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Designing Robust Shipping Schedules

by

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Abstract

The expansion of international trade over the last few years through the globalization process has triggered the demand for more efficient maritime services. New challenges have to be met by the shipping companies in terms of efficient schedules and routes of the vessels. In the quest to achieve that a discrete event simulation model as a tool to aid decision making for the design of more quality-robust shipping schedules able to cope with disruptions has been developed. An inbuilt flexibility to accommodate additional endogenous and exogenous processes characterizes the model whilst regarding the data availability different course of events can be examined. The simulation model aims to evaluate the robustness of a shipping schedule. Parallel through a “what if” analysis, interventions have been applied in the initial schedule in order to upgrade its robustness. On top of that a cost penalty function was developed as a tool to evaluate the trade-off between robustness and the costs of such interventions.

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Chapter I-Introduction

Trade inescapably is positively correlated with transportation. The efficient performance of the transportation system constitutes a prerequisite for the successful coordination of any trade transaction. Simultaneously, 90% of all long distance freight transport is monopolized by the maritime transportation system. Over the past few decades the demand for maritime services has experienced a consistent upward shift whilst there is no indication that the heavily reliance of the worldwide economic trend on maritime transportation will discontinue in the near future. In addition due to the tremendous growth achieved, the maritime transportation has not only increased in size but also has been transformed into a complex network.

However a burden has been aroused in the operational framework of the maritime transportation invigorated by the development of the international trade. Recent developments either in other modes of transportations or in ports have stimulated a high competitive environment within the transportation system. In as much, innovations in air, rail, and road freight transportation have enabled them to provide high speed services. Hence a number of factors have been combined triggering the shipping companies to improve the efficiency of their service provision. In this context, it is imperative for the shipping companies in the strife of ensuring efficiency the generation of quality schedules in terms of reliability and punctuality taking into consideration the long delivery times that this mode involves.

Nevertheless, maritime transportation is taking place in a complex and dynamic environment where uncertainty generated by unforeseen events denotes its intrinsic nature. Within this environment deviational situations are constant whilst all the other influencer parameters are variable.

Since, maritime operations involve a high degree of uncertainty the detailed blueprint in the level of selecting a route and scheduling the fleet is a necessity to reinforce its functioning. Effective scheduling in maritime transportation creates the fertile regime for further cost reduction and generation of higher profit margins. In addition, it contributes to the achievement of an upward shift in customer's utility. As a certain threshold of satisfaction exists through more reliable and punctual services customers can enjoy higher marginal utility. On the contrary customers that have to confront with deviating time deliveries of their cargoes; irrefutably they will withdraw their preference and take their custom to other carriers or modes of operation.

Obviously delays are an inevitable phenomenon in the functioning of the maritime transportation system. A wide spectrum of factors such as adverse weather conditions, mechanical breakdowns, strikes and insufficient infrastructure both in ports and on board interdepended with the maritime operations, produce a time lag between the scheduled and actual delivery times. Such situation beyond the human's manipulation force to tackle them during the time of occurrence stimulates the beforehand considerations of their detrimental impacts as well as the exploration of any alternatives to cope with them.

Therefore a key question is aroused referring to how efficient a schedule can perform under the occurrence of delay(s) for a particular vessel(s). Did the planner during the planning process build enough buffer time enabling the shipping schedule to mitigate the knock off effect of the delay(s)? Absence of the sufficient buffer time indirectly suggests that a non schedule arrival of the ship in one port will create delay propagation with significant resource implications throughout the whole network. Moreover shipping companies have to bear penalties posed by the receivers of the delay i.e. terminals, customers ports. Building a schedule where a large amount of buffer time has been included is very costly. Plausibly the time that the vessel stays idle increases with a geometrical progression. However an approach to confront with these dilemmas is to incorporate robustness in the design of the shipping schedule during the planning process that will ease the adaptation of schedule alterations.

1.1 Objective of the thesis

Regarding the above mentioned it is an evident truth that the concept of proper routing and scheduling constitute a more vigorous request on the field of the liner shipping mode of operation. The adoption of large scale of containers has inaugurated a new environment through which liner shipping services are provided. Standardization, vertical and horizontal integration, competitive advantage, supply chain coordination, introduction of new logistical "just in time'' concepts, are some of the features that define the new era in liner shipping. Nevertheless these characteristics have also influenced the routing and scheduling process. Therefore fixed itineraries published in advance through an extensive in size network constitute a prerequisite for the company to carve a market niche among the competitors.

But carving a market niche requires the elaboration of punctuality and reliability as constant variables where robust schedule constitute the principal thrust to facilitate this effort. By the same token, due to the supremacy of the larger vessels in shipping industry the potential reduction of cost in sea still left is getting smaller and smaller pressuring for the allocation of new cost saving provenances

Under this notion modeling the liner shipping scheduling system where robustness can be accommodated both punctuality-reliability and cost savings can be achieved. But why robustness?

A shipping schedule is considered to be robust when it can perform efficient under the occurrence of difficult situations and thus it is insensitive in adverse conditions. In other words the schedule has the flexibility and ability to recover in the advent of irregularities in the daily operation scheme. The concept that lies behind the robustness approach is to generate a shipping schedule that has the required quality for the majority of the cases and acceptable in the occurrence of the worst case. Consequently a decision can be taken in relation with the outcomes that the worst case has indicated.

Through this concept the main challenge of the thesis is to build on a quantitative basis an aiding decision tool to facilitate the generation of robust liner shipping schedules able to cope with schedule disruptions through the proposal and evaluation of alternatives.

