AIRFREIGHT OPTIMIZATION MODEL FOR DELIVERING SHIP SPARES ONBOARD

DEPARTMENT OF INDUSTRIAL MANAGEMENT AND TECHNOLOGY

LOGISTICS MANAGEMENT

UNIVERSITY OF PIRAEUS

GREGORY SOUVATZIS

PIRAEUS NOVEMBER 2021

ΔΗΛΩΣΗ

Η εργασία αυτή είναι πρωτότυπη και εκπονήθηκε αποκλειστικά και μόνο για την απόκτηση του συγκεκριμένου μεταπτυχιακού τίτλου.

Τα πνευματικά δικαιώματα χρησιμοποίησης του μη πρωτότυπου υλικού ΜΔΕ ανήκουν στο μεταπτυχιακό φοιτητή και το επιβλέπον μέλος ΔΕΠ εις ολόκληρο, δηλαδή εκάτερος μπορεί να κάνει χρήση αυτών χωρίς τη συναίνεση άλλου. Τα πνευματικά δικαιώματα χρησιμοποίησης του πρωτότυπου μέρους ΜΔΕ ανήκουν στον μεταπτυχιακό φοιτητή και τον επιβλέποντα από κοινού, δηλαδή δεν μπορεί ο ένας από τους δύο να κάνει χρήση αυτού χωρίς τη συναίνεση του άλλου. Κατ' εξαίρεση, επιτρέπεται η δημοσίευση του πρωτότυπου μέρους της διπλωματικής εργασίας σε επιστημονικό περιοδικό ή πρακτικά συνεδρίου από τον ένα εκ των δύο, με την προϋπόθεση ότι αναφέρονται τα ονόματα και των δύο ως συν-συγγραφέων. Στην περίπτωση αυτή προηγείται γραπτή ενημέρωση του μη συμμετέχοντα στη συγγραφή του επιστημονικού άρθρου. Δεν επιτρέπεται η κατά οποιοδήποτε τρόπο δημοσιοποίηση υλικού το οποίο έχει δηλωθεί εγγράφως ως απόρρητο.

Περίληψη

Οι μεταφορικές ανάγκες της κοινωνίας του σήμερα έχουν κατά πολύ ξεπεράσει εκείνες του προηγούμενου αιώνα, με τη παγκοσμιοποίηση του εμπορίου να έχει οδηγήσει σε μία αγορά η οποία δε γνωρίζει σύνορα. Σύγχρονα δίκτυα Logistics επιδιώκουν να καλύψουν αυτές τις ανάγκες, οι οποίες πολλές φορές λόγω της πολυπλοκότητάς τους απαιτούν άμεση δράση και ειδική μεταχείριση. Τέτοια προβλήματα μεταφοράς φορτίου, μπορούν να αναλυθούν και να αναπαριστούν μέσω μαθηματικών μοντέλων, αποσκοπώντας στην εύρεση του βέλτιστου μονοπατιού που θα πρέπει να ακολουθηθεί για τη διεκπεραίωση τους, μέσω μεθόδων Γραμμικού Προγραμματισμού. Μέσω της μεταφοράς ανταλλακτικών πλοίων της ωκεάνιας μεταφοράς, θα μπορούσε να δημιουργηθεί ένα μοντέλο εναέριας μεταφοράς, το οποίο να ψάχνει το βέλτιστο σενάριο βάση των στόχων που έχουν τεθεί, όπως την ελαχιστοποίηση του κόστους για το σύνολο των διαδικασιών.

Abstract

The transportation needs of today’s societies have gone far beyond the ones of the past century, with the globalization of trade having led to a market that meets no borders. Modern Logistics networks aim to cover these needs, which many times, due to their complexity, demand special handling and quick response. Such transportation problems can be represented via mathematical models, in order to enable finding the optimized way to proceed with, utilizing Liner Programming methods. Through the analysis of transferring ship spares to be delivered onboard vessels, a model of airfreight transfers can be created, aiming to find the optimized scenario given the objective that has been set, such as minimizing the costs of each operation.

Acknowledgments

I would like to thank Assistant Professor Pavlos Eiriniakis for his guidance and assistance on writing this essay. I would also like to thank my family and girlfriend for their support.

Contents

List of figures

List of Tables

Chapter 1: Introduction

Every object or provision people use in their everyday life has passed through an unnoticed supply chain in order to reach them at the place of purchase. Focusing on the modern societies can make crystal clear the necessity of an unstoppable transportation flow of cargo, in every each of its form. From groceries and clothes, to cars, iron and gasoline, the list of cargo transferred globally everyday can go on and on.

From the ancient times, people needed to froward freights across lands and seas. Nowadays, this need has led to transferring shipments across the world in a flash of time become a reality. A century ago, air transportation as we take it for granted today, would seem as an impossible scenario, but in our days a tuna fish can be fished on the West Coast of the USA and be sold the next morning in Tokyo's fish market, still fresh.

The globalization of trade and modern technology have created a worldwide market that meets no borders. Therefore, the need for global transportation solutions has gone higher than ever. Modern Logistics networks specialized such operations, connect several individuals all over the world in order to provide options and solutions where and when needed.

But since the world keeps changing rapidly, transportation and logistics procedures must follow and adapt. Given the complexity and the limited time available of some international forwarding operations, finding the optimized way to proceed with can become a target uneasy, for a Logistics Coordinator, to reach.

Approaching such cases through mathematics may be the solution. Illustrating a transportation problem through graphs and creating a mathematical model by setting relevant variables and constrains, may be the way to provide the optimized way to proceed with an operation, between several scenarios, through Linear and Integer Linear Programming methods. Entering such models in a computer optimization solver can enable simulating and handling optimally several real-life procedures and operations, in limited time, to provide the best scenario to proceed with.

Dispatching ship spares globally to be delivered onboard vessels can generate the need for this kind of procedure regarding the air freight forwarding cargo industry.

In this thesis, we examine the transportation methods of today, giving specific mention to the airfreight transports. Through the theoretical exploration of graphs and mathematical programming, a transportation optimization model is created, which is solved using the computer solver LP Solve IDE.

Scanning the ship spares forwarding industry, methods of collecting, storing and dispatching spares globally to be delivered onboard vessels are studied analytically. After inspecting relevant charges and procedures, a graph illustrating a global spare's forwarding operation is created. Setting variabilities and parameters, an integer programming model is built, looking to minimize the total final charges. Adjudging the figures of the model, several scenarios with different time available are examined through the LP Solve IDE, comparing the final charges of each plot.

Using this model, a comparison between real-life operation's decisions and computer solver's results is made, making clear the utility and helpfulness this thesis can provide to a logistics operator doing business in this industry. Taking a quick look into the future, further developments and applications of this model are broached.

The remainder of this thesis is organized as follows.

Starting with the freight transportation methods in Chapter 2, this thesis proceeds with a more specific analysis of the airfreight transfers, mentioning relevant charges and procedures. Modeling the problem using graphs is examined, following the theoretical approach of the subject. In Chapter 3, different methods of dispatching and delivering spares on board are inspected through real-life cases on the ship spare parts forwarding industry. Setting variabilities and parameters, a mathematical optimization model of such operation is created in Chapter 4, aiming to minimize the final charges given a specific timeline. By setting the parameters appropriately in Chapter 5, several scenarios run through LP Solve IDE, comparing the results between each case. This essay ends by mentioning future function and possibilities of this model in Chapter 6.

Chapter 2: Background

2.1 Freight transfers

In modern global markets, place of production and point of sale meet no limits, leading companies to plan a worldwide purchase strategy. As a result, logistics and transportation services become a necessity as most of the purchased goods needs to be transferred more than one time and by several transfer modes, before reaching their final destination.

Choosing the most cost-effective way to move their shipments within a predetermined deadline can be the way to success for such companies, therefore Logistics Coordinators are considered as a vital gear for this mechanism to keep working smoothly.

Road Transportation

The most ordinary way of transporting freight nowadays is by road. From delivering by foot or riding a horse, to big trucks and cranes, road transportation may be the most ancient way of transporting goods and the most necessary up to today.

Road transport is the only mode that can offer door – to – door deliveries. Therefore, even if goods are traveling with a different mode, most of the times their transfer will be completed by road. It is the best way to transfer small and light shipments in nearby distance.

Maritime Transportation

Since people created the first boats, goods also started to travel along. Today, it is estimated that around 90% of global international trade is made through ship transportation.

Modern vessels are able to sail almost in every sea point on our planet, offering a great solution for transferring heavy loads over the oceans. But despite being a wonder of modern mechanics, vessels of today still lack of speed, especially compared to the rest transportation modes, creating an important disadvantage that every Logistics Coordinator should take under consideration.

Rail transportation

Limited by the need for infrastructure, rail can be a very useful and cost-effective way of transport, especially for heavy bulk loads across land. It is considered as one of the most reliable ways of transportation as any delays during the trip are quite uncommon.

Due to the time and cost needed for new railways to be created, there are no remarkable changes to the existing infrastructures for the past century, meaning that many countries do lack of rail transportation options.

Pipelines

Although it does not come to everyone’s mind as a traditional way of transportation, pipelines play a huge role in today’s societies, transporting goods like oil, gas and water for many miles with the majority of costs to occur from their construction and not from their operation.

Intermodal Transportation

It is very common for a shipment to change modes of transport during its transit to the final destination. We can dispatch one container via ocean transfer from Europe to New York and further load same to a train and dispatch through railway across the USA, where we can load same to a truck and further deliver it door to door to the final destination.

Airfreight Transportation

Airplanes are the most modern and fastest way to dispatch cargo internationally. With the transit time being limited through air transfers, this mode is the perfect way to proceed for short time cases and operations.

Airfreight can provide unlimited transfer options and routes to follow, considering that each airport is connected to every other in the world, either with a direct or an indirect flight route. This provides numerous dispatch scenarios to proceed with, from which a Logistics Coordinator can choose the proper one for each case, based on a variety of factors like final costs, transit time and frequency of each flight.

Being the fastest way of transportation, relevant costs can go sky high compared to the rest modes. This is why it is uncommon to dispatch very large and heavy objects or proceed via airfreight for short distance transportations.

2.2. Airfreight costs and procedures

Costs for an international airfreight operation occur from the airline’s charges for the loaded cargo and from the forwarding agents who arrange all the necessary import or export procedures.

The airline’s charges occur as a fee per kg of cargo loaded, which means that shipment’s “ticket” price is relevant to its volume. Given that space in each aircraft is limited, airlines calculate the weight of each shipment based on the dimensions of same. Because a large but light item take up more space in the aircraft than a small but very heavy one, airlines charge a fee based on each item's chargeable weight, which is the greater weight between a shipment's actual gross weight and shipment's volumetric weight.

The volumetric weight of a package for the airline transfers is calculated in the metric system, by multiplying the length by the width by the height of same, in centimeters, and then divide the result by 6000, which is the number of cubic centimeters per kg considered by the airlines worldwide.

Package details: 50*60*40 cm // 4 kg *(gross weight)*

Airline's fee per kg transferred (in EURO): EUR 3.2/kg

Calculating volumetric weight → **(**50 x 60 x 40) / 6000 = 20 kg

Airfreight costs: (Airline's fee) x (Chargeable weight) → 3.2 x **20** = **EUR 64**

Figure 1: Calculating airline's freight charges

Other charges that may occur during international airfreight operations may be related to the import and export agents that handle each case. Such costs may consider the preparation of the relevant import and export documents, the transportation to the airport or the collection of cargo from the airline as well as any costs that may occur from any necessary procedure a country or an airport may have set, like fumigation of the wooden boxes, X-ray and security check, along with the relevant procedures.

2.3. Graphs & Mathematical Programming

Deciding how to proceed in each operation can become a huge problem for a Logistics Coordinator. Given the transportation network created over the last decades, client's receivables are increasing while the provided time for an operation to be completed is shrinking. Therefore, creating a model for these everyday problems, in order to search for the optimized solution, can be a useful tool nowadays.

2.3.1. Definitions

A long time ago, people started creating models to illustrate real world's systems and situations. Up to today, models of different shapes, sizes and styles are used to organize factual information into coherent wholes, leading to a unit of structured knowledge which can be used to describe a problem and by the coordinated use of general laws or principles, lead to a solution. Models have an information input, an information processor and an output of expected results. (Hestenes 1997)

There are several problems out of the everyday life that can be illustrated as a graph using nodes and edges. A node is considered as the elemental unit of the graph. This means it is the main feature of the problem. Each node in our graph can be connected with any other by a unique edge, which represents their relationship, or the circumstances under which they can connect. (Bettilyon, 2019)

Models like these can illustrate numerous situations, from simple problems to very complex ones. Searching the fastest way to visit several cities, where the nodes represent the cities and edges the distance in kilometers between, or setting a vehicle routing schedule, or a vessel's ports of call, can all be demonstrated as a graph model. The nodes and the connections within them may represent completely different situations based on different parameters, but for all there is one optimized solution. `

This optimized solution for each problem can be found, in most cases, through specialized algorithms. Approaching these problems through mathematics can provide an alternative way of optimization, creating models and solving them through Mathematical programming.

