INTER- AUCTION TRANSPORT OPTIMIZATION
IN FLORICULTURE INDUSTRY

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ABSTRACT

INTER- AUCTION TRANSPORT OPTIMIZATION
IN FLORICULTURE INDUSTRY

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This study aims to improve transportation held between six auction centers, Inter-Auction Transportation, of FloraHolland. FloraHolland serves ninety eight percent of the Dutch market and is the largest auction in floriculture industry. The company wants to give the best sale opportunities with the costs as low as possible and this is the main initiative of this study. In this line of thought, FloraHolland wants to have a improvement on its current routing and scheduling mechanism. Exact models do not work due to the complexity and the size of the problem. Therefore, we developed a two-stage approach specific to this study. With this approach, we split exact approach into two, a mathematical model followed by a heuristic. In the exact approach, trucks are routed and scheduled at the same time. On the other hand, our solution approach first determines most efficient routes to be followed with Cycle Assignment Model and then, with Scheduling Heuristic, trucks are assigned to the routes, so within day transportation is planned in detail. Overall, each stage of this approach works in harmony and brings good solutions in a short CPU time.

Keywords: Floriculture transportation, inter-auction transportation, vehicle routing, time windows, cyclic routes

ÖZ

ÇİÇEKÇİLİK SEKTÖRÜNDE MÜZAYEDELER ARASI TAŞIMA OPTİMİZASYONU

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Bu çalışmada FloraHolland’ a ait altı müzayede merkezi arasındaki çiçek taşımacılığının iyileştirilmesi amaçlanmıştır. FloraHolland, Hollanda’daki marketin yüzde doksan sekizine sahip, çiçekçilik endüstrisindeki müzayedelerde rol gösteren dünyanın en büyük şirketlerindendir. Söz konusu şirketin en iyi satış imkanlarını en ucuz maliyetle sunmak istemesi bu çalışmanın başlatılmasındaki en büyük nedenlerden biridir. Bu amaçla FloraHolland mevcut rotalama ve çizelgeleme sisteminde bir iyileşmeye gitmek istemektedir. Problemin karmaşıklığı ve büyüklüğünden dolayı kesin çözüm yaklaşımları bu problem için çalışmamaktadır. Bu nedenle, bu çalışmada probleme özgü iki aşamalı bir çözüm yaklaşımı geliştirilmiştir. Kesin çözüm yaklaşımı ikiye ayrılarak birbirini takip eden bir matematiksel modelle bir sezgisel yöntem geliştirilmiştir. Kesin çözüm yaklaşımında kamyonlar eş zamanlı rotalanıp çizelgelenirken, bizim çözüm yaklaşımımızda Döngü Atama Modeliyle en verimli kullanılabilecek rotalar belirlenirken, Çizelgeleme Sezgisel Yönteminde kamyonlar rotalara atanarak günlük çizelge oluşturulmuştur. Çözüm yaklaşımının tamamına bakıldığında, önerilen matematiksel modelle sezgisel yöntemin uyum içinde çalışarak kısa zamanda iyi sonuçlar verdiği gözlenmiştir.

Anahtar Kelimeler: Çiçek taşımacılığı, müzayede merkezleri arası taşımacılık, araç rotalama, zaman pencereleri, döngüsel rotalar

To Mom, Dad and Sis

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TABLE of CONTENTS

ABSTRACT……………………………………………………………………iv
ÖZ…………………………………………………………………...…….vi
ACKNOWLEDGEMENTS……………………………………………….........ix
TABLE OF CONTENTS…………………………………………….....……xi
LIST OF TABLES……………………………………………………….….. xiii
LIST OF FIGURES………………………………………………………...xiv
CHAPTERS
1.INTRODUCTION 1
1.1 Motivation 2
1.2 Company Description 4
1.3 Logistics Flows in FloraHolland 7
1.3.1 Inter-Auction-Transportation (IAT) 8
1.4 Data Analysis 11
1.4.1 Daily Level Analysis 11
1.4.2 Within - Day Analysis 14
1.5 Project Scope & Description 16
2. LITERATURE REVIEW.. 18
2.1 Vehicle Routing Problem with Pick-up and Delivery (VRPPD) 20
3. PROBLEM DEFINITION and MATHEMATICAL FORMULATION............... 24
4. SOLUTION APPROACH 33
4.1 Cycles: Paths between Locations 35
4.2 Flow-Cycle Assignments 38

4.3 Cycle Assignment Model 39
4.4 Scheduling Heuristic 43
5. IMPLEMENTATION 56
6. CONCLUSION and FURTHER RESEARCH 72
REFERENCES 75
APPENDICES
A. IMPRESSION of FLORAHOLLAND 78
B. INTER-AUCTION TRANSPORT SCHEME 79
C. DISTRIBUTION PLOT 80
D. NUMBER of VARIABLES 81

LIST OF TABLES

TABLES

Table 1 - 1: Minimum, maximum and average inflows of 6 auction locations 12
Table 1 - 2: Minimum, maximum and average outflows from 6 auction locations.. 12
Table 3 - 1: Current rates charged by transporters …………………………………... 28
Table 3 - 2: Variables used in calculation of transportation cost in the proposed system... 29
Table 4 - 1: The shortest cycles …………………………………………………… 37
Table 4 - 2: Amounts of flows demanded till 06:30 for the example problem.......... 52
Table 4 - 3: Flow - cycle assignments for the example problem 53
Table 4 - 4: Amounts of flows demanded till 07:00 for the example problem.......... 54
Table 4 - 5: Flow - cycle assignments (updated version) for the example problem .. 54
Table 5 - 1: Number of tours allocated to the cyclic routes for the sample day …... 57
Table 5 - 2: Number of tours allocated to the legs of a sample cycle 59
Table 5 - 3: Number of trucks started a new tour (KOA) 60
Table 5 - 4: Number of trucks continuing their routes (KOA) 61
Table 5 - 5: Number of trucks started a new tour (Supply, Connect, and Import) 62
Table 5 - 6: Number of trucks continuing their routes (Supply, Connect, Import).... 63
Table 5 - 7: Computational time (in seconds)... 66
Table 5 - 8: Cost Comparison (Euros) 67
Table 5 - 9: Maximum number of trucks used.. 68
Table 5 - 10: Distribution of cycles over sample days.. 69
Table 5 - 11: The number of cycles: Cycle assignment model vs. Scheduling Heuristic 70

LIST OF FIGURES

FIGURES

Figure 1 - 1: Location of auction centers 5
Figure 1 - 2: An impression from auctions at FloraHolland 6
Figure 1 - 3: Maximum, minimum and average values of KOA flow between auction locations throughout 2009 13
Figure 1 - 4: Comparison of average values of a sample month................................ 14
Figure 1 - 5: Transaction amounts between two auction centers 15
Figure 4 - 1: Highways between 6 auction locations ………………………….... 36
Figure 4 - 2: A sample cycle representation.. 38
Figure 5 - 1: Representation of a sample cycle …………………………………… 58
Figure 5 - 2: Distribution of KOA flow among sample days..................................... 64
Figure 5 - 3: Distribution of Supply, Import and Connect flows among sample days 65

CHAPTER I

INTRODUCTION

FloraHolland (FH), serving ninety eight percent of the Dutch market, is the largest auction in floriculture industry in the world. Each day, a huge number of transactions take place between approximately 9,000 growers and 3,500 buyers. Due to this enormous size of business, freight transportation plays an important role for the company (Platform Agrologistiek, 2009). In general, freight transportation is a critical activity in the supply chain. It is responsible for more than 50% of the total logistics cost, so draws considerable interest in today's competitive world (Braysy et al. 2005). An important factor to decrease transportation costs is the efficient utilization of resources (such as transportation capacity). At operational level, this underlines the importance of routing and scheduling problems for the daily activities of a company.

Transport flows within FloraHolland consist of the transshipment between different parties: Between supplier - auction place and between auction place-buyer are two of them. Moreover, there are transshipments between different auction locations of FloraHolland, to be called Inter-Auction transport (IAT). IAT mainly concerns with the flow of products transported to more than one auction center during sales processes of FloraHolland. Efficiency of this type of transport is highly important for the company. When the product is transported to more than one auction center, travel time increases. As the product is perishable, longer transport times lead to a decrease in product quality. With the aim of offering the best sales opportunities at the lowest possible costs (FloraHolland, 2009), FloraHolland wants to improve its current structure of IAT. Moreover, in the current situation, there is a lack of standardized system for the organization of IAT. With a central application, it is believed that there will be an increased visibility and traceability in the transport activities. Hence, this will lead to a more responsive Supply Chain, eventually.

In this line of thought, a project has been started at FloraHolland. It is aimed to organize IAT in a more efficient and desired way. In this study, a two-stage-approach is constructed for this problem. Firstly, an aggregate capacity is determined to handle transportation in the daily level. Daily routes between auction locations are determined with Cycle Assignment model. Afterwards, within day transportation is planned in detail with a construction heuristic. In this planning, allocation of the total capacity to the possible routes is made.

1.1 Motivation

The project initiated with FloraHolland grounded in the dual research projects done with Erasmus University Rotterdam (EUR) and Eindhoven University of Technology (TU/e). In this dual project, the role of EUR is to investigate whether current organization of Inter-Auction Transport (IAT) is feasible and desirable in the floriculture supply chain. Accordingly, Jonkman (2010) evaluated the business opportunity in changing the organization of IAT, taking into account both the economical, sustainability and organizational consequences for those parties involved. On the other hand, the role of TU/e is to focus on the issue of designing a new (conceptual) model that can optimize IAT of FloraHolland to facilitate its supply chain partners. Dat (2011) looked into the question how IAT should be organized and managed in order to cluster, collaborate, connect and manage the processes on and between the marketplaces of the floricultural green-ports.

Being the continuation of these two projects, the current project aims to develop models to find the optimal (near optimal) way of organizing IAT in a timely manner, in line with the mission & vision statement of FloraHolland and its supply chain partners. Accordingly, solution techniques, i.e. models and algorithms, are to be introduced in terms of time, cost and environment, with the necessary system inputs given.

There is a huge volume of products carried between auction places of FloraHolland, even if the transactions realized within only one day are considered. For this reason, an efficient organization of transportation activities is crucial for the company. Even a small percentage of improvement in the process leads to a large amount of reduction in transportation costs and this can be considered as a motivation. Moreover, there are other motives triggering the project which are presented below.

First of all, it is not right to say that the current organization of IAT is totally inefficient. Every transport company, working with FloraHolland, coordinates its activity by itself. Therefore, freight transport within FloraHolland is composed of sub–optimized parts. For this reason, a need of coordinating decentralized patterns appears.

Second, it is important to organize IAT in order to prevent inefficient use of resources, such as oil and truck drivers. There are expected shortages in both resources. As it is known, oil is a scarce resource. The same thing also holds for high quality truck drivers. For FloraHolland, it is important to have qualified employees as the product needs to be transported with care. Therefore, having effectively organized IAT is needed not only to lessen existing costs but to prevent any shortfalls in terms of resources.

Third, with all other transport flows outside FloraHolland (such as private cars, public transport vehicles, and various freight transport companies) involved, traffic congestion occurs. This high volume of traffic not only increases travel times, but also lead times. Moreover, increase in congestion might lead to higher transportation costs due to extra charging, with the aim of lessening the traffic density. This also brings us back to increased costs. Besides, from environmental point of view, an increased flow of traffic harms the environment due to air pollution as toxic gases are released from vehicle motors into the atmosphere.

The last, but not the least, Ministry of Transport in the Netherlands plays as a pushing force for the initiation of the project. It is aimed to have the Netherlands be the top logistics country in the world. In this aspect, FloraHolland plays an important role due to its huge business within the Netherlands. In this direction, it takes place within the Dutch Institute for Advanced Logistics (Dinalog) and aims to develop scientific knowledge on advanced logistics systems. Moreover, with the realization of the project, so with a more coordinated mechanism in its logistic activities, it is expected to have a great contribution to achieve the desired situation in a shorter time.

Before giving detailed information about the project, it is important to understand the organization and its working mechanism. Therefore, the next section is devoted to a brief introduction of FloraHolland.

1.2 Company Description

> "The Netherlands is the heart of the international floriculture sector. It has an intricate and high-quality network of companies, ranging from breeders and growers to sales experts and export firms, representing every aspect of the business. The Netherlands is the place where supply and demand come together, from Europe and beyond.
>
> FloraHolland flower auction plays a key role in the Netherlands, land of Floriculture where its position as marketplace fulfils the role of matchmaker, intermediary and knowledge center." (FloraHolland, 2011)

FloraHolland is a flower auction company in the Netherlands and serves as an intermediary service between thousands of suppliers and customers each day. Figure1 in Appendix gives an impression from FloraHolland. Being a primary cooperative, the company is owned by the suppliers of floricultural products. Out of approximately 9,000 suppliers that are involved in flower auction, almost 5,000 of them are members of the company and supply various kinds of flowers to 3,500 customers each day.

As described in its mission and vision statement, FloraHolland is a non-profit service providing company. It is aimed to offer the best sales opportunities to the members, so the company wants to preserve its strong market position. Providing the lowest possible costs is a critical factor to attract the potential customers and keep the existing ones. Therefore, many improvement projects are carried out throughout the company.

FloraHolland is located at six different locations in the Netherlands: Aalsmeer, Naaldwijk, Rijnsburg, Venlo, Bleiswijk and Eelde. Whereas Aalsmeer, Naaldwijk and Rijnsburg mostly serve the global market; Bleiswijk, Eelde and Venlo are regional locations and continue to operate within the respective regions. Figure 1-1 is a map of the Netherlands that shows the locations of these auction centers.

Figure 1 - 1: Location of auction centers

The main selling mechanism used in FloraHolland is known as “Dutch auction”, a type of auction where the auctioneer presents decreasing prices until some participant is willing to accept the auctioneer's price, or minimum acceptable price is reached. During the auction process, the products are driven into the auction room on a chain track. Every day, a total of 39 auction clocks are in operation at 6 different auction centers located in the Netherlands. Figure 1-2 gives an impression of the auctioning process at FloraHolland.

Figure 1 - 2: An impression from auctions at FloraHolland

Floricultural products can also be directly bought through the intermediary service of FloraHolland, FloraHolland Connect. This service is especially used by buyers that demand a steady flow of constant-quality, constant-priced products.

FloraHolland operates on a daily basis and 125,000 auction transactions are realized each day. This number can be translated into 12 billion cut flowers and 1.3 billion plants a year. It is possible to say that 1 out of 9 trucks in the Netherlands carries FloraHolland products, which is an indicator of this huge organization. There are about 80 transportation companies that work in collaboration with FloraHolland for collecting and transporting floriculture products between the six auction centers.

The logistics flows in FloraHolland take place at the heart of the project. Therefore, it is important to give a clear definition of the flows that are involved in the problem context. The following section is devoted to logistics flows at FloraHolland.

1.3 Logistics Flows in FloraHolland

Logistics flows within FloraHolland exist between different parties: Between supplier - auction place and between auction place-buyer are two of them. Moreover, there are transshipments between different auction locations of FloraHolland, to be called Inter-Auction transport (IAT). IAT mainly concerns with the flow of products transported to more than one auction center during sales processes of FloraHolland. IAT is exactly the focus of this project. Transportation of products to any other places except auction centers are left out of scope as it falls in the liability of the respective party.

1.3.1 Inter-Auction-Transportation (IAT)

Although they are not physically separated, four different types of IAT can be differentiated based on their origin timing within FloraHolland.

- Flows before sales
    - Clock Flow: Supply from the Netherlands and the EU
    - Import Flow: International Supply from outside the EU
- Connect Flow, which is independent from auction sales
- KOA Flow: Flows after sales

Clock Flow: Supply from the Netherlands and the EU

A grower has the option of selling his products on several auction centers, with the motivation that prices are different between the centers or that important buyers are located at a specific auction center, to which the grower has to supply his supplies.

In the current procedure, growers transport their products to several auction places either by their own ways or by using a collective floriculture transporter. Therefore, unless grower chooses to transport the products by its own, it is necessary to transfer them from the auction center where the grower makes the delivery to the destined auction center. Clock flow is the flow occurred due to transport of products to the auction centers where they will be sold.

In the near future, with the effect of virtualization processes, suppliers will not need to send the products to the location that the auction takes place, but only to the nearest auction center. Therefore, the products will be transported to the buyer without being sent to the auction place. By this way, this type of flow will be increased in amount and inefficient flows between auction places will be prevented.