1.2 Methodology

To deliver the objective of the generation of robust liner shipping schedules a discrete event simulation model on the basis of a "what if" decision support system has been developed. For the model development Excel spreadsheets has been utilized. The simulation applied in an explanatory case study tackles various scenarios which are displaying a number of alternatives namely, increase of the nominal speed, possibilities of skipping a port in order to evaluate and upgrade the robustness of a liner shipping schedule. The model developed focuses on the analysis of delays statistics as a result of the difference between the actual arrival time and the nominal-scheduled arrival times. The nominal arrival times are given from the pro-forma schedule that the vessel follows. Whilst for the computation of the actual arrival times apart from the data indicated by the pro-forma schedule, statistical distribution of adverse weather and port conditions that may occur has been taken into consideration. Moreover a cost penalty function is introduced as a tool to evaluate the different interventions undertaken for the improvement of the schedule robustness However the statistical distributions and the costs describing the above events has been assigned by experimental judgment as the limited time frame for the completion of the thesis didn't allow the collection of the various types of data required.

The interventions in the initial schedule that the scenarios describe and their simulation performance metrics will be compared with the simulation results of the schedule indicated a priori. The value of the cost penalty function in conjunction with the degree of the schedule robustness will enable us to draw conclusions applicable to the liner shipping schedule system.

1.3 Thesis Flow

The flow of the thesis is outlined as follows, Chapter II discuss the development of the maritime industry and the demand for more efficient routes and schedule while a briefly description of the planning-scheduling process and characteristics of the maritime transportation system are presented. In Chapter III a literature review that describes previous efforts for managing scheduling irregularities and a comparison among maritime operations and other modes of transportation on the field of scheduling is attempted in order to illustrate the complexity of the maritime system and factors to be taken into account for the design of shipping schedules. Chapter IV describes some aspects of the operational level of planning related with the uncertainty in maritime operations and the concept of robustness in the planning process of the maritime system. In this chapter we also try to investigate the main sources of disturbances that will affect the performance of a shipping schedule. Chapter V presents a more in depth analysis of the liner shipping scheduling system and cost related issues in order to lay the ground for the model development introduced in later chapters. In Chapter VI we proceed with the development of a simulation model to evaluate and upgrade the robustness of a liner shipping schedule. It also describes the model details and how the model was tested in an explanatory case study where through a scenario evaluation process seeks to propose alternatives and incorporate robustness in the scheduling process. In Chapter VII concluding remarks, limitation of the model and future encashment are discussed.

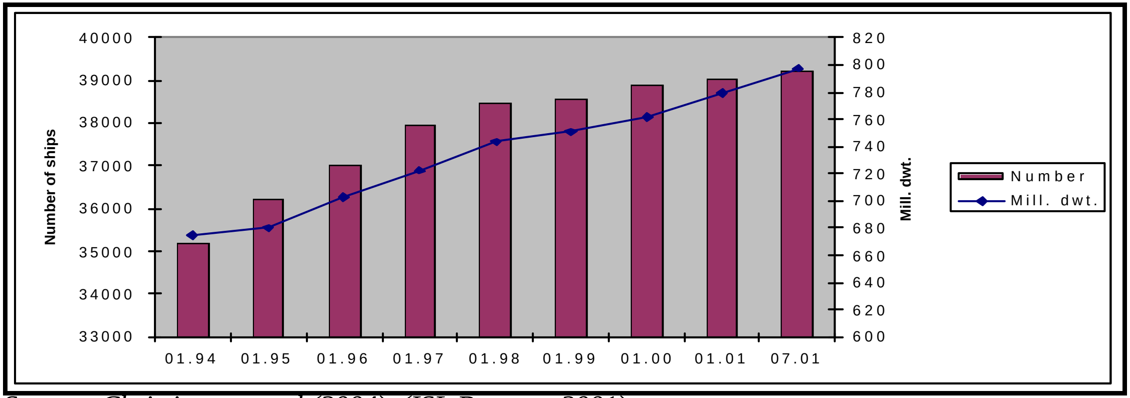
Chapter II - Importance of Maritime Transportation, Characteristics & Terminology of Scheduling and Planning

This chapter is composed of three sections. In the first section the development of maritime transportation and the need of more efficient-reliable maritime services is presented. In Section 2 an analysis of the basic characteristics of the maritime transportation system in relation with the planning and scheduling process is discussed. Finally this chapter is concluded with the definitions of terms used in the scheduling and planning of the maritime transportation system.

2.1 Maritime Transportation & the Significance of Proper Routing & Scheduling

Maritime transportation is the fastest growing industry generating an accelerating world trade growth even more rapidly than usual. Stimulated by a growing consumer demand whilst the principles of globalization and liberalization have launched a fresh impetus into the quest of developing a fertile regime for expansion, seaborne shipping constitutes the cardinal mode of transportation in today's world. Reciprocally, recent statistics covering the period 1947-2002 (Figure 2.1) have indicated a rapid expansion in the world fleet development. During this period the world shipbuilding output accounts for a number of 108.000 ships recording an average of about 2000 new builds per year.

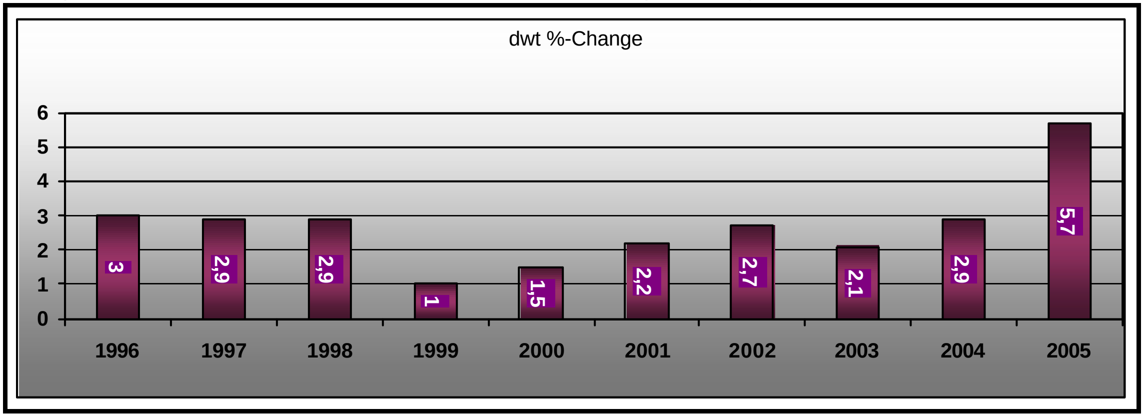
Figure 2. 1: World fleet development 1994-2001 for Vessels over 300 gross tons



Source: Christiansen et al (2004), (ISL Bremen, 2001)

Accordingly, the above trend sustained for the period 2001-2005 (Figure 2.2) where the average growth rate of the tonnage supply was 3.3%, representing a 109 millions dwt increase of the world's fleet while latest data of ISL, regarding ships of 300gt and over, displays for the year 2005 a 5.7% increase of the tonnage supply in comparison with last year figures.

