Chapter 1

1 INRODUCTION

1.1. Overview

Supply Chain Management could be defined as the practice of analysing all aspects of acquiring, storing, moving, and delivering materials from the time they are acquired through any conversion or production processes through to the time final products are used or sold. A company's supply chain may consists of geographically dispersed facilities where raw materials, intermediate products, or finished products are acquired, transformed, stored, or sold, and transportation links connecting the facilities along which products flow.

Supply Chain Management thus involves whatever an organisation does to plan, source, make and deliver its products.

There is a distinction between manufacturing facilities and distribution centres. In manufacturing facilities, physical product transformations take place and at distribution centres, products are received, sorted, put into inventory, then picked from inventory and dispatched. These products are not physically transformed.

The company's goal is to add value to its products as they pass through its supply chain and transport them to geographically dispersed markets in the correct quantities, with the correct specifications, at the correct time, and at a competitive cost.

Supply chain management crystallises those concepts of integrated business planning that have been espoused for many years by logistics experts, strategists, and operations research practitioners. Today, integrated planning is possible due to advances in Information Technology (IT).

Due to the expansion of online retail and online Business To Business (B2B) transactions, there is a great need for companies to invest in effective solutions that will aid them in ensuring that their supply chains, and particularly the distribution side of the supply chain, work as effectively and seamlessly as possible. A company will battle to be successful if it has the best products but a poor fulfilment side to its business. Without effective fulfilment, customers will not be satisfied and hence all confidence in that particular company will be lost. Many online retailing ventures have failed solely due to the fact that their fulfilment systems were not effective enough and traditional brick and mortar companies have under-optimized fulfilment systems where great improvements are possible.

Current predictions are that business-to-business (B2B) online trading will grow from US$336 billion in 2001 to US$6.3 trillion in 2005.

There is an indication that online supply chains will dominate the B2B commerce arena, swelling from 3% currently to 42% of the total B2B USA trade over the next 5 years. Specifically, five major industries – aerospace and defence, chemicals, computer and telecommunications equipment, electronics, and motor vehicles and parts – will conduct more than half of the B2B transactions online by 2004. Computers and telecommunications will become the biggest online B2B market, with sales soaring past US$1 trillion by 2005. The other four areas will each top US$500 billion by 2005. [1]

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[1] Source: Jupiter Research [24] (p. 13)

From the above statistics, this market is destined for phenomenal growth and hence there is great scope for any products or business ventures related to ensuring that this environment operates optimally.

The focus of this thesis is on fulfilment operations, specifically routing and distribution, but other factors that influence fulfilment must be taken into account.

The following diagram illustrate fulfilment within the supply chain and factors that influence it:

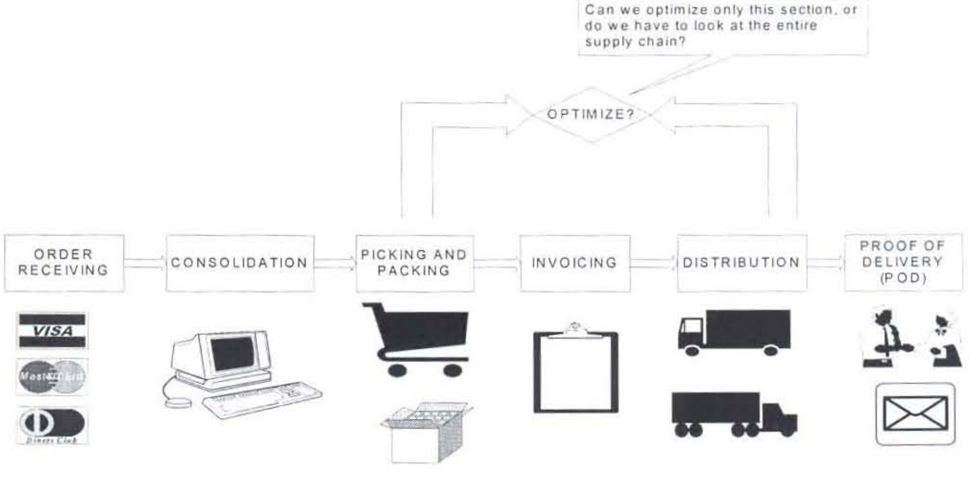

Figure 1: What part of the supply chain to optimize

The above diagram (Figure 1) depicts a typical supply chain from order receiving through to proof of delivery. The idea behind the development of this order fulfilment system is to optimise the supply chain from picking and packing through to distribution. Many packages focus entirely on the distribution side without looking at other affecting factors like picking and packing.

It is evident that there are at present a number of shortfalls within the fulfilment environment. There is thus scope for an effective, all-encompassing order fulfilment engine that addresses all problems, and ensures that all the positive aspects are maintained.