For this type of flow, the origin, amount of products and destined auction location are known at the moment when the grower sends an Electronic Delivery Form (EAB). The EAB must be available before the products arrive at any auction location.

The supply of products roughly has three peaks during the day: between 11:00 and 16:00, between 20:00 and 23:00 and between 01:30 and 03:00.

- **<u>Import Flow: International Supply from outside the EU</u>**

Products from outside the EU are transported to the Netherlands by air or sea freight. Aalsmeer, Naaldwijk, Rijnsburg and Venlo are four main auction centers where imported products arrive.

After Import Handling (IH) departments receive the products from growers outside the European Union, they transfer them to their destined auction center for selling process after relevant processing is done. Import Flow occurs due to transport between Import Handling (IH) departments and destined auction location of the products.

These products are accompanied by an Electronic Delivery Notice (EDN), which is sent on beforehand by the grower or entered by an IH employee. The EDN contains information on the final destination of the products. With the EDN available, in most cases twelve hours before the actual arrival of products, IH can start planning its processing activities.

Imported products can be transported between the auction centers the entire day, depending on the time IH finishes processing. However, this type of IAT is mostly carried out in the afternoon and evening. As most products are destined for sale on the clock, the deadline for delivery at their destined auction is also 04:00.

- ***<u>Connect Flow</u>***

Products that are sold via the intermediary service FloraHolland Connect are directly sent to the box of the buyer, but usually have to be transported to another auction as the buyer is located in a different auction place than the place where products are supplied. This type of transport is called Connect Flow due to the name of Intermediary service in FloraHolland.

Products sold through Connect also have to be supplied to the auction centers with an Electronic Delivery Form (EAB), which contains the name and location of the buyer. With EAB, the origin, destination and the number of products, so all necessary information for transporting the products are known.

Connect deals are made and its transport is carried out usually during the day. However, many exporters order products through Connect in the morning, so they want to receive them during noon.

- ***<u>KOA Flow: Logistics Flows after Sales</u>***

Incoming supplies are divided in two flows: Clock supplies and Connect supplies. Although the amount of products sold via Connect is non-negligible, most of the products are sold through the auction clocks. Buyers can buy on the clock by being physically present at the auction, or real-time via the internet, using a service called Remote Buying (Kopen Op Afstand - KOA).

Via remote buying services, customers can buy products from different auction centers. While buying, they indicate the location their products should be distributed to, so these products have to be transported to the auction place where the buyer's box is situated. The flow realized due to this kind of transport is called KOA flow due to the name of remote buying service in FloraHolland.

This flow occurs during and after the auction. After auction, products shoule be sent to the buyer within two and a half hours. This type of IAT starts at about 07:00 and last to the early afternoon.

A flow diagram that shows the points of time where different IAT flows come out can be seen in Figure 2 in Appendix.

When the characteristics of four IAT flows are analyzed, it is seen that the most differentiating factor between those flows is criticality of the delivery time. While, in KOA flow, sales are realized without any anticipation and the product should be delivered to the buyer within a short period of time, time considerations are more relaxed in other types of flows. For example, in Supply flow, products should be delivered to the destined auction location before 4AM of the auction day. Therefore, in our solution, KOA flow and other types of flows should be treated differently.

After giving detailed information about logistics flows at FloraHolland, it is good to give a quantitative analysis. The following section presents the results of data analysis which gives information about the size of the auction centers and the amounts of flows between them.

1.4 Data Analysis

There are two types of variety in the amounts of flows between auction locations: between days and within days. Both are analyzed in the following two subsections:

1.4.1 Daily Level Analysis

In this section, daily flows (in term of buckets) between auction locations are analyzed. Having done this analysis, it is seen that daily flows between different locations show varieties due to the size and location of each auction center. For example, average flows to/from Aalsmeer, Naaldwijk or Rijnsburg are larger compared to other flows as they are big auction locations within FloraHolland and most of the transactions are realized in these centers. Minumum, maximum and average values of both inflows and outflows realized in six auction locations are given in Table 1-1 and Table 1-2, respectively.

Table 1 - 1: Minimum, maximum and average inflows of 6 auction locations

FLOW-IN	Min	Max	Avg
A	63,755	445,062	212,299
B	6,305	90,072	29,679
E	7,231	72,011	33,792
N	48,020	281,293	145,665
R	20,791	154,405	63,688
V	1,096	73,248	25,060

Table 1 - 2: Minimum, maximum and average outflows from 6 auction locations

FLOW-OUT	Min	Max	Avg
A	32,317	254,239	108,156
B	11,084	100,142	46,836
E	259	20,758	5,353
N	32,217	317,427	131,999
R	12,013	91,241	36,407
V	1,608	31,940	11,311

Moreover, maximum, minimum and average values show that the flow throughout a year is not stable. As an illustration, maximum, minimum and average values of KOA flow between auction locations throughout 2009 is shown at Figure 1-3. It can be easily seen that these values show high varieties.

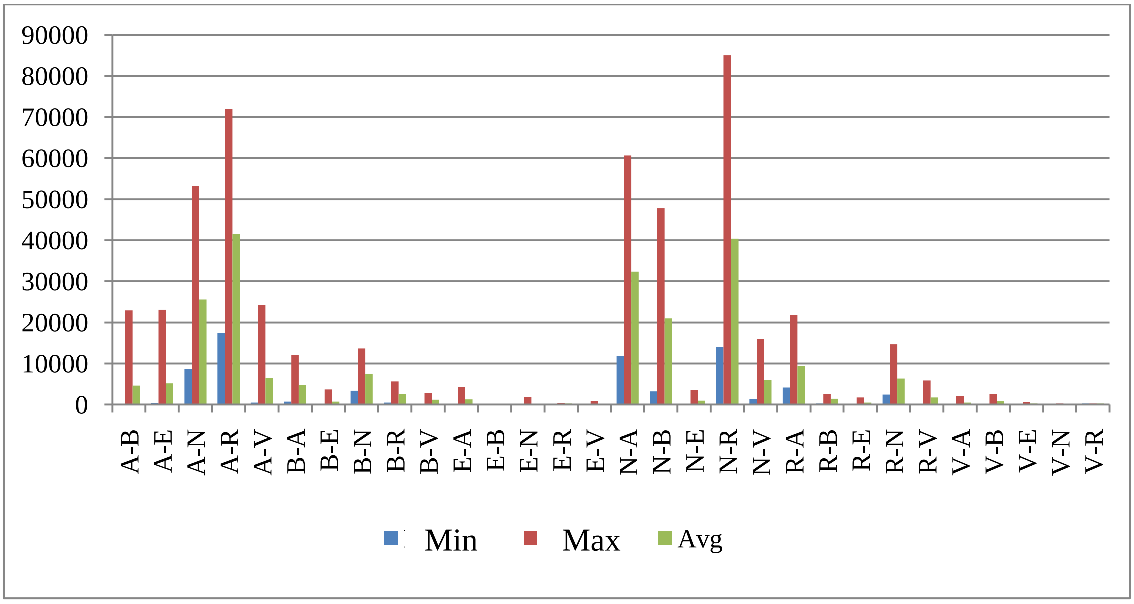

Figure 1 - 3: Maximum, minimum and average values of KOA flow between auction locations throughout 2009

In this graph, each letter represents a specific auction location. The representation "A-B" shows the amount of flow transported from auction location Aalsmeer to Bleiswijk.

High variety in the amounts of flows is also verified by using Individual Distribution Identification tool of Minitab. Probability plots are drawn for the data of KOA flow in 2009. It is shown that hardly any flow adequately fits to a specific distribution as the related p values are very small. Please see Figure 3 in Appendix for a sample of these plots.

Variety in the data can be explained by seasonality factor. Considering this, the data is divided into seasons and months, and then probability plots are drawn again. When the sample month A is taken into account, it is seen that most of the flows fits to normal.

Although data does not show high variety within a month, it is not possible to say that it'll be steady over different years. When data of 2010 is analyzed for month A, it is seen that most of the flow are normally distributed like 2009. However, the amounts of flows change from year to year. Comparison of average values of a sample month over years can be seen in Figure 1-4.

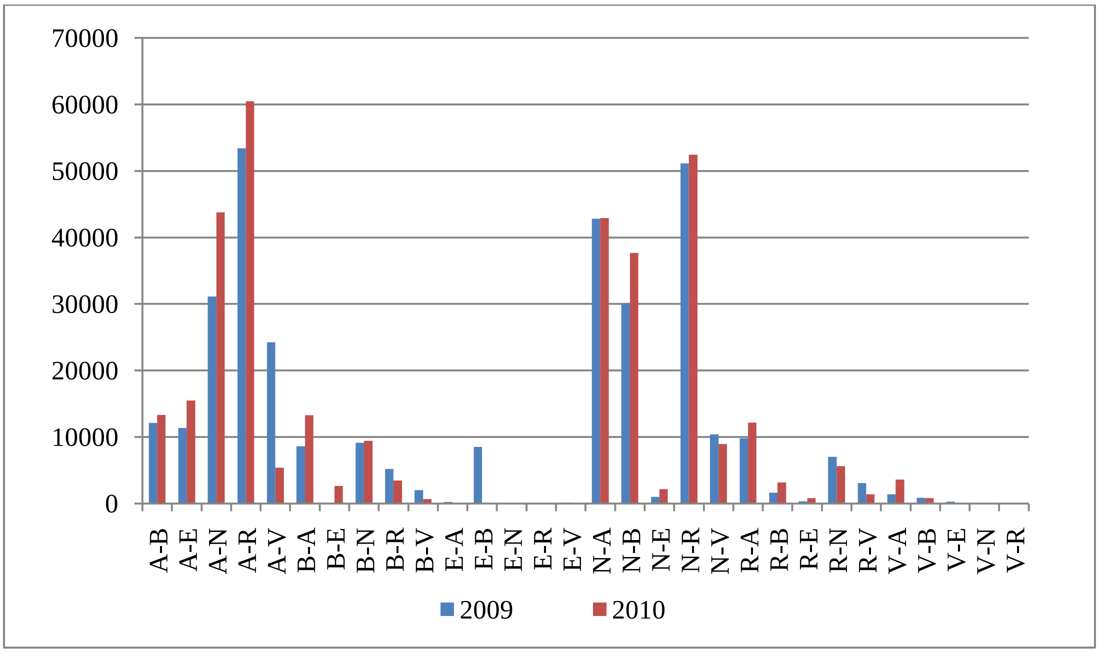

Figure 1 - 4: Comparison of average values of a sample month

1.4.2 Within - Day Analysis

In this section, within-day flow between auction locations is analyzed. The data belong to the year 2010. This analysis is only made for the flow named KOA as we know timing of only this kind of flow. However, it is not a problem as KOA is the only flow realized as a result of auctioning process and the most critical one with respect to timing issues.

The amounts analyzed in this section belong only to the one-way flow realized between two pre-determined auction locations, such as from location A to N. It is seen that sales is realized within a few hours and within day flow between locations decreases from the beginning of auctioning process towards the end. About 40% of the sale is realized between 6AM and 7AM, on average. It decreases to 25%, 17%, 14% and 4% in the following hours. In overall, it is safe to say that more than half of the sales are made at the first half of the auction. However, these rates and also the amounts show some variety between days. To illustrate, the total amount sold during 8AM – 9AM between two predetermined points throughout 2010 can be seen in Figure 1-5.

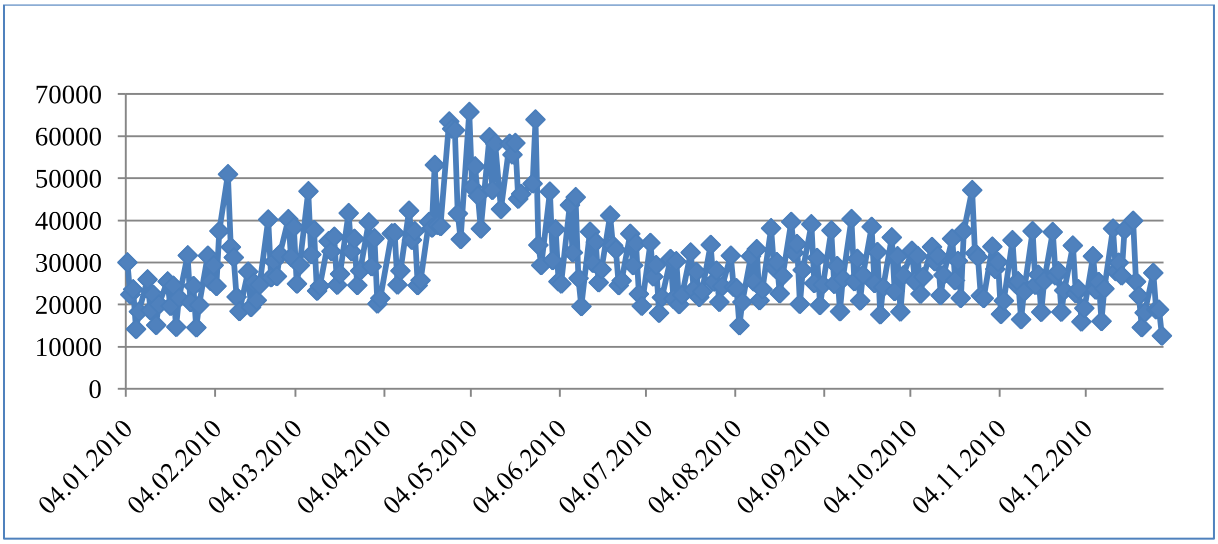

Figure 1 - 5: Transaction amounts between two auction centers

1.5 Project Scope & Description

Every day, a huge flow of transportation is realized between 6 auction centers of FloraHolland. About 80 floriculture transporters collect and transport flowers and plants between these centers.

With the aim of offering the best sales opportunities at the lowest costs, FloraHolland wants to analyze and improve its current Inter-Auction Transport (IAT), the flow of products transported to more than one auction center during sales processes. Therefore, IAT is exactly the focus of this project. Transportation of products to any other places except auction centers are left out of scope as it falls in the liability of the respective party.

As floriculture products are perishable, total transportation time is also a critical factor to the company. Products should not be kept for long hours due to quality considerations. Therefore, time limitations should be given great attention during planning and it is the critical factor to differentiate different types of IAT. Although the flow KOA has really strict timing considerations, such that the products must be delivered to the buyer within 2.5 hours after sales, other types of flows are more relaxed in this aspect. Import and Clock flows should be delivered to the final destination before 4 AM on the day the product is to be auctioned. Connect Flow should also be delivered to the buyer in the short notice, but timing limitations of this flow is more relaxed compared to KOA and the amounts are more stable, so that it is easier to organize it.

The goal of this project is to develop models to find the optimal (near optimal) way of organizing IAT in a timely manner, in line with the mission & vision statement of FloraHolland and its supply chain partners. In order to do that, efficiency of this transport should be increased. Balancing loads carried between locations is necessary to increase truck utilization; therefore, routing problems should be given attention. Scheduling of trucks is also critical due to the restricted delivery time to the buyer. In the light of this information, routing trucks between auction centers and their scheduling are given importance in our methodology. This type of problems can be modeled as Vehicle Routing Problem with Time Windows. However, due to the size and complexity of this problem, exact models do not work. Accordingly, we’ve developed a two-stage approach specific to this study. For the first stage, we constructed a mathematical model to find the most efficient routes to be followed for the whole day. Next, we formed within-day schedules with a heuristic in the second stage. As a result, we have proposed an approach which fulfills all necessary requirements necessary to be implemented in the problem.

The rest of this report is organized as follows: First, the related literature is discussed in Section 2. Then, in Section 3, problem definition and mathematical formulation is given. Section 4 is devoted to the original solution approach on this problem. The report continues with Section 5, the Implementation. Finally, the report is concluded with Section 6, Conclusion and Future Research.

CHAPTER II

LITERATURE REVIEW

Constituting more than half of the total logistics costs (Braysy and Gendreau, 2005), freight transportation is one of the most critical activities in the supply chain and draws considerable interest in today's competitive world. One of the most important factors to achieve decrease in the transportation cost is better utilization of resources such as vehicles, which underlines the importance of routing and scheduling problems.

The Vehicle Routing Problem (VRP) is a generic name given to the combinatorial optimization problem that seeks for the minimum-cost vehicle routes between a center and a number of geographically dispersed points (cities, stores, warehouses, customers etc). The routes must be determined in such a way that all routes start and end at the center, each point is visited only once by exactly one vehicle, and the total demands of all points on one particular route must not exceed the capacity of the vehicle.