"Mathematical programming is that branch of mathematics dealing with optimization (maximizing or minimizing) an objective function subject to linear, nonlinear and integer constraints on the variables." (Dantzig and Thapa 1997)

"Linear Programming is concerned with the optimization of a linear objective function in many variable subject to linear equity and inequality constraints." (Dantzig and Thapa 1997)

"When some of the variables in a linear optimization problem are continuous and some are discrete the corresponding optimization problem is called a mixed integer linear program. When all of the variables are required to be integer it is an integer linear program. (Martin R.K. 1999)

2.3.2. Shortest Path Problem

The Shortest Path Problem is one of the most well – known problems that can be illustrated as a graph and solved through mathematical programming, searching for the optimized connection between two nodes. This optimized solution can be based on several criteria, such as minimizing the distance traveled or minimizing the costs of connection between the nodes. In the following example, searching for the shortest way to travel from city A, starting point, to city D, destination, each node represents a city and each edge the distance between them in kilometers.

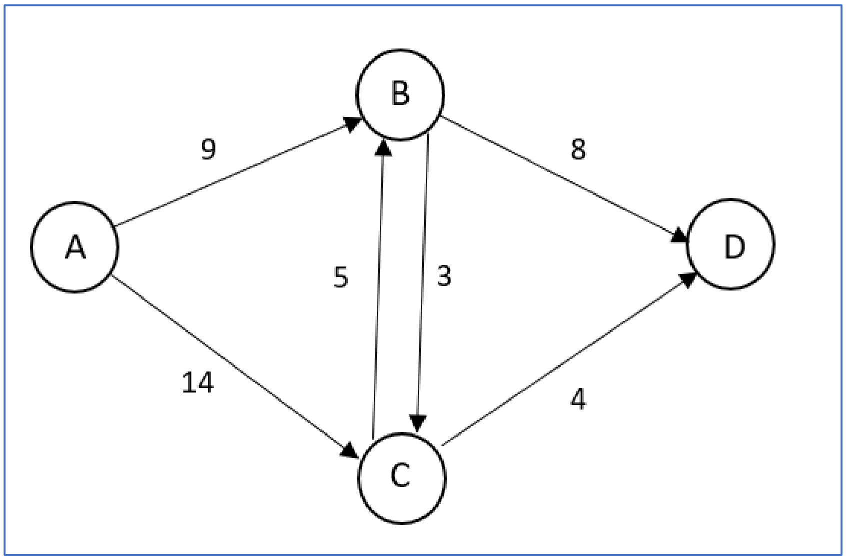


Figure 2: Example of the shortest path problem

Subtotals

I = {A, B, C)

J = {B, C, D)

Variables

x_{ij} = {0, 1}, if the path from i to j will take place or not, ∀ i ∈ I, j ∈ J.

Parameters

d_{ij}: Fixed distance between node i and j, ∀ i ∈ I, j ∈ J

Objective function

Given graph G, let VG and AG be its set of vertices and arcs, respectively.

$$\min \left\{ \left(\sum_{i,j \in VG} dij * xij \right) \right\} \tag{1}$$

Constraints

$$\sum_{ij} xij = 1 \forall i = A \tag{2}$$

$$\sum_{ij} xij = 1 \forall j = D \tag{3}$$

$$\sum xij = \sum xjk \forall \mathrm{i, j, k} \in AG,\ \mathrm{j} \neq \mathrm{k} \tag{4}$$

In the presented graph of Figure 2, nodes A, B, C, D represent cities on a map while edges within the nodes the distance between them. In this case, the goal is to find the optimized path from city A to city D.

The variable xij, will equal to 1 if the path from city i to j will be followed or to 0 if not, while the parameter dij, represents the distance between city i to j, as set in Figure 2.

The objective function (1) is searching for the minimized connection within the nodes of the graph. Constraint (2) sets that one and only path will exit city A, which is the starting point, while constrain constraint (3) sets that one and only path will lead to city D, which is the final destination. These two constrains make clear that the objective function will search for the minimized connection within these cities. Constraint (4) sets that every import path that may enter a city, will exit that city through one and only of the possible exit paths.

2.4. MILP solvers

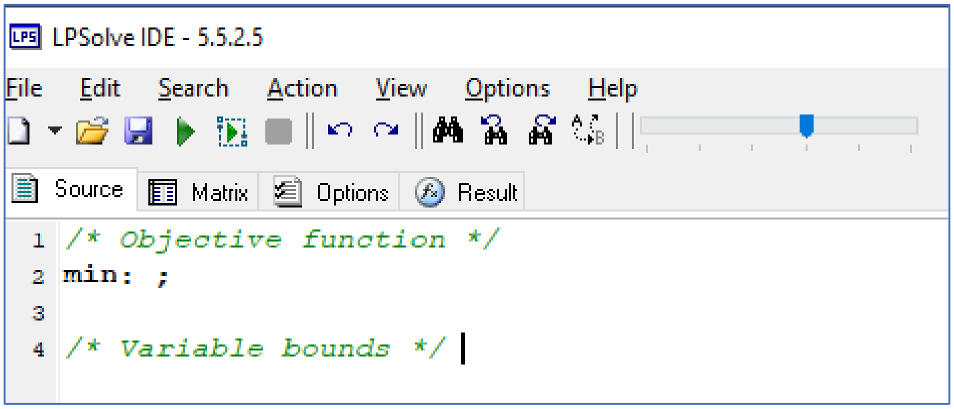
In order to find a solution to the problem, it is essential to set variables, parameters, the objective function and the relevant constrains. Most of these cases need to be inserted in a computer program, known as solvers. There are several tech companies providing relevant software programs, like the following:

1. **CPLEX**: Originally developed by Robert E. Bixby launched on 1988, it is a well-known optimizer for solving integer programming problems. Nowadays, owned by IBM since 2009, CPLEX continues to be actively developed.
2. **Gurobi**: Is considered as one of the fastest optimization mathematical solvers. It was founded on 2008 by Robert Bixby (founder of CPLEX), Zonghao Gu and Edward Rothberg.
3. **LP Solve IDE**: Is very user-friendly software for optimization problems. It is used for simpler models compared to the previous software. LP Solve IDE does not require knowledge of computer programming languages, making it more approachable for any user. Entering your model's objective function with relevant restrictions and setting your variabilities is enough for this program to solve your problem and provide the optimized result.

2.4.1. Solving through LP Solve IDE

For this essay, the chosen solver to be used and proceed with is LP Solve IDE, given the easy-to-use environment, where everything is graphical and mouse controlled. With no complex computer language needed, this solver provides a very user-friendly editor to enter or change the model's syntax and set the relevant parameters and constraints.

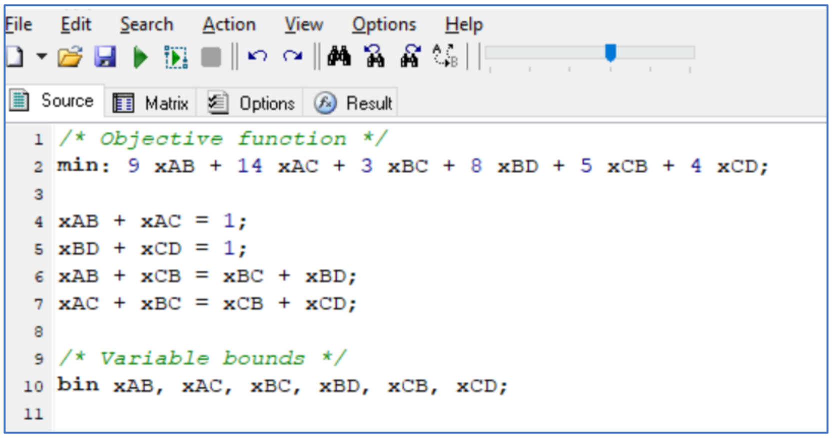
Opening a new file of the program the following screen will come up. The user enters the Objective function along with relevant constrains on the top space and underneath describe the type of each variable used. If entered correctly, the solver will run the model and provide the final form of each variability used based on the optimized outcome of the objective function, considering the constraints, in the "Result" sheet.



```
/* Objective function */
min: ;

/* Variable bounds */
```

Figure 3: LP Solve IDE opening page

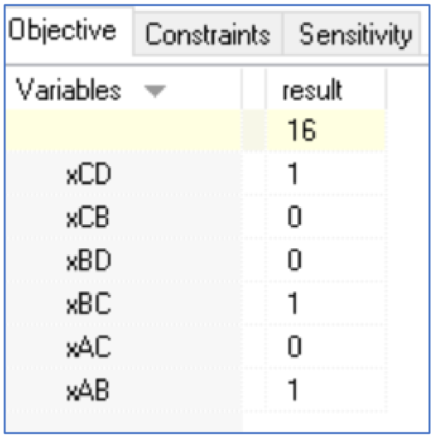
Entering the figures of the Shortest Path Problem, as described in chapter 2.3.2., in LP Solve IDE, the program will take the form of Figure 4:



```
/* Objective function */
min: 9 xAB + 14 xAC + 3 xBC + 8 xBD + 5 xCB + 4 xCD;

xAB + xAC = 1;
xBD + xCD = 1;
xAB + xCB = xBC + xBD;
xAC + xBC = xCB + xCD;

/* Variable bounds */
bin xAB, xAC, xBC, xBD, xCB, xCD;

```

Figure 4: Shorter Path Problem, LP Solve IDE illustration

Running LP Solve calculates the optimized results, as shown in Figure 5:



Variables	result
	16
xCD	1
xCB	0
xBD	0
xBC	1
xAC	0
xAB	1

Figure 5: LP Solve IDE results

The program provides the route A – B – C – D as the optimized solution, with the total distance covered 16 km.

Chapter 3: Problem description

3.1 Ship spares in transit

Like cars, trucks and airplanes, vessels need to be supplied with numerous spare parts, in order to assure their smooth operation. As a huge and complex machine, any ship requires a big variety of spares, some of which needs to be resupplied frequently, some on long term. Ship companies take very seriously the supply of spares to their vessels, as any unexpected delay to her schedule due to mechanic failure, can infer heavy loses.

Manufacturers, all over the world, provide a variety of purchase options for the ship companies to choose from. Thanks to modern technology and the globalization of trade, a buyer can benchmark several quotations from manufacturers all over the world and choose the most suitable purchase option. As a result, a shipping company's purchase department can acquire several parts from different countries globally, all meant for a specific vessel, which must be stored and at some point, delivered on board.

Since vessels on oceanic transports spend most of the time operating on open sea, delivering these spares from all around the world on board can be quite a logistic challenge. Most deliveries take place when a vessel calls a port, somewhere in the world, during a scheduled operation, such as loading - unloading cargo or gas refueling. These operations may last only a couple of days or even a couple of hours, therefore all purchased necessary spares must be on time to the correct predetermined location, to be further delivered on board.

There is a whole industry, connecting Logistics and Transport companies, warehouses and import – export agents, in a global network working on the collection, storing and further delivering of ship spares on board vessels, where and when are needed.

3.2 Working on the ship spares forwarding industry

Working as a Logistics Forwarder on the Ship Spares Industry requires specialization on the coordination of the collection, storage and further delivery of ship spares on board vessels. By providing 3rd Party Logistics services to ship companies globally, the logistics coordinator is responsible for arranging the pick-up of each order directly from supplier's premises, storing them on the nearest cooperating warehouse and further delivering them where and when instructed.

These operations can be separated in two stages. The first includes all the necessary actions to collect each order from each supplier and further deliver it to the nearest or most convenient warehouse. Second stage involves the coordination of all the participated sides, in order to dispatch each order from each warehouse and further deliver it on board vessel.

3.3 Warehouses and the collection of spares

Selecting the location of each warehouse is a quite strategic decision to make. Since Ship Companies purchase spares globally, warehousing solutions all over the world seems as a logical necessity for Logistics companies of this industry. But despite finding a warehouse solution worldwide is not an unresolved equitation for most countries, Logistics companies usually maintain some main hubs, where they store most of the spares. Most companies in the industry maintain at least one main warehouse located in countries with large production of ship spares, such as China and South Korea, as well as in countries with high marine activity, like Singapore and The Netherlands. The exact location is affected by the international cargo flows within each country. Importing and exporting cargo is a necessity for this industry, therefore most of these warehouses are located dear busy ports and airports.