Figure 2.2: World Merchant Fleet-Annual Tonnage Changes 1996-2005 dwt-per cent



Source: ISL, Market Analysis 2005

Parallel to the growth of the cargo carrying capacity, the seaborne trade has also followed a consecutive acceleration of growth. Over the last two decades, world seaborne trade has achieved an increase of up to 59% in terms of weight, as indicated in (Table 2.1), revealing a direct correlation between seaborne shipping and trade.

Table 2.1: Development of International Seaborne Trade (millions of tons)

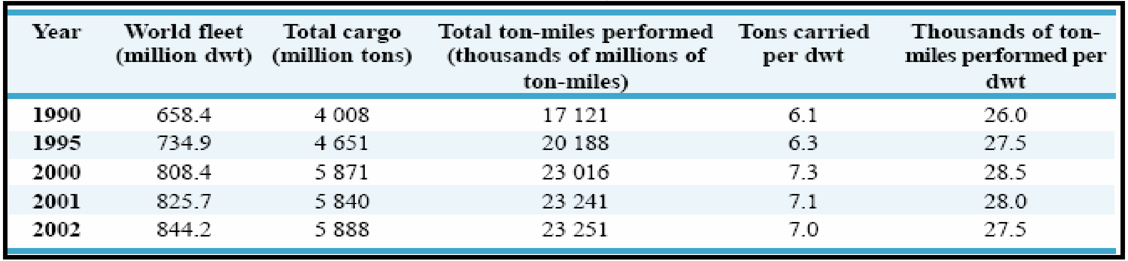
	Bulk								Oil		Gas		
Year	**Iron Ore**	**Coal**	**Grain**	**Bauxite Alum.**	**Phos. Rock**	**Minor Bulk**	**Cont.**	**Other Dry**	**Crude**	**Products**	**LPG**	**LNG**	**Total**
1986	311	275	187	42	45	555	173	555	1030	401	22	35	3631
1987	319	293	211	46	45	575	192	532	977	379	24	37	3631
1988	346	313	216	49	47	603	211	550	1086	417	23	41	3902
1989	362	314	220	55	44	614	231	578	1198	480	26	44	4167
1990	347	327	215	55	37	607	246	626	1155	448	28	53	4153
1991	358	360	218	53	31	606	268	652	1161	403	30	52	4192
1992	337	368	224	48	30	618	292	673	1245	407	32	53	4326
1993	352	372	223	51	27	626	322	687	1354	438	34	55	4530
1994	380	374	207	49	29	659	357	689	1375	432	33	58	4643
1995	402	402	216	52	30	699	389	696	1400	448	34	33	4801
1996	392	425	219	54	31	698	430	753	1469	477	36	66	5050
1997	428	450	229	55	32	707	470	789	1550	496	37	74	5316
1998	428	451	226	55	31	686	503	810	1544	478	35	75	5322
1999	405	464	247	54	31	683	559	799	1578	504	37	82	5442
2000	449	506	264	54	28	697	622	806	1655	498	39	92	5709
2001	454	535	260	54	27	698	630	861	1656	548	36	94	5855
2002	474	547	268	54	26	705	669	854	1608	560	36	100	5901
Share '86 (%)	8.6	7.6	5.2	1.2	1.2	15.3	4.8	15.3	28.4	11.0	0.6	1.0	100.0
Share '02 (%)	8.0	9.2	4.5	0.9	0.4	11.9	11.3	14.5	27.2	9.5	0.6	1.7	100.0
Annual growth 1986-2002	2.7	4.4	2.3	1.6	-3.4	1.5	8.8	2.7	2.8	2.1	3.1	6.8	3.1

Source: Clarksons

The outlook of international trade within a global market triggered the demand for the transportation of a spectrum of finished goods and commodities at low cost which prompted an annual growth rate of seaborne trade of up to 3.3% during the period 1987-1995. Statistics pertaining to the seaborne trade development point out a total seaborne trade of 134 billion tones over the period 1963-2002. Moreover, global cargo movements through water transportation have virtually generated a volume of 268 billions tones in terms of terminal productivity as these cargoes are passing through the ports all over the world at least twice, based on the fact that it is a two folded action of exports and imports. Consequently most of the countries around the world have realized the gravity of seaborne trade as a significant indicator and element for economic growth encouraging them to undertake breathtaking investments in port facilities for handling different categories of commodities and cargoes.

However, examination of the statistics relevant to the seaborne shipping activity over the last 20 years depicts a gap between the growth of world fleet and seaborne trade. Trade in 2002 recorded a total volume of 5888 million tones and a 59% increase while world fleet enlargement reached 24% increase with a total dwt of up to 844 millions. The above deviation can be attributed to the fact that the world fleet productivity has also experienced a notable expansion. Data compiled by the UNCTAD (2003) illustrates an increase in the utilization of world fleet from 6.1 up to 7.0 tons carried/ dwt during the period 1990-2002. In addition, the above increase led to an annual output in 2002 of up to 27.5 thousands tons per deadweight ton in comparison with 26 thousands tons per dwt ton in 1990 (Table 2.2, Figure 2.3)