Being known as a central problem in the fields of transportation, distribution and logistics, VRP is not only one of the well known problems of operations research in practical terms, but also it is one of the most difficult problems to be solved. Even for a small number of customers, the planning task is highly complex. It falls into the category of NP Hard, so the computational effort required solving this problem increases exponentially with problem size.

For problem instances with few nodes, the branch and bound technique gives the best possible solution as an exact method. However, it is believed that optimal solutions to large instances cannot be found. For this reason, it is often desirable to obtain approximate solutions. Usually this is done by using various heuristic methods, which rely on some insight into the problem nature.

Usually, in real world VRPs, additional constraints should be taken into consideration. The VRPPD is an extension of the classical VRP which also takes part in a larger family of pickup and delivery problems (PDPs). While, in PDPs, it is dealt with the construction of optimal routes in order to transport goods/commodities from their origin points to their destination points, in VRP, all pickup points or delivery points are located at the depot. On the other hand, in VRPPD, the aim is to determine routes for vehicles originating from a given depot location in order to pick up goods/commodities from the supply points and to deliver goods/commodities to the demand points in the least costly manner (minimizing travel cost/distance/time) honoring the vehicle capacities.

Another important extension is the vehicle routing problem with time windows (VRPTW). In addition to a standard VRP, this problem involves the added complexity that every customer is served within a given time interval, called the time window.

The combination of these two VRP extensions, Vehicle routing Problem with Pick-up and Delivery and Time Windows (VRPPDTW), gives us a close representation of the problem on hand. In the problem situation, there are flows of products between 6 auction centers with all possible combinations and routing of these flows is necessary for load balancing and efficiency considerations. Each flow between 6 centers has a pick-up point, where the flow is originated, and a delivery point, where the flow is finished. Each flow has also its own timing considerations, so VRPTW extension is critical in modeling. In addition, it is necessary to expand the model to a multi-depot, where the locations are depots and dispersed through 6 auction centers in the Netherlands, and each depot has its own fleet. Therefore, it is possible to say that we should also look at Multi Depot Vehicle Routing Problem with Pick and Delivery and with Time Windows (MDVRPPDTW) in order to see what has been done up to day about this type of problems.

2.1 Vehicle Routing Problem with Pick-up and Delivery (VRPPD)

For the single vehicle version of this problem (SVRPPD), one of the first studies was made by Stein (1978) for the uncapacitated case. Later, another heuristic for the uncapacitated SVRPPD was proposed by Psaraftis (1983) with the computational experiments indicating that his heuristic performs better than Stein's heuristic on realistic size instances.

Exact algorithms for the SVRPPD were developed by Kalantari et al. (1985), Fischetti and Toth (1989), and Ruland and Rodin (1997). Kalantari et al. (1985) have presented exact algorithms for both capacitated and uncapacitated versions of the SVRPPD. Computational results on the single vehicle-infinite capacity problem indicate that the algorithm can solve problems of size 31 customers in a reasonable amount of computing time.

As most of the practical applications of the VRPPD include time restrictions, it is necessary to present a variant of the problem, VRPPD with time windows (VRPPDTW).

For the single-vehicle problem with time windows, Desrosiers et al. (1986) have proposed an exact dynamic programming algorithm for the capacitated version. Van der Bruggen et al. (1993) presented a local search heuristic again for the capacitated problem. The results were near-optimal on instances of up to 50 vertices.

A column generation method was developed by Xu et al. (2003) to address a complex pickup and delivery problem which involves a series of limitations that are commonly seen in real world logistics such as multiple time windows, capacitated heterogeneous vehicle fleet, travel time restrictions, pairing and precedence constraints. The proposed approach is capable of generating good solutions for randomly generated instances up to 200 requests in a reasonable time.

Bent and Van Hentenryck (2006) proposed a two-stage heuristic, composed of a simulated annealing algorithm and a large neighborhood search (LNS) algorithm. This heuristic has produced new best solutions on several instances with 100, 200 and 600 customers and took at most 90 minutes of computing time.

A large neighborhoods search heuristic for VRPPDTW was also developed by Ropke and Pisinger (2006a). The heuristic generally performed better than those of Bent and Van Hentenryck (2006) in approximately the same computing time.

Recently, Ropke et al. (2007) proposed a branch-and cut-and-price algorithm for VRPPDTW. In computational results, it is shown that the algorithm was able to solve some instances up to 500 requests optimally.

Although single depot version of VRPPDTW is common in the literature, it does not completely address all practical considerations. Real world problems usually include cases where the company has several depots at different locations. For example, in our case FloraHolland has six depots at different locations of the Netherlands. For this reason, Multi Depot Vehicle Routing Problems with Pick-up and Delivery and with time Windows should be checked in this literature study.

As it is expected, Multi-Depot VRPPDTW is a more challenging model to be solved than its single – depot versions. Therefore, it gets more time-consuming to solve this problem and exact algorithms get less attractable over heuristics.

One of the first studies was made by Dumas et al. (1991). A column generation algorithm was proposed. This algorithm was capable of solving instances up to 39 requests to optimality. Although the problem gets harder to be solved as the number of requests increases, this approach gave good results for larger problems except for the biggest problem of 55 requests.

Savelsbergh and Sol (1998) have developed another exact algorithm, similar to that of Dumas. The algorithm was designed to be used at a distribution company and solved many of the problems to optimality up to 30 requests.

Nagy and Salhi (2004) has proposed several heuristic for the same problem but without considering time windows. Although the heuristics provided better results than some benchmark procedures for problem instances of 50-249 customers and 1-5 depots, the gap between optimal solutions are not provided.

Sigurd et al.(2004) developed a tighter formulation based on Dantzig-Wolfe decomposition. It is demonstrated that instances with up to 200 customers can be solved to optimality with very few time windows.

Dondo and Cerda (2004) also introduced a cluster based hierarchical hybrid approach for the multi-depot version, but for VRPTW problem. A heuristic clustering algorithm was integrated into an optimization model. This approach was able to solve problems up to 25 nodes optimally. Although the approach was developed for VRPTW, their future works included extension of this approach to more difficult problems such as VRPPDTW.

An adaptive large neighborhood search algorithm was developed by Ropke and Pisinger (2006a) for the problem. The heuristic was tested on about 350 benchmark instances up to 500 requests. It was indicated that, at more than 50% of the problems, best known solutions from the literature were improved.

More recently, Sombuntham and Kachitvichayanukul (2010) proposed a Particle Swarm Optimization Algorithm and it was tested on some instances to compare with the benchmark solution. The algorithm is promising for clustered problem, but it was indicated that there is still room for improvement randomly-distributed-geographical instances.

In our study, it is necessary to handle a huge flow of products carried between 6 auction centers of FloraHolland. The products should be taken from their current auction center and sent to their destined location, so it is required to handle pickup and delivery of goods. Time windows and multiple depot characteristics are also taken into account in this study. The objective is stated as to minimize total transportation costs under all model restrictions. Hence, Multi Depot Vehicle Routing Problem with Pick-up and Delivery and Time Windows (VRPPDTW) gives the exact modeling of this problem.

In FloraHolland’s case, each sale has to be treated separately as the respective destination and travelling time differs from one to another. Consequently, the problem size gets really big as a new sale is made in each second. Even though the day is divided into 30-minute-time buckets, about 1800 request should be handled in order to solve the problem optimally. However, exact models MDVRPPDTW only works for small problem sizes, so it is known with certainty our problem can not be solved optimally. Moreover, this model is required to be solved frequently, at least once in 30 minutes. Even if the model is solved for small problem instances, it takes days to find a solution. For this reason, we conclude that existing approaches in the literature are not sufficient in this case. Therefore, alternative problem solving approaches have to be developed.

CHAPTER III

PROBLEM DEFINITION and MATHEMATICAL FORMULATION

Throughout this study, we work on improving Inter-Auction-Transportation within FloraHolland. The problem can be briefly stated as constructing a feasible trip for each vehicle to be used and scheduling so that all orders are shipped within time window restrictions at a minimum cost. At this point, the following trade-offs is observed: Delivering products as fast as possible versus utilizing trucks as much as possible to minimize cost. These trade-offs should be considered with care and the problem should be solved to optimality while satisfying all restrictive conditions. Behind this basic idea, this problem has its own features defining the parameter, constraints and variables in the formulation.

There are 6 auction centers serving FloraHolland. It is assumed that all growers leave products at the closest auction location, so they can be clustered according to its nearest auction location. Buyers, on the other hand, are mostly located within auction places as it is their own cost to transport from auction location to another place. Thus, buyer locations can also be clustered based on the auction location where their boxes are situated. For detailed information about clustering of growers and buyers by their postal code, please see Dat (2011). Therefore, it is possible to say that transportation of products is realized between these centers in different combinations and all six auction centers can be described as both pick-up and delivery points of different orders. Moreover, the depots of logistics companies are also located in these centers. At each auction location, several logistics companies have depots with different truck capacities. Therefore, six auction locations serve also as depots.

There are several types of Inter-Auction-Transport (IAT) realized between six centers. Consequently, different types of transport requests are realized at different times of the day. Restrictions due to delivery time of these requests also change depending on the type of IAT. However, it is possible to classify them into two where KOA flow is treated specially as it occurs without any anticipation of future and it has more restricted delivery time.

Products are sold in buckets, so transactions are based on the unit of buckets in the database. However, before loading to trucks, they are transferred to trolleys based on their destination points. Therefore, in the model, trolley is the smallest unit to be used in calculations. However, in database, transactions are based on the unit of buckets. Moreover, buckets vary on their sizes depending on the product. For this reason, it is necessary to find a conversion parameter for each product/bucket type. Dat (2011) has made an assumption related to this issue and calculated the average number of buckets per trolley. This assumption is used throughout our calculations.

Due to huge size of problem the day can be divided into 30-minute-time-slots rather than seconds in order to decrease problem size without affecting solution quality. Therefore, transportation requests realized within 30-minute-intervals are treated as the same if they also have common origin and destination points and same delivery time restrictions. It is believed that clustering orders with this consideration does not affect solution quality because even in the current situation, after sale is realized, products spend some time in the distribution area of the auction centers in order to cluster buckets in the same trolley with respect to the buyer.

Each transportation request has one pick-up and one corresponding delivery point. Here, $n \in N$ denotes transportation requests, $i \in P$ denotes pick-up points and $j \in D$

denotes delivery points. In the model, it can be said that when the model is solved on the daily level, there are 360 transportation requests for KOA flow and 1440 requests for other types of flows in total. This makes 1800 transportation requests, 3600 pick-up and 3600 delivery points on the daily level. These numbers come from the following calculations: Although auction transactions are assumed to be realized between 6AM-10 AM on the weekdays, when sale transaction data is analyzed, it is seen that on some days it may start at 5:30 AM and continue till 11:30 AM. As transactions are clustered in 30-minute-intervals, this makes 12 time slots for KOA flow. Other types of flows continue throughout the day and this makes 48 time slots in total. As there are 30 different combinations of IAT flows between 6 auction centers (6*5=30), multiplying 30 with the number of time slots in a day, the given figures can be easily obtained. The size of the problem is even high for the case where requests are clustered in 30-minute- intervals. When this is not the case, the size will be 1800 times bigger as a new request occurs at each second and it will be harder to solve the problem.

One important characteristic of this model is that it handles pickups and deliveries in an integrated manner. For each customer, pickup occurs before delivery and the objective is to find the minimum cost solution to servicing all customers and satisfying the time window constraints in this special case of the problem. q_i' and q_i are associated with the number of buckets to be picked-up and delivered for the specific transportation request, respectively. Both pick-up and delivery points are associated with separate time window requirements in order to meet the necessary service level requirements. For both pick-up and delivery points, time windows are specified between e_i, starting point of the time windows, and l_i, end time of time windows. These time windows are calculated depending on the product to be carried, such that for KOA flow, the product should be loaded into a truck and started its trip to the destined location within half an hour and should reach its destination within a total of 2.5 hours.

Driving time between different auction locations is determined depending on the distance and it is denoted as t_{ij} in the formulation. Average speed is taken as 80 kms/hr. Service time, s_i, is defined as the time spent by the vehicle to load or unload the goods at auction centers and taken as 30 minutes on average at each auction location.

The route of a vehicle is defined as a trip starting from the depot and ending at the same depot after picking and delivering orders along the route. Hence, the total route time of a vehicle is the sum of travel time (which is proportional to the distance traveled), waiting time and service time. The total route time should not exceed the maximum number of hours allowed for a single trip, which is given by N_v in the formulation. The maximum hours allowed for a single trip is determined by the maximum hours allowed for a truck driver to work, which is about 8 hours per day.

As it is indicated previously, each auction location also serves as depots and at each depot several logistics companies are located with a limited fleet of vehicles. $v \in V$ represents the set of vehicles. Vehicles should start and end their trips at the same depot where they are located. Only one vehicle is allowed to serve a single request. Vehicles are assumed to be homogeneous and Q_v is the associated capacity. For calculating truck capacity, Jonkman (2010) assumed that an average truck has a capacity of 22 trolleys. Also, Dat (2010) assumed that a trolley has an average capacity of 29 buckets. Considering these, we can assume that a truck has a capacity of 22*29=638 buckets and necessary calculations are made in the light of this assumption. For detailed information about capacity calculation, please see Jonkman (2010) and Dat (2011).

In current situation, logistics companies charge FloraHolland based on the number of trolleys to be transported from one auction center to another. Although these companies do not give information about their actual costs, current rates are estimated by Jonkman (2010) through interviews. Table 3-1 lists the rates charged by logistics companies for different directions.

Table 3 - 1: Current rates charged by transporters

From/To	Aalsmeer	Naaldwijk	Rijnsburg	Bleiswijk	Venlo	Eelde
Aalsmeer		€ 9.60	€ 9.95	€ 9.60	€18.60	€19.75
Naaldwijk	€ 9.60		€ 9.60	€ 8.10	€18.60	€19.75
Rijnsburg	€ 7.05	€ 7.40		€ 7.10	€18.60	€19.75
Bleiswijk	€ 7.10	€ 8.10	€ 7.10		€18.60	€19.75
Venlo	€18.60	€18.60	€18.60	€18.60		€19.75
Eelde	€19.75	€19.75	€19.75	€19.75	€19.75	

On the other hand, in our case, cost calculation is based on the distance travelled. C_{ijv} represents unit cost of travelling from node i to node j by vehicle v. The unit cost calculation can be given as follows:

The problem scope is only limited to transportation made between auction centers. Therefore, in our calculation, only operational costs due to transportation between auction centers are included. Irrelevant costs, such as costs due to internal distribution within auction centers are ignored. This is important to get consistent results when cost comparison is made between the actual and the proposed system. In our solution approach, the costs are calculated on the basis of following:

According to Jonkman (2010) transportation costs are composed of the cost of operating trucks and the cost of truck drivers. Truck operation cost is estimated per kilometer (1 Euro per km), whereas the amount paid to truck drivers is calculated based on the total hours of transport (23 Euros per hour). For detailed information about cost calculation, please see Jonkman 2010. In order to find the working hours of a driver, the distance travelled is divided by 80 km/hr as it is taken as the average speed in our calculations. In order not to undervalue the cost of the proposed system, indirect cost should be included, so an average of 10% is added per-kilometer-cost to take in-direct costs into account. Finally, profit margin of logistics companies is set as 10% margin as a result of the literature study made for calculating logistics costs. As the length of cycles are found previously, total transportation cost, so the objective function, is calculated easily by multiplying the unit cost charged in our proposed system with the total distance travelled in the respective cycle, for each truck. Table 3-2 lists the variables used in calculation of transportation cost in the proposed system.

Table 3 - 2: Variables used in calculation of transportation cost in the proposed system

Truck cost per km	€	1.00
Truck driver cost	€	23.00/80
Indirect Cost	€	0.10
Profit margin		10%

Given the problem definition, it can be said that Vehicle Routing Problem with Pick-up and Delivery and with Time Windows (VRPPDTW) gives the exact mathematical formulation of this problem. Moreover, there is an additional characteristic of this model: There are six auction locations in FloraHolland and there are separate vehicle depots at all six auction centers. Therefore, this problem should be modeled as Multi-Depot Vehicle Routing Problem with Pick-up and Delivery and with Time Windows (MDVRPPDTW). This makes this mathematical model even harder to be solved. To the best of our knowledge, this type of model is discussed in a few articles so far. Among these studies, only one of them solves it to optimality, but only for small problem instances. This fact is also confirmed by our computations. The mathematical model did not reach any integer solution in a reasonable time for this problem case even with daily aggregated demand and relaxed time windows constraints. For this reason, mathematical formulation of this model is presented in this section, but no computational result can be given in Chapter V, the Implementation.

