%
	Base Data-3		101.24	2.91%
	Difference	**0.00**	**105.23**	**3.03%**

Annual Saving as Percentage of Sales: 3.03 %

With this, Table 50: Industry Related Model Conclusions (1) demonstrates the linchpin for these conditions. From this table, it can be seen that the delivery costs in the GKFI sub-group of 115 manufacturers account for 5.94 % of the total turnover. The saving for an average manufacturer, resulting from the experiment in this thesis, amounts to 0.92 Million Euros which makes a saving of 105.23 Million Euros for the corresponding group of 115 manufacturers. The annual saving as percentage of sales amounts to 3.03 percent. With reference to the research question of this thesis and, in particular, to the question if significant savings arising from the removal of soft TWC could lead to the shift of TWC demand from the consignee to the manufacturer, the saving of 3.03% represents a strong argument for the positive answering of the research question. There is no public statistical evidence available on the profitability of the GKFI for the year 2002. Only since 2006, are companies obliged to state their profit and loss statements and their balance sheets publicly in Germany. Subsequently, no final statements on the overall significance of the findings of this thesis to the GKFI and the chosen population can be made. An investigation for the years 2006 and 2007 at the Federal Bureau of Statistics (Bundesanzeiger) has revealed that until September 2009, only five of the twelve manufacturers contributing to this thesis's base data have published those results. For reasons of validity a conclusion for this thesis's results could not be drawn on that basis.

The contribution to research on UMTO distribution cost may be concluded from a practical and from a theoretical background. The practical contributions may be concluded as follows:

1. Impacts of applied TWC may be as high as 50% on the cost of distribution.
2. Changes through shifting the demand over TWC from the client to the UMTO may only be applied when the 'promise' for delivery within one and the same calendar week is retained and does not raise costs higher than the achieved savings from the consignees' perspective.
3. Shifting the TWC demands in favour of the UMTO is not an a-priori planning element for the distribution strategy of a UMTO. It may only be considered as a retro-active measure for the initial planning improvement. An implementation would appear to only take place in either a step-by-step approach, or through an industry-wide general approach.
4. Applying the knowledge gained from the experiment in this thesis, UMTO may gain awareness of alternative distribution planning

strategies, by planning their deliveries in a repetitive geographical environment through constant client negotiations on the cost of delivery, and an increased awareness of the costliness of increasing TWC in delivery. And

5. arising from the findings of this thesis, one may ask the question, if the production-distribution horizon in some industries of one calendar week, may be extended further to i.e. two or three weeks, thus enabling the UMTO to capture even higher potential savings through consolidating specific geographic areas of delivery.

The above five findings are considered as the 'real' contribution to knowledge and to practitioners. The contribution to knowledge for the theoretical background however, may be identified differently:

1. UMTO specifics with distribution planning problems dominating production planning to a large extent, may gain new knowledge by identifying their existing cost for distribution by using simulation software (DPS)
2. Applying simulation software by means of a DPS on existing routes with numerous deliveries may lead to controversial findings as in the initial planning status of those tours; hence this implies a different methodological approach to the general CVRPTW.
3. Re-planning of tours as a different approach to the CVRPTW and research on the effects of existing constraints through their removal may contribute towards another new methodological approach; and
4. Finally, the general questioning of so-called 'client demands' in logistics may gain new theoretical knowledge by actually questioning existing marketing strategies (for delivery) which have their impact on operations management.

Both, the practical and theoretical conclusions for contributions to knowledge on UMTO distribution cost may raise new and even controversial discussions. The fact finding of this thesis however, with identifying significant savings in the cost of distribution may provide grounds on discussions for the demand over TWC in delivery in general.

8.4.2 Reflections on the Customer Service Dimension

The experiment in this thesis has revealed a one-sided result only, by demonstrating the cost savings in favour of the UMTO and to the disadvantage of his clients through a change of set delivery times within one calendar week. That this solution to the problem may only be seen as a purely theoretical one has been discussed in Section 6.2 Customer Service Perspective. From the customer service perspective the removal of TWC in favour of his supplier is a clear reduction in expected service levels. That this reduction of service level is intended to be compensated by a reduction of price or other financial incentives will be discussed in Section 8.4.3 Implementation Scenarios. In case of reductions of service levels one may however expect that some customers will either refuse such or accept them only to certain degree. Reflections on this have been discussed in Section 6.3 Sensitivity Analysis. From this it can be stated that not all clients would agree to the change of demand for TWC, thus leading to a mix of customers per geo-time planning horizon for a UMTO. One solution to answer the question or solve the problem of identifying customers willing to accept the change of demand would be a manual and individual questioning. Here, the financial compensation in favour of the removal of TWC would lead to altered deliveries and altered or only partly repetitive delivery schedules per weekly geo-time delivery. After establishing which customer would accept the TWC removal in return for a financial compensation, those who will refuse such can be identified. From such an intermediate solution against that from this thesis, it may be assumed that the customers with removed TWC will be scheduled for their delivery according to those customers which have not accepted the TWC removal. From this assumption however, it may be assumed further that the reduction of kilometrage and route duration effects will not be the anticipated route and distribution optimization envisaged by a UMTO. Referring however to the highly competitive market situation of the GKFI, the spread of market information on available innovative financial advantages may lead to a certain degree of the 'Me-too effect'.

Summarizing the possible customer service dimensions one may conclude that the removal of TWC is a solvable task in this industry, provided that the cost arising here from is in no case higher than the financial compensation offered by the UMTO. In this context it may be allowed to refer to a different level of comparability of this problem of customer service dimension from the automotive industry. Here the determination of TWC is in some cases regulated through bi-directional systems interfaces which automatically determine advantages and disadvantages from both sides and find mutually suitable solutions through pre-set algorithms. Those algorithms are based on the bi-lateral cost advantages and disadvantages. However, these decision models always contain a preferential solution in favour of the customer service dimension. In relation to the experiment from this thesis, the total removal of TWC remains a purely theoretical approach. From a practical point of view on this, the customer service dimension always experiences preferential treatment over the optimization interest of a supplier.

In the analysis section a ceteris paribus cost reduction resulting from a complete removal of all soft TWC has been modelled and calculated. A statement regarding the profitability of an implementation needs to take into account the aggregate compensations beside this cost reduction. The balance of these is the resulting change in profitability. From this research it can only be stated that the ceteris paribus variation of TWC leads to a significant cost reduction. The aggregate compensations are not known. Hence, it cannot be concluded how the UMTO's profitability will change and to what extent the customer service expectations from this can be met.

8.4.3 Implementation Scenarios

The previous section stated savings of 3.03% of sales through the experiment in this thesis. Now there is the question, how to operationalise the removal of TWC practically and thereby reduce the cost of delivery. The operationalisation, or the implementation of the findings, would however need to consider the relevant participants of the value chain from this population. These are the manufacturers, the buying cooperatives and the retailers.

The basis for implementation is the realization of the potential of ~3.0% savings options. For this, both the retailers and their purchasing co-operations must be involved in this model. (Sahin and Robinson, 2005)

Table 51: Scenarios of Implementation

Scenarios of Implementation				
	Retail	**Buying Coop**	**Manufacturer**	
Scenario-A	1.0%	1.0%	1.0%	**3.0%**
Scenario-B	0.5%	1.0%	1.5%	
Scenario-C	2.0%	0.5%	0.5%	

The above table can only give a small idea of potential scenarios. At this point, it would probably be wrong to devise a generally applicable and unique scenario which, following this hypothesis, might not offer a possibility for implementation. Hence 3 scenarios were randomly composed. In reality, however, a separate scenario per purchasing co-operation would be implemented i.e. agreed upon. What, however, happens when one and the same retailer is a member in various purchasing co-operations which could quite easily be the case? The retailers would always try, in spite of an existing agreement, to negotiate an agreement via their purchasing co-operation for themselves and for their own benefit. Therefore, it is determined that an implementation always involves a great many imponderables. Nevertheless, an optimization potential of 3.0% offers an array of negotiations between manufacturer, purchasing co-operation and retailer.

8.4.4 Summary of Implications

The core statement of this section consists of a theoretical implementation for the selection and assignment of TWC in favour of the manufacturer. This approach is and will remain a purely theoretical assumption in the competitive environment of GKFI. The clients, and therefore all retail companies involved in this trade, have a very high influence on this market. However, this approach to an implementation entails business and, therefore, economic incentives which are not so easy to ignore. With an overall improvement potential of 3% of total cost and a cost advantage share of 0.5% – 1.5% in favour of the manufacturer, this model certainly offers a novel approach to co-operation alternatives between UMTO and their distribution channels. At the beginning of Chapters 1 and 2, it was ventured with an assumption at various points that, in case of a reduction in distribution costs, the profit for a manufacturer can be significantly enhanced; thus this approach constitutes a research innovation in the SCM area.