Following is a real-life example of the operating warehouse's location, a Logistic Company operating in the Ship Spares Forwarding Industry, maintains:

1. Amsterdam Warehouse *(The Netherlands)*, located near AMS* airport.
   **Amsterdam Airport Schiphol, one of the busiest international airports in Europe, home base of KLM airlines. The City of Amsterdam is located around 1 hour drive, normal traffic, from the Port of Rotterdam. (Source: www.airmundo.com)*

2. Shanghai Warehouse *(China),* located near PVG* airport.
   **Shanghai Pudong International Airport is one of the busiest international airports in Shanghai. It is the home base of Air China and considered very important cargo airport, being home hub for China Cargo Airlines and China Southern Cargo, as well as for huge courier companies like DHL, FedEx and UPS. (Source: www.shanghai-airport.com)*

3. Osaka Warehouse *(Japan),* located near KIX * airport.
   **Kansai International Airport is the closest international airport to Kyoto and Osaka, handles most of Kansai's international flights. (Source: www.insidekyoto.com)*

4. Singapore Warehouse *(Singapore)*
   **Singapore Changi Airport is Singapore's main international airport and one of the busiest passenger hubs for south east Asia and also located less than 30 minutes away from Singapore's Port. (Source: www.internationalairportreview.com)*

5. Incheon Warehouse *(South Korea)* located near ICN* airport
   ** Incheon International Airport of Seoul is the largest airport in the country and one of the busiest in the world. It had been rated as the best airport worldwide (2005-2013) by Airports Council International. (Source: www.worldtravelguide.net)*

Each warehouse is located near a major international airport in order to minimize the distance and transit time needed between them. Within these airports, main hubs for the biggest courier companies are located, which enables more frequent transits and deliveries.

When an item is ready, the usual procedure followed is to be collected and further transferred to one of the above warehouses, given the country of origin. If an order is ready in China, it will be collected and stored to Shanghai's Warehouse. If spares are ready in a supplier's location within Europe, it will further be collected in Amsterdam's Warehouse, etc.

Most spares are collected via truck or courier, based on the urgency and package details. Small boxes, up to 25 kg, are most commonly collected via courier express service, with required transit time within Europe, around 1 working day. For bigger and heavier items, pick-up is usually made via truck, with transit times to vary based on the collection point. Collecting several items to each warehouse, results to quite large volume of cargo stored in each one, categorized by the vessel which are meant for.

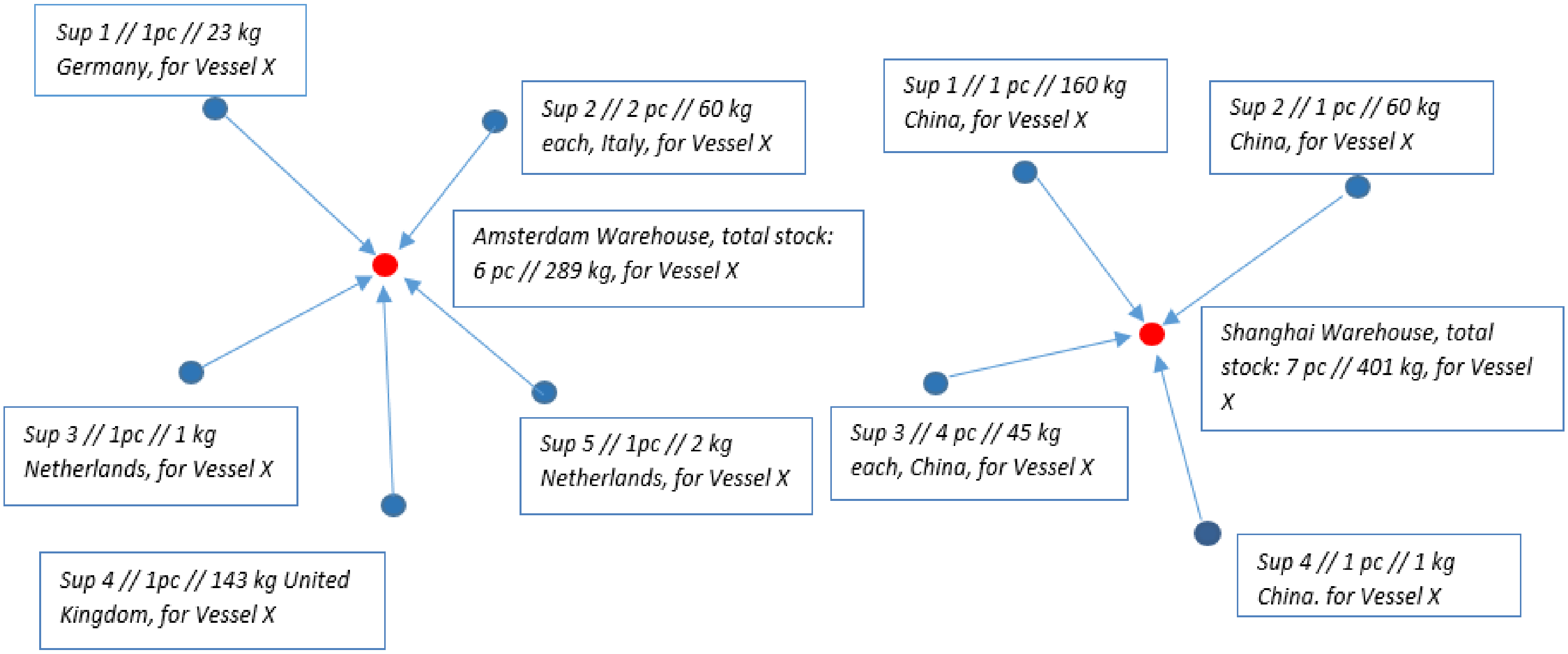


Figure 6: Example of collecting orders to Shanghai and Amsterdam Warehouse for Vessel "X"

3.4 Delivering spares on board

It is very difficult, even for Shipping Companies themselves, to advise long time in advance the exact port and date that a vessel will call. Her schedule can change rapidly or port of call may be undetermined up to the last day, since decisions like these are based on business economic plans of the Shipping Company. Therefore, available time to dispatch all orders from each warehouse can be quite limited.

Most times, due to lack of time, spares are dispatched to the country the vessel will call via airfreight, due to the fact it is the fastest way to dispatch cargo internationally. Starting from the nearest airport to the warehouse stored into, spares are dispatched to a predetermined airport, near the port vessel will call. From there, each airfreight shipment is collected by the authorized local agent, who will further proceed with the delivery to the vessel.

We can illustrate these procedures in a simple way as below, based on the example for Vessel "X":

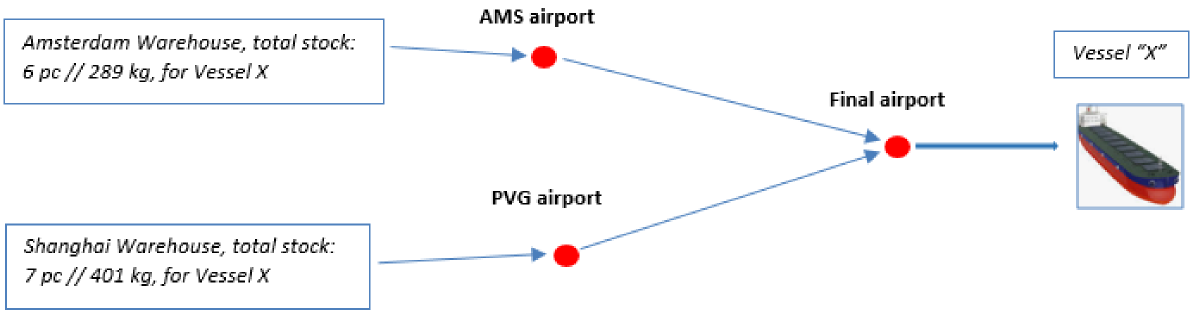


Figure 7: Example of dispatching orders from Shanghai and Amsterdam Warehouse via airfreight, for delivery on board Vessel "X"

3.5 Costs and procedures

Charges for these operations mostly occur from the airfreight rate, measured as a fee per kilogram of cargo in transit, as well as from the export and import procedures at each country. These procedures involve all the necessary actions for a shipment to be exported from one country and imported to another, such as proper customs paperwork preparation, air space booking procedures and delivering to the airline. Import procedures differ from country to country and can be a simple procedure, requiring only a couple of hours to be completed, or can be a quite thoroughly and time-consuming course.

When the shipments are imported at the country of destination, then spares are transferred to the vessel, based on a settled schedule. Three are the most common ways to deliver spares on board, simply analyzed below:

- Deliver spares alongside vessel: Deliver the spares by truck alongside the ship, when anchorage within port's terminal and load them onboard using vessels or an external crane.
- Hand carry spares on board, possible only for light objects.
- Load all spares on a launch and deliver spares alongside the vessel by sea, either when anchorage within or without port's terminal, loading them by using vessel's crane.

Charges for these procedures usually apply per import shipment delivered, not by the volume of cargo loaded and can go sky high, depending the country of delivery. For the abovementioned example of Vessel "X", following is how final charges could shape, considering port of call the Port of Fujairah in UAE, where nearest international airport is DXB (Dubai International Airport)

Example of costs for direct dispatch of shipments:

- Shipment from Amsterdam:

(Airfreight rate ex AMS to DXB) * (Volume of cargo in Amsterdam warehouse, in kg)

+ (Export procedures ex Amsterdam)

- Shipment from Shanghai:

(Airfreight rate ex PVG to DXB) * (Volume of cargo in Shanghai warehouse, in kg)

+ (Export procedures ex China)

- Delivery on board at Port of Fujairah:

(Import, collection and further delivery on board per import airfreight) * 2 Airfreights

3.6 Consolidating shipments

Import, collection and further delivery on board at the final destination can cost quite a lot to the shipping company, especially when applied per import shipment. Therefore, Logistics companies' trend to proceed with consolidation of shipments at one main warehouse, and further dispatching them to the final destination as one, in order to minimize these costs for their clients. In the example for Vessel "X", such an operation can be illustrated in Figure 8:

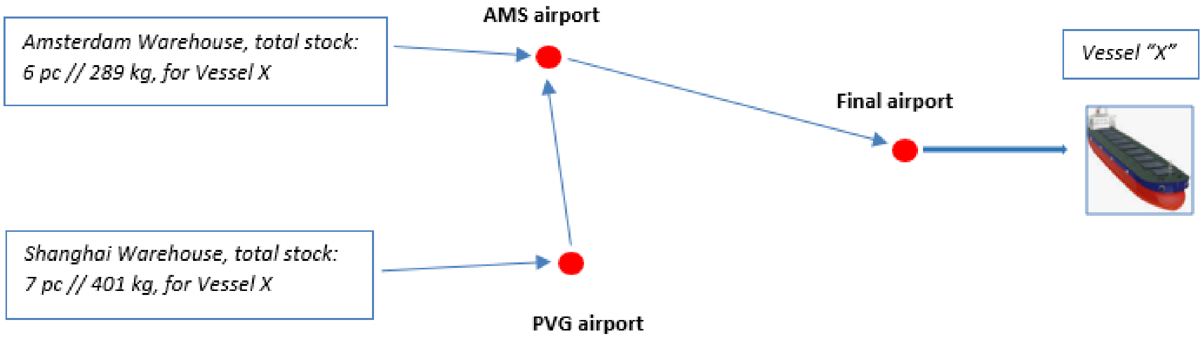


Figure 8: Example of dispatching orders from Shanghai and Amsterdam Warehouse via airfreight, to be delivered on board, for Vessel "X" at Port of Fujairah

Example of costs for consolidated dispatch of shipments:

- Shipment ex Shanghai:

(Airfreight rate ex PVG to AMS) * (Volume of cargo in Shanghai warehouse, in kg)

+ (Export procedures ex China)

- Shipment ex Amsterdam:

(Airfreight rate ex AMS to DXB) * (Volume of cargo in Amsterdam warehouse + volume of cargo ex China Warehouse, in kg)

+ (Export procedures ex Amsterdam)

- Delivery on board at Port of Fujairah:

(Import, collection and further delivery on board per import airfreight) * 1

Consolidation of shipments requires enough time, in order for the intermediary connection to be completed. This includes transit time from starting hub 1 to starting hub 2 as well as the needed time for custom import formalities to the second one. When completed, both shipments will be dispatched, as one, to the final destination, requiring relevant transit time. If the shipping company provides a deadline of arrival to the final destination, long enough to proceed with consolidation of several shipments, normally will be more economical than separate shipments.