The notation used during formulation followed by the mathematical model of this problem is given as follows:

MDVRPPDTW

Sets:

P: {1,…, n}: Pickup nodes

D: {n+1,…, 2n}: Delivery nodes

V: Set of vehicles

$N = P \cup D \cup V$

Parameters:

e_i : lower end of TW at node i

l_i : upper end of TW at node i

s_i : service time at node i

t_{ij} : travel time between nodes i and j

q_i : delivery demands at node i

q_i' : pickup demands at node i

Q_v : Capacity of vehicle v

C_{ijv} : Cost of travelling from node i to node j by vehicle v

N_v : Max. tour time allowed for vehicle v.

Variables:

a_i : arrival time at node i

$a_{o(v),v}$: time for vehicle v to return the depot

d_i : time to depart from node i

$d_{o(v),v}$: time for vehicle v to depart from the depot

Q_{iv} : Free capacity of vehicle v on arrival at node i

w_i : waiting time before departure from node i

Decision Variables:

x_{ijv} : 1 if vehicle v departs from node i toward node j, 0 o/w.

Mathematical Model:

Min $\sum_{i\in N}\sum_{j\in N}\sum_{v\in V} c_{ijv}x_{ijv}$ (1)

s. to $\sum_{v\in V}\sum_{j\in N\cup\{d(v)\}} x_{ijv} = 1$ $\forall i \in P$ (2)

$\sum_{j\in N} x_{ijv} - \sum_{j\in N} x_{j,N+i,v} = 0$ $\forall i \in P, v\in V$ (3)

$\sum_{i\in N\cup\{o(v)\}} x_{ijv} - \sum_{i\in N\cup\{d(v)\}} x_{jiv} = 0$ $\forall j \in N, v\in V$ (4)

$\sum_{j\in P\cup\{d(v)\}} x_{o(v),jv} \le 1$ $\forall v \in V$ (5)

$\sum_{i\in D\cup\{d(v)\}} x_{i,d(v)v} \le 1$ $\forall v \in V$ (6)

$\sum_{j\in P\cup\{d(v)\}} x_{o(v),jv} \le \sum_{i\in D\cup\{d(v)\}} x_{i,d(v)v}$ $\forall v \in V$ (7)

$e_i \le a_i \le l_i$ $\forall i \in N$ (8)

$a_{o(v),v} \le N_v$ $\forall v \in V$ (9)

$d_i \ge a_i + s_i$ $\forall i \in N$ (10)

$w_i = d_i - a_i - s_i$ $\forall i \in N$ (11)

$d_i + t_{ij} \le a_j$ if $x_{ijv} = 1$ $\forall i, j \in N, v\in V$ (12)

$d_{o(v),v} + t_{o(v),j} \le a_j$ if $x_{o(v),jv} = 1$ $\forall j \in N, v\in V$ (13)

$d_i + t_{i,o(v)} \le a_{o(v),v}$ if $x_{i,o(v),v} = 1$ $\forall i \in N, v\in V$ (14)

$Q_{jv} \le Q_{iv} - q_i^{'} + q_i$ if $x_{ijv} = 1$ $\forall i, j \in N, v\in V$ (15)

$Q_{jv} \le Q_v$ if $x_{o(v),jv} = 1$ $\forall j \in N, v\in V$ (16)

$Q_{iv} \le Q_v$ $\forall i \in N, v\in V$ (17)

Objective function (1) represents the total cost of transporting products between auction centers. Constraint set (2) guarantees that each order is picked while constraint set (3) ensures that these orders are delivered to the destined auction location. Constraint set (4) ensures that if a vehicle enters a node, it leaves it before entering another node. While constraint set (5) guarantees that each vehicle leaves the depot at most once, set (6) guarantees that each vehicle enters the depot at most once. Set (7) does not let a vehicle to enter the depot unless it leaves it beforehand. Constraint set (8) ensures that arrival time is within time windows for each node.

Constraint set (9) assures that all vehicles return to their depot before their shift ends. Constraint set (10) provides that departure time is greater than or equal to the completion time of service. Constraint set (11) calculates waiting time. Constraint sets (12-14) calculates arrival time at each node. Constraint sets (15-16) calculate the available capacity of vehicles at any time and constraint set (17) restricts the capacity of the vehicles.

This formulation is non-linear because of the constraints (12-16). These constraints can be linearized using Big M method, so the model can be converted into Mixed Integer Linear Programming (MILP). Nonlinear constraints can be replaced by the following constraints:

$$d_i + t_{ij} - M_{ijv}(1 - x_{ijv}) \le a_j \qquad \forall i, j \in N, v \in V \qquad (12)$$

$$d_{o(v),v} + t_{o(v),j} - M_{o(v),jv}(1 - x_{o(v),jv}) \le a_j \qquad \forall j \in N, v \in V \qquad (13)$$

$$d_i + t_{i,o(v)} - M_{i,o(v),v}(1 - x_{i,o(v),v}) \le a_{o(v),v} \qquad \forall i \in N, v \in V \qquad (14)$$

$$Q_{jv} \le Q_{iv} - q_i^{'} + q_i - M_{ijv}(1 - x_{ijv}) \qquad \forall i, j \in N, v \in V \qquad (15)$$

$$Q_{jv} \le Q_v - M_{o(v),jv}(1 - x_{o(v),jv}) \qquad \forall j \in N, v \in V \qquad (16)$$

In order to have an idea on the size of this model, it has 331,297,500 variables, 330,750,000 of which are decision variables and 1,324,903,200 constraints in our problem even if the demands are aggregated in 30-minute-time slots. In order to have detailed information on the number of variables, please see Appendix Table 1. These numbers may give an idea for the complexity and the size of the problem. Therefore, alternative solution approaches are developed in order to obtain good solutions in a timely manner.

CHAPTER IV

SOLUTION APPROACH

FloraHolland has 6 different auction centers in operation and a huge amount of transport is realized between these centers each day. The current project concentrates on the organization of this transport in operational terms. However, it is a hard task to make this organization as it is not possible to determine the routes to be formed between these centers, at a glance. There are several alternatives, so it is not easy to select one among many. It is even harder to determine possible consolidation scenarios for a more efficient organization. Moreover, when delivery time restrictions are taken into account, it is known for sure that mathematical models and algorithms are necessary to solve this problem.

As we concluded that exact model of this problem could not be solved due to its complexity and the size of the problem, we have developed a multi-stage approach in our solution methodology. We did this with the purpose of dividing solution approach into stages so that each stage contains different aspect of the exact approach. In the exact approach, trucks are both routed and scheduled simultaneously. On the other hand, our solution approach first determines most efficient routes to be followed by trucks and then schedules each truck on these routes. Overall, every part of this approach works in harmony and brings good solutions in a short period of time.

The route of a vehicle is defined as a trip starting from the depot and ending at the same depot after picking and delivering orders along the route. Therefore, it is possible to say that these trucks make cycles over six auction centers of FloraHolland. Routing part of our approach is based on this idea, determining the most efficient cycles to be utilized. This approach works well with FloraHolland's situation. One reason is that there are 6 auction centers, so the number of all possible cycles is restricted. However, if the number of auction centers gets higher, the problem size grows exponentially and the Cycle Assignment Model may not work for the problem of that size. Moreover, routing trucks over cycles is advantageous for FloraHolland. Firstly, with this solution approach, FloraHolland can improve the efficiency of its current IAT organization. Moreover, FloraHolland can get a bargaining power over the costs of cycles. In the current system, total transportation cost is obtained by multiplying unit cost of transporting trolleys between different auction centers. With this solution approach, total transportation cost can be calculated over cycles and cost of each cycle can be determined by agreements with logistics companies depending on the length and the utilization rate of the respective cycle. Another reason is that this approach is good for humanitarian purposes. The model forms cycles as the routes to be followed, so the vehicle stops where its tour is originated. As the vehicle finishes its tour at the same location where it starts, truck driver can easily goes to where he lives when the tour ends.

In order to route trucks, first all possible cycles, that the trucks can be assigned, are determined. While determining these cycles, it is important to eliminate the ones that are infeasible when the problem constraints are considered. In order to determine the most efficient routes to be followed for the given day, Cycle Assignment Model is solved. This model looks at the aggregate demand of product flows to be carried between different auction locations and assigns these flows to possible cycles. Therefore, the cycles which enable highest truck utilization, so the minimum costs are found. Consequently, an aggregate capacity is determined to handle transportation on the daily level. Moreover, this model gives an idea of the frequency of the tours to be followed.

Following Cycle Assignment Model, within day transportation is planned in detail. A construction heuristic is developed for this planning. Solving this heuristic, trucks are scheduled on the routes determined by Cycle Assignment Model given delivery time restrictions of the orders.

In the following sections, each step of this solution approach is explained in detailed. Firstly, cycle forming procedure is described and then, the criteria for flow-cycle assignments are explained. Next, Cycle Assignment Model is explained and finally scheduling heuristic is given.

4.1 Cycles: Paths between Locations

In this section, the cycles that are possible to be formed between 6 different locations are given. While doing that it is necessary to find the highways between locations, so that they can be used as the paths to be followed. Please see the Figure 4 - 1, which shows the highways between 6 centers. In this figure, the auction centers are represented with their first letters.

Although, this figure shows the highways between 6 auction centers, different paths may be used for different cycles. For this reason, shortest paths are found for each alternative cycle. In order to do that, TSP solver in the following link is used: “http://travellingsalesmanproblem.appspot.com/”

Figure 4 - 1: Highways between 6 auction locations

The reason of finding shortest paths is to eliminate the cycles that take longer time than necessary. To illustrate, if the shortest path between 1, 2, 3 and 4 is 1-3-2-4-1, then eliminating cycles 1-2-3-4-1, 1-4-3-2-1, etc. is good both for eliminating the cycles with the same points but a longer length and reducing the problem size. By doing this, the number of cycles to which the flows are assigned is reduced to 99 while it was 409 initially. Moreover, cycles that last more than 8 hours are eliminated as a truck driver can work a maximum of 8 hours in a day. The cycles with the shortest lengths can be seen in Table 4 -1.

Table 4 - 1: The shortest cycles

Cycle	Length	Cycle	Length
A-R-A	63	**A-E-R-A**	458
B-N-B	63	**R-E-A-R**	458
B-R-B	71	**A-B-E-A**	486
N-R-N	74	**E-B-A-E**	486
A-B-A	113	**B-E-R-B**	492
A-N-A	116	**R-E-B-R**	492
A-V-A	351	**A-E-N-A**	512
B-V-B	360	**N-E-A-N**	512
N-V-N	384	**E-B-N-E**	516
A-E-A	404	**N-B-E-N**	516
R-V-R	419	**E-N-R-E**	518
E-R-E	452	**R-N-E-R**	518
B-E-B	459	**A-R-B-N-A**	157
E-V-E	491	**N-B-R-A-N**	157
E-N-E	510	**A-R-B-V-A**	422
B-N-R-B	104	**V-B-R-A-V**	422
R-N-B-R	104	**A-R-N-V-A**	438
A-B-R-A	123	**V-N-R-A-V**	438
R-B-A-R	123	**A-N-B-V-A**	445
A-N-R-A	126	**V-B-N-A-V**	445
R-N-A-R	126	**B-N-R-V-B**	458
A-B-N-A	146	**V-R-N-B-V**	458
N-B-A-N	146	**A-R-B-E-A**	501
B-N-V-B	402	**E-B-R-A-E**	501
V-N-B-V	402	**A-N-B-E-A**	519
A-B-V-A	412	**E-B-N-A-E**	519
V-B-A-V	412	**B-E-R-N-B**	524
A-R-V-A	417	**N-R-E-B-N**	524
V-R-A-V	417	**A-E-R-N-A**	525
A-N-V-A	423	**N-R-E-A-N**	525
V-N-A-V	423	**A-R-N-B-V-A**	456
B-R-V-B	425	**V-B-N-R-A-V**	456
V-R-B-V	425	**A-E-B-N-R-A**	530
N-R-V-N	436	**R-N-B-E-A-R**	530
V-R-N-V	436		

A sample cycle can be represented over a map as it is in Figure 4-2. As it is seen, in this figure the cycle formed between auction centers Aaalsmeer, Naaldwijk and Eeelde is given. The cycles A-E-N and N-E-A are possible to be formed between these centers and trucks can start their tour starting from any of these locations.

Figure 4 - 2: A sample cycle representation

4.2 Flow-Cycle Assignments

After determining the cycles that are possible to be used during transportation activities, it is necessary to determine which flow can be assigned to which cycle. While doing that it is necessary that the origin and the destination point of the flow are included in the cycle in the same order. For example, the flow from 1 to 2 can be assigned to the cycles 1-2-1, 2-1-2, 1-2-3-1, 1-5-2-3-1, etc. Here, the important thing is to limit the travel time between the origin and destination points of KOA flow to

2.5 hours. This is due to service level agreements of FloraHolland. To illustrate, if the travel time from 1 to 2 is more than 2.5 hours in the cycle 1-5-2-3-1, KOA flow of 1-2 cannot be assigned to this cycle. This constraint is relaxed for the flows of Supply, Import and Connect.

An important point of flow-cycle assignment matrix is whether consolidation is made when a flow is assigned to a specific cycle. For example, when the flow 1-2 is assigned to the cycle 1-2-3, the products are directly sent from location 1 to 2. However, when the flow 1-2 is assigned to the cycle 1-3-2, the products are sent from location 1 to location 3 initially. Here, some other products are loaded into the truck. Then, the products are sent to their final destination, which is location 2. Consolidation is allowed only if it does not violate timing restriction of service level agreements. By doing it, trucks can be more efficiently loaded by using the opportunity of using it for closely located centers.

4.3 Cycle Assignment Model

Cycle Assignment model is constructed with this purpose, finding the most efficient routes to be followed throughout a day. As these routes are formed as cycles between six auction centers of FloraHolland, this model tries to find the most efficient cycles to be utilized. By doing this, the model helps FloraHolland to determine a lower bound on the capacity that is necessary to handle transport on the given day. Moreover, the model assists to make within-day-schedules, which is the following stage of this solution approach.

While determining cycles, the model looks at the daily aggregated demand of product flows to be carried between different auction locations. Based on this data, it assigns flows to the cycles in a way that buyers receive their orders on time and all the paths, to be called legs from this point forwards, through the cycles are fully utilized in terms of truck capacity. By doing this, it determines the routes over which minimum transportation cost is obtained. Here, $i \in I$ is denotes the flows between auction locations, $j \in J$ denotes cycles and $k \in K$ denotes the legs of cycles. $f^K{}_i$ represents the amount to be transported for KOA flow while $f^S{}_i$ is the amount to be transported for other types of flows, namely Supply, Import and Connect. c_j is given as the specific cost of cycle, which is calculated based on total distance of the cycle. Detailed information on the cost of cycles is given in Chapter III, Problem Definition and Mathematical Formulation. Flow-cycle assignments are restricted by a few parameters due to the reasons explained in the previous section, Flow-Cycle assignments.

The cycles to be used and the number of tours that should be allocated to these cycles are given as output of the model. The model also specifies the flows to be routed over the given cycles. Number of routes allocated to cycles are determined by the decision variable y_j, while flow-cycle assignments are given by the variable set of x and v.