There are sufficient grounds to assume, that with further research, manufacturers and retailers alike, may re-orientate themselves along the entire supply chain. Practice and research-oriented CPFR (Collaborative Planning, Forecasting & Replenishment) projects (Hokey and Wen-Bin 'Vincent, 2008) between the manufacturing industry and retail already deal with similar approaches in a number of projects and, along the supply chain, they have provided many new stimuli for the improvement of mutual logistics problems. (Weisbrodt and Kessel, 2001) Many of these research look at similar problems such as the avoidance of traffic congestions (McKinnon and Ge, 2006) or bottlenecks at the retailers' ramps.

A new, or rather resurgent, approach, and also an incentive for the implementation of this thesis's findings, has its origin in the environmental responsibility of all parties; however, not only environmental responsibility plays an important role, but also the simultaneous combination of environmental and economic points of view. Throughout Europe, individual governments are about to impose much higher taxes for CO_2 emissions. This fundamental change will largely contribute to the fact that, next to low-emission vehicles, CO_2 emissions caused by commercial vehicles will have economic consequences. At present, it is not clear yet if, and by how much, this combination of environmental and economic statutory provisions will be established in the future. What is certain, however, is that it will and must come in order to reduce environmental pollution. Further considerations of this are documented in Chapter 7 Supporting Environmental Considerations.

8.5 Further Research Opportunities

Concluding further research opportunities resulting from this thesis may be divided into two separate issues. The first relates to the research question of this thesis and the second relates on the environmental issues. Both of them may have certain correlations from a methodological point of view. The latter that could combine the two opportunities, is the experimental research design basis, using simulation to identify the X-Y=Z result according to Poe (1994).

The importance of distribution cost from a UMTO perspective was demonstrated in detail in this thesis, using the GKFI as a sample industry. That the cost of distribution can be significantly reduced through the removal of TWC was identified in the experiment of this thesis. However, the service perspectives from the customers may surely lead towards a reduction of those savings. This is a first further research opportunity, where one may look at the rate of acceptance from a price and service point of view, by applying questionnaires to the sample customers of the GKFI. Future research should empirically test the acceptance of the removal of TWC from this thesis in different industries and different countries, to enable comparative studies. A larger sample would also allow more accurate assumptions which were not possible in the context of this study. With the result from those empirical studies it may become evident, to what degree the acceptance of TWC against a financial compensation may be realised. (See Figure 31: Sensitivity Reflections) Further supporting research results from those empirical studies could then reveal improved transferability to the entire furniture industry and generalisability to other industries that have similar UMTO and distribution structures to the retail industry.

A highly significant further research opportunity may be seen in the environmental issues arising from this thesis. Prior to looking at them, one may refer this further research opportunity to the findings from recent environmental trends and strategies research in logistics and their sustainability. (Straube and Pfohl, 2008) Resulting from these authors' findings, Table 40: Drivers for Environmental Changes in Logistics and Table 41: Missing Tools & Concepts for 'Green Logistics' deliver the basis for such methodological research opportunities. While the drivers for environmental changes state that government (Germany) is seen in the leading role for such changes and 'own motivation' is only in the second position for such changes, the environmental findings from this thesis could become a basis for identifying new research opportunities. Those could focus on the savings on CO_2, NO_x, SO_2 and NMVOC as well as the reduction of accidents with injuries and deaths according to the X-Y simulated model from this thesis. The latter however, needs to be seen with the general awareness of organisations and their implementation of sustainability in road freight transport and logistics. (McKinnon, 2003) Despite such a growing awareness and public discussions, governments will take the lead in a similar way that they have done with the general reduction of CO_2 since the establishment of the Kyoto Protocol.

The further research opportunities arising from this thesis in this environmental context may therefore be seen in reducing kilometrage and minimising route duration for in-house road transport in certain industries. If those reductions will lead to a linear reduction of payable corporate taxes or result in actual further taxation (other than road toll fees in Germany, Austria, France, etc.) of such kilometrage is still open, but not certainly yet questionable. (McKinnon, 2006) It will however lead to towards less traffic congestions and improve the overall efficiency of logistical operations. (McKinnon, 1999a) This is where further research could support the findings from this thesis.

In order to further substantiate the findings from this thesis in the environmental context, further research opportunities could contribute to new knowledge by investigating the exact effects of in-house transport from its high percentage of empty return loads and low capacity usage. (McKinnon and Ge,

2006) By doing this, one could model, empirically measure and evaluate the other road transport externalities from this thesis and draw conclusions about their reduction possibilities. Such an approach would contribute to the findings for greener logistics in the furniture industry (Handfield et al., 1997) and many of those organisations that operate in-house transport. Such further research in context to possible governmental actions would deliver new knowledge for the sustainability of logistics.

IX Appendix

The appendix of this thesis consists of five major sections covering additional and supplemental information to support its basic contents. Thoughts on the trends and strategies supplied herewith will show from recent research in this field, how current and future developments will impact organisational behaviour in the field of SCM. Here, a continuous customer focus will guide operational and strategic developments in the future. These developments will be strongly influenced by information systems that steer the supply chain of organisations under the aspects of cost leadership.

The supplements to the practical background are shown in this appendix to support the statements made in Chapter 1 of this thesis.

The supporting environmental challenges, the third section of this appendix, will use the economic findings from Chapter 6 of this thesis and transfer them to environmental results. Here, the focus lies on CO_2 emissions resulting from the kilometrage savings in the descriptive analysis in Section 6.1.3: Results - Base Data-3. The reasons for applying such environmental considerations are based upon strongly predictable cost effects of environmental pollution arising from commercial transport in Germany over and above those already implied by general taxation and the German Road Toll.

Replicability is a very important scientific concept that essentially means that the outcome of a particular study will occur again if the study is replicated by another investigator. In order to comply with this, the fourth section of the appendix contains a detailed description of the applied DPS. This description is a brochure of the system supplier *WANKO Unternehmenslogistik GmbH*. Cost determination in this system as it was used for this thesis's experiment is consistent with the cost function formulated in Section 4.2 Definition of the Cost Function.

Finally, the data sets used in the experiment:

- Base Data-0 (raw data)
- Base Data-1
- Base Data-2
- Base Data-3

are here attached on a CD-Rom. Base Data-1 and 2 contain corresponding tour reference numbers. Upon those reference numbers, the number of units and the volume, the comparison of both data sets can be undertaken. Base Data-3 has its own tour reference numbers, as this base data contains new tour compositions as shown in Figure 19: Overview of the Simulation Process. The comparison from Base Data-3 to the other data sets can be undertaken by checking the total number of units and volume only. The attached Base Data-0 to 3 is evidence of the data used in the experiment and supports the importance of transparency for replication.

Also attached on a CD-Rom is the DPS operational specification of the applied system from Wanko Unternehmenslogistik GmbH. This attachment serves the purpose to identify the used simulation system and add towards the replicability of the simulation experiment.

IX.A Trends and Strategies in Logistics and SCM

This section in the appendix serves the purpose to support some of the general findings and statements in this thesis on SCM and logistics. It particularly supports the previous statements made, why companies in their SCM adapt a strong customer focus, such as the acceptance of TWC. For this reason, this section describes important trends and strategies in SCM deriving from recent publications. Here, the majority of the findings come from the Logistics and SCM Research Centre of the Technical University, Berlin, lead by Prof. H. Baumgarten. The trends and strategies in SCM in the recent years were strongly influenced by a booming economy until the middle of 2008. Reports on double digit growth rates especially for the logistics and SCM service providers industry were reported on a daily basis in the specialist press. Yet, the cost of logistics for the entire range of all German firms has decreased through a growing competition among the service providers and the growing ability of the firms to handle their logistics and SCM. (See Figure 32: Cost of Logistics in % of total Cost) From this boom, a number of trends and strategies were derived, which are dealt with in this section of the appendix in order to demonstrate why (1) planning systems in SCM have gained continuous importance, (2) the theory of SCM is implemented more and more in production schemes, (3) SCM implies a strong customer focus, (4) the use of information systems to steer and control supply chains rapidly gains more importance and (5) why a strict cost orientation for achieving cost leadership is so important. All these issues accompany, strengthen and support findings and statements of this thesis.