What is needed is an "order fulfilment engine" that provides companies with the tools they need to get the correct product to the correct place, at the correct time and cost, in the most optimal way – for every order and every customer. In order to develop such a fulfilment engine specific market requirements and information are essential.

1.2. Application Service Provider

There exist a need in the industry for an affordable service, which can assist with the optimization of distribution routes. Not all businesses have a large enough fleet to verify the costs associated with a fleet management system that includes optimization. Such a system normally requires a skilled operator, that add to the cost. A solution to this problem is the implementation of an optimization server in public domain. This is done by implementing a routing engine on an Application Service Provider (ASP). The ASP is a web-enabled distribution and fulfilment planning and optimization system that assist its users in the fulfilment of their customers' orders. This allows the provider to manage the system from one centralised server that allows other users to access the system via the Internet. This approach reduces infrastructure costs and speeds up the process as a powerful server instead of the computers of individual users manages the system.

Implementing software that enables you to optimize vehicle routes can result in major cost savings for a company. Unfortunately the costs associated with implementing such a system prevent companies to take this step. The environment we are proposing is an e-fulfilment engine that is a web-enabled distribution and fulfilment planning and optimization system that is hosted in the form of an ASP (Application Service Provider). This means that a company no longer hosts and maintains its own computer software, but access the system via the Internet in real-time.

The implementation of the system on the ASP results in huge saving in terms of capital-, operational- and maintenance costs. To implement a sufficient solution, the system must incorporate

- **An effective optimization engine**. This will ensure that the client receives useful results. The engine is the heart of the system and is the topic of our discussion. The requirements of the engine are motivated from the implementation method, i.e. the engine must be able to handle different scenarios because it is located in an ASP environment, which is in essence a multi-user environment.
- **The ability to handle multiple clients**. This is the goal of the system, to provide cost effective solutions to clients that cannot afford the capital layout required to implement such a system. Each client has its own set of customers and depots, which the system cannot predict. It is therefore important for the engine to be robust and effective across different input scenarios.
- **Geographic locations of the customers**. This has a cost advantage for the clients because they do not need to keep geographic data on their systems. They can benefit from experts as well as additional data that will allow for professional maps as output. They can also benefit from an up to date road network on which the optimization is done. The service provider can ensure that the network used in the routing is representing the current status in the road network, e.g. peak and

off-peak travel times, road segments that is closed due to accidents or maintenance, as well as the addition of new segments. The optimization engine operates from a time and distance matrix between customers, which imply that these matrices must be up to date with the network and the engine must be able to handle multiple time matrices.

- **A management console**. To allow the user to specify certain parameters. These parameters can include the maximum route length or time, the open and close times of the depots, etc. The optimization engine must be able to enforce these constraints.

- **An easy operation interface**. This is not in the scope of this discussion, but form part of a successful ASP implementation. This include the ability to upload and download data to and from the system, which consists of customers with their order detail that must be uploaded from the client, and routes in the form of reports or maps that must be downloaded to the client.

Implementing the VRP with additional constraints has been defined as a complex problem. Implementing the VRP with additional constraints in an environment as described above, adds to the already complex problem. The algorithm cannot be designed to function well in one specific known environment, but must be able to adapt to the environment as specified by the client. This environment, or characteristics thereof, is not known at implementation time and the algorithm must be able to produce good results independent of the specific environment. The designed algorithm must be able to perform stable and reliable under these conditions, as well as producing acceptable results.

1.3. VRP and its Origin.

Vehicle Routing Problems (VRP) are an extension to the well-known Travelling Salesperson Problem. A number of visits being given, the goal is to perform these visits with vehicles, using a set of minimal-cost tours, each of which must start and end at the same position. The VRP is like the TSP, an NP-hard problem. If no extra constraints on the capacity or vehicles is given and a maximum driving time or tour length is not given, the solution to a VRP would be a single tour. However, real-life VRP comes precisely with these kinds of constraints, or even more complex ones.

Vehicle routing problems are all around as in the sense that many consumer products such as soft drinks, beer, bread, gasoline and pharmaceuticals are delivered to retail outlets by a fleet of trucks whose operations fits the vehicle routing model. In practice, the VRP has been recognized as one of the great success stories of operations research and it has been studied widely since the late fifties. Public services can also take advantage of these systems in order to improve their logistics chain. Garbage collection, or town cleaning, takes an ever-increasing part of the budget of local authorities.

The VRP was introduced by Dantzig and Ramser (1959) more than four decades ago. There has been since then a steady evolution in the design of solution methodologies, both exact and approximate, for this problem. The VRP is an NP-hard problem that is exceedingly difficult to solve to optimality. Yet, no known exact algorithm is capable of consistently solving to optimality instances involving more than 50 customers[2] and often requires relative few side constraints.