Which shipments are to be consolidated and where is a decision that a Logistics Operator has to make, most times through experience on the field. Most important factors refer to the import and export airfreight options to the Hub of consolidation along with relevant costs and procedures.

A busy International Airport can provide numerous daily flight options to numerous destinations, therefore consolidating shipments to a warehouse located near it can provide enough alternatives to choose from and proceed accordingly. In the above example, if the flight from AMS to DXB airport was 1 time per week, then consolidating shipment ex Shanghai to Amsterdam could be risky as any unexpected delay to the intermediary connection could jeopardize the whole operation. If there were several daily flights, we would have alternatives as our shipment could be dispatched with the next flight. Just like a traveler missing his flight and taking the next one.

In the Netherlands, import and export procedures are quite fast, easy and low cost. On the other hand, import and export procedures in China can be riskier and more expensive. When having to choose where to consolidate a shipment, an Operator has to think in advance relevant details, especially when having more than one shipment.

3.7 What is the best path to follow?

In the world of today, there are flights from almost everywhere to anywhere. The planet can be seen as a network of airports connected to each other either direct or indirect. Hence an Operator can work on several scenarios and proceed with what he believes is the best option for him. Finding the ideal path though, is not as easy as it may sounds.

The goal is to deliver all spares stored around the world on board, through the most economical way. The more the items we have on stock in different warehouses, the more shipments we have to handle globally and the more dispatch scenarios up to the final delivery to the vessel, creating a complex mathematical problem searching the optimized option. What if we could create a mathematical optimization model, in order to find which is the best way to proceed with, through linear programming? Such a model is presented next.

Chapter 4: Modeling

4.1 Optimizations model on airfreight transfers

This model aims to minimize the airfreight transfer costs of several shipments, all having different starting points but one and common final destination.

Each starting point, represents one warehouse somewhere in the world. In each warehouse, there are orders on stock, ship's spare parts in this case, which must be delivered on board vessel at the port she will call, when requested. Since this is an airfreight optimization model, stock orders from each warehouse will be dispatched as an airfreight shipment, from the closest international airport located in the city. For example, in case of a warehouse located in Amsterdam, shipment will be dispatched from AMS airport (Schiphol international airport), if in Singapore from SIN airport (Singapore Changi international airport) and so go on.

Therefore, in order to make the understanding of the model a little simpler, each starting point will actually be the airport and not the warehouse itself. It is important to mention that in real life, this assumption can be valid, as most of the warehouses cooperating with companies specialized in world while air transportations, have their premises near, the city's they are located, international airport, in order to minimize the transfer time needed between them. Sometimes, warehouses as these, may even be located inside the airport's limits.

So, each of the starting hubs in the model will illustrate one international airport somewhere on the planet. Each airport "carries" a fixed volume of cargo, calculated in kg, representing the total weight of the orders, stocked in the nearest cooperating warehouse of that area, marked for a specific vessel.

Each cargo has to be dispatched to the nearest airport to the port that vessel is scheduled to call, in order to be further delivered on board. That airport illustrates the common and final destination for each one of the shipments located in the starting hubs.

Each hub of this model will be connected with all the rests, as this is actually a studying of transfers between airports. Each shipment, from each starting hub, can be either dispatched directly to the final destination, or can be transferred to a different starting point, in order to be consolidated with one, or more, of the rest shipments and be further dispatched together as one load to the final destination.

4.2 Routes, costs and deadline

Each connection within hubs represents an airfreight shipment, therefore relevant air transportation costs have to be calculated. These charges, as analyzed in chapter 3.5 , occur as fee per kg of cargo transported. For this model, costs will be predetermined for each route separately, as will illustrate different flights from different airports.

Costs will also occur for each shipment, when same is exported from one hub and imported to another. So, some fixed costs for each connection between airports will represent export cost from the starting point and import cost to the hub of destination. These charges will be disparate, regarding the hub of export and the hub of import and will be applied only if a shipment goes through that route.

Regarding the final hub, a quite higher import cost per shipment will be considered, since costs for the collection from the airport, the handling, the transport and any other necessary action may take place until same is delivered on board will be included.

At this point, it is important to highlight that in the upcoming model, import and delivery on board costs at the final hub will occur per import shipment, not per volume of the imported cargo. For example, if two shipments of 50 kg each will be dispatched to the final destination, charges for import and delivery on board will occur twice. But if only one shipment of 100 kg will be dispatched, relevant costs will be charged only once.

This model will search for the most economical way to dispatch all the shipments, currently on stock in each warehouse, to the final destination for further delivery on board, based on a particular time deadline, that will affect each option.

Each of the flights between hubs, as in real life, may be direct or indirect. This means that transit time needed for the transfer of the shipment from one airport to another, including export and import procedures, will be minimum 1 day, based on direct option, and can be diverged based on our flight options. Transit times in the model will be based on both scenarios.

4.3 Assumptions

The following assumptions will be made:

- If a shipment is to be consolidated from its starting hub to another, it will be further dispatched from there to the final destination.

- All shipment from each starting point must be transferred to the final destination.

- No delays will occur regarding flights schedule and transit time. Dailies flights for each connection. Airspace is secured for each flight despite the volume of cargo.

4.5 Final model

Starting building the model, relevant variables need to be amended. Beginning from the starting hubs, 5 points will illustrate the airports that each shipment is currently on stock and 1 for the final destination, as follows:

STARTING HUBS	HUB OF DESTINATION
A	
B	
C	T
D	
E	

Table 1: Model's hubs

These hubs represent international airports and therefore are connected either with direct or indirect flights. Model will have the form of Figure 10:

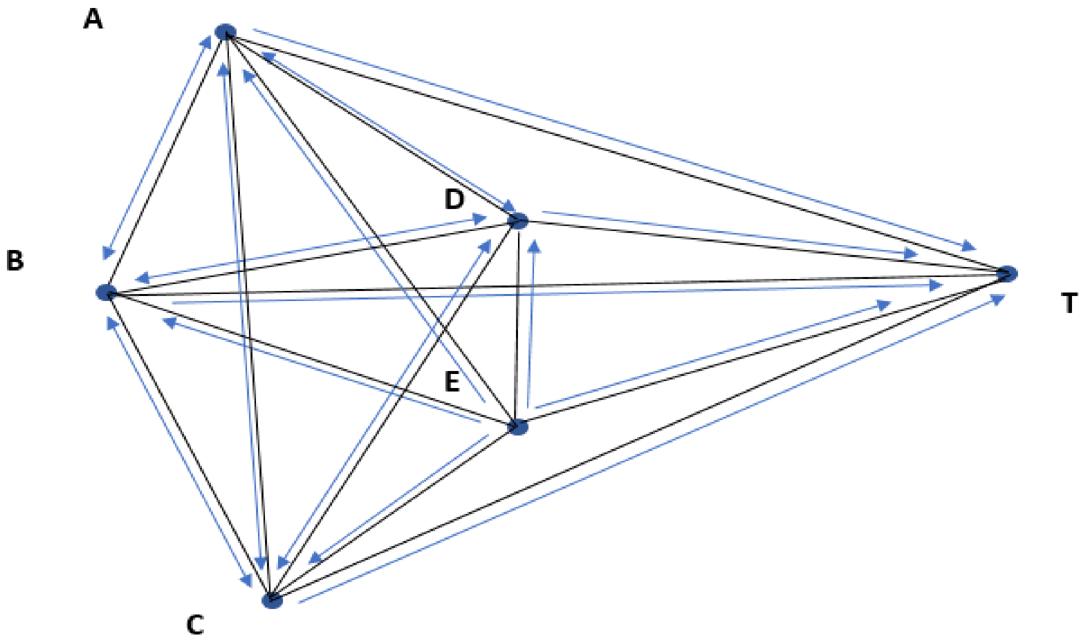


Figure 9: Final model illustration

As the black lines suggest, each hub is connected to all the others. The blue arrows represent our flights options, meaning the routes that each shipment can take from each hub. Most of them point both ways, except the ones connected to hub T and hub E.

The double direction arrows indicate that connection between hubs can be both ways, meaning each shipment from each hub can be dispatched to the other. For example, shipment of hub A can be dispatched to hub B and the other way around.

Wanting to take this model closer to the reality, consolidation options in hub E will not be examined, as the assumption it is located in a country with complicated and time-consuming import procedures is made, which is discouraging to do so. As advised, not all hubs are workable for consolidating shipments. Therefore, for hub E only export options will be considered and the one-way arrows to represent that accordingly.

For hub T, the connections are one way, since it is the final destination and shipments will not be re-export from there.

Subtotals

$I = \{A, B, C, D, E\}$

$K = \{A, B, C, D, T\}$

Variables

The variables to be used in the model will be the following:

y_{ijk}: {0,1}, if the shipment from starting hub i will follow the route from hub j to hub k, $\forall$ $i \in I$, $j \in I$ and $k \in K$

CW_{jk}: Fixed airfreight cost per kg of cargo transferred, in Euro, from hub j to hub k, $\forall$ $j \in I$ and $k \in K$

C_{jk}: Export and import costs from j to k, $\forall$ $j \in I$ and $k \in K$

W_i: Fixed weight of cargo, stocked in each starting hub, in kg, $\forall$ $i \in I$

C_{jk}: Fixed cost for export from hub j and import to hub k, in Euro, $\forall$ $j \in I$ and $k \in K$

T_{jk}: Fixed transit time, in days, needed for the routing ex hub j to hub k, to be completed, $\forall$ $j \in I$ and $k \in K$

z_{jk}: {0,1}, if routing from hub j to hub k will take place, $\forall$ $j \in I$ and $k \in K$

d: Deadline, in days, the maximum total days available to transfer all the shipments to the final destination.

Parameters

$W_i \geq 0$, ∀ $i \in I$, weight of each shipment, from starting hub

$CW_{jk} \geq 0$, ∀ $j \in I$ and $k \in K$, airfreight cost per kg of cargo transferred from j to k

$C_{jk} \geq 0$, ∀ $j \in I$ and $k \in K$, charges from export from hub j and import to hub

$T_{jk} \geq 0$, ∀ $j \in I$ and $k \in K$, transit time needed from hub j to hub k

$d \geq 0$, ultimate deadline for the hole operations to be completed

Objective function

Given graph G, let VG and AG be its set of vertices and arcs, respectively.

$$\mathbf{min}\left\{\left(\sum_{\boldsymbol{i\in VG}}\sum_{\boldsymbol{(j,k)\in AG}} \boldsymbol{CWij * Wi * yijk}\right)+\left(\sum_{\boldsymbol{(j,k)\in AG}} \boldsymbol{Cjk * zjk}\right)\right\} \tag{6}$$

Constraints

$$\textstyle\sum_k yijk = 1, \forall \ i \in I \tag{7}$$

$$\textstyle\sum_j yijT = 1, \forall \ i \in I \tag{8}$$

$y_{iij} = y_{ijT}$, ∀ $i \in I$, j \neq i and j \neq T (9)

$\Sigma\, y_{ijk} * T_{jk} \leq d$, ∀ $i \in I$, $j \in I$ and $k \in K$ (10)

$y_{ijk} = z_{jk}$, ∀ $i \in I$, $j \in I$ and $k \in K$ (11)

Constrain (7) make sure that all shipments on stock in each starting hub will be dispatched and constrain (8) that will end up in the final destination. Constrain (9) indicates that if a shipment is to be consolidated from its to another starting hub, it has to be further dispatched from there to hub T, while (10) that the total transit time of the route each shipment will take must be less or equal to the provided deadline. Constrain (11) indicates that if a shipment will be dispatched form j to k, then that route will be activated

4.5.1 Example: dispatching options for shipment A

Following are the dispatch options for the shipment ex hub A, along with relevant costs, in order to understand how this model will work:

1. **A → T**, direct dispatch to hub T

Costs:

(Airfreight rate from A to T, in Euro) * (Volume of cargo in A, in kg)

+ (Export costs from hub A and import and DOB costs in hub T)

2. **A → B → T**, dispatch to hub T through hub B

Costs:

(Airfreight rate from A to B, in Euro) * (Volume of cargo in A, in kg)

+ (Export costs from hub A and import to hub B)

+ (Airfreight rate from B to T, in Euro) * (Volume of cargo in A + B, in kg)

+ (Export costs from hub B and import and DOB costs in hub T)

3. **A → C→ T**, dispatch to hub T through hub C

Costs:

(Airfreight rate from A to C, in Euro) * (Volume of cargo in A, in kg)

+ (Export costs from hub A and import to hub C)

+ (Airfreight rate from C to T, in Euro) * (Volume of cargo in A + C, in kg)

+ (Export costs from hub C and import and DOB costs in hub T)

4. **A → D → T**, dispatch to hub T through hub D

Costs:

(Airfreight rate from A to D, in Euro) * (Volume of cargo in A, in kg)

+ (Export costs from hub A and import to hub D)

+ (Airfreight rate from D to T, in Euro) * (Volume of cargo in A + D, in kg)

+ (Export costs from hub D and import and DOB costs in hub T)

- Each of the shipments have relevant dispatch options, based on the predetermined routes

- More than two shipments can be consolidated at one hub, for further dispatch as one load

- Each shipment’s routing dispatch option is limited by the deadline we have set

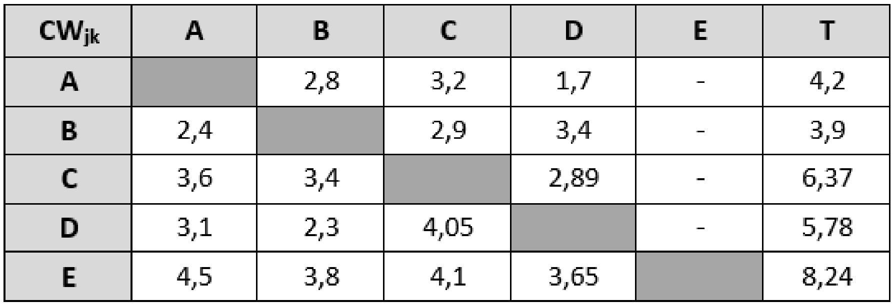
Chapter 5: Airfreight optimization cases

5.1 Model's validation

In this chapter, the model analyzed in chapter 4.5 will be examined through LP Solver IDE, using costs based on real life circumstances, searching the optimized way to dispatch shipments from starting hubs A, B, C, D and E to final hub T, given a specific deadline.