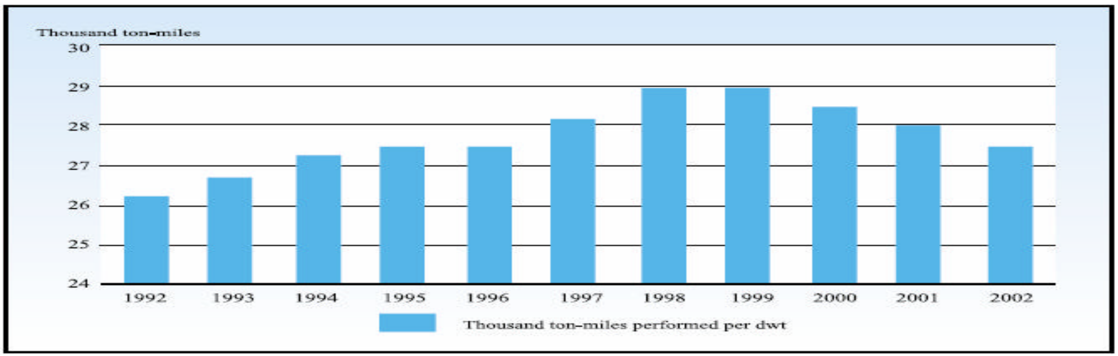
Table 2.2: Total Productivity of the World Fleet



Year	World fleet (million dwt)	Total cargo (million tons)	Total ton-miles performed (thousands of millions of ton-miles)	Tons carried per dwt	Thousands of ton-miles performed per dwt
1990	658.4	4 008	17 121	6.1	26.0
1995	734.9	4 651	20 188	6.3	27.5
2000	808.4	5 871	23 016	7.3	28.5
2001	825.7	5 840	23 241	7.1	28.0
2002	844.2	5 888	23 251	7.0	27.5

Sources: Review of Marine Transportation UNCTAD 2003

Figure 2.3: Index of tons/mile performed per dwt of total world fleet , 1992-2002



Source: UNCTAD calculations, Review of Marine Transportation UNCTAD 2003

Interpreting the above statistics we can infer as well as promulgate the magnitude of maritime transportation as a prerequisite for the efficient ongoing enlargement of world's economic activity. Moreover, the notion of deep sea trades representing the main artery for the transportation of high volume cargoes underpins and justifies the reliance of international trade on water transportation. Correspondingly, taking into consideration the verity that forecasts are estimating a steady increase of the world population growth along with the integration of the world economy into one market through the

globalization process, one should expect that seaborne activities will increase in the near future.
In this boosting period for the maritime industry new challenges have to be met. The efficient functioning of the whole cycle of the maritime transportation system aligned with the evolution of the supply chains and logistical models will be equally stressed both in time performance capabilities and costs. Under this framework a fundamental challenge that the maritime industry has to confront with corresponds to the design of more efficient and agile schedules of the vessels. In addition, as the market environment, in which shipping industry is operating substantially changes as a function of time due to the ever-increasing competition, the generation of profit margins are becoming an unachievable vision. Simultaneously considering the fact that a ship entails a considerable capital investment, normally millions of dollars, whereas the breakeven point for the daily operating costs of a vessel lies between 10 to 50 thousands US dollars or more, triggers the necessity to rifle through all the optimal solutions that will ameliorate the schedule of a fleet. Respectively higher in quality economic performance and more preferable financial results can be accomplished.

In other words, it is irrefutable that the shipping companies ought to deploy a decision support system that will pledge the criteria to confront the considerable planning dilemmas and complexity. Thus it is essential to encompass and evaluate all the parameters that will provoke disruption in the schedule of a vessel on the scope of deploying a collaborative and integrated approach regarding the generation of more qualitative and robust schedules.

The capacity of planning more efficient and robust schedules constitutes a prerequisite for the ongoing flourishing of the maritime industry. Moreover a spectrum of incentives including higher profit, cost reduction, generation of revenue and customer values stimulate shipping companies to improve the provision of their services in terms of, frequency, reliability and punctuality. Such generic strategies can be boosted by the ability of the planner to detect and mitigate all the disturbances that may curb the credibility of the planning process regarding the construction of schedules that can perform well under the occurrence of unforeseen events that the maritime transportation is contingent to. Therefore the company will not only be able to fulfill its obligation to the customers but also to ensure the survival and future growth of the company

2.2 Basic Characteristics of the Maritime Transportation System

2.2.1 Maritime Transportation planning

The framework according to which shipping companies are taking planning decisions in order to optimize as well as to confront planning problems consist of three levels., the strategic, tactical, and the operational level (*Christiansen et al 2004*). Each one of the above levels can bifurcate into various functional components whereas an interrelation exists among them within the same level and further influence the functions of the next levels.

A demarcating line can be posed among the above level of planning regarding the planning horizon that each one is referred to. Thus the sphere of strategic level concerns long-term decisions. By the same token medium term planning decisions are pertinent to tactical level while the interrelation of the two levels of planning lay the stage for the operational level which is referred to short term decisions. However, the boundaries among the above levels of planning are delineated gray rather than solid. It is a common phenomenon some planner's to approach decisions that are "traditionally" designated as part of the strategic level, as part of the tactical level and decision accredit on the tactical level as operational one and via versa. Moreover, in order a planner to take decisions on the level of the strategic planning information are required from the other two levels of planning. Hence an overlap among the decisions of the three levels of planning usually occurs.

According to *Christiansen et. al (2004*) the problems that a planner has to prevail in each one of the above levels of planning on an endeavor to blueprint the provision of sophisticated, efficient and competitive services can be broken down into the following sub-categories.

Strategic Level: The problems related with the strategic level of planning can be listed as follows:

- The target market selection that the company aims to penetrate. Considerations regarding the size of the market, the growth rate of the market, competition, attainable market share, required market share, potential volume trades and expected profit are required to be analyzed and evaluated by the planner. Moreover, the contestability of the market constitutes another significant characteristic considering the ability of the shipping company to leave the market without generating sunk costs.
- On a second basis problems related with selection of candidate calling ports where factors such as, port dues, pilotage and other related costs as well as cargo handling productivity, navigation matters, and hinterland accessibility of the port have to be considered.
- Network planning and design of the cargo movements through the interchange points between the different trade routes, their connectivity as well as the network scale in terms of geographical coverage. In addition this stage involves problems regarding the transshipment points that have to be determined and will connect the shipping services with the intermodal services.
- Problems regarding the optimal mix and size of the fleet to be deployed. Questions referring to the expansion of the fleet by buying or chartering vessels or conversely to charter out/sell owned vessel for reducing the size of the fleet.
- Problems related with the allocation of the optimal ship design that the company has to deploy in a specific trade route. Geophysical parameters have also to be considered mainly referring to draft restrictions in ports and entry channels that will determine the design of the ship.