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[2] Source: Golden et al., 1998; Naddef and Rinaldi, 2002 in [14], p. 3

Besides being one of the most important problems of operations research in practical terms, the vehicle routing problem is also one of the most difficult problems to solve. It is quite close to one of the most famous combinatorial optimization problems, the Travelling Salesperson Problem (TSP), where only one person has to visit all the customers. The TSP is an NP-hard problem. It is believed that one may never find a computational technique that will guarantee optimal solutions to larger instances for such problems. The vehicle routing problem is even more complicated. Even for small fleet sizes and a moderate number of transportation requests, the planning task is highly complex. Hence, it is not surprising that human planners soon get overwhelmed, and must turn to simple, local rules for vehicle routing.

In the m-TSP problem, *m* salesmen has to cover the cities given. Each city must be visited by exactly one salesman. All salesmen start from the same city (the depot) and must end their journey in this city again. We now want to minimize the sum of distances of the routes. The VRP is the m-TSP where a demand is associated with each city, and each salesmen/vehicles has a certain capacity (not necessarily identical). The sum of demands on a route cannot exceed the capacity of the vehicle assigned to this route. As in the m-TSP we want to minimise the sum of distances of the routes. Note that the VRP is not purely geographic since the demand may be constraining. The VRP is the basic model for a large number of different vehicle routing problems.

Many new side constraints have been added to meet real life needs. If we add a time window to each customer in the VRP we get the vehicle routing problem with time windows. In addition to the capacity constraint, a vehicle now has to visit the customer within a certain time frame. The vehicle may arrive before the time window opens. It is not allowed to arrive after the time window has closed.

Some models allowed for early or late servicing but with some form of additional cost or penalty.

1.4. Success of automated methods

Researchers often use models exhibiting some, but not all of the characteristics of real-world problems in order to test and evaluate their ideas.

The Vehicle Routing Problem (VRP) is no exception. The class of Vehicle Routing Problems is an intensive research area because of its usefulness to the logistics and transportation industry. For distribution companies, the transportation cost is the perfect target. Toth and Vigo (2002) (in Cordeau and Laporte [14], (p. 3)) report that the use of computerized methods in distribution processes often results in savings ranging from 5% to 20% in transportation costs. It is estimated that distribution costs account for almost half of the total logistics costs and in some industries, such as in the food and drink business; distribution costs can account for up to 70% of the value added costs of goods. This share has experienced a steady increase, since smaller, faster, more frequent, more on time shipments are required as a result of trends such as increased variability in consumer's demands, quest for total quality management, near-zero inventory production and distribution systems, sharp global-size competition.

1.5. Problem Environment

Knowledge of the problem environment can assist in developing a more effective algorithm. The problem environment consists of the constraints imposed on the problem, the input data that we have to work with and the objective function to minimise on.

This thesis considers a set of additional constraints added to the basic VRP. Although the ASP environment allow flexibility for the client to use these constraints or not, the design does implement a different method for each possible combination of constraints. The design treats the omission of a constraint as a simple implementation of the constraint, e.g. if the client does not have heterogeneous fleet, the scenario can still be executed because homogeneous fleet is a subset of heterogeneous fleet. Thus a client with homogeneous fleet has a special case of the heterogeneous fleet problem. A client with single time windows has a special case of the multiple time windows problem. This implementation of a solution for an ASP ready algorithm will not include pre-processing of data to determine such special cases, but the guidance algorithm will handle the effectiveness of the algorithm.

Working in the ASP environment results in an unpredictable data environment. The input can differ from client to client. The objective of this study is to develop a solution that can operate in such surroundings. The thesis will provide a method to solve the problem efficiently, and is the first step towards providing a solution in the ASP environment that is flexible enough to provide a feasible solution. Although the primary goal of the ASP is to provide an affordable solution to the South African market, we cannot limit the input data efficiently. We can define the following basic scenarios:

- Short hauls with time window complexity –
- Short hauls with weight restriction
- Long hauls with time window complexity
- Long hauls with weight restriction
- Random located stops
- Cluster located stops

We must also take into account the driving conditions between the stops. The goal is to provide the algorithm with as much as possible data that simulates the practical environment. We simulate the travelling between stops with different travel times depending on the time of day, i.e. simulating peak and off-peak travel times.

1.6. Summary

Practical Vehicle Routing Problems come with additional constraints; for example, multiple capacity constraints can be expressed in several units and dimensions (weight, volume, length, number of pellets, etc.). Some problems involved constraints where the total capacity of the vehicle cannot be used; instead, the loading after vehicle must follow specific rules or legislation. This is for example the case in Europe with oil tanks.

The Application Service Provider environment allows the sharing of data and utilities via the Internet. This results in a cost-effective way to implement utilities that require specialized data and procedures. For a routing engine to function in this environment, it must be stable and flexible, and be able to handle the diversity of requests from multiple clients.