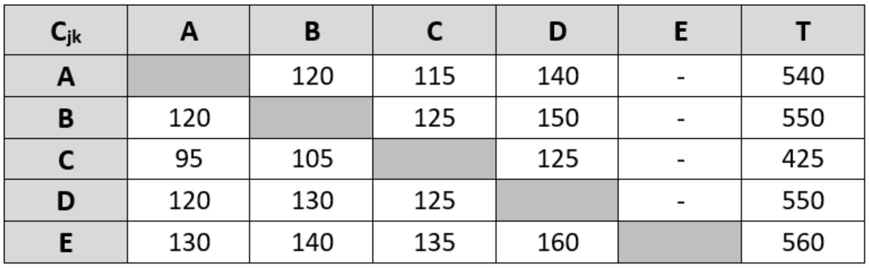
At first, the costs for direct dispatch of each shipment from each starting hub to the final destination will be calculated, in order to compare the results with the ones including consolidated alternatives. Further to that, different deadlines will be set, in order to examine how the final costs will be affected.

Setting the parameters of chapter 4.5 as per the following tables:



CW_{jk}	A	B	C	D	E	T
A		2,8	3,2	1,7	-	4,2
B	2,4		2,9	3,4	-	3,9
C	3,6	3,4		2,89	-	6,37
D	3,1	2,3	4,05		-	5,78
E	4,5	3,8	4,1	3,65		8,24

Table 2: Airfreight cost per kg transferred from hub j to k



C_{jk}	A	B	C	D	E	T
A		120	115	140	-	540
B	120		125	150	-	550
C	95	105		125	-	425
D	120	130	125		-	550
E	130	140	135	160		560

Table 3: Total costs for export from hub j and import to hub k

T_{jk}	A	B	C	D	E	T
A		1	2	1	-	2
B	1		1	1	-	2
C	1	1		2	-	4
D	2	2	2		-	2
E	2	1	2	2		3

Table 4: Transit time in days from hub j to k

W_i	Kg
A	230
B	300
C	120
D	235
E	56

Table 5: Weight of each cargo in each starting hub i

d	6

Table 6: Deadline in days

The analytical form of objecting function, along with relevant constrains, can be found in Appendix 1of this essay.

Having already the model on paper, it is time to insert same to LP Solve IDE, which is the selected computer optimization program to be used for this essay. The goal is to prove that consolidating as many shipments as possible, will lead to a more economical option than direct dispatch, all based on available time.

For the first alternative, the direct dispatch of each shipment, no time restrictions will be taken, as the goal is to simply calculate the total charges of this operation, not to find the most economical option within a given time frame.

5.1.1. Benchmarking - Direct dispatch

For this alternative, only the charges for the direct dispatch will be included in the objective function, in order to make the model a bit simpler. This model will be instructed to dispatch each shipment directly to the final destination, in order to compare the final charges with the upcoming alternatives examined in the following chapters, which will include the consolidation options. The analytical form of this model can be found in Appendix 2.

Running the program provide the paths as seen in Figure 10 for each shipment to be followed, along with relevant charges.

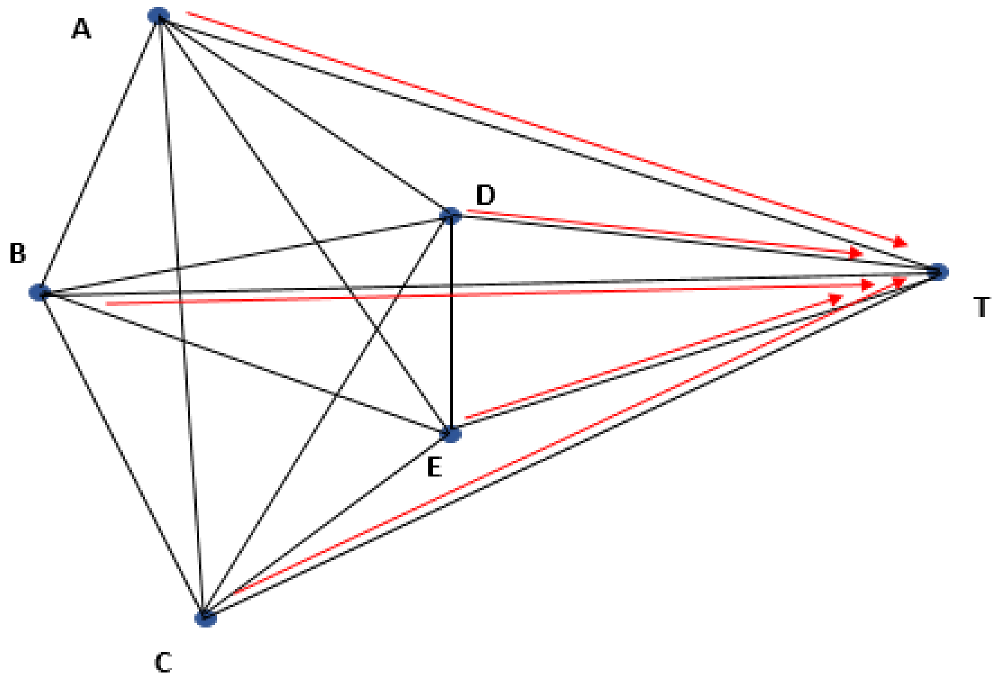


Figure 10: Direct dispatch illustration

All shipments we dispatched directly from their starting hub to the final destination, with the total costs of: **EUR 7’345.14**

Therefore, variabilities $\mathbf{y_{AAT}}$, $\mathbf{y_{BBT}}$, $\mathbf{y_{CCT}}$, $\mathbf{y_{DDT}}$ and $\mathbf{y_{EET}}$ resulted all as {1}

Final costs =

$966*y_{AAT} + 540*z_{AT}$

$+ 1170*y_{BBT} + 550*z_{BT}$

$+ 764.40*y_{CCT} + 425*z_{CT}$

+ 1358.30*y_{DDT} + 550*z_{DT}

+ 461.44*y_{EET} + 560*z_{ET}

Final costs = 7'345.14

5.1.2 Dispatch with deadline 6 days

For this alternative, deadline of 6 days will be set, including consolidating options, as seen in Appendix 1.

The program provides the results of Figure 11:

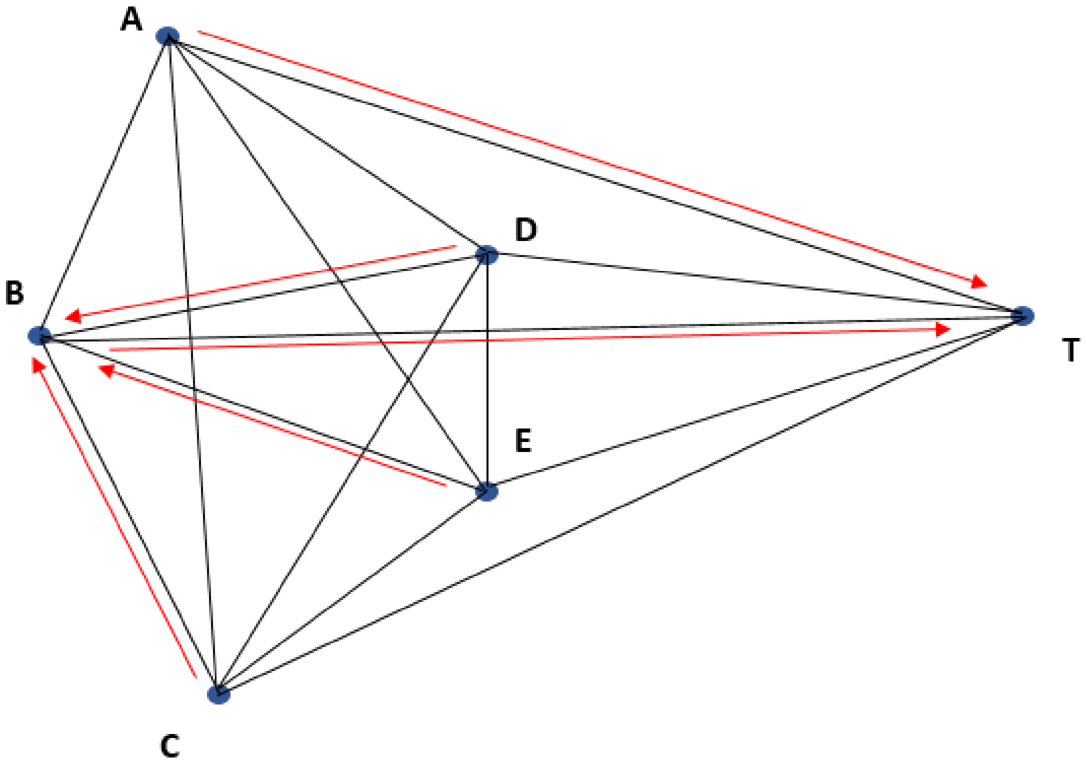


Figure 11: Consolidated dispatch given deadline 6 days illustration

Program proceeds with consolidation of shipments ex hubs C, D, E to hub B and further dispatch all of them to T from there. Shipment from hub A is dispatched separately to hub T. Total costs of the above operations: EUR 6365.20

Variabilities $\mathbf{y_{AAT}}$, $\mathbf{y_{BBT}}$, $\mathbf{y_{CCB}}$, $\mathbf{y_{DDB}}$, $\mathbf{y_{EEB}}$, $\mathbf{y_{DBT}}$, $\mathbf{y_{CBT}}$, $\mathbf{y_{EBT}}$, $\mathbf{z_{CB}}$, $\mathbf{z_{EB}}$, $\mathbf{z_{DB}}$, $\mathbf{z_{AT}}$, $\mathbf{z_{BT}}$, all resulted as {1}.

Relevant expenses as follows:

Final costs =

$966*y_{AAT} + 540*z_{AT}$

$+ 1170*y_{BBT} + 550*z_{BT}$

$+ 408*y_{CCB} + 105*z_{CB} + 468*y_{CBT}$

$+ 540.50*y_{DDB} + 130*z_{DB} + 916.50*y_{DBT}$

$+ 212.8*y_{EEB} + 140*z_{EB} + 218.4*y_{EBT}$

Final costs = EUR 6’365.20

It is quite clear that this scenario is more cost effective than the direct option of chapter 5.1.1. Benchmarking - Direct dispatch

Direct dispatch – consolidated dispatch given deadline 6 days =

7’345.14 – 6365.20 =

979.94 EUR

By consolidating the shipments, we can save around 13 % of the total costs, comparing to direct dispatch options.

But why was shipment of hub A dispatched separately from the rest of the shipments?