Tactical Planning: On the level of the tactical planning the major issues that must be contemplated can be addressed as follow:

- Modification of the fleet mixture and its size
- Detail assignment of the trade routes to each specified vessel.
- Supply chain management of maritime activities
- Shipping routing and scheduling taking into account a subcategory of factors that can be classified as
  - Berth window scheduling according to the time slot agreed with the terminal upon which the ship will be able to berth.
  - Crane scheduling referring to the determination of the appropriate crane capacity in order to achieve the desirable crane productivity.
  - Container management that can be broken down into three functional areas:
    - Optimum Container fleet size
    - Storage yard efficiency and productivity of the terminal operators.
    - Allocation, distribution and movements of the empty containers.

Operational Planning: Finally the planning horizon of the operational level can be described on the confrontation of problems related to:

- Optimum speed during the sailing time.
- Ship loading issues, related to the safe load of a ship. In this respect the ship will maintain its stability while floating on the water and passes through the candidate calling ports as the vessel load/unload cargoes in ports. In liner shipping that is referred as stowage planning regarding the way the containers are arranged in a container ship in order to improve the efficiency of the shifting and crane movement while the ship maintains its stability.
- Environmental routing related to the environment that a vessel is operating, considering weather conditions, ocean currents etc.

2.2.2 Modes of Operation and Categories of Shipping Services

The maritime transport system as it has been developed by the shipping industry and the necessity to transport a significant range of different commodities can be segregated into three major modes of operation. Therefore we can distinguish them as liner, tramp, and industrial shipping. More specifically, the characteristics that can determine a shipping service as being a liner are basically that the operation is held according to a published in advance itinerary similar to the schedule of a railway. Moreover, the quintessential trade of liner operators is concentrated on the transportation of containers and general cargoes. Accordingly, the regularity, geographical coverage, reliability and punctuality of their fixed schedules are the driving forces that will influence the demand for liner shipping services.

On the other hand, tramp shipping doesn’t follow any itinerary as services are scheduled in accordance with any cargo available to be transported. It roughly reminds one of how a taxicab operates as tramp operators operate under contracts of affreightment that engage the transportation of cargoes of specified quantity on a particular route or routes within a specified time frame using ships of their choice for an agreed per unit of cargo amount. The ships that a tramp operator usually deploys are oil-chemical tankers, dry bulk and refrigerated vessels. Maximization of profits is the driving force for both of the above modes of maritime transportation.

In the case of industrial shipping, cost minimization is the main objective as operators strive to push down the cost for the transportation of their own cargoes with ships that they own or have chartered for a specific period of time. Moreover vertical integrated companies are the main industrial operators for the transportation of high volumes of liquid and dry bulk cargoes such as oil and chemicals.

Due the fact that maritime industry is a highly volatile business, operators are usually confronted with situations of excess or lack of demand. In the situation of excess demand whereby industrial operators must transport their cargoes, they complement their fleet from the tramp market and consequently size their fleet according to long term needs. On the contrary, in liner shipping, operators may be able give up in the situation of excess demand when the available capacity exceeds the demand by reducing the size of their fleets. This in turn can be achieved by reshuffling their fixed schedules leading to the provision of less frequent services or by exiting from a number of markets. As far as ease of entry or exit in one of the above operations is concerned, tramp shipping has fewer barriers to entry as a high risk market. In the opposite direction, liner market poses significant economies of scales as well as extensive infrastructure that elevate the barriers to entry and limits the ability of entry.