SCM plays a progressively increasing and significant role in business decisions, and it is an important success factor for competitive advantage today. (Baumgarten and Thorns, 2002) This will become even more the case in the future. Success in a time and cost-oriented, globally marketed and sourced business environment is the basis of future-orientated logistics systems which derive from quality in delivery, cost-orientation and speed. Competency in SCM will, therefore, be a growing important competitive advantage by adding such characteristics to the attributes of a product or a service to be sold. (Wiendahl, 2002)

The "State of the Art" definition of SCM can be summarised as follows:

> *"A supply chain is a set of interconnecting and interdependent organisational groupings - connected through from raw materials to final consumer, and back again - responsible for transforming resources and transacting agreements. It does this in order to satisfy an ultimate customer demand so that all in the chain receive acceptable rewards." (Macbeth, 2005)*

This indicates that SCM is a subject of relevance in industry, trade and service. It also states that wherever there is an interconnecting flow of materials, information, people and money, they are to be steered and managed to satisfy customer demand. Trends and strategies in SCM have changed substantially in the past years. Coming from logistics as a holistic approach or integrated logistics as a comprehensive view along the entire value chain of a corporate design, SCM has established itself from the transformation of the business environment towards attached environmental developments. (Straube and Pfohl, 2008)

Some of the greatest requirements from logistics by far, are to be found in increased customer requirements and cost savings as a result of a continuous information and communication flow. (Straube and Pfohl, 2008) From this, ‘Customer Focus’ and ‘Cost Leadership’ lead to an overall corporate strategy that places SCM as a core competence of business enterprises. Leading SCM designs are ‘Time’ and ‘Cost’ orientated, but, most of all, they are flexible and adaptable towards innovations and changes driven by customers. They additionally steer their own development along or even ahead of the markets’ requirements. The latter is meant to be a crucial success factor for any corporate design. The result could well be that leadership in SCM creates new potentials in terms of 'Time and Cost Management' through innovative information technology and communication systems. (Baumgarten and Thorns, 2002)

The bases for this were the developments arising from previous knowledge on the importance of logistics. Here, past research has stated that the requirements from logistics go far beyond transport, warehousing and general freight handling. The following figure illustrates some of the trend findings from more than 10 years ago. – Examining them from today’s perspective, one may conclude that they were appropriate and found their implementation in logistics and later on in SCM.

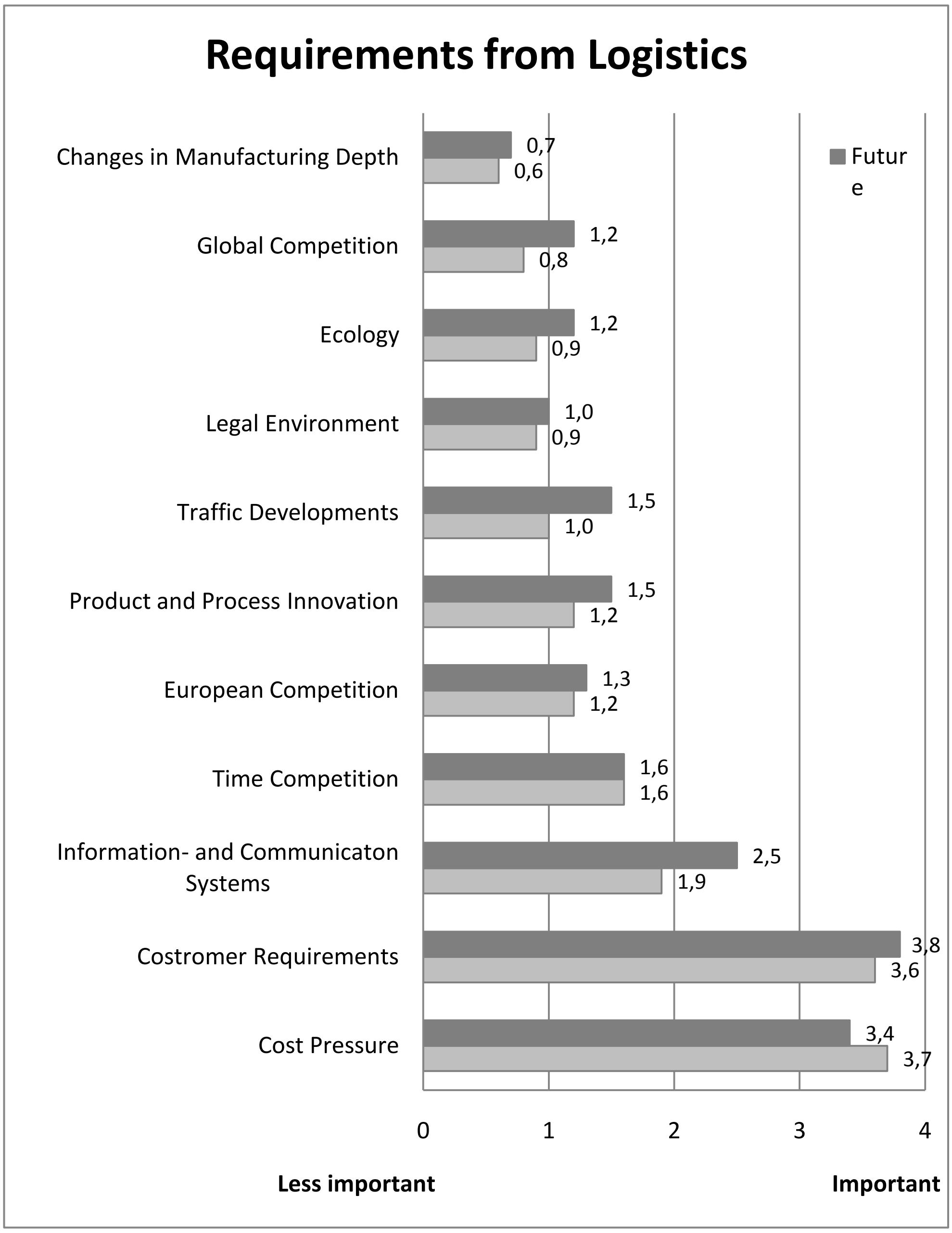

Figure 33: Requirements from Logistics

Source: Baumgarten (1996)

Logistics have systematically grown towards a functional, instrumental and institutional consequence on all managerial levels. (Pfohl, 2004b) The theoretical developments of logistics in business and management in Germany began at the end of 1960's and early 1970's (Pfohl, 1994) when publications about logistics were first recognised. From the past, the functions of logistics as primary transportation, storage and warehousing in the military environment have changed to commercially adapted systems, as have the requirements.

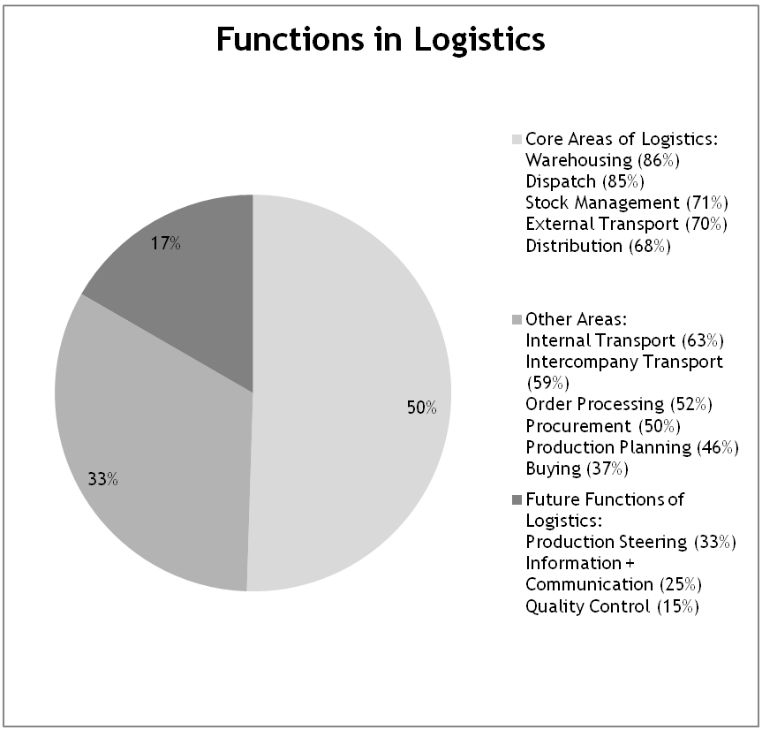

Figure 34: Functions in Logistics

Source: Baumgarten (1996)

The core areas of logistics remain warehousing and transportation, but information and communication systems application, production steering and quality management along corporate value chains are gaining more and more importance in the portfolio of logistic functions and are found in today's SCM. The integration of those additional tasks and functions underlines the important role of logistics as a strategic instrument on all managerial levels as shown in the above figure. The new areas of logistics lead to new potentials towards a continuous optimisation of processes driven by increasing customer demands. The potentials for optimisation in production planning and production steering become an integrated, mostly accepted and sometimes future-orientated part of logistics. Their functions indicate the trend of the overall logistics importance for the realisation of cost saving potentials in many other organisational structures.