Calculating the costs to dispatch shipment ex hub A directly to hub T and costs to dispatch same through hub B:

- Direct dispatch = $966\ y_{AAT} + 540\ z_{AT}$ = EUR 1’506

- Indirect dispatch = $644\ y_{AAB} + 120\ z_{AB} + 897\ y_{ABT}$ = EUR 1’661

- Difference = Indirect – Direct = 1’661 – 1’506 = EUR 155

As seen, for that particular shipment the costs to dispatch through hub B was slightly higher that direct dispatch, hence program “sends” it through direct options, since the goal is the most economical way to proceed with this operation.

For this case, deadline of 6 days provides "enough" time to proceed with each dispatch. The most time needed for a shipment to be dispatched to hub T in this case, is for shipment ex hub D, 4 days, as shipment D requires 2 days transit time from hub D to hub B and then 2 days transit time from B to T, as mentioned in Table 5: Weight of each cargo in each starting hub i.

5.1.3 Dispatch with deadline 4 days

Setting the deadline to 4 days, the only amendment needed regards constrain (10).

The program provides the results of Figure 12:

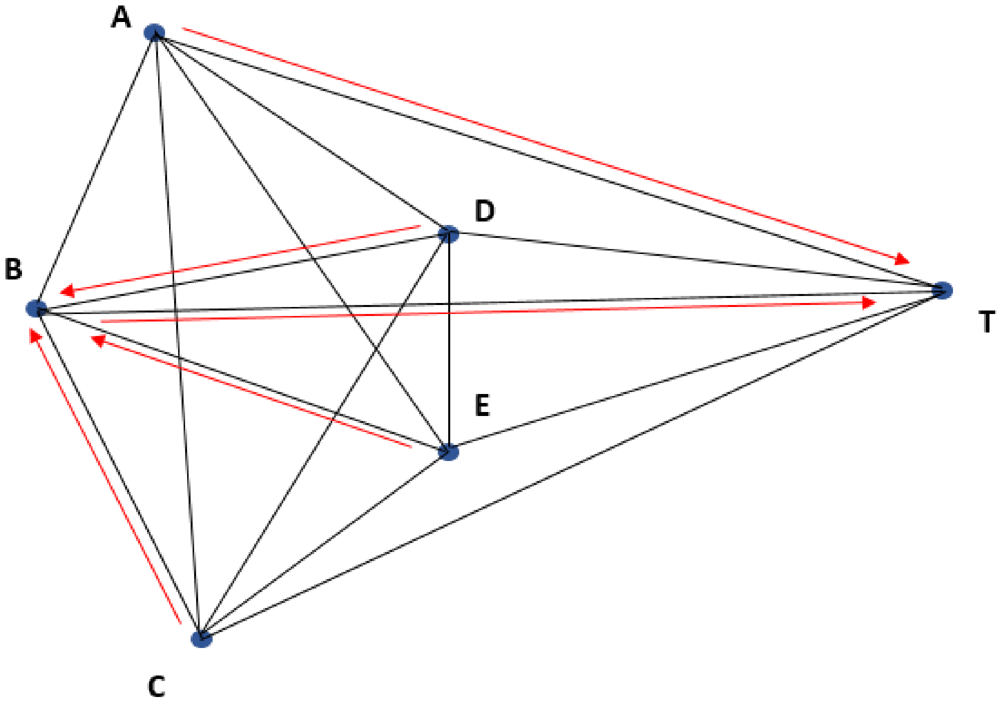


Figure 12: Consolidated dispatch given deadline 4 days illustration

The program provides the exact same options with Chapter 5.1.2., consolidating shipments ex hubs C, D, E to hub B and further dispatch of them all to T, while shipment from hub A is dispatched separately to hub with a final total cost of: **EUR 6365.20.**

It is easy to understand why:

As mentioned in the previous chapter, the longest time needed for a route to be completed, if we proceed this way, is 4 days, referring to shipment ex hub D to be dispatched to T through hub B. Hence, proceeding with the optimized way is still an option for a deadline of 4 days. This is the minimum time needed in order to achieve the most economical option.

In real life, proceeding this way will means time frame will be very tight, therefore any unexpected delays may jeopardize the whole operation.

5.1.4 Dispatch with deadline 3 days

Changing the deadline to 3 days, the only amendment needed regards constrain (10).

The program provides the following results, of Figure 13:

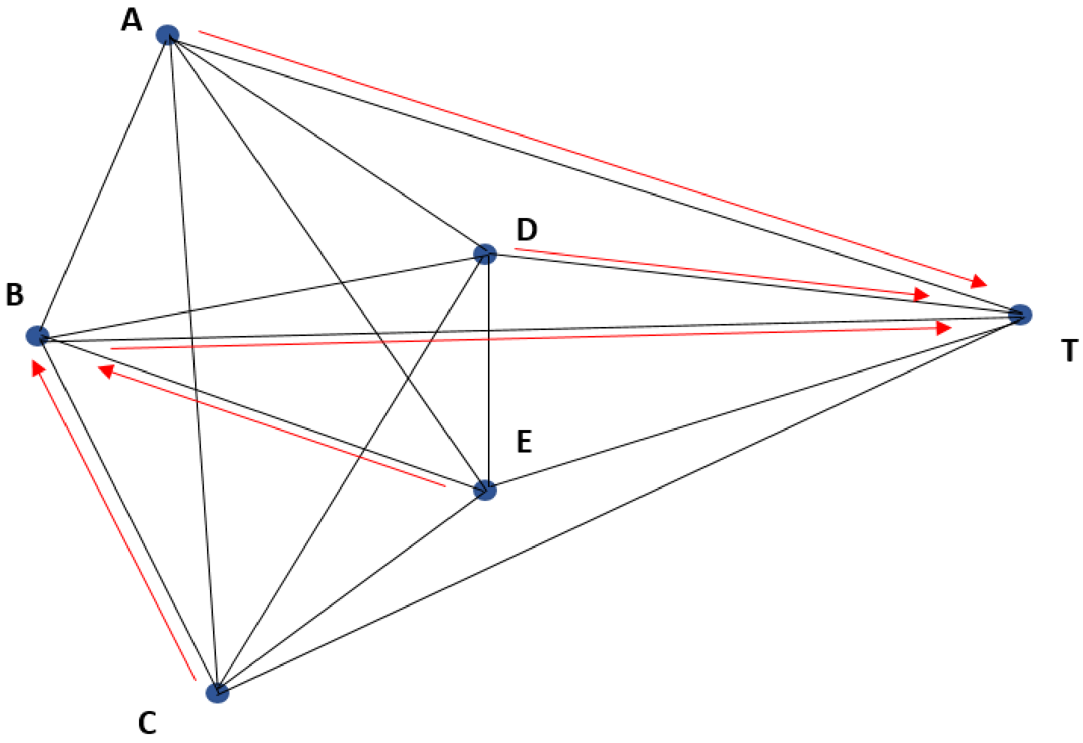


Figure 13: Consolidated dispatch given deadline 3 days illustration

Given the deadline of 3 days, dispatch of all shipments on time for the delivery is still possible. Shipments from hubs E and C will still be consolidated in hub B for further dispatch to the final destination, as shipments A and D will be dispatched directly, getting a most economical option than the direct scenario of Chapter 5.1.1, but slightly higher compared to consolidated alternatives of Chapter 5.1.2 and Chapter 5.1.3. Final costs for this operation: **EUR 6686.50.**

Variabilities $\mathbf{y_{AAT}}$, $\mathbf{y_{BBT}}$, $\mathbf{y_{CCB}}$, $\mathbf{y_{DDT}}$, $\mathbf{y_{EEB}}$, $\mathbf{y_{CBT}}$, $\mathbf{y_{EBT}}$, $\mathbf{z_{CB}}$, $\mathbf{z_{EB}}$, $\mathbf{z_{DT}}$, $\mathbf{z_{AT}}$, $\mathbf{z_{BT}}$, all resulted as {1}.

Final costs =

$966*y_{AAT} + 540*z_{AT}$

$+ 1170*y_{BBT} + 550*z_{BT}$

$+ 408*y_{CCB} + 105*z_{CB} + 468*y_{CBT}$

$+ 1358.30*y_{DDT} + 550*z_{DT}$

$+ 212.8*y_{EEB} + 140*z_{EB} + 218.4*y_{EBT}$

Final costs = EUR 6686.50

Difference between direct scenario of Chapter 5.1.1 and consolidated options given deadline 3 days =

7’345.14 – 6686.50 =

658.64 EUR

Differences between Chapter 5.1.2 – 5.1.3 and 5.1.4:

Consolidated dispatch given deadline 6-4 days – consolidated dispatch given deadline 3 days =

6686.50 - 6365.20 =

321.30 EUR

Charges for deadline 3 days are around 5% higher comparing to those for deadline 4 days, but still around 9% less than direct dispatch options.

Shipment D is dispatched directly, as it is the only option to include it in the upcoming delivery, since transit time to T through hub B is 4 days, as it is through hub A.

5.1.5 Dispatch with deadline 2 days

Changing the deadline constrain to 2 days, program cannot provide a result. Constraint (7) of the model created in Chapter 4.5., instructs the program to search dispatch options for all the shipments stocked in the starting hubs. Checking Table 4, despite time is enough for shipments A, B and D to be dispatched to hub T (direct option), rest shipments ex hubs C and E, require a minimum 3 days transit time, analyzed below:

C → T

T/T 4 days

C → A → T

T/T 1 day to A and 2 days to T, total 3 days

C → B →T

T/T 1 day to B and 2 days to T, total 3 days

C → D → T

T/T 2 days to D and 2 days to T, total 4 days

E → T

T/T 3 days

E → A → T

T/T 2 day to A and 2 days to T, total 4 days

E → B → T

T/T 1 day to B and 2 days to T, total 3 days

E → C → T

T/T 2 days to C and 4 days to T, total 6 days

E → D → T

T/T 2 days to D and 2 days to T, total 4 days

Therefore, LP Solve IDE does not provide any result, meaning this case is impossible, based on current constrains.

In a real-life situation, subject to client's approval, the alternative to exclude shipments C and E from this operation and proceed with the delivery of the shipments A, B and C.

5.2 Comparing LP Solve IDE's results with real life operating decisions

In this chapter, a comparison between real life operating decisions on a specific case and the results of LP Solve IDE for the same operation will be made.

5.2.1. Operation with two starting points

All spares stocked in Holland's and Korea's warehouses must be delivered on board vessel at Bosporus. Starting points are Amsterdam's (A) and Seoul's (S) International Airports and final destination is Istanbul's (I), where spares will be collected for further delivery onboard vessel.

Due to a loose deadline, there is the option either to dispatch each shipment directly from each starting point to the final destination or to proceed with consolidation at the most convenient hub, as illustrated in the following graph:

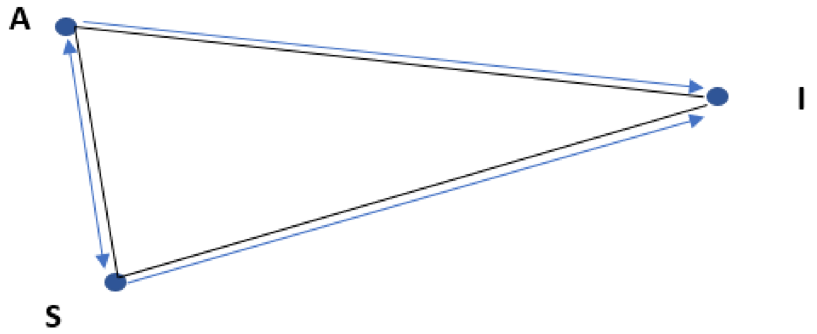


Figure 14: Dispatch ex Seoul and Amsterdam to Istanbul illustration

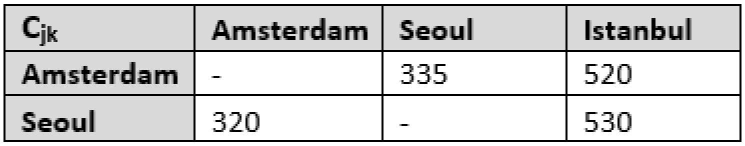
All fixed costs, transit times and weights are mentioned in the following tables:

CW_{jk}	Amsterdam	Seoul	Istanbul
Amsterdam	-	2,9	2,1
Seoul	12,2	-	13.5

Table 7: Airfreight cost per kg between Seoul, Amsterdam and Istanbul

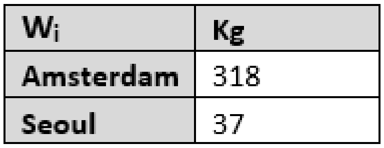
T_{jk}	Amsterdam	Seoul	Istanbul
Amsterdam	-	1	1
Seoul	1	-	1

Table 8: Transit time in days between Seoul, Amsterdam and Istanbul



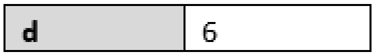
C_{jk}	Amsterdam	Seoul	Istanbul
Amsterdam	-	335	520
Seoul	320	-	530

Table 9: Total import and export charges between Seoul, Amsterdam and Istanbul



W_i	Kg
Amsterdam	318
Seoul	37

Table 10: Volume of cargo stocked in Seoul and Amsterdam



d	6

Table 11: Deadline

Subtotals

$I = \{A, S\}$

$K = \{A, S, I\}$

Variabilities

$yijk = \{0, 1\}, \forall \ \ i, j \in I, k \in K$

$zjk = \{0, 1\}, \forall \ \ j \in I, k \in K$

Using the model created in Chapter 4.5, the objecting function and relevant constrains will be formed as seen in Appendix 3.