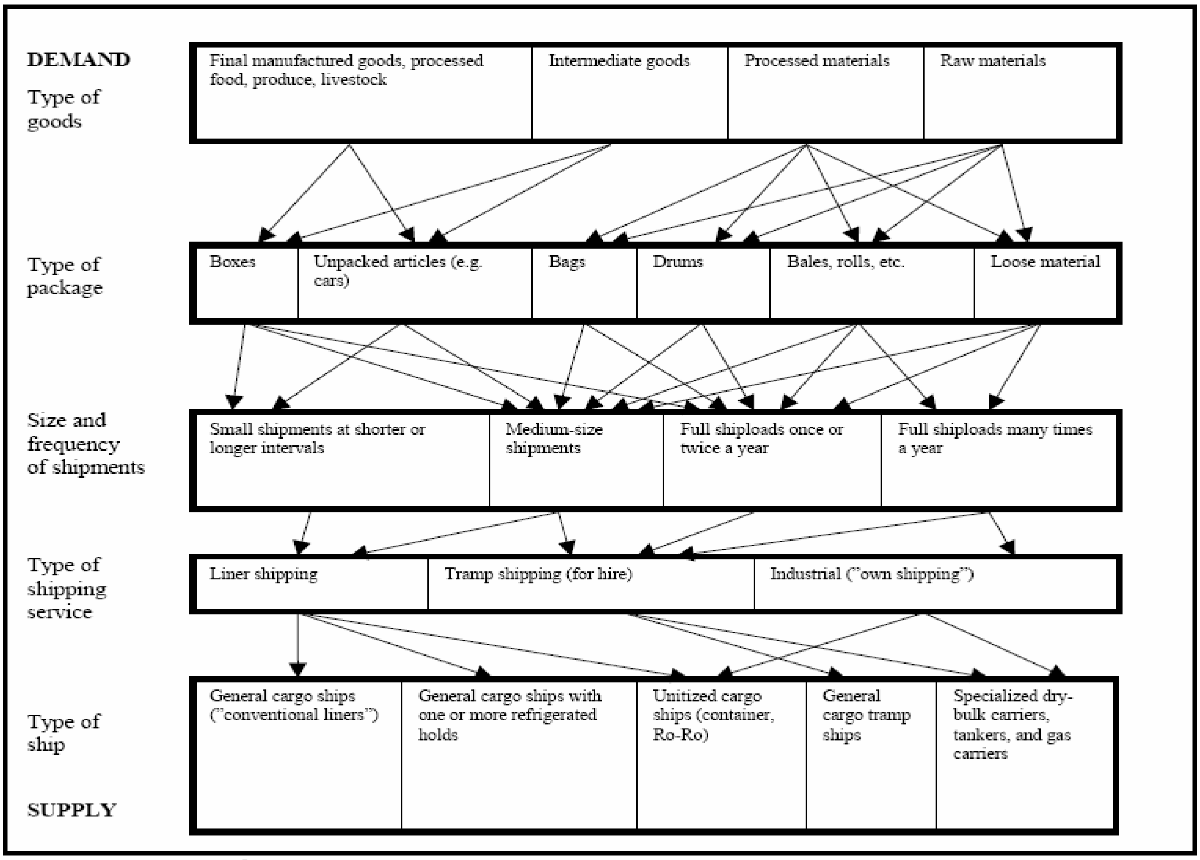
2.2.2 Categories of Shipping Routes

We can categorize the shipping route as being *deep-sea, short-sea, coastal and inland waterways* (*Christiansen et al 2004)* according to their geographical characteristics. In the deep sea trades, the ships that are usually deployed are large size vessels corresponding to the demand for cost savings gained from the economies of scales. However due to the facilitation of today's world trade of deep sea carriers through hub and spoke ports, feeders and smaller containerships are employed in short sea routes to transfer cargoes to the large containership. Furthermore because of accessibility limitations and draft restrictions in ports, barges are usually deployed to move cargoes from hinterland to ocean going ships and via versa or among inland ports through hinterland waterways.

Among the above characteristics we must also consider the ship characteristics which is operating between ports and thus to consider the port characteristics as well the cargo characteristics that the maritime transportation is assigned to transport.

Generally we can plot the basic characteristics of maritime transportation into the next graph (Figure 2.4) that combines the demand and supply for shipping services portraying the different functional stages of shipping and tie them together:

Figure 2.4 Characteristics of Maritime Transportation,



Source: Ronen et al 2004.

2.3 Keywords and Terminology

Shipping: the movements of cargoes by vessels. *(Ronen et al 2004)*

Routing: the assignment of a number of ports in a sequence the vessel has to call at. *(Ronnen, 1983).* The choice of the route and order to serve customers.*(Dekker 2005)*

Environmental-Weather Routing: Selection of the optimum path that a vessel should follow floating in the body of water. *(Ronen et al 2004)*

Scheduling: The procedure consists of the specification of time windows for the different events that are taking place in a route. *(Ronen 1983).* Determination of the day and the order in which customers are served *(Dekker 2005)*

Fleet Deployment: The procedure consists of the allocation of ships in trade routes, determine frequencies and chartering decisions regarding the necessity to supplement the owned fleet in order the fleet to converge with the trade route requirements.(*Perakis and Jaramillo 1991)*

Voyage: A voyage is the process consists of a number of port calls in sequence. A voyage begins in the port where the empty vessel loads the first cargo and ends in the port where the vessel unloads the last cargo and gets to be empty again. In liner shipping a containership may not become empty among consecutive ports and thus the liner shipping operator assigns the port as the starting point of the voyage. *(Ronen et al 2004)*

Arrival and Departure Delay: The difference between the nominal planned time of an event and its actual time that turns to be positive. *(Vromans 2005)*

Robustness: The robustness of a maritime transportation system indicates the influenceability of the system by disturbances. *(Vromans 2005).* Fastness with which deviations from the schedule can be dampened out. *(Dekker 2005)*

Reliability: The capability of the maritime transport system to carry out the functions that this mode involves under specified conditions and for a fixed period of time. (*Vromans 2005).* The ratio between planned goal that a schedule is designed to achieve and the results of the schedule in real time operations *(Wu, 2003.)* The match of actual arrival/departure times with the published scheduled times expressed in percentage (%). *(Dekker 2005)*

Chapter III - Literature Review in Ship Routing and Scheduling

A discussion on the factors that research on ship routing and scheduling problems has been step behind is described in the first section of this chapter as well as an indication of the complexity that this problem involves. In the following section a literature review related to scheduling problems is presented while in the last section a comparison between maritime and other modes of transportation on the field of routing and scheduling problems is attempted.

3.1 Scarcity of Research in Ship Routing and Scheduling Problem

Since operational research has been considered as a fundamental tool for optimizing the way that transportation functions, proper routing and scheduling as an aspect of improving and smoothing the daily distress of the flows in a supply chain network to converge with the customer demands on cost minimization basis, has extensively been discussed. A significant amount of research has been carried out concerning mainly the modes of inland transportation whilst water and air transportation has not been given similar attention.

Researchers tried to apply quantitative approaches on real world problems in an endeavor to provide solutions. The result was a large number of studies that have inaugurated a new perception of transportation planning and constituted the platform for the incarnation of the logistical framework that today's international trade is facilitated by. However the majority of these studies are dealing with the vehicle routing and scheduling problem. On the contrary, the other modes of transportation have drawn sizably less investigation on the same field. Taking into account the fact that air, sea and rail are heavily capital intensive industries accompanied with notable operating costs, one should have expected a cornucopia of published work and research.

Accordingly, the literature related to ship routing and scheduling is more embryonic as the first survey enumerating the perplexity of such problems on the sphere of maritime transportation dates back to '83. *David Ronen* and his survey *"Cargo ships Routing and Scheduling: Survey of models and Problem" (1983)* tried to portray the hindrance involved in the way shippers are designing and planning water transportation. His findings gave a fresh impetus into the quest for further research on the field. In 1993 *Ronen* published a second revised survey on shipping scheduling, routing and related areas indicating the scarcity of such research as well as the shallow penetration of quantitative applications in shipping. Nonetheless, in his paper, he summarized trends and clarified an array of factors that research stepped behind.