New trends in requirements and functions of logistics do not ignore new trends in logistics cost. The growing competition in the market of service providers, characterised by strong concentrations through mergers and acquisitions, leads towards benefits for the manufacturing industry or the clients in general. Parallel to the privatisation of formerly state-owned transportation systems (i.e. railroads, airlines, mail etc.), the competitiveness of the transportation market has changed the entire field of logistics. In addition, the trend towards outsourcing (McKinnon, 1999b) of internal logistics functions to external logistics service providers has added further competition in this field.

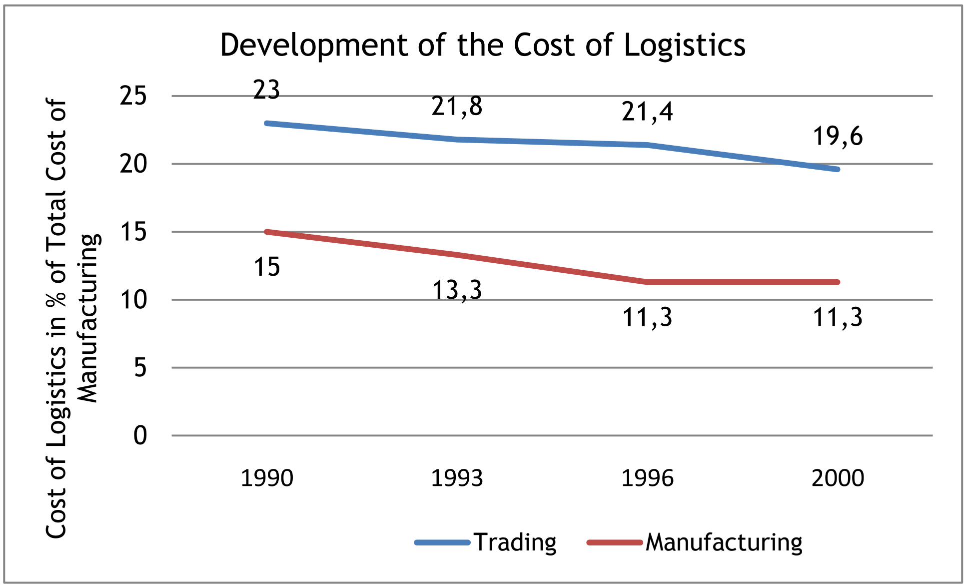

Figure 35: Development of the Cost of Logistics

Source: Baumgarten (2000)

Consequently, the costs of logistics have declined continuously since 1990 *(See* Figure 35*:* Development of the Cost of Logistics and Figure 36*:* Reasons for a Co-Operation with Service Providers*)*. Manufacturers in Europe define the cost of logistics individually. (Weber, 2002) In general, there are few common parameters. Some define it purely as the cost of distribution; some identify it as the total flow of merchandise with or without the cost of information. The above figure is intended to convey a brief understanding of the declining cost of logistics in general. This decline results from an increased transparency and comparability of corporate cost. (Kearney, 1999) Cost reduction strategies in logistics enable the improvement of cost efficiency along the entire corporate supply chain.

Summarising from the above, one may conclude that increasing requirements from logistics and SCM services and processes lead towards new functions in this line of business. They are accompanied (sometimes, but not always) by a decline in cost through improved comparability by benchmarking and improved transparency by more efficient cost controlling. Furthermore, cost reduction is a result of a variety of changes in the market of the logistics services providing industry. The logistics service industry has reacted to the increasing demands of their clients for new services through cost reductions by their general attitude for the concentration on their core competencies. The logistics providing service industry, by itself, has developed its own core competencies and successfully generated the following reasons for a possible co-operation with manufacturers and trading firms:

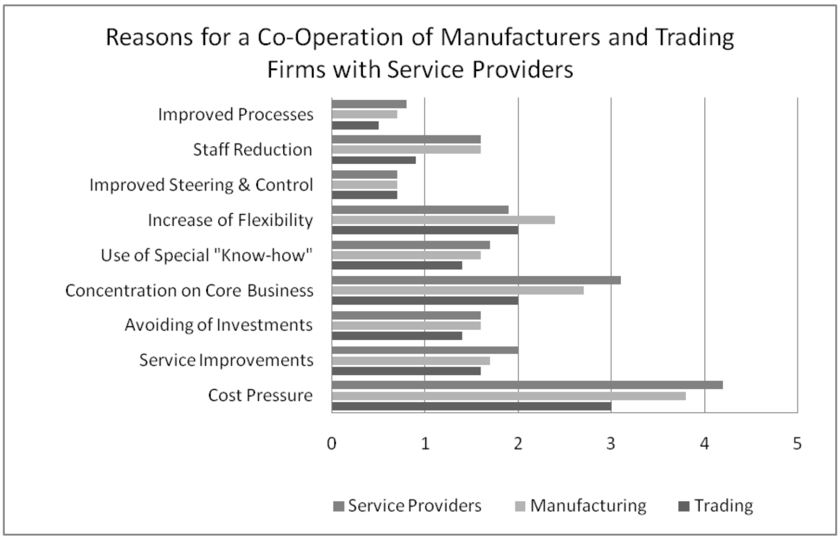

Figure 36: Reasons for a Co-Operation with Service Providers

Source: Baumgarten (2000)

Logistic service providers benefit from different labour cost (union tariffs) in comparison to manufacturers and trading firms. Their services can be offered with less cost for the same or improved processes and functions. Their core competencies in providing logistics services (McKinnon, 1999b) give them a strategic advantage over the internal solutions of manufacturers and trading firms. As a result, many firms decide to subcontract their logistics services to external providers.

IX.A.i Customer Focus

Customer focus on logistics has undergone major changes since many years ago. (Baumgarten and Thorns, 2002) This is why the following section deserves detailed interest and also, in particular, supports the importance of the research question of this thesis. The customer focus is a major strategic criterion for UMTO firms when distribution and production planning are set up for a corporate design. The increasing requirements (See Figure 33: Requirements from Logistics) of customers on the capacities and ranges of services rendered by a UMTO have lead to more transparency and so-called 'added values' in logistics. However, not only in logistics has the customer focus changed and placed increasing requirements on the supply market. (Frese and Noetel, 1992) There, competition is the catalyst of change, combined with organisational, strategic and other operational changes. Time management has gained more and more importance since the creation of JiT-systems (Just-in-Time) and the awareness of the right goods at the right time in the right place for the right price, in the right quality. In general, the following criteria or problem zones characterise the views of customer focus, particularly in average-sized companies and their manufacturing or marketing policies (Kummer, 1992):

a) high amount of stocks in production and in storage
b) lack of transparency on stocks and stock structures
c) long internal paths of transport
d) cost intensive staff requirements in storage, transport and dispatch
e) problems in fulfilment of delivery service and long lead times

f) uncertainty from legal authorities in logistics management

g) lack of logistics cost controlling

h) insufficient use of economic tools

As a result, companies focus on improving capabilities to match their clients' focus. The application of the requirements from logistics (See Figure 33: Requirements from Logistics) in this statement would result in a change of the corporate strategy and bring about an increased marketing activity. Today, customer focus stands for the change from a push-principle to a pull-principle in customer relations. The customer is the source and the driving power of all corporate actions. (Hines, 2004) Customer focus in respect of this study has a particular relationship to the entire corporate SCM. The transparency of each and every individual step along that chain enables management to steer and to control more accurately than before. UMTO have a strong customer focus by the nature of their business, as every order is made to the clients' specifications and individual requirements. This is, where this thesis adopts a critical position in the logistics practical traditions by asking, how much the customer focus of adhering to the TWC in delivery is costing a UMTO.

Customer focus, as a wholly justified fashionable strategy incorporates the willingness of UMTO to fulfil the clients' requests on TWC unquestioned. Thus the logistics structures of UMTO have developed over the years by accepting such trends without illuminating the economic consequences. This work has taken a new approach by analysing customer focus in logistics distribution and questioned what is generally accepted. This thesis has stated that it does not need to be accepted, yet fulfilling the promise of delivery, thus applying the original quality of delivery promised to the client, and additionally reducing the cost of delivery.