➢ **Real life's operating decision**

In real life, the decision was to proceed with separate shipments from Seoul and Amsterdam to Istanbul, which resulted to the following charges:

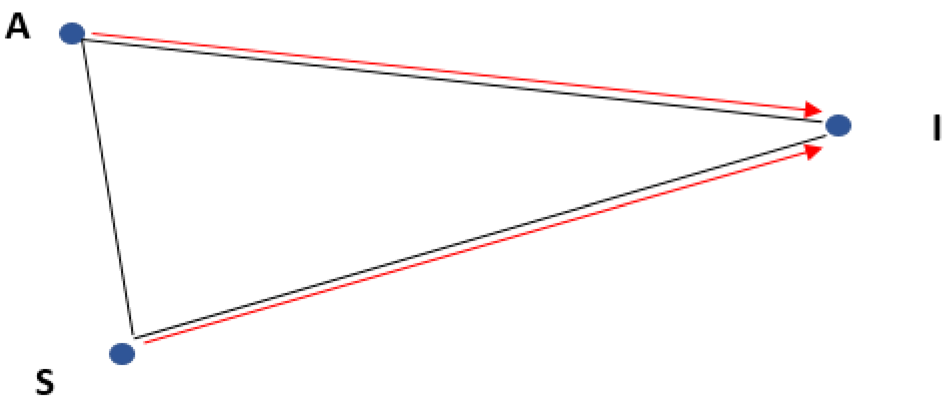


Figure 15: Real life dispatch decision illustration

A. From Amsterdam to Istanbul Airport

Weight 318 kg.8

Airfreight rate: EUR 2.10/kg → EUR 667.8

Export procedures: EUR 175

Total: EUR 842.80

B. From Seoul to Istanbul Airport

Weight 37 kg

Airfreight rate: EUR 13.5/kg → EUR 499.5

Export procedures: EUR 220

Total: EUR 719.50

C. Import, clearance and delivery on board at Istanbul

Import shipment ex Amsterdam: EUR 345

Import shipment ex Korea: EUR 310

Total: EUR 655

Grand Total (A + B + C) = **EUR 2’217.30**

- **LP Solver's optimized option**

Entering the data if this operation to LP Solver IDE, the program provides the following results of Figure 16:

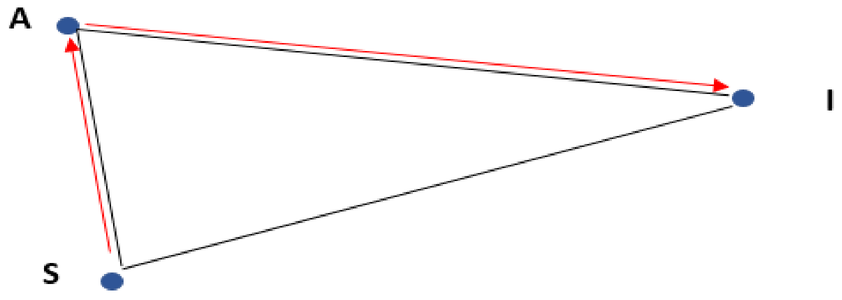


Figure 16: LP Solves IDE results illustration

This result differs from the one in the previous chapter, since LP Solve indicates the optimized option to proceed with this operation is to consolidate shipment from Korea to the Netherlands and further dispatch as one to Turkey. **Total costs: EUR 2036.90**

Variabilities, z_{AI}, y_{SSA}, z_{SA}, y_{SAI}, all resulted as {1}

Final costs:

667.8 * y_{AAI} + 520* z_{AI} + 451.4* y_{SSA} + 320 z_{SA} =

2'036.90 EUR

Difference between real life operation and solver's results:

Real life cots – LP Solver's costs = 2'217.30 – 2'036.90 = **180.40 EUR**

The most economical way to proceed is by consolidating both shipments in The Netherlands for further dispatch to Turkey. This operation requires 2 days to complete, 1 day for the shipment from Korea to reach The Netherlands and 1 day for the consolidated shipment to reach Istanbul. Given the loose deadline compared with the transit time required, the aforementioned operation can be succeeded. Compared to the direct dispatch of each shipment separately, transit time is longer, meaning that in case of urgent need of the spares on board, the direct option would be preferred, since that way both shipments will be delivered a day sooner, given the 1-day transit time required for both to reach Istanbul.

But despite LP Solve IDE indeed provided the optimized solution, this case was simple enough given the two starting points, meaning that the most economical way to proceed with could easily be calculated on paper by an Operator, given the small number of available scenarios to check. The more the starting hubs, the more flying options to choose from and more complicated case to handle.

5.2.2. Operation with more than two starting points

Having more than two shipments from different starting points to handle can create numerous dispatch scenarios which can differ significantly when comes to total final costs. Especially when some of these shipments are small and low weighted, direct dispatch of each shipment separately for import and delivery on board at the final destination can create unnecessary charges, which could be avoided if those shipments were consolidated before dispatch.

Spares stocked in several warehouses along the world must be delivered onboard while a vessel goes into a dockyard for repairs in Bosporus. Spares are located in Amsterdam (A), Seoul (S), China (C) and Japan (J) and will be dispatched from the International Airport of each city to Ataturk Airport (I) in Istanbul. Shipment from Japan (J) must urgently be delivered on board hence in the following graph of this case no connections but to Istanbul (I) will be illustrated for this hub since J and I hubs are connected directly with transit time 1 day, as seen to the below tables, and any other dispatch option through a different hub would lead to a longer transit time which is not accepted due to urgency.

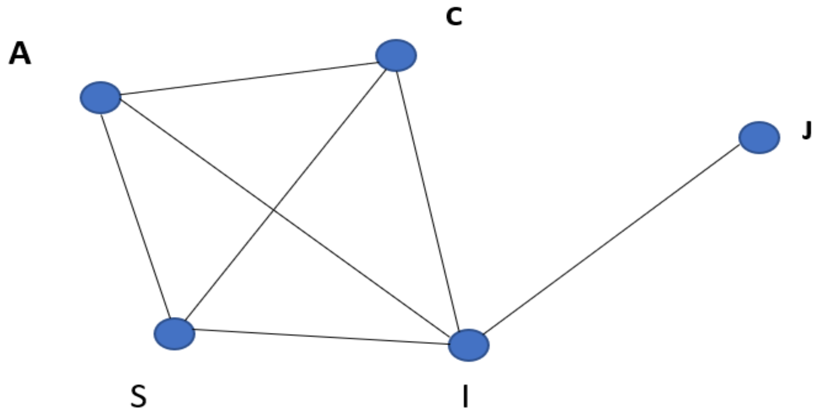


Figure 17: Dispatch to Istanbul from several starting points illustration

Cjk	A	S	C	J	I
A	-	2.9	4,3	-	2,1
S	12,2	-	4,5	-	13,5
C	4,2	2,4	-	-	14,8
J	-	-	-	-	13,7

Table 12: Airfreight cost per kg

Tjk	A	S	C	J	I
A	-	1	2	-	1
S	1	-	1	-	1
C	2	1	-	-	2
J	-	-	-	-	1

Table 13: Transfer time within hubs

Cjk	A	S	C	J	I
A	-	335	280	-	520
S	320	-	190	-	530
C	290	180	-	-	540
J	-	-	-	-	470

Table 14: Import charges to each hub

Wi	
A	120
S	58
C	30
J	10

Table 15: Shipment's weight in each hub

d	4

Table 16: Deadline

Subtotals

I = {A, S, C, J}

K = {A, S, C, I}

Variabilities

$y_{ijk} = \{0, 1\}, \forall \; i, j \in I, k \in K$

$Z_{jk} = \{0, 1\}, \forall \; j \in I, k \in K$

Using the model created in Chapter 4.5, the objecting function and relevant constrains will be formed as seen in Appendix 4.

- ➢ **Real life's operating decision**

In real life, the decision was to proceed with separate shipments from each hub to Istanbul, which resulted to the following charges:

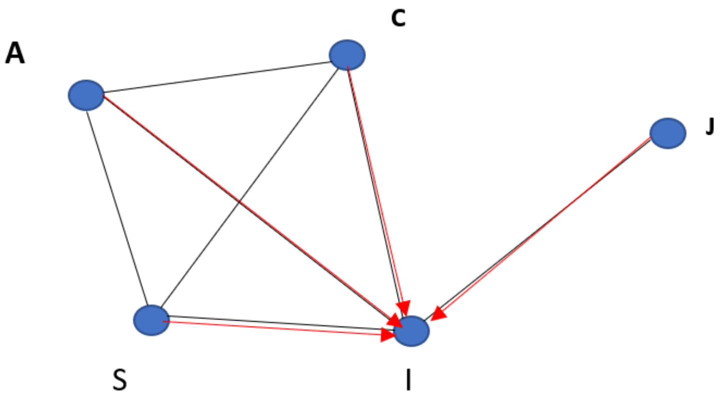


Figure 18: Direct dispatch of each shipment illustration

A. From Amsterdam to Istanbul Airport

Weight 120 kg

Airfreight rate: EUR 2.10/kg → EUR 252

B. From Seoul to Istanbul Airport

Weight 58 kg

Airfreight rate: EUR 13.5/kg → EUR 783

Export procedures: EUR 220

C. From Shanghai to Istanbul Airport

Weight 30 kg

Airfreight rate: EUR 14,8/kg → EUR 444

D. From Japan to Istanbul Airport

Weight 10 kg

Airfreight rate: EUR 13,7/kg → EUR 137

E. Import, clearance and delivery on board at Istanbul

Import shipment from Amsterdam: EUR 520

Import shipment from Korea: EUR 530

Import shipment from China: EUR 540

Import shipment from Japan: EUR 470

Total: EUR 2.060,00

Grand Total (A + B + C + D + E) = **EUR 3.113,00**

- **LP Solver's optimized option**

Entering the data if this operation to LP Solver IDE, the program provides the following results:

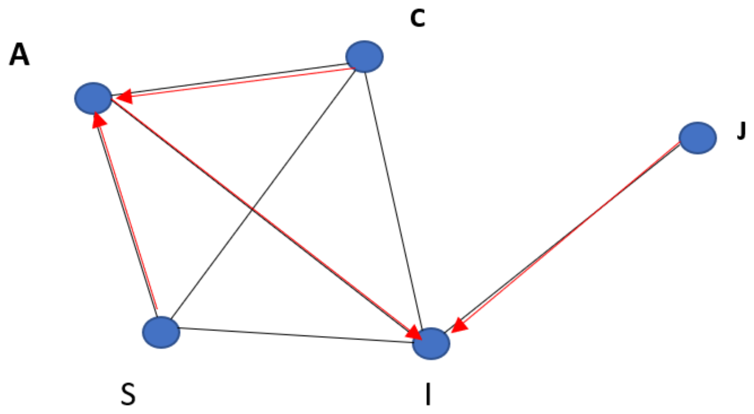


Figure 19: LP Solver's results

The optimized way to proceed with this case, according to LP Solve IDE, is to consolidate shipments from China and Korea to Amsterdam's hub for further dispatch to Istanbul along with the one already stocked there, as one. Shipment from Japan will be dispatched separately due to urgency, meaning that shipment J will arrive to Istanbul after 1 day, while the rest shipments after 3 days, due to the 2 days transit time for the shipment of China to arrive to The Netherlands. The total costs we get are slightly lower that the direct dispatch of the previous chapter, **Total: EUR 3.000,40**, which is around 3,6% lower.