Among these factors he elucidated that ship routing and scheduling entails a high level of complexity due to the heterogeneity in structure as well as due to the diversity in the operating environments. Moreover, he highlighted the uncertainty that exists in the maritime transportation as disturbances that are beyond human's sovereignty can usually disrupt any ideal planning. Sources of such disturbances can be severe weather conditions, strikes not only in ports but also on board, mechanical problems etc, delays originating from the above factors or/and the necessity for rerouting the pro forma schedule, usually leads to an uneven loss of capital.

Further to his survey, *Ronen* also pointed out the lack of openness for fresh ideas in an industry whereby tradition and conservatism impede any radical changes. He also remarked the fact that despite the evolution in computer science and its applications on an effort to yield optimal solution in other modes of transportation, comparatively trivial research has been done in the area of the shipping industry.

3.2 Related Studies on Ship Routing and Scheduling problem

As mentioned above, *Ronen* was the first to publish a survey related to shipping routing and scheduling problems and motivated a further research on the field, as a recent bulk of publications reflects the increasing interest of researchers to carry out more in depth research in this area.

In the following section, a description of published work related to the routing and scheduling problem of maritime transportation is presented. The objective of this review is two folded .On a first level to elucidate and deliver an insight of the quantitative approach and operational techniques employed in an endeavor to provide a comprehensive view and solutions in problems related to ship routing and scheduling. And on a second level to emphasize the complexity involved in routing and scheduling process in maritime transportation.

3.2.1 Literature Review in Models related to Ship Routing and Scheduling Problems

As mentioned before, the modes of operation in maritime transportation can be broken down into three sub-categories, liner, tramp and industrial operational. Correspondingly, taking into account the different characteristics that determine each mode, the literature modeling and quantitative approaches that have been developed are also classified into three categories depending on the mode that is being referred to. On that account, the section bellow is divided into three sub sections describing the modeling formulation for each mode separately and. Moreover, it is essential to mention the scarcity on research for passenger transportation as the majority of them is dealing with the movements of cargo trough water transportation.

3.2.1.1 Liner Shipping Scheduling Models

Considering the nature and the environment that liner shippers are operating where parameters such as frequency, punctuality, geographical coverage, transit times, are the dominant variables to determine liners profit, decisions on routing and scheduling play a more assertive role in their financial performance, as network management decisions account for 25% of the total cost. As a result, profit optimization per time unit rather than by pushing down the costs which will prevent the provision of more sophisticated services, constitutes the main goal for liner operators. Moreover there is a high degree of uncertainty that exists in liner operation, originating from the fact that liners have to call a substantial number of ports in order to extend their geographic coverage. Thus, through these constrains and mainly due the uncertainty involved, the majority of models employed in liner shipping on a operational level have been simulation as well as heuristic decision rules.

Datz (1969) developed a simulation model as a tool to construct a schedule for liner operations depending on the cargo available and estimated the financial performance of this schedule. In the formulation of the model and further to the financial outcomes, he also considered the probability of a contracted cargo not reaching its destination. Similarly, a more elaborate model to assign the optimal number of ships to be deployed in order to meet a predetermined service in terms of frequency has been developed by *Kydlan(1969)* For his purpose *Kydlan* employed a stochastic simulation model applying linear programming. In the same direction, *Olso et al. (1969*) has also employed a deterministic simulation model in order to appraise decisions related to scheduling issues as well as to evaluate the repercussions in such decisions if the ship has to stay idle in the port waiting to load additional cargo. For that purpose and thus to construct mid-term shipping schedules, he implemented his model in a liner shipping company that was operating in the route between US coast and Hawaii.

By the same token, *Davennay et al (1975*) developed a computer based model. The objective of the model was to find the optimum point at which specified demand for liner operations can be satisfied at the minimum total cost of a fleet. The controllable inputs of the model embodied dimensions and other design characteristics of the ships deployed in the fleet while a number of assumptions incorporated to lessen the complexity of the problem. Among these, *Davenney* assumed that the ships of the fleet are identical; port time is not influenced by the volumes of cargo that are loaded/unloaded and also that the shipping company charges identically the same for the transportation of any type of cargo. Although the above assumptions contributed in making the problem simpler, they also delimited the application of the model in a broader range and restricted its usefulness.

Correspondingly, *Bofey et al. (1979)* built an interactive computer based program and tried to solve the problem of scheduling containerships on the North West Europe to North East Coast and Canada Trade. In his methodology he utilized a heuristic optimization model, first to determine the ports-points that must be called at and in which order and then to transform them into a route that the ship will follow. The objective of the model was to provide information related with the profitability, transit time, and total buffer time of the route taking into consideration as decision variables in his model the speed of the ships and different synthesis of ports to be called. The relatively simplicity of the program makes it favorable as it is easily understood and used by managers and also to modify its function and calculate for example port charges.

Lane et al (1987) introduced a dynamic program in order to locate the optimum cost of a fleet, given the trade route and demand that must serve under the constraint of a specified time horizon. The problem formulation consisted of a number of different stages where in every stage the objective was to minimize the cots of a liner service. The model could also be applicable in a range of different ships design and in combination with various port characteristics and cargo types.

Rana and Vickson (1988) employed a deterministic mathematical model to determine the optimal route for a chartered containership while in *1991* they reformulated the model to a greater extent to be able to embody multiple ships. The model would be able to determine the order of the ports at which each ship will call, specify the number of voyages that each ship has to make, and the volume of the cargo that the ship has to deliver among any two ports. For the construction and solution of this model, they used Langragean relaxation while they divided the model into a number of sub-models; one for each ship and further for each sub-model they applied a number of mixed integer linear programming.