IX.A.ii Logistics Information Systems for the VRP

This thesis deals with the use of a DPS to plan, calculate cost, dissolve or reconstruct deliveries in tours. Until a few years ago, the planning of tours was done manually by using pins and connecting them with cotton threads on large geographic maps. Today all those works are undertaken by modern DPS, as described in this thesis.

In today's world, it is difficult to find strategic trends in business and management without the influence of information technology. Information technology is not only a critical success factor for any economic process, but also one of the most rapidly changing challenges in business. In logistics management, Global Positioning Systems (GPS), for example, can track vehicles nationwide, direct or redirect them at any time and transmit data of any relevance. Delivery details by barcode information or radio frequency identification (RFID), routing and lead times controlling etc, are digitalised and communicated along corporate supply chains. Data on all stations and processes of the material flow becomes available and transparent at all times.

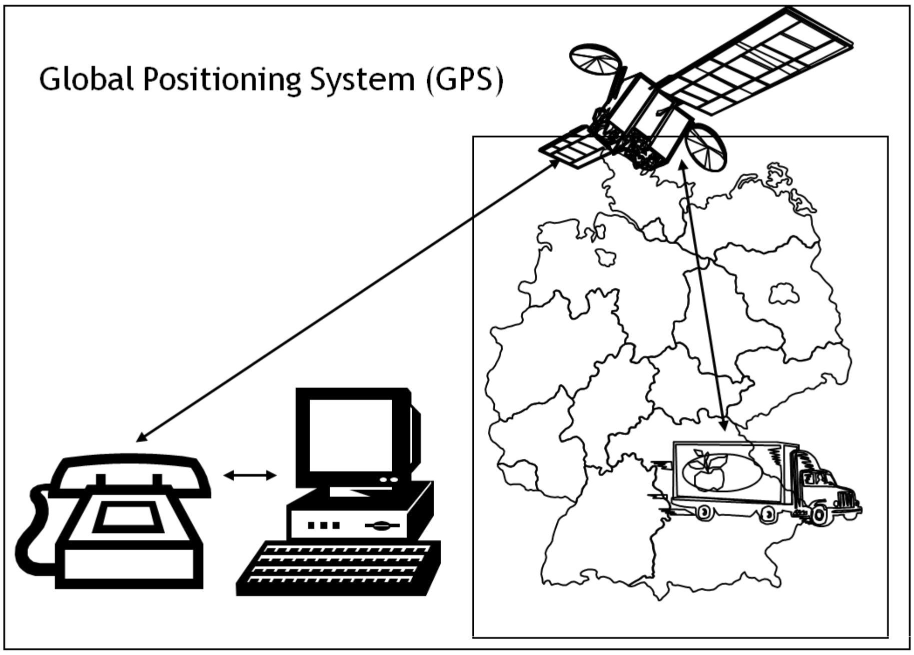

Figure 37: Global Positioning System (GPS)

Communication and information systems have recently moved rapidly into the field of logistics and have achieved efficient positive results. Here, research for the use of RFID is the most current and important innovation.

The reasons for this development are the customer requirements. (Baumgarten and Thorns, 2002) The trend of co-operation between manufacturers and the service industry is that the electronic interchange of data for the purpose of transparency and logistics steering is gaining vast importance and general market implementation.

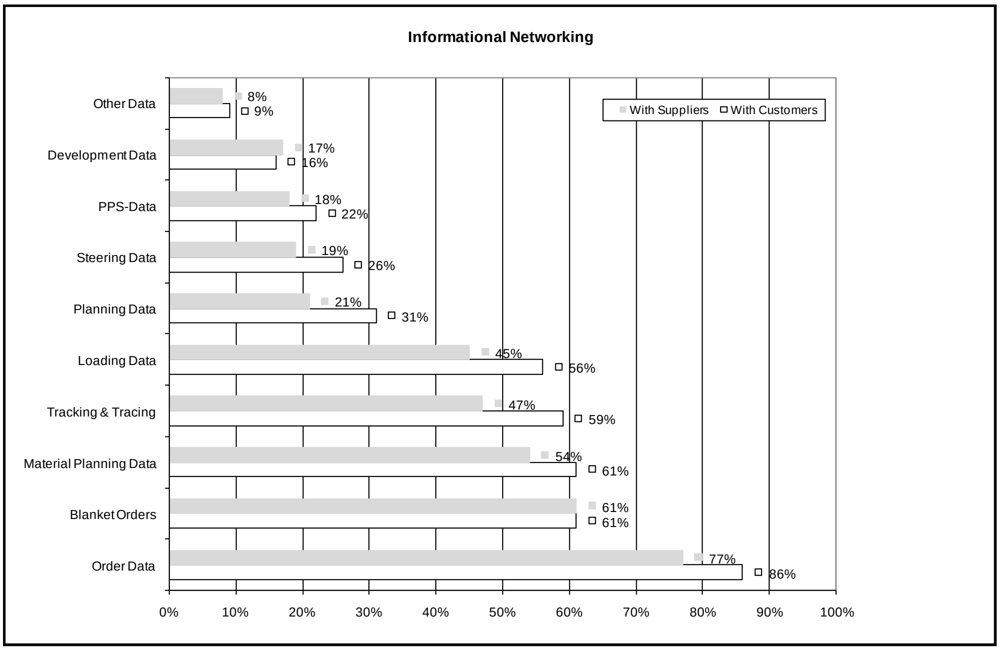

Figure 38: Informational Networking

Source: Baumgarten (2000)

The current market situation shows that 73.6% of companies have an information network with their customers, whereas only 56.9% of the companies have an information network with their suppliers. This proves again that customer requirements as an increasing demand in logistics are the main focus and trend. However, looking at these new tendencies in the market and looking at the pricing or marketing policy of many firms, the price or cost sensitivity on their marketing activities leaves them little space for improvement. Consequently, a tendency for improvements on the buying and supplying side is likely to follow within the next years.

An intensively used platform for communication between companies is the Internet. There, the availability of data and information is almost limitless. Gradually, communication between companies is gathering pace on the Internet. At the same time, data and information on logistics are communicated via the Internet in order to increase the information availability with greater simplicity for customers and suppliers. Product ranges and services are offered and the integration of the internet is universally seen as the portal to the future. (Straube and Pfohl, 2008)

IX.A.iii Competitive Advantage by Cost Leadership

The experiment undertaken in this thesis states a significant cost reduction in the cost of delivery. Why is this important at all and why should organisations such as UMTO invest time and efforts to achieve such savings, if current market conditions deliver them customer satisfaction and corporate survival, even though the latter shows clear indications of risk? This subsection of the appendix will answer that question and by doing so, it will highlight the organisational importance of cost leadership resulting from logistics and SCM restructuring. This subsection will also include opportunities other than those demonstrated earlier in this thesis.

One of the sections of cost leadership is the concentration on reducing the cost of logistics. As part of this strategy, a company would try to maintain its service and time management in delivery and in parallel reduce the cost of all logistic activities. (Gudehus, 2005, Kummer, 1992, Shapiro, 2006)

In support of this strategy, the following selection of opportunities in logistics may be considered:

- Consolidation of materials for transportation in order to reduce cost per item, but face possible longer lead times (Gudehus, 2005)
- Use of low cost carriers (Göpfert, 2000)

- Increase of order processing speed i.e. with simultaneously adjusted speed in the flow of materials (Fleischmann, 1996)
- Automation of handling and storage processes. (Kummer, 1992)
- Reduction of stocks i.e. by Efficient Customer Response (ECR) methods (Gudehus, 2005, Göpfert, 2006)
- Outsourcing i.e. to logistic service providers with higher competence and lower cost (Göpfert, 2000, McKinnon, 1999b, Straube and Pfohl, 2008, Wendt et al., 2006)
- Reduce fixed cost i.e. by higher utilisation of investments (Pfohl, 2004a)
- Reduction of creditors i.e. by concentration on a minimum of external partners (Tempelmeier, 2001)

Even though there might be numerous methods for cost reduction in logistics, the above are generally applied opportunities. In this respect and in view of logistics cost leadership, one of the major critical success factors is the make-or-buy decision for all of the above methods and for others in logistics. (McKinnon, 1994) Externally developed corporate structures create problems of non-comparability and compatibility in the market of logistic services. Consequently, cost leadership is primarily viewed from an internal perspective and then secondarily with the help of external benchmarks. (Gudehus, 2005) However, many external benchmarks, in particular the comparison with competitors, can produce comparisons with motivations for improvement, even though such data often needs correction. (Luczak et al., 2004)

The cost of logistics and the decision for the strategic choice of cost leadership are in a direct relationship to the services rendered to the customers. Customer focus or the point of view, that it is the delivery to the customer rather than the financial effects of that, shows the importance that the perfect delivery has in strategic management decisions. (Thomas and Griffin, 1996)

Concluding from the above and in respect of the trends and strategies in logistics as shown in Figure 35: Development of the Cost of Logistics and Figure 33:

Requirements from Logistics, cost leadership and quality management are two of the important driving forces for competitive advantage.