Variabilities, y_{AAI}, y_{CCA}, z_{AI}, y_{SSA}, z_{SA}, y_{SAI}, y_{CAI}, y_{JJI}, z_{JI}, z_{CA} all resulted as {1}

Final costs =

252 * y_{AAI} + 520 * z_{AI} + 707,60 * y_{SSA} + 121,80 * y_{SAI} + 320 * z_{SA} + 126 * y_{CCA} + 63 * y_{CAI} + 290 * z_{CA} + 137 * y_{JJI} + 470 * z_{JI}

Final costs = EUR 3.007,40

Difference between direct and consolidated options = 3'113.00 – 3'007.40 = **EUR 105.60**

Chapter 6: Conclusions and Future work

Finding the optimized way to transport ship spares globally for further delivery onboard requires many parameters to be taken under consideration and several scenarios to be checked, aiming to minimize the charges of the whole operation. Limited by the available time for these deliveries, airfreight transfers play a crucial role, since a vessel's sail schedule may be uncertain up to the last moments and spares must be dispatched from their stock location to the port of call the soonest possible. When having to handle several shipments with different starting points, finding the best option to proceed with becomes very difficult given the numerous scenarios to check within very tight time frames.

For this thesis, the transportation methods were examined, emphasis, giving emphasis to the airfreight transports, through the analysis of relevant charges and procedures. Graphs and mathematics were used to create a ship spare's forwarding operation model, aiming for the optimize way to proceed with.

The mathematical model created in Chapter 4.5 illustrates properly an airfreight dispatch operation of ship spares for further delivery on board, having several starting points and one common final destination. This model searched to minimize the total costs to dispatch all the spares currently on stock in the starting points to the final hub where will be delivered on board, given a specific deadline.

Using figures to create dispatch scenarios, the model ran through a computer solver, which provided the most economic way to proceed with, given the parameters set, validating the model was correctly written. The influence of time for such operations was investigated, comparing the final charges the program provided for different time limits.

Running the model with the computer optimization program LP Solve IDE, in Chapter 5, has identified those consolidating individual shipments for further dispatch and delivery on board vessels can be a more cost-effective option to proceed with, subject to time availability, since reducing the number of loads imported to the final destination, can significantly lower the total charges of these operations. The Solver provided the optimized way of handling each shipment checking all the possible scenarios within seconds, minimizing the total charges. Real life operations decisions were compared with solver's results for this same case, providing most economical dispatch options, making this model a useful tool for each Logistics Coordinator working in the industry.

The airfreight model of chapter 4.5 can be used by any Logistic Forwarding Company in the ship spares industry as a consulting tool on how to proceed with their operations, amending relevant parameters accordingly for each case. Using a more complex computer solver, the model can be adjusted to include more variables, parameters and constraints, such as air space availability, offering an even more realistic illustration of the real-life operation.

Such an optimization model could be connected to the company's ERP system, so as to automatically update the model's parameters for each case. Values like the total volume of the stock orders for each vessel and import – export charges based on current stock location and the final destination can be incorporated into the solver, making the procedure even faster for the Logistic Coordinator.

Since airfreight rates, flight’s frequency and air space availability can change rapidly in real-life situations, the solver can provide continuous updates directly from the airlines online services, regarding these parameters of the model, adjusting accordingly and providing the optimized result based on the latest and more accurate information each time, thus providing a valuable decision support tool.

Bibliography

Bettilyon T. (2019) “What Is A Graph”, Available at: *https://medium.com/tebs-lab/what-is-a-graph-4565dda44df5*

Hestenes D. (1997), “Modeling Methodology for Physics Teachers”, New Delhi APH Publishing Corporation

Martin R.K. (1999) Integer Programming. In: Large Scale Linear and Integer Optimization: A Unified Approach, Boston: Springer Boston, MA

Dantzig G. and Thapa M. (1997) Linear programming 1: introduction, Ney York: Springer Science & Business Media

Appendix

Appendix 1: Chapter's 4.5 analyzed model

Objective function:

Min $644*y_{AAB} + 120*z_{AB} + 897*y_{ABT} + 736*y_{AAC} + 115*z_{AC} + 1465.1*y_{ACT} + 391*y_{AAD} + 140*z_{AD} + 1329.4*y_{ADT} + 966*y_{AAT} + 540*z_{AT} + 720*y_{BBA} + 120*z_{BA} + 1260*y_{BAT} + 870*y_{BBC} + 125*z_{BC} + 1911*y_{BCT} + 1020*y_{BBD} + 150*z_{BD} + 1734*y_{BDT} + 1170*y_{BBT} + 550*z_{BT} + 432*y_{CCA} + 95*z_{CA} + 504*y_{CAT} + 408*y_{CCB} + 105*z_{CB} + 468*y_{CBT} + 346.80*y_{CCD} + 125*z_{CD} + 693.6*y_{CDT} + 764.40*y_{CCT} + 425*z_{CT} +728.50*y_{DDA} + 120*z_{DA} + 987*y_{DAT} + 540.50*y_{DDB} + 130*z_{DB} + 916.50*y_{DBT} + 951.75*y_{DDC} + 125*z_{DC} + 1496.95*y_{DCT} + 1358.30*y_{DDT} + 550*z_{DT} + 252*y_{EEA} + 130*z_{EA} + 235.2*y_{EAT} + 212.8*y_{EEB} + 140*z_{EB} + 218.4*y_{EBT} + 229.60*y_{EEC} + 135*z_{EC} + 356.72*y_{ECT} + 204.40*y_{EED} + 160*z_{ED} + 323.68*y_{EDT} + 461.44*y_{EET} + 560*z_{ET}$

Constrains:

$y_{AAB} + y_{AAC} + y_{AAD} + y_{AAT} = 1$

$y_{BBA} + y_{BBC} + y_{BBD} + y_{BBT} = 1$

$y_{CCA} + y_{CCB} + y_{CCD} + y_{CCT} = 1$

$y_{DDA} + y_{DDB} + y_{DDC} + y_{DDT} = 1$

$y_{EEA} + y_{EEB} + y_{EEC} + y_{EED} + y_{EET} = 1$

$y_{AAT} + y_{ABT} + y_{ACT} + y_{ADT} = 1$

$y_{BBT} + y_{BAT} + y_{BCT} + y_{BDT} = 1$

$y_{CCT} + y_{CAT} + y_{CBT} + y_{CDT} = 1$

$y_{DDT} + y_{DAT} + y_{DBT} + y_{DCT} = 1$

$y_{EET} + y_{EAT} + y_{EBT} + y_{ECT} + y_{EDT} = 1$

$y_{AAB} = y_{ABT}$ $y_{BBA} = y_{BAT}$

$y_{AAC} = y_{ACT}$ $y_{BBC} = y_{BCT}$

$y_{AAD} = y_{ADT}$ $y_{BBD} = y_{BDT}$

$y_{CCA} = y_{CAT}$ $y_{DDA} = y_{DAT}$

$y_{CCB} = y_{CBT}$ $y_{DDB} = y_{DBT}$

$y_{CCD} = y_{CDT}$ $y_{DDC} = y_{DCT}$

$y_{EEA} = y_{EAT}$

$y_{EEB} = y_{EBT}$

$y_{EEC} = y_{ECT}$

$y_{EED} = y_{EDT}$

$y_{AAB} = Z_{AB}$ $y_{BBA} = Z_{BA}$ $y_{CCA} = Z_{CA}$ $y_{DDA} = Z_{DA}$ $y_{EEA} = Z_{EA}$ $y_{EET} = Z_{ET}$

$y_{AAC} = Z_{AC}$ $y_{BBC} = Z_{BC}$ $y_{CCB} = Z_{CB}$ $y_{DDB} = Z_{DB}$ $y_{EEB} = Z_{EB}$

$y_{AAD} = Z_{AD}$ $y_{BBD} = Z_{BD}$ $y_{CCD} = Z_{CD}$ $y_{DDC} = Z_{DC}$ $y_{EEC} = Z_{EC}$

$y_{AAT} = Z_{AT}$ $y_{BBT} = Z_{BT}$ $y_{CCT} = Z_{CT}$ $y_{DDT} = Z_{DT}$ $y_{EED} = Z_{ED}$

$1 * y_{AAB} + 2 * y_{ABT} + 2 * y_{AAC} + 4 * y_{ACT} + 1 * y_{AAD} + 2 * y_{ADT} + 2 * y_{AAT} = < 6$

$1 * y_{BBA} + 2 * y_{BAT} + 1 * y_{BBC} + 4 * y_{BCT} + 1 * y_{BBD} + 2 * y_{BDT} + 2 * y_{BBT} = < 6$

$1 * y_{CCA} + 2 * y_{CAT} + 1 * y_{CCB} + 2 * y_{CBT} + 2 * y_{CCD} + 2 * y_{CDT} + 4 * y_{CCT} = < 6$

$2 * y_{DDA} + 2 * y_{DAT} + 2 * y_{DDB} + 2 * y_{DBT} + 2 * y_{DDC} + 4 * y_{DCT} + 2 * y_{DDT} = < 6$

$2 * y_{EEA} + 2 * y_{EAT} + 1 * y_{EEB} + 2 * y_{EBT} + 2 * y_{EEC} + 4 * y_{ECT} + 2 * y_{EED} + 2 * y_{EDT} + 3 * y_{EET} = < 6$

Appendix 2: Direct dispatch model of Chapter 5.1.1

Objective function:

Min $966 * y_{AAT} + 540 * z_{AT} + 1170 * y_{BBT} + 550 * z_{BT} + 764.40 * y_{CCT} + 425 * z_{CT} + 1358.30 * y_{DDT} + 550 * z_{DT} + 461.44 * y_{EET} + 560 * z_{ET}$

Constrains:

$y_{AAT} = 1$

$y_{BBT} = 1$

$y_{CCT} = 1$

$y_{DDT} = 1$

$y_{EET} = 1$

$y_{EET} = Z_{ET}$ $y_{AAT} = Z_{AT}$

$y_{BBT} = Z_{BT}$ $y_{CCT} = Z_{CT}$

$y_{DDT} = Z_{DT}$

Appendix 3: Chapter 5.2.1 model

Objective function

Min $703.5*y_{AAI} + 520*z_{AI} + 922.20*y_{AAS} + 335*z_{AS} + 4'293* y_{ASI} + 499.50*y_{SSI} + 530*z_{SI} + 451.4*y_{SSA} + 320*z_{SA} + 77.7*y_{SAI}$

Constrains

$y_{AAS} + y_{AAI} = 1$

$y_{SSA} + y_{SSI} = 1$

$y_{AAI} + y_{ASI} = 1$

$y_{SSI} + y_{SAI} = 1$

$y_{AAS} = y_{ASI}$

$y_{SSA} = y_{SAI}$

$y_{AAS} = z_{AS}$

$y_{AAI} = z_{AI}$

$y_{SSA} = z_{SA}$

$y_{SSI} = z_{SI}$

$1* y_{AAI} + 1* y_{AAS} + 1* y_{ASI} < = 6$

$1* y_{SSI} + 1* y_{SSA} + 1* y_{SAI} < = 6$

Appendix 4: Chapter 5.2.2. model

Objective function

Min $252\ y_{AAI} + 348\ y_{AAS} + 1620\ y_{ASI} + 516\ y_{AAC} + 1776\ y_{ACI} + 520\ z_{AI} + 335\ z_{AS} + 280\ z_{AC} + 783\ y_{SSI} + 707.60\ y_{SSA} + 121.8\ y_{SAI} + 261\ y_{SSC} + 858.40\ y_{SCI} + 530\ z_{SI} + 320\ z_{SA} + 190\ z_{SC} + 444\ y_{CCI} + 126\ y_{CCA} + 63\ y_{CAI} + 72\ y_{CCS} + 405\ y_{CSI} + 540\ z_{CI} + 290\ z_{CA} + 180\ z_{CS} + 137\ y_{JJI} + 470\ z_{JI};$

Constrains

$y_{AAI} + y_{AAC} + y_{AAS} = 1$

$y_{SSI} + y_{SSA} + y_{SSC} = 1$

$y_{CCI} + y_{CCA} + y_{CCS} = 1$

$y_{JJI} = 1$

$y_{AAI} + y_{ACI} + y_{ASI} = 1$

$y_{SSI} + y_{SAI} + y_{SCI} = 1$

$y_{CCI} + y_{CSI} + y_{CAI} = 1$

$y_{AAS} = y_{ASI}$

$y_{AAC} = y_{ACI}$

$y_{SSA} = y_{SAI}$

$y_{SSC} = y_{SCI}$

$y_{CCA} = y_{CAI}$

$y_{CCS} = y_{CSI}$

$y_{AAI} = z_{AI}$

$y_{AAS} = z_{AS}$

$y_{AAC} = z_{AC}$

$y_{CCA} = z_{CA}$

$y_{CCI} = z_{CI}$

$y_{CCS} = z_{CS}$

$y_{SSA} = z_{SA}$

$y_{SSI} = z_{SI}$

$y_{SSC} = z_{SC}$

$y_{JJI} = z_{JI}$