Formulation of Cycle Assignment Model is given as follows:

Cycle Assignment Model (CAM)

Sets

I : Flows

K : Legs

J : Cycles

Parameters

$f^K{}_i$: Amount to be transported in flow (KOA) i

$f^S{}_i$: Amount to be transported in flow (Supply, Import, Connect) i

c_j : Total cost of cycle j

$a^K{}_{ij}$: The parameter showing whether flow (KOA) i can be assigned to cycle j (without condolidation)

a^{Kc}_{ij} : The parameter showing whether flow (KOA) i can be assigned to cycle j (with consolidation)

a^{S}_{ij} : The parameter showing whether flow (Supply, Import, Connect) i can be assigned to cycle j (without condolidation)

a^{Sc}_{ij} : The parameter showing whether flow (Supply, Import, Connect) i can be assigned to cycle j (with consolidation)

n^{K}_{ijk} : The parameter showing whether flow (KOA) i can be assigned to leg k of cycle j (without condolidation)

n^{Kc}_{ijk} : The parameter showing whether flow (KOA) i can be assigned to leg k of cycle j (with consolidation)

n^{S}_{ijk} : The parameter showing whether flow (Supply, Import, Connect) i can be assigned to leg k of cycle j (without condolidation)

n^{Sc}_{ijk} : The parameter showing whether flow (Supply, Import, Connect) i can be assigned to leg k of cycle j (with consolidation)

Decision Variables

x^{K}_{ij} : 1, if flow (KOA) i is assigned to cycle j (without consolidation); 0 o.w

x^{Kc}_{ij} : 1, if flow (KOA) i is assigned to cycle j (with consolidation); 0 o.w

x^{S}_{ij} :1, if flow (Supply, Import, Connect)i is assigned to cycle j (without consolidation); 0 o.w

x^{Sc}_{ij} :1, if flow (Supply, Import, Connect)i is assigned to cycle j (with consolidation); 0 o.w

v^{K}_{ijk} : 1, if flow (KOA) i is assigned to leg k of cycle j (without consolidation); 0 o.w

v^{Kc}_{ijk} : 1, if flow (KOA) i is assigned to leg k of cycle j (with consolidation); 0 o.w

v^{S}_{ijk} : 1, if flow (Supply, Import, Connect)i is assigned to leg k of cycle j (without consolidation); 0 o.w

v^{Sc}_{ijk} : 1, if flow (Supply, Import, Connect)i is assigned to leg k of cycle j (with consolidation); 0 o.w

Integer Variables

w_{kj} : Number of trucks in the leg k of cycle j

y_j : Number of trucks in cycle j

CYCLE ASSIGNMENT MODEL

Min $\sum_j c_j * y_j$ (1)

s.to $x_{ij}^{K} \leq a_{ij}^{K}$ for all i, j (2)

$x_{ij}^{Kc} \leq a_{ij}^{Kc}$ for all i, j (3)

$x_{ij}^{S} \leq a_{ij}^{S}$ for all i, j (4)

$x_{ij}^{Sc} \leq a_{ij}^{Sc}$ for all i, j (5)

$\sum_j x_{ij}^{K} + \sum_j x_{ij}^{Kc} = 1$ for all i (6)

$\sum_j x_{ij}^{S} + \sum_j x_{ij}^{Sc} = 1$ for all i (7)

$x_{ij}^{K} \leq y_j$ for all i, j (8)

$x_{ij}^{Kc} \leq y_j$ for all i, j (9)

$x_{ij}^{S} \leq y_j$ for all i, j (10)

$x_{ij}^{Sc} \leq y_j$ for all i, j (11)

$w_{kj} \leq y_j$ for all k,j (12)

$v_{ijk}^{K} = n_{ijk}^{K} * x_{ij}^{K}$ for all i, j, k (13)

$v_{ijk}^{Kc} = n_{ijk}^{Kc} * x_{ij}^{Kc}$ for all i, j, k (14)

$v_{ijk}^{S} = n_{ijk}^{S} * x_{ij}^{S}$ for all i, j, k (15)

$v_{ijk}^{Sc} = n_{ijk}^{Sc} * x_{ij}^{Sc}$ for all i, j, k (16)

$\sum_i \left(\frac{f_i^{K}}{638}\right) * (v_{ijk}^{K} + v_{ijk}^{Kc}) + \sum_i \left(\frac{f_i^{S}}{638}\right) * (v_{ijk}^{S} + v_{ijk}^{Sc}) \leq w_{jk}$ for all j, k (17)

Objective function (1) represents the total cost of transporting products between auction centers. Constraint sets (2-5) put an upper bound on the assignment variables due to the flow-cycle assignment parameters. Constraint sets (6&7) guarantee that all flows are assigned to a cycle. Constraint sets (8-11) does not allow the number of trucks in a cycle to be greater than zero unless any flow is assigned to that cycle. Constraint set (12) sets the number of trucks allocated to a cycle to the maximum number of trucks in the cycle's legs. Constraint sets (13-16) allocate flows to the respective legs of the cycle that they are assigned. Constraint set (17) calculates the total number of tours allocated to the legs of the respective cycles.

4.4 Scheduling Heuristic

Scheduling heuristic is constructed with the aim of creating hourly schedules of trucks travelling between 6 auction centers of FloraHolland so that all products are delivered to their destined location in a timely manner with the objective of cost minimization. This heuristic takes the output of Cycle Assignment Model: the number of tours allocated to the cycles enabling highest truck utilization and flow-cycle assignments. Then, trucks are scheduled on the given tours considering delivery time restrictions of the orders.

Some critical decisions given in this heuristic can be stated as follows:

- In which order, flows should be assigned to the routes and scheduled?
- On which time slot, a truck should be scheduled for the given flow?
- Out of given alternatives by the output of Cycle Assignment Model, to which cycle the flow should be assigned?

At any time slot that the trucks are to be scheduled, the priority is given to the smaller flows, so the heuristic makes schedules starting from the smallest flow. This can be explained as follows: At a given time slot, it is assumed that sales are realized uniformly throughout 30 minutes. To illustrate, if the realized demand for Flow A is 638 buckets, just enough to fill a full track, the demand for the first 20 buckets are assumed to be realized in the first minute. However, if the realized demand for Flow

B is 6380 buckets, which is enough to fill 10 full trucks, the first 20 buckets of the last full truck are assumed to be realized within the last 3 minutes of the respective time slot. Therefore, scheduling of the last truck of Flow B is not as critical as Flow A due to timing considerations, especially for the cases when the capacity for any time is not enough to cover all flows. Critical flows are assigned first, so other flows can be awaited until some trucks finish their tours and be available for scheduling. This explains the fact that the heuristic schedules the flow in ascending order. This is also valid for scheduling KOA flow. KOA flow has a strict delivery time in order to meet service level requirements. Therefore, KOA flows are scheduled first for the given time period, so that they do not suffer in cases where the capacity is limited.

In order to utilize trucks more efficiently, it is desired to load them to their maximum capacity. Therefore, in the heuristic, only full-trucks are scheduled unless some flows are needed to be sent to their destined location immediately. This is usually the case for KOA flows. On average, for any KOA flow, products can be kept about half an hour after sale transaction. Therefore, if it does not fill a full truck, KOA flow can be awaited to be scheduled at the subsequent time slot. However, in the following time slot, it should be scheduled to be sent to its destined location in order that it is delivered to the buyer on time. This explains the decision criterion in order to determine the time slot that a truck is to be scheduled for any flow.

In order to determine the route that any truck is to be assigned, the output of Flow-Cycle Assignment Model is checked. The model gives some alternative cycles for each flow, so a decision should be given in order to select one of them. While doing this, the heuristic first looks at the amount of products assigned to alternative cycles for the given flow. Among those, cycles with the highest amount of assignment is chosen. After scheduling is made, flow-cycle assignments are updated so that the cycles can be equally distributed over time slots.

In reality, the difficulty faced with within day scheduling is that it is impossible to determine the timing of the sales beforehand. Therefore, in this heuristic, the planning is made when the demand is realized in the current period. For example, the scheduling in the time period 6:00-6:30 is made at 6:30 when all the demand within this period is realized while nothing is known about the subsequent horizons. Therefore, it can be said that this heuristic works as an online algorithm as it makes its decisions with the given input up to that time without any future information. Although this may lead to an increase in transportation costs as it is impossible to foresee consolidation scenarios that may appear in the future with this online heuristic, a more realistic approach is proposed in this way and FloraHolland needs this kind of an algorithm since it wants to make this organization in its highly dynamic environment.

In this respect, Cycle Assignment Model and Scheduling Heuristic complete each other such that the model determines the possible consolidation scenarios with the daily aggregated data estimations and the heuristic dynamically updates these decisions when the demand is realized as the time goes by.

Another difficulty faced during within-day scheduling is that, it is not possible to change any decision given in the past. For example, any truck that is scheduled one hour before the current time can not be decided not to be scheduled. Therefore, this heuristic looks at the previous decisions given and tries to give the best current decision possible without having any future data available.

For the input of this heuristic, demands realized within a day can be taken from the transaction data of FloraHolland for KOA flow. However, there isn't any timing information regarding Supply, Import or Connect. Therefore, it is assumed that these kinds of flows are uniformly distributed throughout the day, so that their schedules are formed with this consideration.

Before continuing with the steps to be followed in this heuristic, it is necessary to give inputs, outputs and the decisions variables. To begin with, demands realized in each time slot are required for all types of flows. In our solution approach, a day is equally divided into 30-minute- time slots. Moreover, output of Cycle Assignment Model is fed into this heuristics, so flow-cycle assignments and the number of tours allocated to the cycles are also taken as input. Distance between auction locations is also necessary to calculate driving time between auction locations. When this heuristic is run, the number of trucks scheduled on their assigned routes is given for each time slot of the day, so that daily trucks schedules is created. The number of tours scheduled on each cycle is also given as output and this helps to calculate total transportation cost of the given day. Before continuing with the detailed explanation of this heuristic, it is good to give its parameters and decision variables.

Inputs:

D1(t,i) :Amount of KOA flow i that is demanded at time slot t

CD1(t,i) : Cumulative amount of KOA flow i that is demanded till time slot t

D2(t,i) : Amount of other types of flow i that is demanded at time slot t

CD2(t,i) : Cumulative amount of other types of flow i that is demanded till time slot t

X1(i,j) : Amount of KOA flow i to be carried on cycle j as a result of Cycle Assignment Model

X2(i,j) : Amount of other types of flow i to be carried on cycle j as a result of Cycle Assignment Model

l(i) : Distance between auction locations, so the respective flow i

N(j) : Number of cycles available

Variables:

FK(t,i) :Amount of (KOA) flow i collected with the trucks started their trips previously from another point at time t

FK(t',i') = V1(t,i) where d(i,i')/80=t'-t where t' is between 5:30-10:30

FS1(t,i) :Amount of (Supply, Import & Connect) flow I collected with the trucks started their trips to collect KOA flow, but have unfilled capacity at time t

FS1(t,i) = $(TK(t,i)-QK(t,i))^+$ where t is between 5:30-10:30

FS2(t,i) :Amount of (Supply, Import & Connect) flow i collected with the trucks started their trips previously from another point to collect KOA flow at time t

FS2(t',i') = V1(t,i) where d(i,i')/80=t'-t where t' is between 11:00-5:00

FS3(t,i) :Amount of (Supply, Import & Connect) flow collected with the trucks started their trips previously from another point

FS3(t',i') = V2(t,i) where d(i,i')/80=t'-t where t' is between 5:30-5:00

TK(t,i) :Total amount of (KOA) flow i collected at time t

TK(t,i) = FK(t,i)+ V1(t,i)

CTK(t,i) :Cumulative total amount of (KOA) flow collected at time t

CTK(t,i) = Sum(t,FK(t,i))

TS(t,i) :Total amount of (Supply, Import & Connect) flow i collected at time t

TS(t,i) = FS1(t,i)+ FS2(t,i) + FS3(t,i)

CTS(t,i) :Cumulative total amount of (Supply, Import & Connect) flow i collected at time t

CTS(t,i) = Sum(t,TS(t,i))

QK(t,i) :Amount of (KOA) flow i to be collected at time t

QK(t,i) = D1(t,i) -TK(t,i)

CQK(t,i) :Cumulative amount of (KOA) flow i to be collected at time t

CQK(t,i) = Sum(t,QK(t,i))

QS(t,i) :Amount of (Supply, Import, Connect) flow i to be collected at time t

QS(t,i) = D2(t,i) –TS(t,i)

CQS(t,i) :Cumulative amount of (Supply, Import & Connect) flow i to be collected at time t

CQS(t,i) = Sum(t,QS(t,i))

Outputs:

V1(t,i) : Number of trucks that start their trip for KOA flow i at time slot t

V2(t,i) : Number of trucks that start their trip for Supply, Import & Connect flow i at time slot t

Y(j) : The number of tours scheduled on the cycle j

Steps followed during scheduling process can be given as follows:

1) Set V1, V2 and Y to zero.

   Update FK(t,i), FS1(t,i), FS2(t,i), FS3(t,i), TK(t,i), CTK(t,i), TS(t,i), CTS(t,i), QK(t,i), CQK(t,i), QS(t,i) and CQS(t,i).

   While the time stamp is between 5:30-10:30, take the first time stamp, in which no assignment is made.

2) Start to Schedule KOA.
   Check CQK(t,i).

   2.1) Sort the flows (in this time stamp) in ascending order.

   2.2) Start from the flow with the smallest amount.

   2.2.1) Check X1(i,j) for the flow-cycle assignments.

   2.2.2) Start from the cycle with the highest number of tours.

   2.2.2.1) Check the max no. of tours that can be assigned to that cycle. (Check all the flows assigned to that cycle.)

   2.2.2.2) If the total no. of tours assigned to that cycle does not exceed the given amount by the assignment model, assign flow to this cycle.

   2.2.2.2.1) Check the amount of the flow.

   2.2.2.2.2) Check whether any flow is collected in the previous time stamp of the respective flow.

   2.2.2.2.2.1) If yes, send the full trucks. Do not send the trucks with un-filled capacity.

   2.2.2.2.2.2) If no, send the amount at least an amount equal to the amount that's not send in the previous time stamp's.

   2.2.2.2.2.3) Update Y'(j)=Y3(j)-no. of trucks assigned to that cycle

   2.2.2.3) If it exceeds, go to the next most frequent cycle. Go to the step 2.2.2. Follow 2.2.2 for all the cycles assigned to that flow.

2.2.3) Fill the V1.

2.2.4) Update FK(t,i), FS1(t,i), FS2(t,i).

2.2.5) Update TK(t,i), CTK(t,i).

2.2.6) Update QK(t,i) and CQK(t,i).

2.2.7) Go to step 2.2.

2.3) When all KOA flow is scheduled for the respective time slot, go to Step3.

3) Start to Schedule other types of flows.

Check CQK(t,i).

3.1) Sort the flows (in this time stamp) in ascending order.

3.2) Start from the flow with the smallest amount.

3.2.1) Check X2(i,j) for the flow-cycle assignments.

3.2.2) Start from the cycle with the highest number of tours.

3.2.2.1) Check the max no. of tours that can be assigned to that cycle. (Check all the flows assigned to that cycle.)

3.2.2.2) If the total no. of tours assigned to that cycle does not exceed the given amount by the assignment model, assign flow to this cycle.

3.2.2.2.1) Check the amount of the flow.

3.2.2.2.2) Send only the full trucks. Do not send the trucks with un-filled capacity.

3.2.2.2.3) Update Y’(j)= Y(j)-no. of trucks assigned to that cycle

3.2.2.3) If it exceeds, go to the next most frequent cycle. Go to 3.2.2. Follow 3.2.2 for all the cycles assigned to that flow.

3.2.3) Fill the V2.

3.2.4) Update FS3(t,i).

3.2.5) Update TS(t,i) and CTS(t,i).

3.2.6) Update QS(t,i) and CQS(t,i).

3.2.7) Go to step 3.2.

3.3) When step 3.2 is complete for all the flows in the respective period, go on with the subsequent period and follow steps 2 and 3 until all flows are scheduled for the given day, then finish the heuristic.

Scheduling heuristic consists of several steps to create within-day truck schedules. The first main step initializes the decision variables. While second main step is designed to schedule KOA flow, third main step creates schedules of other types of flows. KOA flow is scheduled first as it has tightened delivery time restrictions and should have the priority over other flows due to limited capacity. Steps 2 and 3 have similar sub-steps with a few differences. Steps 2.1 and 3.1 find the smallest transport request for different types of flows at the given time period. The reason behind starting with smaller requests is due to capacity restrictions as it was explained in this section, before giving the heuristic. The flows that are bigger in amount are less critical compared to smaller flows as their demands appear more frequently in the given time period, so the amount that is not assigned to any truck is more probably to be realized at the end of that period. Thus, they can be thought less critical in timing considerations.

Scheduling heuristic routes trucks based on the output of Flow-Cycle Assignment Model. In steps 2.2.1 and 3.2.1, flow-cycle assignments are controlled in order to make scheduling accordingly. Next, in steps 2.2.2.1 and 3.2.2.1, the number of tours allocated to the cycles is checked in order to have an idea on the capacity of the cycles and make the selection accordingly. Steps 2.2.2.2 and 3.2.2.2 control if the selected cycle has enough capacity to carry products between the desired auction locations and if it doesn't, the heuristic selects another cycle in steps 2.2.2.3 and 3.2.2.3.