IX.B Supplements to the Practical Background

In the beginning of this thesis, a first introduction to the GKFI in subsection 1.3 Practical Background supported a detailed understanding of this industry. This subsection of the appendix aims to contribute further to the understanding of this industry by supplying more information about the furniture industry in Germany and in Europe in general.

IX.B.i The Furniture Industry in Germany and Europe

The following Table 52 Turnover in European Furniture Industry by Country provides a good overview of sales in the furniture industry and a per head consumption. From this, Germany and Austria have a 50%- 70% higher per head consumption than Great Britain, France or Italy. One of the reasons for this is that in the German-speaking community of Europe, homeowners mostly take their built-in furniture (i.e. kitchens or clothing cabinets) with them when they move to another location, but built-in furniture in the UK and in France are usually included as part of the house sale.

Moving house inevitably prompts changes, as it often triggers the desire for new interior decoration which stimulates the sales and production figures of furniture manufacturers. Moreover, the building of new homes is another indicator for the development of this industry. Traditionally, the four big manufacturing countries for general furniture are Italy, Germany, Great Britain and France as shown in the table below. Here, Germany’s furniture manufacturing has a share of almost 32% of the entire European market measured on sales.

Table 52: Turnover in European Furniture Industry by Country

Turnover in European Furniture Industry

Year 2002: at Recommended Retail Price

Country	Sales in Bill. Euro	Inhabitants in Millions	Per Head Consumption in Euro
Germany	30.45	82.6	368
Austria	2.8	8.2	344
Sweden	2.92	8.9	327
Denmark	1.73	5.4	320
Belgium/Luxemburg	3.32	10.8	307
Great Britain	1.3	59.1	242
Finland	1.26	5.2	241
Netherlands	3.69	16.2	228
Italy	1.69	56.5	207
Ireland	0,79	3.9	202
France	11.93	59.6	200
Spain	8.06	40.7	198
Greece	1.96	11.0	178
Portugal	1.14	10.4	109
European Union Total:	**96.02**	**378.5**	**254*)**

*) = Average

Source: Verband der deutschen Möbelindustrie

Another good indicator for the performance of the furniture industry is the building industry for private homes. The construction industry provides some good indications for the prospective sales of furniture and the general condition of this industry. New homes usually require a new interior, new furniture and new investments in lifestyle. This may differ from country to country within Europe, but, generally, one may assume a fair correlation between the two industries.

Table 53: Finished Flats in Europe 2000-2009

Finished flats*) in Europe 2003 - 2006) (in 1000 flats)**

	2000	2001	2002	2003	2004	2005	2006	2007***)	2008***)	2009***)
Belgium	45.0	40.3	37.9	38.5	36.8	37.0	54.5	56.2	54.9	54.1
Denmark	15.0	15.4	17.0	20.0	20.5	21.0	30.0	30.5	30.5	30.5
Germany	368.5	286.0	265.0	232.0	262.0	251.0	22.5	241.5	228.5	215.0
Finland	32.7	31.2	29.0	28.0	29.5	29.5	34.5	34.5	33.5	32.0
France	311.0	303.0	290.0	294.0	298.0	288.0	405.0	420.0	402.0	390.0
Great Britain	167.0	162.0	167.0	179.0	184.0	188.0	199.0	204.0	204.5	210.0
Ireland	79.8	52.6	48.0	65.0	59.5	54.5	90.0	85.0	75.0	70.0
Italy	167.0	195.0	203.0	252.0	257.0	254.0	293.4	298.1	286.0	274.0
Netherlands	70.7	70.0	70.0	60.0	65.0	67.5	75.0	77.5	77.5	77.5
Norway	23.3	24.7	24.4	22.3	21.4	19.0	30.5	33.0	34.5	34.0
Austria	54.0	49.0	45.0	42.5	43.0	42.8	43.0	44.0	44.5	44.0
Portugal	112.0	110.0	105.0	65.3	64.9	65.0	54.5	52.3	52.8	53.9
Sweden	13.0	18.7	20.1	19.9	19.8	20.4	31.7	34.0	34.5	34.1
Switzerland	32.7	31.3	30.5	29.3	31.6	33.0	38.0	37.9	37.5	36.8
Spain	367.0	502.0	450.0	560.0	583.0	560.0	718.0	761.0	715.0	660.0
Western Europe	**1,858.7**	**1,891.2**	**1,801.9**	**1,907.8**	**1,976.0**	**1,930.7**	**2,119.6**	**2,409.5**	**2,311.2**	**2,215.9**
Poland	87.8	106.1	78.0	142.0	115.0	90.0	116.8	121.5	134.0	149.0
Slovakia	12.9	10.3	12.0	12.0	12.0	11.0	15.5	16.0	17.0	18.0
Czech Republic	25.2	24.8	28.5	31.2	33.7	33.4	32.7	34.0	31.0	33.0
Hungary	21.6	28.1	32.0	35.0	33.0	35.0	41.0	39.0	38.0	40.0
Eastern Europe	**147.5**	**169.3**	**150.5**	**220.2**	**193.7**	**169.4**	**206.0**	**210.5**	**220.0**	**240.0**
Total Europe	**2,006.2**	**2,060.5**	**1,952.4**	**2,128.0**	**2,169.7**	**2,100.1**	**2,325.6**	**2,620.0**	**2,531.2**	**2,455.9**

*) Building of new homes (Flats, Houses and Blocks) Start of building for France.

**) EUROCONSTRUCT-Area: 15 west- and 4 central European Countries.

***) 2004, 2005, 2007, 2008 Prognosis, 2009 Forecast.

Source: EUROCONSTRUCT/ ifo-Schnelldienst 15/2003, ifo Institut (Conference in Funchal/Madeira).

Reasons for individual geographic behaviour may be for example: interest or mortgage rates, general local political and economic conditions (i.e. unemployment). The above table shows that the total number of new homes in Western Europe has changed remarkably over the past ten years (plus 19%). Starting from a low basis, the increase has been even more significant for Eastern Europe (63%). Overall the increase is 22%. A closer look at the large markets reveals that in Germany the number of new homes built has decreased by almost 42%, but for France the figure increased by 25%. The number of new homes in Great Britain and Italy also increased. The change in Great Britain is 26%. The corresponding figure for Italy is 64% while the increase in Spain was 80%.

Table 54: Furniture Manufacturing in Germany

Furniture Manufacturing in Germany

Year	Germany*) in total	
	No. of Firms*)	Sales in Million Euro
1992	16,341	21,614
1994	13,171	21,221
1996	12,763	20,726
1997	12,605	20,851
1998	12,683	21,938
1999	12,696	22,757
2000	12,749	22,983
2001	12,696	19,099
2002	12,407	19,024
2003	12,124	17,585
2004	11,983	17,473
2005	11,885	17,890

*) Until 1994 taxable firms with deliveries of over 12,500 Euro per year, from 1996 over 16,615 Euro are registered.

Source: Reinbender (2005)

Germany, as one of the global leaders in furniture manufacturing, has undergone significant changes during the years 1992 to 2005. The number of manufacturers has decreased by 27% between 1992 and 2005. It would appear that after the unification of Germany, some firms have closed, possibly because of recession within the building industry or due to increased European and global competition. In general, it can be said that 27% fewer manufacturers in Germany now serve a market reduced by 17%.

The following Table 55: Structure of German Furniture Industry describes the structure of the German furniture industry with firms employing more than 20 staff. It shows that the decline in the number of furniture manufacturers as shown above, affects small business units with less than 20 employees (mostly cabinet makers and self-employed or one person firms). The reduction here of manufacturing firms is only 20% in the time period of 2001 until the year 2006.