In steps 2.2.2.2.1 and 3.2.2.2.1, the amount transport request is checked. Step 2.2.2.2.2 is differentiated for KOA flow, so different sub-steps are taken at step 3.2.2.2.2. In both of these steps, trucks are scheduled if it is possible to use full-capacity. If it is not, the truck is left to be scheduled for the subsequent period. However, for KOA flow, it is not desired to keep products more than half an hour due to delivery time restrictions. Therefore, if a flow is not assigned to a truck in one time slot, it should be assigned in the subsequent one for sure in order to satisfy delivery time constraints. In the rest of this heuristic, decision variables are calculated and it is continued to go over the same steps until all flows are assigned trucks to be sent to their destined locations.

To illustrate this heuristic on a small example, the following example can be given:

Table 4-2 gives the amounts of flows realized between 06:00-06:30 and Table 4-3 gives flow-cycle assignments for the example problem. Scheduling Heuristic firstly looks at the amounts of flows at the time period at which the scheduling is to be performed and sorts them in ascending order.

Table 4 - 2: Amounts of flows demanded till 06:30 for the example problem

Time Slots	Flows		
	V-R	R-N	N-A
06:00-06:30	400	900	1300

Table 4 - 3: Flow - cycle assignments for the example problem

Flows	Cycles		
	A-R-N	N-A	R-N-V
V-R	0	0	600
R-N	500	0	600
N-A	500	2100	0

At 06:30, the ascending order of flows is V-R, R-N and N-A. As the smallest flow is V-R, it has the highest priority for scheduling. The amount of flow V-R is 400 and it is less than a full truck load, so it is decided to be awaited about 30 minutes with the aim of utilizing truck as much as possible. The next flow is R-N and the amount is big enough to fill a full truck, so one truck is scheduled at 06:30 from Rijnsburg to Naaldwijk. For the selection of cycle, there are two alternatives: A-R-N and R-N-V. The cycle R-N-V has higher amount of flows assigned, so has higher number of tours compared to A-R-N. Thus, this flow is assigned on the cycle R-N-V. After this assignment, flow-cycle assignments and the demands of flows are updated. The next flow is N-A. Two full trucks are scheduled from Naaldwijk to Aalsmeer on the cycle N-A.

These trucks continue their trips on these cycles and to carry goods on their routes. For example, the truck travelling along the route R-N-V, goes from Rijnsburg to Naaldwijk. When it reaches to Naaldwijk, it delivers products and then, takes shipments from Naaldwijk to continue its way so that it delivers products to the next destination. It is the same for the cycle N-A. When the truck delivers the products carried from Naaldwijk to Aalsmeer, it takes shipments from Naaldwijk and then, delivers to Aalsmeer.

After scheduling of the flows between 06:00-06:30 is made, transactions continue to be realized between the period 06:30-07:00. Table 4-4 shows the cumulative amount of flows realized, but not scheduled to be transported till 07:00. Table 4-5 shows the updated version of flow-cycle assignments.

Table 4 - 4: Amounts of flows demanded till 07:00 for the example problem

Time Slots	Flows		
	V-R	R-N	N-A
06:30-07:00	600	462	1324

Table 4 - 5: Flow - cycle assignments (updated version) for the example problem

Flows	Cycles		
	A-R-N	N-A	R-N-V
V-R	0	0	600
R-N	500	0	0
N-A	500	824	0

At 06:30, the ascending order of flows is R-N, V-R and N-A. As the smallest flow is R-N, it has the highest priority for scheduling. The amount of flow R-N is 462 and it is less than a full truck load, so it is decided to be awaited about 30 minutes with the aim of utilizing truck as much as possible. The next flow is V-R and the amount is not big enough to fill a full truck again. However, this flow is not scheduled at the previous time slot, so it has to be scheduled in order that the products are delivered in a timely manner. The only cycle alternative is R-N-V, so one truck is scheduled at

07:00 from Venlo to Rijnsburg on the cycle R-N-V. For the flow N-A, two trucks are scheduled at 07:00 from Naaldwijk to Aalsmeer on the cycle N-A.

After scheduling each flow, flow-cycle assignments and the demands of flows are updated. This is continued until all flow are assigned in the respective day.

CHAPTER V

IMPLEMENTATION

As it is described in Chapter IV, we developed a two-stage- approach for this problem. In this section, initially, we explained each stage of this approach in detail on a sample problem. Then, we gave the results of five sample days in the upcoming parts of this section.

The case study presented in this section is based on the commercial data of FloraHolland in the year 2010. We took five sample days to test the results and the efficiency of the solution approach. Each day is selected from different time of the year to have the effect of seasonality factor into account.

Cycle Assignment Model is constructed on GAMS. Scheduling Heuristic, on the other hand, is coded using C programming language. We conducted experiments on a personal computer with 2GB RAM and Intel Core2 Duo 2 GHz processor.

When the input of sample day is fed into Cycle Assignment Model (CAM), cyclic routes to be followed between six auction centers and the number of tours allocated to these routes are obtained as the output of the model. This gives an aggregate capacity to handle transportation in the daily level.

In order to have an idea on the size of CAM, it has 54414711 variables and 54664842 constraints. In order to have detailed information on the number of variables, please see Appendix Table 2. Even though the problem size seems big, the model is solved in a reasonable time. Moreover, the solutions obtained by solving Cycle Assignment model are with less than 0.5% gap from the best possible relaxed solution.

The cyclic routes and their frequencies differ from day to day. It depends on the amounts to be transported throughout the given day. In Table 5-1, we gave the cyclic routes and the number of tours allocated for the sample day. As it can be seen, some of the routes are favored than others. This is because these routes are more efficient for use than others.

Table 5 - 1: Number of tours allocated to the cyclic routes for the sample day

Cycles	No. of Tours	Cycles	No. of Tours
A-B	18	**E-B-A**	1
A-B-N	80	**E-V**	1
A-B-R	24	**N-B-A**	52
A-E	5	**N-E-A**	4
A-E-B-N-R	1	**N-R**	100
A-E-N	4	**R-B-A**	35
A-E-R	2	**R-E-A**	1
A-N	18	**R-N-A**	47
A-N-R	11	**R-N-B-E-A**	2
A-N-V	24	**V-B-A**	1
A-R	27	**V-B-N-A**	1
A-R-B-V	6	**V-B-R-A**	2
A-R-V	4	**V-E-A**	3
A-V	53	**V-N-A**	36
B-N-R	1	**V-R-N**	1

As it can be seen, the model has a tendency to open smaller cycles. Almost all of the cycles are formed between 2 or 3 locations. If some of the flows can not be carried with smaller cycles, the model starts to open bigger cycles such that trucks follow these routes as fully utilize as possible. Out of 562 tours, 10 of them are assigned to a cyclic route formed between 4 auction centers while only one cyclic route is formed between 5 of the auction centers. At this point, it is good to mention one more time that any tour on these cycles do not exceed a total of 8 hour travel time. Moreover, products carried over any of these bigger cycles are ensured that on time delivery is made to their respective buyers.

The representation of a sample cyclic route V-N-A on the map of the Netherlands can be seen in the Figure 5-1.

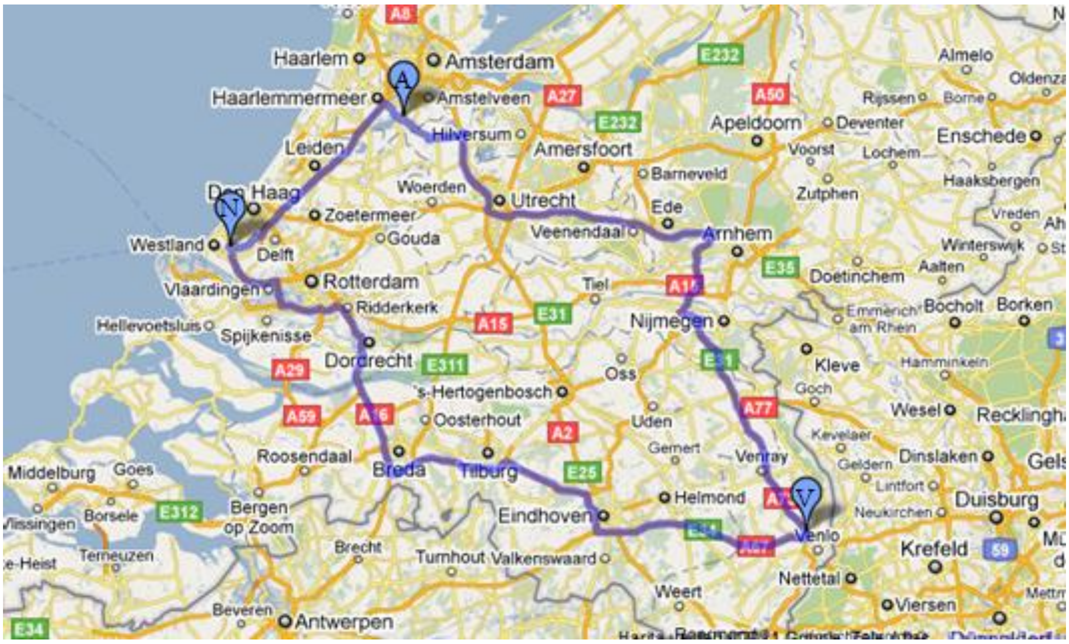

Figure 5 - 1: Representation of a sample cycle

Route V-N-A is assigned to make 24 tours on the given day. This means, every hour a new tour can be started on this cycle. This helps to construct within-day-schedules easier as the frequency of the tours will be known as an output of the model and it gives an idea about the timing of the tours.

As it is seen on Table 5-2, the loads on the legs of this cycle are balanced to make tours as efficient as possible. Indeed, this is the basic idea behind forming cycles. 24 tours are decided to be made on the legs A-N and V-A and all these tours are assigned to carry Supply, Connect and Import types of flows. On the other hand, out of 24 tours, 15 of them are assigned to carry Supply, Connect and Import types of flows and 9 tours are assigned to carry KOA flow on the leg N-V.

Table 5 - 2: Number of tours allocated to the legs of a sample cycle

	Supply & Connect & Import	**KOA**	**TOTAL**
A-N	24	0	24
N-V	9	15	24
V-A	24	0	24

After determining cyclic routes, we planned within day transportation in detail with the Scheduling heuristic. In this planning, trucks are assigned to cyclic routes and truck scheduling is made on these given routes. In the tables 5-3, 5-4, 5-5 and 5-6, the number of trucks scheduled in each time period is given with origin and final destination for the sample day. While Table 5-3 and 5-5 show the schedule and direction of the trucks that started a new tour, Table 5-4 and 5-6 show the trucks continuing on their routes with their given directions and schedules.

Table 5 - 3: Number of trucks started a new tour (KOA)

Time Periods	Flows																													
	A-B	A-E	A-N	A-R	A-V	B-A	B-E	B-N	B-R	B-V	E-A	E-B	E-N	E-R	E-V	N-A	N-B	N-E	N-R	N-V	R-A	R-B	R-E	R-N	R-V	V-A	V-B	V-E	V-N	V-R
05:30 - 06:00	0	0	0	0	0	3	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06:00 - 06:30	0	0	7	9	0	1	0	2	2	1	0	0	0	0	0	14	6	0	17	2	5	0	0	2	0	0	0	0	0	0
06:30 - 07:00	1	1	9	15	3	2	0	1	1	0	0	0	0	0	0	13	7	1	17	3	4	1	1	3	1	0	1	0	1	0
07:00 - 07:30	2	1	5	11	3	0	0	1	1	1	1	1	0	0	0	4	4	0	8	2	1	0	0	1	1	0	0	0	0	0
07:30 - 08:00	0	2	6	7	5	0	0	1	1	0	0	0	0	0	0	6	4	0	10	2	0	1	0	0	0	0	0	0	0	0
08:00 - 08:30	0	0	5	2	1	0	0	1	0	0	1	0	0	0	0	2	2	0	1	0	1	0	0	0	1	0	0	0	0	0
08:30 - 09:00	0	1	5	9	2	0	0	0	1	0	0	0	0	0	0	0	5	0	10	2	0	1	0	0	0	0	0	0	0	0
09:00 - 09:30	0	0	0	10	2	0	0	0	0	0	0	0	0	0	0	0	5	0	6	3	0	0	0	0	1	0	0	0	0	0
09:30 - 10:00	0	1	0	3	2	0	0	0	0	0	0	0	0	0	0	0	2	0	3	1	0	0	0	0	0	0	0	0	0	0
10:00 - 10:30	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10:30 - 11:00	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0

Table 5 - 4: Number of trucks continuing their routes (KOA)

Time Periods	Flows																													
	A-B	A-E	A-N	A-R	A-V	B-A	B-E	B-N	B-R	B-V	E-A	E-B	E-N	E-R	E-V	N-A	N-B	N-E	N-R	N-V	R-A	R-B	R-E	R-N	R-V	V-A	V-B	V-E	V-N	V-R
05:30 - 06:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06:00 - 06:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06:30 - 07:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07:00 - 07:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0
07:30 - 08:00	3	0	0	5	0	6	0	0	0	0	0	0	0	0	0	2	0	0	2	0	2	0	0	26	0	0	0	0	0	0
08:00 - 08:30	16	0	0	4	0	7	0	0	0	1	0	0	0	0	0	1	0	0	3	0	1	0	0	32	0	0	0	0	0	0
08:30 - 09:00	19	0	0	1	0	5	0	0	0	0	0	0	0	0	0	10	0	0	1	0	12	0	0	8	0	0	0	0	0	0
09:00 - 09:30	7	0	6	0	0	6	0	14	0	1	0	0	0	0	0	16	0	0	0	0	1	0	0	17	0	0	0	0	0	0
09:30 - 10:00	8	0	7	1	0	2	0	13	0	0	0	0	0	0	0	1	0	0	0	0	2	0	0	1	0	3	0	0	0	0
10:00 - 10:30	4	0	4	0	0	6	0	4	0	1	0	0	0	0	0	8	0	0	0	0	1	0	0	19	0	6	0	0	0	0
10:30 - 11:00	1	0	4	0	0	5	0	6	0	0	1	0	1	0	0	0	0	0	0	0	16	0	0	0	0	7	0	0	0	0

Table 5 - 5: Number of trucks started a new tour (Supply, Connect, and Import)

Time Periods	Flows																													
	A-B	A-E	A-N	A-R	A-V	B-A	B-E	B-N	B-R	B-V	E-A	E-B	E-N	E-R	E-V	N-A	N-B	N-E	N-R	N-V	R-A	R-B	R-E	R-N	R-V	V-A	V-B	V-E	V-N	V-R
05:30 - 06:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06:00 - 06:30	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	1	0
06:30 - 07:00	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	1	0	0	1	0
07:00 - 07:30	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
07:30 - 08:00	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	1
08:00 - 08:30	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0	0	1	0
08:30 - 09:00	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	2	0	0	1	1	0	0	0	0	0	1	0	0	1	0
09:00 - 09:30	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
09:30 - 10:00	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
10:00 - 10:30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	1
10:30 - 11:00	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
11:00 - 11:30	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
11:30 - 12:00	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0
12:00 - 12:30	0	0	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0
12:30 - 13:00	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
13:00 - 13:30	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	1	0
13:30 - 14:00	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
14:00 - 14:30	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0
14:30 - 15:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
15:00 - 15:30	0	0	0	0	0	2	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
15:30 - 16:00	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0
16:00 - 16:30	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
16:30 - 17:00	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
17:00 - 17:30	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	1
17:30 - 18:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0
18:00 - 18:30	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
18:30 - 19:00	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
19:00 - 19:30	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	1	0
19:30 - 20:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
20:00 - 20:30	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
20:30 - 21:00	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
21:00 - 21:30	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
21:30 - 22:00	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
22:00 - 22:30	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1
22:30 - 23:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0
23:00 - 23:30	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0
23:30 - 00:00	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
00:00 - 00:30	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0
00:30 - 01:00	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
01:00 - 01:30	0	0	0	0	0	2	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
01:30 - 02:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0
02:00 - 02:30	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	0
02:30 - 03:00	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
03:00 - 03:30	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	0	1
03:30 - 04:00	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
04:00 - 04:30	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	1	0	1	0
04:30 - 05:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
05:00 - 05:30	0	0	0	0	0	2	0	2	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	2