Table 55: Structure of German Furniture Industry

Structure of German Furniture Industry 2001-2006

Manufacturing of Furniture in Total

	2001	2002	2003	2004	2005	2006	Index: 06/05 %
Number of Firms*)	1,393	1,339	1,293	1,196	1,155	1,114	-3.6
No. of Employees**)	157,412	147,547	137,233	127,328	123,294	121,198	-1.7
Employees per Firm	113	110.2	106.1	107	107	109	-
Working Hrs. ('00) p.a.	172,745	156,651	200,856	191,091	186,555	188,458	1
Wages in Mln. Euro	2,882	2,674	2,481	3,791	3,702	3,702	-
Salaries in Mln Euro	1,696	1,627	1,520	1,509	1,498	1,477	-1
Wages and Salaries per Employee per Month in Euro	2,424	2,429	2,430	2,481	2,502	2,547	1.8
Wages/hr. in Euro	16.68	16.92	19.92	20	20	20	-
Sales***) in Million Euro	22,417	20,219	19,798	20,083	21,249	22,695	6.8
Export Quota****)	17.8	18.3	18.9	20	20	21	5
Wages & Salaries in % from Sales	20.4	21.3	20.2	19	17	16	-5.8

*) Firms with more than 20 Employees

**) Including owners and unpaid working family members.

***) Sales (by invoiced totals, excl. Vat) from own manufacturing

****) Share of Export Sales from Total Sales in %.

Source: Federal Bureau of Statistics Fachserie 4, Reihe 4.1.1.

From the statistics above, one may conclude that the major force for sales in the furniture industry (the building industry in Europe) has stagnated while the local German market has experienced a decline by 25%. Consequently, whilst sales figures have remained level, the number of manufacturers has decreased. This was compensated by European market expansions, (export), in a highly competitive market which was difficult for small firms to enter and where larger firms had better opportunities. Summarising these facts, the market and the sales for German furniture manufacturers have been complex. The German furniture industry, particularly manufacturers of kitchen furniture, is known for high quality and high level prices. The share of the kitchen manufacturers in the entire German furniture manufacturing market is 5.86% by number of manufacturers and 17.98% by sales. Unlike other furniture, kitchen units are made to customers' specifications. Office furniture, mattresses and general seating accommodation, such as upholstery and chairs, are largely standardised products which may vary in colour and style.

The cost of inventory and the large variety of articles in form of different possible combinations of cabinet sizes, type and style contribute towards the main characteristics of UMTO. They incorporate highly customized manufacturing within combinations of sizes and types of front décor for a new kitchen.

Table 56: The German Furniture Industry in 2005 by Sections

The German Furniture Industry in 2005

Number of Manufacturers

Sections	Number in Total	in Percent of Total
Seating	1,448	12.18%
Office Furniture	607	5.11%
Mattresses	133	1.12%
Kitchen Furniture	697	5.86%
Other Furniture	9,000	75.73%
Total Manufacturers	11,885	100.00%

Sales Turnover in Euro

Sections	Billion Euro	in Percent of Total
Seating	2.9	16.29%
Office Furniture	2.4	13.48%
Mattresses	0.5	2.81%
Kitchen Furniture	3.2	17.98%
Other Furniture	8.8	49.44%
Total Manufacturers	17.8	100.00%

Source: Furniture, Figures, Data, Yearbook, 2005

Since the German unification in 1989, the production of kitchen furniture has experienced a significant change. From 1989 to 1994, there were constant increases. After this period, there followed years with a reduced national production output from a national market satisfaction. To compensate this decline whilst manufacturing capacities remained the same, this industry increased their international sales considerably. While the value of orders received on the domestic market has decreased by 40% during the years 1996 to

2007, the value of orders received on the international market has increased by 60%. This has lead to an overall increase of 4% for orders received during that period. The sharpest drops on the national market compared to previous years were experienced in 2001 and 2002. In terms of volume of orders received, the total decrease from 1995 until September 2007 was 22%. (See Table 57: Orders received: Kitchen Furniture Industry)

Table 57: Orders received: Kitchen Furniture Industry

Orders received: Kitchen furniture industry

	Index of Value*) (2000=100)			Change in % versus previous year		
Year	Total	National	Int'l.	Total	National	Int'l.
1996	100.6	108.0	71.4	1.3	0.7	4.1
1997	97.5	102.9	76.2	-3.1	-4.7	6.7
1998	101.9	106.5	84.1	4.5	3.5	10.4
1999	102.8	106.2	89.6	0.9	-0.3	6.5
2000	100.0	100.0	100.0	-2.7	-5.8	11.6
2001	95.3	93.1	104.0	-4.7	-6.9	4.0
2002	89.0	84.0	108.5	-6.6	-9.8	4.3
2003	87.9	81.0	115.0	-1.2	-3.6	6.0
2004	88.8	79.7	123.5	1.0	-1.6	7.4
2005	92.6	80.0	141.7	4.3	0.4	14.7
2006	102.7	88.1	159.9	10.9	10.0	12.8
2007***	104.7	83.7	186.6	3.5	-2.3	15.6
	Index of Volume**) (2000=100)			Change in % versus previous year		
Year	Total	National	Int'l.	Total	National	Int'l.
1996	110.9	118.9	79.5	-1.5	-1.9	0.9
1997	105.1	110.7	83.1	-5.3	-6.9	4.5
1998	107.7	112.3	89.8	2.5	1.4	8.1
1999	106.3	109.7	93.6	-1.3	-2.3	4.2
2000	100.0	100.0	100.0	-5.9	-8.8	6.8
2001	88.3	86.7	94.2	-11.7	-13.3	-5.8
2002	79.6	75.7	95.2	-9.9	-12.7	1.1
2003	77.6	72.3	98.3	-2.5	-4.2	3.3
2004	78.1	70.4	105.6	0.6	-2.6	7.4
2005	79.4	70.4	118	1.7	0.1	11.7
2006	87.8	77	130.1	10.6	9.2	11
2007***	86.6	70.9	148	0.1	-5.5	12.5

*) at actual prices.- **) at prices of 2000 .-***) from january to september

Source: Federal Bureau of Statistics, Fachserie 4, Reihe 2.2.

Again, the drop of volume of orders is similar to the value of orders received. More significantly, as the national or domestic market experienced a downwards trend of 40% it was leveraged by a 46% increase of the international volume of orders. This proves the previous statement of a shift in sales from the national market to more sales on the international market and general market stagnation. Interestingly the value of orders received did not drop simultaneously with the volumes.

Table 58: Kitchen Furniture Production

Kitchen Furniture Production 1990 - 2002

Year	No. of Kitchen Sold	Value of Production (000'€)	Average Retail Price per Kitchen in '000 Euro
1990	1.531	2.465	1.611
1991	1.715	2.733	1.594
1992	1.842	2.979	1.617
1993	1.964	3.272	1.666
1994	2.045	3.490	1.706
1995	1.787	3.279	1.835
1996	1.918	3.387	1.766
1997	1.928	3.317	1.720
1998	1.997	3.409	1.707
1999	2.051	3.457	1.685
2000	2.040	3.364	1.720
2001	2.056	3.292	1.602
2002*	2.001	3.125	1.562

*) Data for 2002 is provisional. - a) Calculated upon the average of 12 cabinets per kitchen

b) The Quotient of value of production and the total number of kitchen manufactured

Source: Federal Bureau of Statistics: Fachserie 4, Reihe 3.1.(2002)

Taking into consideration the general and national cost index, the above table, albeit to a small degree, accentuates this statement. The average retail price per kitchen has decreased by 3% from 1990 until 2002.

The table above and Figure 39: Revenue Development in the GKFI confirms the statements on the differing developments of the inland and export markets. In summary, this confirms that the distances to be travelled to serve a client have become longer and also more expensive.

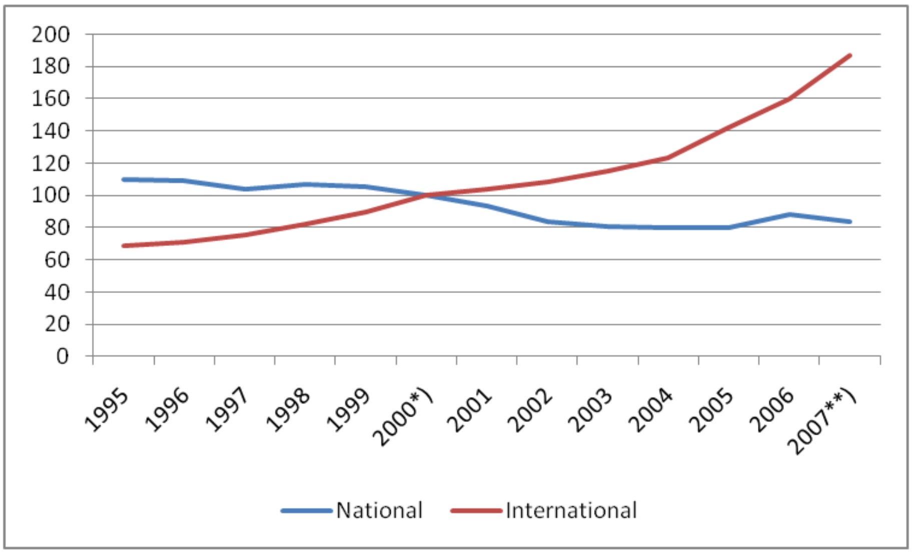

Figure 39: Revenue Development in the GKFI

This research concentrates on the distribution and delivery in the extended domestic market and neighbouring countries. This becomes evident, when one considers that the average distance to serve a national client from the centre of Germany is about 360 Km. However, as the majority of furniture manufacturers are not based at this theoretical centre point, an average distance of ± 1,200 km appears to be more appropriate, taking into account the deliveries to neighbouring countries and the return journeys. As distribution and delivery in the international markets (i.e. overseas shipping) are subject to individual local parameters of each destination, the cost of delivery is largely dependent on such local conditions.