Table 5 - 6: Number of trucks continuing their routes (Supply, Connect, Import)

Time Periods	Flows																													
	A-B	A-E	A-N	A-R	A-V	B-A	B-E	B-N	B-R	B-V	E-A	E-B	E-N	E-R	E-V	N-A	N-B	N-E	N-R	N-V	R-A	R-B	R-E	R-N	R-V	V-A	V-B	V-E	V-N	V-R
05:30 - 06:00	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06:00 - 06:30	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	1	0
06:30 - 07:00	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	1	0	0	1	0
07:00 - 07:30	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
07:30 - 08:00	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	1	0	1	0	0	1	1
08:00 - 08:30	0	0	1	2	0	1	0	1	1	0	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0	1	0	0	1	0
08:30 - 09:00	0	0	1	2	0	2	0	0	0	0	1	0	0	0	0	2	1	0	1	1	0	1	0	2	0	1	0	0	1	0
09:00 - 09:30	2	0	1	2	0	1	0	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	3	0	0	0	0	0	0
09:30 - 10:00	1	0	2	1	1	2	0	1	1	0	0	0	0	0	0	2	1	0	0	0	1	0	0	2	0	1	0	0	1	0
10:00 - 10:30	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	3	0	1	0	0	1	1
10:30 - 11:00	2	0	2	2	0	1	0	1	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	2	0	0	0	0	0	0
11:00 - 11:30	1	0	2	0	2	1	0	1	1	0	0	0	0	0	0	2	0	0	0	0	1	0	0	1	0	1	0	0	1	0
11:30 - 12:00	0	0	0	0	2	1	0	0	0	0	1	0	0	0	0	2	2	0	1	0	0	0	0	3	0	1	0	0	1	0
12:00 - 12:30	2	0	0	0	2	2	0	1	1	0	0	0	0	0	0	2	1	0	1	1	0	0	0	1	0	1	0	0	1	0
12:30 - 13:00	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	1
13:00 - 13:30	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	1	0	1	0	0	1	0
13:30 - 14:00	2	0	1	0	3	1	0	1	1	0	0	0	0	0	0	2	1	0	0	0	1	0	0	2	0	1	0	0	1	0
14:00 - 14:30	1	0	2	0	0	1	0	1	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0	1	0
14:30 - 15:00	1	0	1	1	2	1	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	1	0	1	0	0	1	0
15:00 - 15:30	1	0	2	0	2	2	0	1	1	0	1	0	0	0	0	2	2	0	0	0	1	0	0	0	0	1	0	0	0	1
15:30 - 16:00	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	2	1	0	1	1	0	0	0	2	0	1	0	0	1	0
16:00 - 16:30	1	0	1	0	2	1	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	1	0	0	0	0	1	0
16:30 - 17:00	1	0	0	2	2	1	0	1	1	0	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0	1	1	0	0	0
17:00 - 17:30	1	0	2	0	2	1	0	1	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	1	0	1	0	0	1	1
17:30 - 18:00	1	0	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	2	0	0	0	0	1	0
18:00 - 18:30	1	0	0	1	4	1	0	1	1	0	0	0	1	0	0	2	2	0	0	0	1	0	0	0	0	1	0	0	0	0
18:30 - 19:00	1	0	2	0	2	2	0	1	0	0	0	0	0	0	0	2	0	0	1	0	0	1	0	1	0	1	0	0	1	0
19:00 - 19:30	1	0	1	1	1	1	0	1	1	0	0	0	0	0	0	2	0	0	1	1	0	1	0	1	0	1	0	0	1	0
19:30 - 20:00	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0	0	0	0	1	1
20:00 - 20:30	1	0	0	2	1	1	0	1	1	0	0	0	0	0	0	2	0	1	1	0	0	1	0	1	0	1	0	0	0	0
20:30 - 21:00	1	0	3	1	2	1	0	1	0	0	0	0	0	0	0	2	1	0	0	0	1	0	0	1	0	1	0	0	2	0
21:00 - 21:30	1	0	0	1	1	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	1	1	0	1	0	0	0	0	0	0
21:30 - 22:00	2	0	0	2	1	2	0	1	0	0	0	0	0	0	0	2	2	0	1	0	0	0	0	2	0	1	0	0	0	0
22:00 - 22:30	1	0	2	0	4	1	0	1	1	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	1	0	0	1	1
22:30 - 23:00	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	2	0	0	1	1	0	1	0	2	0	1	0	0	1	0
23:00 - 23:30	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	1	0	0	0	1	1	0
23:30 - 00:00	1	1	0	3	1	1	0	1	1	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	1	0	0	1	0
00:00 - 00:30	0	0	1	0	3	1	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	1	0	1	0	0	0	0
00:30 - 01:00	2	0	1	0	1	1	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	2	0	2	0	0	0	0	1	1
01:00 - 01:30	1	1	0	1	1	2	0	1	1	0	0	0	0	0	0	2	1	0	0	0	1	0	0	0	0	1	0	0	1	0
01:30 - 02:00	0	0	2	1	1	1	0	0	0	0	0	0	0	0	0	2	1	0	1	0	0	0	0	1	0	1	0	0	0	0
02:00 - 02:30	2	0	0	1	2	1	0	1	1	0	0	0	0	0	0	2	0	0	1	1	0	1	0	1	0	1	0	0	1	0
02:30 - 03:00	1	0	1	0	0	1	0	1	0	0	0	0	0	0	1	2	1	0	0	0	1	0	0	1	0	0	0	0	1	0
03:00 - 03:30	0	0	0	3	2	1	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	1	0	1	0	1	0	0	0	1
03:30 - 04:00	2	0	1	1	2	1	0	1	1	0	1	0	0	0	0	2	1	0	0	0	1	0	0	1	0	1	0	0	1	0
04:00 - 04:30	1	0	1	0	1	2	0	1	0	0	0	0	0	0	0	2	0	1	1	0	0	2	0	1	0	1	1	0	1	0
04:30 - 05:00	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	2	0	0	0	0	2	0
05:00 - 05:30	1	0	2	0	3	2	0	2	2	0	0	0	0	0	0	3	1	0	0	0	1	0	0	0	0	2	0	0	0	2

We've selected five sample days to evaluate the performance of the proposed approach. Each day is taken from different times of the year to include flows with different characteristics, so to take seasonality effect into account. Therefore, the data is representative of different situations and effectiveness of our approach can be shown in all cases.

Commercial data used in calculations belong to Tuesdays of the 6th, 16th, 26th, 39th and 49th weeks. These days symbolize important days and different seasons, such as Christmas, end of winter and spring where the demand is at the peak. The variety between these sample days can also be observed by looking at the changes in percentages of flows originating from a specific auction centers. While Figure 5-2 shows this variety for KOA flow Figure 5-3 shows it for other flows.

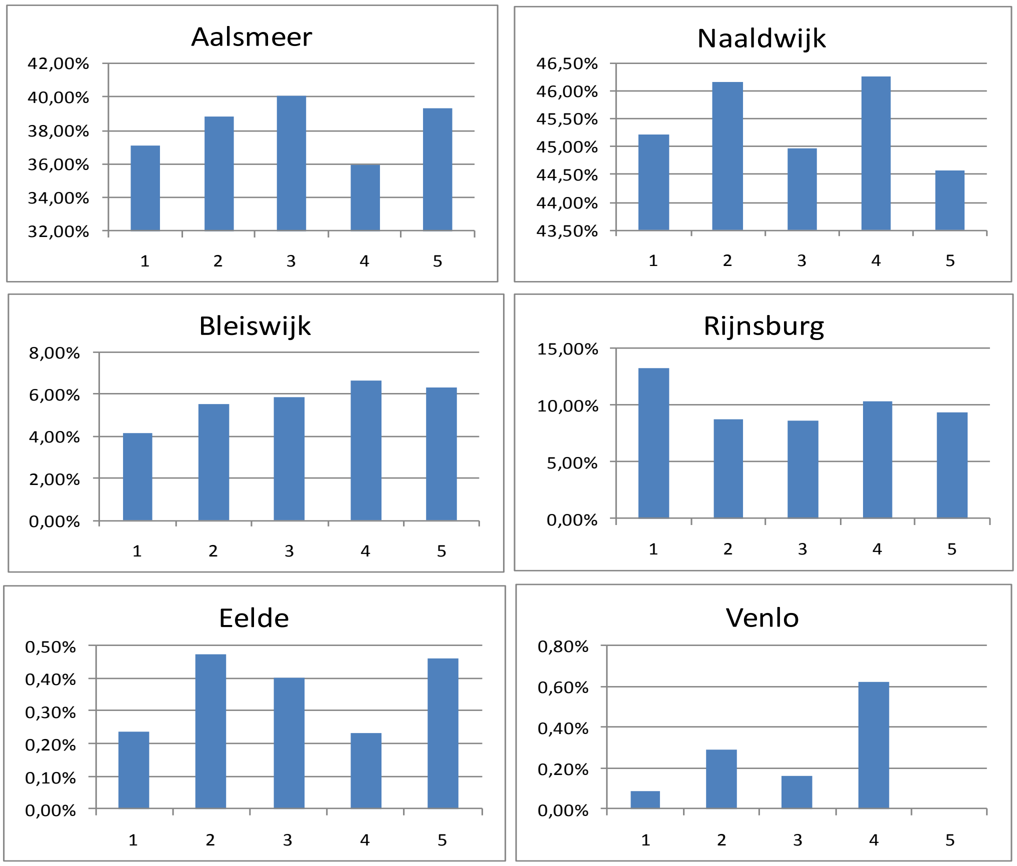

Figure 5 - 2: Distribution of KOA flow among sample days

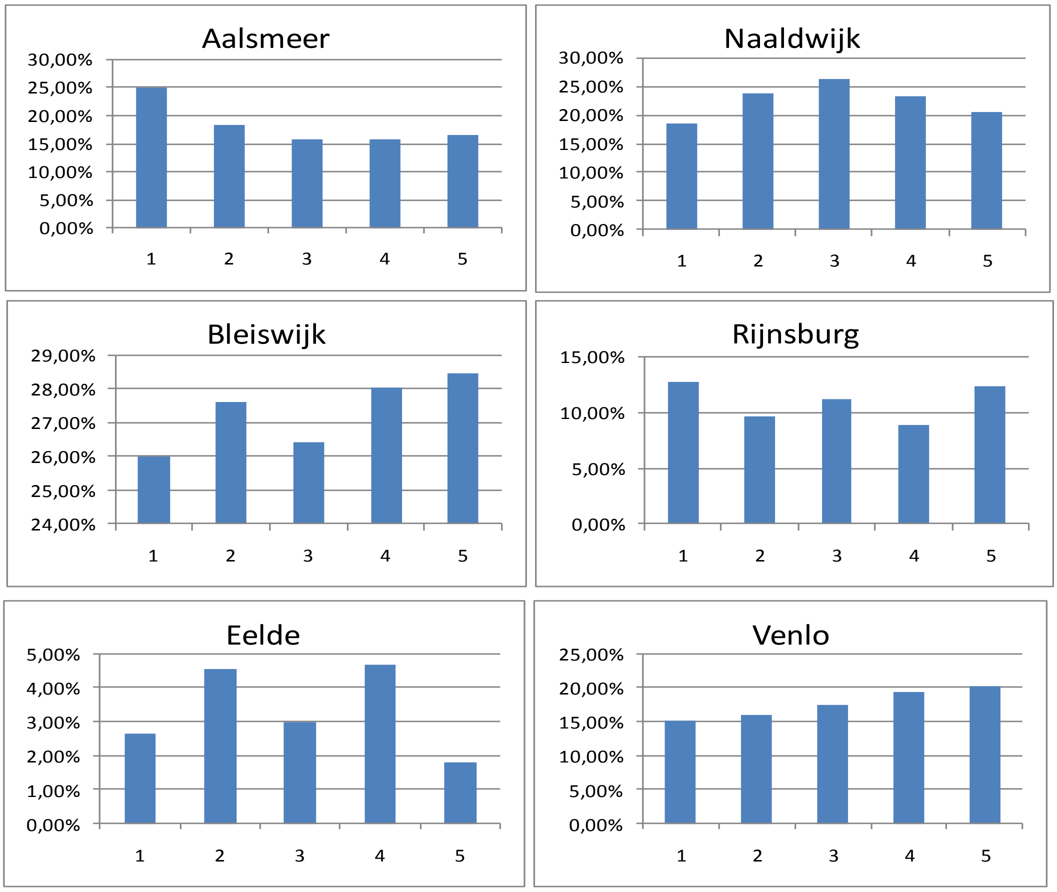

Figure 5 - 3: Distribution of Supply, Import and Connect flows among sample days

Table 5-7 presents the time required to solve each problem case for both Cycle Assignment Model and Scheduling heuristic. As it is seen, computational time is fair enough to solve this problem. Although computational time of Cycle Assignment Model seems long at first, it doesn't create so much effect on the speed of the solution approach as it is solved only once at the beginning of the day. The model stopped due to 1000 CPU time limit on all of five sample cases, but it doesn't created much effect on the solution quality as it reached almost optimal solution at that time.

On the other hand, Scheduling Heuristic is solved every half an hour, so it is important this heuristic is as fast as possible. It is seen that it takes less than a second to run the heuristic with a whole day data. Therefore, it can be said that the solution approach is good in computational efficiency.

Table 5 - 7: Computational time (in seconds)

Case	Cycle Assignment Model	Scheduling Heuristic
C1	1,004.136	0.21
C2	1,003.571	0.25
C3	1,003.216	0.22
C4	1,004.111	0.22
C5	1,004.745	0.22

When we compared the objective function value of our solution approach with the actual amount paid to the logistic companies, we saw that on the average 36% cost reduction is possible. At this stage, we desired to compare these values also with the objective function value of MDVRPPDTW model. However, as it was stated in Literature Study, the model can not be solved even for the case with daily aggregated amount and relaxed time window restrictions. Therefore, this comparison can not be made.

For detailed information about the cost reduction over all cases, please see Table 5-8. In this table, the total costs calculated a result of solving the Cycle Assignment Model is also given separately. These figures are presented to show the results given by Cycle Assignment Model and the effect of making daily schedules. As it can be seen, the improvements obtained by Cycle Assignment Model are reduced by Scheduling Heuristic. However, these changes are expected due to many reasons as it was explained in the previous chapters.

Table 5 - 8: Cost Comparison (Euros)

Case	Actual Value	Cycle Assignment Model		Scheduling Heuristic	
		Result	Difference	Result	Difference
C1	259219	140837	46%	147243	43%
C2	343464	199816	42%	229771	33%
C3	276661	167045	40%	194831	30%
C4	258940	165947	36%	165499	36%
C5	219498	126609	42%	138982	37%

The reduction obtained may seem high at first. There are many reasons behind it. First of all, as we indicated before, we don't have exact information on the logistical data and the tariff rates of logistics companies. Logistics companies do not give this information due to privacy issues. Therefore, we make assumptions in order to use them in our calculations. For logistical flow data, we use commercial data of FloraHolland. For the tariffs, we use estimations made by Jonkman, 2010 through interviews. About the cost structure of our approach, we determined it by looking at cost calculation structure of a logistics company. About the tariffs, we made educated guesses through the data given by Jonkman, 2010 and other relevant studies on logistics cost calculation. Moreover, we do not completely take uncertainties in our Cycle Assignment Model. Therefore, it may give a lower value than the result obtained by taking all uncertainties into account. Although this is the case, we are sure that routing over cycles gives better results than the current case. This fact is also supported by Jonkman, 2010. In his study, he states the following:

"The current model only works with bi-directional truck movements, e.g. Eelde-Bleiswijk and back, and does not allow for trucks to make a round-trip between for instance Eelde, Aalsmeer and Bleiswijk. We expect that in more detailed calculations, allowing trucks to make a round-trip between more than two auction locations will further increase the achieved savings and reduce the total number of (empty) truck movements in a coordinated scenario. Naturally, a truck having to travel empty from Naaldwijk to Aalsmeer under our assumption could then also be used to transport products from Naaldwijk to Rijnsburg, before travelling back to Aalsmeer."

The solution approach gives reasonable values also in terms of capacity. In Table 5-9, the maximum number of trucks used at any time is given for the five sample days. Although it is not clearly defined by logistics companies, there are more than 300 trucks available for transport of FloraHolland. Therefore, these figures state that the capacity is big enough to handle Inter-Auction Transportation and it does not create restriction on the proposed solution approach although Scheduling Heuristic works well also under limited capacity.

Table 5 - 9: Maximum number of trucks used

Case	Max. No. of Trucks
C1	131
C2	145
C3	124
C4	111
C5	104

When the output of the model is analyzed, it is easily seen that most of the flows are assigned to smaller cycles. Table 5-10 shows the distribution of cycles over sample days. Almost all of the flows are assigned to cycles of sizes 2 or 3 nodes. One reason behind that is time restriction due to service level requirements of KOA flow. Another reason is that model only consolidates flows unless it is necessary, i.e. more efficient than sending flows separately. For this reason, the model favors some cycles in the solution. 10 most frequent cycles can handle 81% of the flows. This brings another advantage. When a cycle is more favorably used, it can be more frequently scheduled in a day, so it gets easier to know when to schedule it. For example, the cycle A-B is assigned to make 38 tours in the sample day 2. Therefore, almost in each half an hour, a truck can start a new tour.

Table 5 - 10: Distribution of cycles over sample days

	C1	**C2**	**C3**	**C4**	**C5**
2	64%	34%	32%	38%	56%
3	34%	63%	65%	61%	42%
4	2%	3%	2%	1%	2%
5	0%	0%	0%	0%	0%

Table 5-11 compares the result obtained after solving Flow-Cycle Assignment Model and after applying Scheduling Heuristic. This is done to show whether forming a detailed schedule makes a considerable change on the results. As it can be seen, some cycles are decided not to be formed and some new cycles are decided to be formed after making the detailed schedule. Moreover, the cycles formed between bigger auction centers such as Aalsmeer, Naaldwijk and Rijnsburg, are appeared to be higher in number due to size of the sales realized and the amount of flows from/to these centers.

Table 5 - 11: The number of cycles: Cycle assignment model vs. Scheduling Heuristic

	Cycle Assignment Model					Scheduling Heuristic				
Cycles	**C1**	**C2**	**C3**	**C4**	**C5**	**C1**	**C2**	**C3**	**C4**	**C5**
A-B	0	61	18	0	0	0	38	9	0	0
A-B-E	0	1	0	0	2	0	1	0	0	23
A-B-N	13	95	80	74	26	13	97	81	73	22
A-B-R	2	21	24	23	22	1	19	24	21	5
A-B-V	1	0	0	2	0	0	0	0	2	0
A-E	4	11	5	13	0	6	16	3	14	0
A-E-B-N-R	0	1	1	0	0	0	1	1	0	0
A-E-N	3	5	4	6	2	3	7	4	6	2
A-E-R	3	2	2	6	1	2	3	2	5	0
A-E-V	0	9	0	1	7	0	10	0	0	6
A-N	100	2	18	24	67	107	0	0	20	70
A-N-B-E	2	0	0	1	1	1	0	0	0	1
A-N-R	0	6	11	5	3	0	7	9	4	4
A-N-V	13	31	24	12	7	10	35	58	10	7
A-R	69	36	27	15	19	80	37	36	19	19
A-R-B-V	3	14	6	3	2	7	19	10	2	3
A-R-N-B-V	0	1	0	0	0	0	0	0	0	0
A-R-V	5	1	4	6	6	10	3	9	12	12
A-V	43	41	53	62	56	39	48	49	61	52
B-E-R-N	0	0	0	1	0	0	0	0	1	0
B-N	36	0	0	0	33	36	0	0	0	36
B-N-R	25	1	1	1	3	23	0	0	0	1
B-N-V	1	1	0	1	0	2	0	0	1	0
B-R	19	1	0	1	0	19	0	0	0	0
B-R-V	0	1	0	1	0	0	2	0	2	0
B-V	1	1	0	0	0	2	2	0	0	0
E-B-A	0	2	1	0	0	0	2	2	0	0
E-B-N	0	0	0	2	0	0	0	0	2	0
E-V	1	1	1	0	0	3	1	1	0	0
N-B-A	7	65	52	50	3	10	87	70	60	2
N-E-A	0	9	4	0	3	0	8	5	0	3
N-R	87	100	100	94	77	86	101	100	85	76
N-R-E-A	1	1	0	0	0	1	0	0	0	0
N-R-E-B	1	0	0	0	1	2	0	0	0	2

Table 5 - 11 (continued): The number of cycles: Cycle assignment model vs. Scheduling Heuristic

N-R-V	1	5	0	2	1	1	7	0	3	1
R-B-A	85	8	35	54	78	83	12	24	44	78
R-E-A	3	1	1	1	0	2	1	1	1	0
R-N-A	0	63	47	26	0	0	106	67	35	0
R-N-B	0	2	0	0	0	0	2	0	0	0
R-N-B-E-A	0	1	2	0	0	0	0	2	0	0
R-N-E	1	0	0	0	0	1	0	0	0	0
V-B-A	0	4	1	1	0	0	3	1	0	0
V-B-N-A	0	0	1	0	3	0	0	0	0	2
V-B-R-A	2	1	2	1	1	2	1	2	1	1
V-E-A	1	1	3	2	2	0	0	3	1	0
V-N-A	32	36	36	38	23	35	45	38	38	24
V-R-E	0	0	0	0	0	0	0	0	0	1
V-R-N	1	1	1	2	1	1	1	2	3	1

The changes observed in Table 5 – 11 are expected. Although Scheduling Heuristic is based on Cycle Assignment Model, it works based on the realized data without any insight on future, so it doesn't foresee consolidation opportunities that may occur in the future. Another reason is that Cycle Assignment Model is solved with daily aggregated data without any effect of timing of demand realizations. However, in the actual case, sales are made different times of the day and the timing of these sales change depending on the center where the particular auction is made. While, in some of the auction centers, sales are more expectedly occur between 6 AM-8 AM, in some centers it starts at 7 AM and continue till 11 AM. This result in some cycles are not to be utilized as expected in Cycle Assignment Model, so this changes cyclic routes to be followed and their frequencies.

CHAPTER VI

CONCLUSION and FURTHER RESEARCH

In this study, we studied transportation of floriculture products between different auction centers, i.e. Inter-Auction Transportation (IAT), of FloraHolland, the largest auction of floriculture products, in the world. Due to the size of the business, there is a huge flow of products between these centers. Therefore, efficient organization of IAT carries great importance for the company due to many reasons.

FloraHolland is a non-profit company and wants to serve its members the best sales opportunities at the lowest costs. This means the excellence of the service superiors the cost. The quality of the product is an important criterion for the service, so the products should be delivered in a short period of time as they are perishable. For this reason, timing restrictions is critical factor for the service and shouldn't be compensated.

In order to coordinate and optimize transport flows between FloraHolland auction locations, we concluded that exact models do not work due to complexity and size of our problem. Therefore, we developed a multi-stage approach specific to this problem. With this approach, we split considerations of exact approach into two, a mathematical model followed by a heuristic. As a result, we have obtained good solutions within a short period of time.

As the first step of our solution methodology, Cycle Assignment Model determines most efficient routes to be followed between auction centers of FloraHolland. This model also determines a lower bound on the capacity to handle transportation on the daily level. Next, with Scheduling Heuristic, trucks are assigned to the routes determined by Cycle Assignment Model and within day transportation is planned in detail.

This approach brings advantages to FloraHolland. Firstly, due to the coordination of existing flows, the efficiency of IAT will be improved at FloraHolland. This will also lead to better utilization of the resources and more environment-friendly solutions. Moreover, with a decrease in total transportation costs, logistics companies can decrease their current tariffs. Current cost calculation structure can also be changed with this approach. Rather than paying for bi-directional truck movements, FloraHolland may pay for movements over cycles. By doing this, the company may negotiate with logistics companies about the costs of cycles depending on the length and the utilization rate. Routing over cycles is good for truck drivers, too. Vehicles go back to their starting points when their tours end, so that drivers neither stay somewhere different from their homes and nor drive empty trucks.

This approach can also be generalized to be used also in different problem situations. Especially Cycle Assignment model can be applied to many cases where transshipments are realized between different locations and time windows constraints can be relaxed. Therefore, vehicles can be routed over cyclic paths and resources are utilized efficiently. On the other hand, Scheduling Heuristic is developed specifically for FloraHolland, but it can be easily adapted to other cases easily only with small modifications.

For the case study, five sample days are selected from different times of 2010 to represent different periods with different characteristics. By this way, seasonality effect is also taken into account while evaluating the performance of the proposed approach. Commercial data of FloraHolland is used in calculations.

When results are analyzed, it is seen that this approach has a potential to reduce current transportation cost for the given days in a short period of time. It can be said that computational time of this approach is short, especially when it is considered these problems are of sizes 1800 requests and about 100 vehicles. Although it is desired to compare these results with the results of exact approaches, it is not possible even for the case with daily aggregated amount and relaxed time windows. Therefore, this comparison is not given.

It is believed that this approach is developed with realistic assumptions; there is still room for improvements. This brings future research directions. In our calculations, it is assumed that there is a homogenous fleet of vehicles. However, in reality logistics companies have other sizes of trucks. Therefore, the solution approach can be extended to the multi-vehicle case. Moreover, it is assumed that trolleys can take 29 buckets on average. In the actual case, there are different types of buckets and the capacity of a trolley changes depending on the size of buckets to be placed on trolley. With this consideration, bucket size can also be fed into the model as a parameter. An improvement can also be made for transportation of flowers that need special compartments in trucks. Although all plants are carried at the same temperature, some flower types need cooler conditions, so they need special compartments while they are being carried. For this reason, the model can be modified that some flowers are treated specially.

In addition to these extensions, our Scheduling Heuristic can be improved as a future direction. Although it brings good solution in short CPU time, some modifications can be made so that it may take future anticipations more effectively into account to perform better.

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APPENDIX A

IMPRESSION of FLORAHOLLAND

Figure 1: An impression from FloraHolland

APPENDIX B

INTER-AUCTION TRANSPORT SCHEME

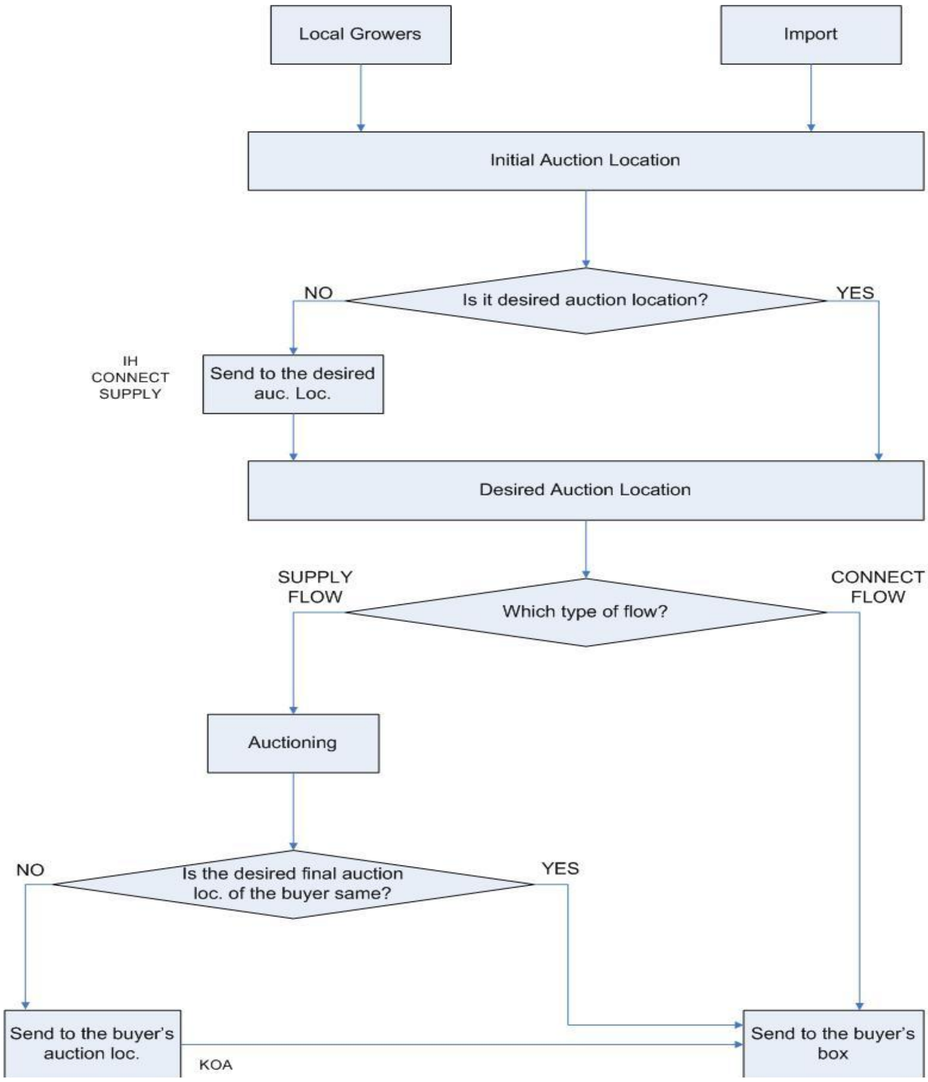

Figure 2 : Schematic representation of Inter-Auction-Transportation at FloraHolland

APPENDIX C

DISTRIBUTION PLOT

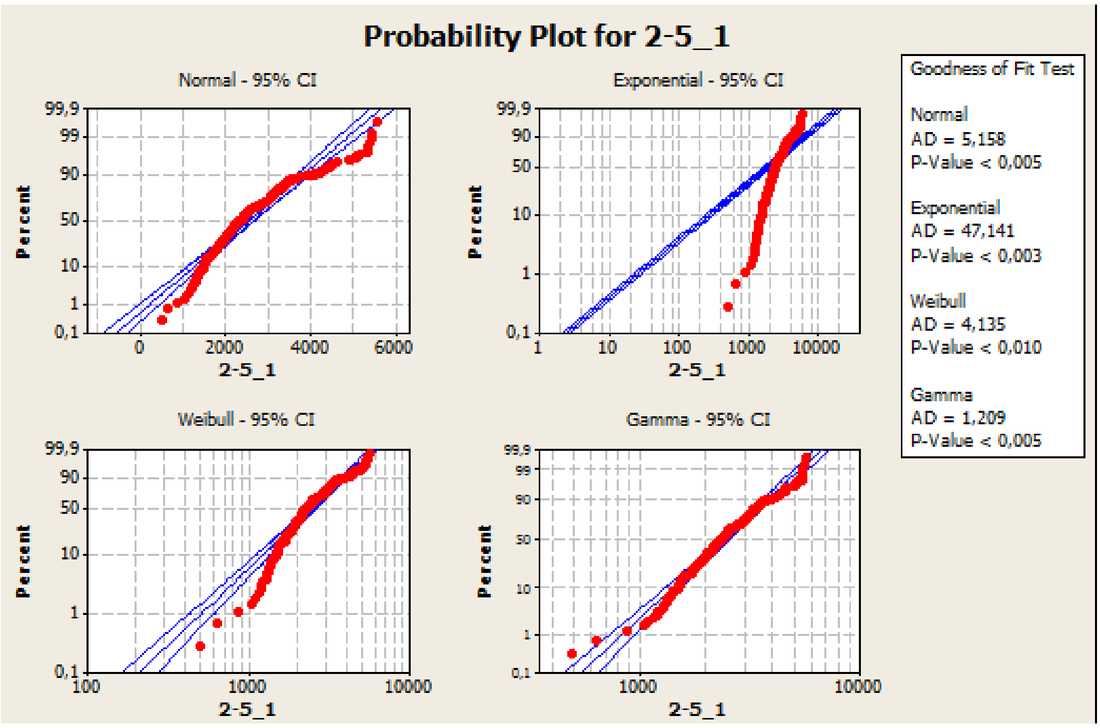

Figure 3: Distribution Plot of KOA Flow between 2 Auction Centers in 2009

APPENDIX D

NUMBER of VARIABLES

Table 1 – The number of variables in MDVRPPDTW Model

Variable Set	No. of variables
x	330,750,000
a	1,950
d	1,950
Q	540,000
w	3,600
Total	331,297,500

Table 2 – The number of variables in Cycle Assignment Model

Variable Set	**No. of variables**
x	248,400
v	54,151,200
w	15,042
y	69
Total	54,414,711