Table 59: Index of Gross Production for Kitchen Furniture

Index of Gross Production for Furniture

Production of Kitchen Furniture: Germany Total

Year	Kitchen Furniture	
	2000 = 100	Index of Change against previous Year in %
1995	113.2	-2.4
1996	112.6	-0.5
1997	106.7	-5.2
1998	107.1	0.4
1999	106.3	-0.7
2000	100.0	-5.9
2001	89.9	-10.1
2002	81.6	-9.2
2003	78.4	-3.9
2004 1st Quarter	80.2	0.5
2nd Quarter	81.3	3.0
3rd Quarter	78.7	5.8
Jan.-Sept.	80.1	3.0

*) Development of Net-Production with exclusion of annual price increase (Original Values).

Source: Federal Bureau of Statistics

On the national and domestic side, the decline of revenue by 24% during the period of 1995 to 2004 is a dramatic trend downwards. When one considers that an average annual price increase of 1.4% took place in that period (Federal Bureau of Statistics, Wiesbaden, 2009), this means that the freight amount handled in volume and weight has experienced an even sharper drop.

The above table with the index of gross production of kitchen furniture shows the increased market requirements due to German unification and a sharp drop after market saturation during the years between 1996 and 2001.

Kitchen manufacturers faced increased national competition where price competition has become a major survival criterion: there were 115 manufacturers with 19,738 employees in 2002. In 2006 there were only 96 manufacturers with 16,471 employees left. (See Table 54: Furniture Manufacturing in Germany) This trend appears to be continuing.

IX.B.ii Production Planning for UMTO

Distribution planning and production planning are two separate processes. But with UMTO, they are always combined with one another. (Vidal and Goetschalckx, 1997) Therefore, the following information in the appendix of this thesis deals with structures of production planning and what is used for some UMTO firms like the GKFI. Incoming orders from clients can have a high degree of individualism and customising due to the selection of the kitchen models, the front design and make, sizes of cabinets, type of door-handles to be fixed and many more aspects. The following table gives only a small selection and overview of the varieties that an entire customs-built kitchen may have.

A variety of up to 477 articles or a standard of 202 may lead in combination with each other, with a selection of up to 40 or a standard 32 front décors, up to 327,758 different possibilities to fit a kitchen. The simple choice of lower, upper and corner cabinets is a part of this variety with 10,098 articles.

This shows the complexity production planning can undergo at a kitchen manufacturer. The majority of kitchen manufacturers in Germany have their production split into areas where each one may consist of a number of production lines. These areas are:

- cabinets: lower, upper, corner
- cover boards: lower and upper
- cabinets: fridge, oven, microwave, others
- worktops
- front decors
- special editions, extras
- accessories and attachments

Table 60: Total and Standard Varieties of Articles for an average UMTO

Total and Standard Varieties of Articles for an average Customs Kitchen Manufacturer				
Article Description	*Total Variety of Articles*	*Standard Total No. Of Articles*	*Total No. Of Articles in Combination with each other*	*In Combination with Standard No. Of Front Decors*
Lower Cabinets	90	51		
Upper Cabinets	110	33		
Corner Cabinets	12	6	10,098	323,136
Lower Foot Cover	28	6		
Upper Head Cover	33	9	54	1,728
Fridge Cabinets	22	11		
Oven Cabinets	17	8	88	2816
Working Boards	***125***	***46***		
Front Decors	40	32		
Total	**477**	**202**	**10,240**	**327,680**
Extras	3000	3000		

Each production set-up of an average GKFI can consist of one or more lines which are normally planned in sequence to one another and steered towards a sequential outcome, in form of consolidating the products to one complete shipment at the end of a working period.

The average time span between the date of receipt of order and delivery is approximately 4 - 8 weeks. This time taken is used to fill the volume capacity of vehicles by allocating weekdays or periods of delivery to certain geographical areas (See Section: 3.1.8 Capacitated Vehicle Routing and Figure 40: Production and Delivery-Data Allocation for UMTO) The time span is also used to fill the production capacities to their maximum. The allocation of incoming orders over a time period of 4 - 6 weeks reaches a critical point 2 weeks prior to the planned week of delivery. There, final decisions are made in order to close the process of production planning due to the critical time span for the procurement of raw materials and semi manufactured components. The identification of this critical point of closing the process of planning for production and the procurement of the necessary materials for production may vary from case to case with kitchen manufacturers. In general, however, this is one week or two weeks prior to the start of production planning. The following Figure 40: Production and Delivery-Data Allocation for UMTO will show this entire process of production and delivery date allocation in some more detail. This figure demonstrates the general principle, which this thesis refers to within the GKFI.

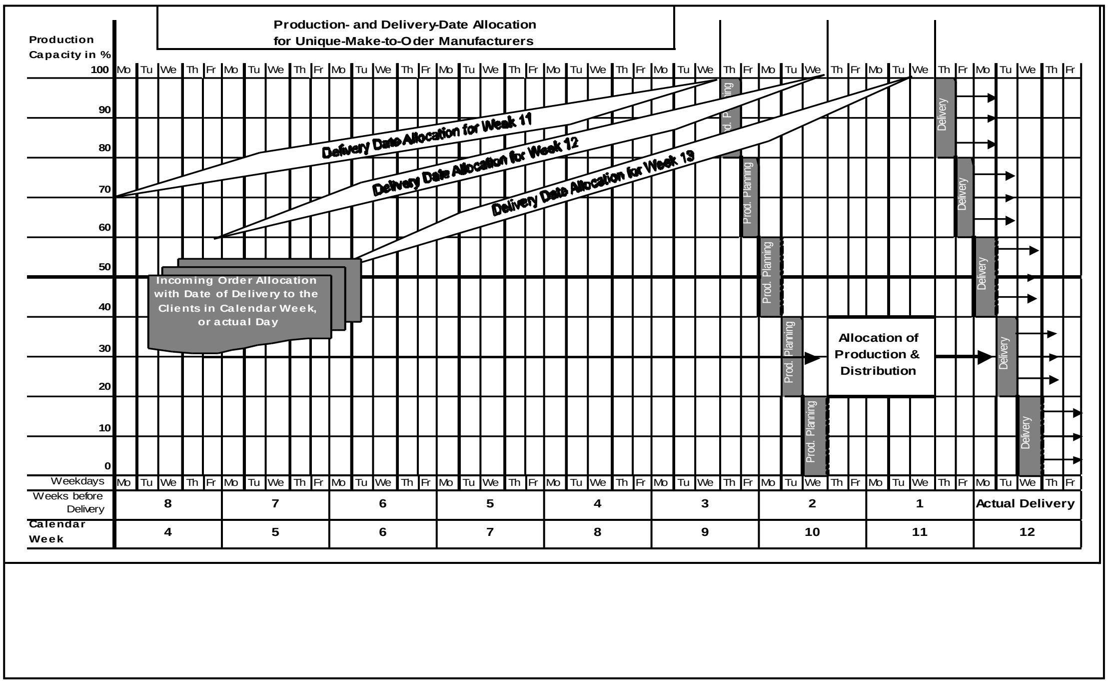

Figure 40: Production and Delivery-Data Allocation for UMTO

A custom made kitchen is produced within one day only. Once all parts are manufactured, they are packed for transport and consolidated from the different production areas or lines in the dispatch area, separated by their geographical destination areas.

IX.D Supplement Information on CD-Rom

1. Broschuere_PRACAR_v2.1_engl.pdf

   All system information of the applied simulation software from WANKO GmbH is stored as a Pdf file on the attached CD-Rom.
2. Base Data-0.pdf
3. Base Data-1.pdf
4. Base Data-2.pdf
5. Base Data-3.pdf

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