Additionally, *Hersh and Ladany (1989)* formulated a dynamic programming model in favor of a company that was leasing a luxury ocean liner. The company was offering cruise during Christmas in the Southern California to the Caribbean route. However, the main problem of the company was to decide on what type of cruises should be offered in terms of the optimal itineraries and fares. The model was constructed in two stages. In the first stage, they applied non-linear regression analysis in order to determine the demand curve for cruises and the factors that influence its size and shape. In the second stage, a dynamic programming model was developed with decision variables, such as the length of the cruise, the route, the departure days and the fares. The objective of the model was to determine the optimum values which will specify the maximum net profit that the company will generate during a season. A significant element of the model was that the input data used in the second stage were the demand relationships indicated from the first stage.

Another significant attempt in the researchers endeavor to confront problems related with routing and scheduling in liner shipping is accounted by the linear programming model developed by *Perakis and Jaramillo (1991).* The objective function of the above model was to minimize the annual operating costs for a fleet. Factors determining the annual operating costs were port dues, canal fees, bunkering, crew and other related daily operating costs. In addition, they also indicated a number of different approaches for adjusting the frequency of the service provision as well as the speed of the vessels. In a second paper, *Perakis and Jaramillo* dealt with the determination of the optimal fleet deployment subject to a number of constraints such as frequency, time and other realistic characteristics. They formulated their model under the assumptions that speed and frequency of the service are predetermined and thus conveyed a linear programming model avoiding any non linearity generated by these factors.

They also applied sensitivity analysis in an aim to deliver an insight of the relevance between costs, frequency and profitability in liner shipping. Specifically, the outcomes revealed a positive relation among operating cost and frequency of the service and the number of the vessels owned by the operator. In other words, the operating cost grows as the frequency grows as well as when more ships of the fleet are owned.

3.2.1.2 Literature Review in Tramp Shipping Scheduling Models

The lack of literature modeling related to routing and scheduling problems of tramp shipping is an evident truth. In principal, tramp market is consider a secondary one in the maritime community as it is consist of small operators along with the uncertainty involved in terms of the ships availability. Ship owners usually enter in the tramp market either when seasonal variation in demand portend a fertile regime to yield favorable profits or when there is no other beneficial employment of their ships. Hence comparatively trivial attention has been given in tramp shipping while the research is circumscribed only on the field of highly specialized trade such as refrigerated shipping

Towards this direction, *Appelgren (1969)* investigated the schedule problem of a Swedish company operating on a world wide scale deploying a large number of ships. A number of cargoes were available in advance for the planning horizon which was ranging from 2 to 4 months. For each one of these cargoes, a specific load date was assigned within the planning horizon while the discharging date wasn't specified with the flexibility of being delivered afterwards at a later date of the planning time frame. Furthermore, *Appelgren* took into account a number of factors to map the determining characteristics of the cargoes such as size, type, port of loading and unloading, time needed for the stevedoring process, voyages costs, potential revenues of cargoes. The majority of the cargoes that the company had to ship were contracted in advance while sporadically non-contracted cargoes were available in the spot market. Under this context the objective of *Appelgren* was to develop a model in order to schedule optimally the order at which each cargo will be assigned to the each of the ships deployed. For the solution of the problem he employed an integer programming model using Dantzig-Wolfe[1] decomposition algorithm. For the sub models, he used dynamic programming and tackle them as a network flow problems[2]

However, in a following paper *Applegren (1971)* dealt again with the same problem in order to improve the shortcomings related with the previous algorithm as some of the solution could not be interpreted as feasible schedule. In his second paper he employed a branch and bound algorithm[3] where the success of the second case was the construction of a more simple in structure linear programming.

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[1] Dantzig-Wolfe decomposition is one way of breaking a problem into an "easy" part (or parts) and a hard part. The easy part may be easy because it consists of smaller sub problems that can be solved independently, or the easy part may have some special structure (such as a network structure) that allows for quicker solution. This technique uses column generation to create "proposed solutions" for the set of easy constraints.

[2] The problem of finding the maximum flow between any two vertices of a graph.

[3] An algorithmic technique to find the optimal solution by keeping the best solution found so far. If a partial solution cannot improve on the best, it is abandoned.

3.2.1.3 Industrial Shipping Scheduling and Literature Modeling

Industrial shipping, which usually refers to more integrated companies as both cargoes and vessels are owned by the operator, has also been a subject of research on the scope of applying quantitative techniques in routing and scheduling problems. *Dantzing and Fulkerson (1954)* were the first to discuss a scheduling problem of a tanker on a perspective to minimize the number of tanker given a fixed schedule. Considering that dates of loading and unloading are announced in advance they formulated their model under the assumption that ships are identically the same and that for each tanker there is one port for loading and one for unloading per voyage.

Subsequently, *Briskin (1966)* dealt with the same problem on a wider scope. In his approach he permitted multi-ports of discharging, which also implies that determination of the appropriate volumes to be unloaded at each port of call is an essential factor on the routing and scheduling scheme. *Briskin* solve the problem by first clustering the candidate ports of calling in which the tankers will unload and then he used the transportation method to construct the schedule for the tankers while further by using dynamic programming he found the schedule for each tanker.

Later, *Laderman (1966)* discussed a linear programming model with the objective to minimize the number of ships needed in the trade of bulk commodities between pairs of ports. The model developed by *Laderman* was subject to a number of constraints such as, the fleet was consisting of not identical ships, ports were specified as well as the volume of the cargoes. In the same notion, *Rao and Ziots (1968)* expanded the same problem by adding the probability of ships to be chartered in order the fleet to be in a position to meet the trade commitment. Their objective was to minimize the costs of taking the decision of chartering plus the operating costs. For the solution of the problem, a column generation algorithm was developed to mitigate the shortcomings of the linear programming model.

In *1986 Ronen*, in an endeavor to enquire into the problem of planning the short term schedules of ships involved in the trade of bulk or semi-bulk commodities he developed a mix-integer linear programming. By allocating a set of cargoes (described by their size and destinations) that need to be shipped from a single location and by an available fleet the objective function was to determine the minimal operating costs of the fleet. Moreover, it was not a prerequisite the fleet to be composed by identical ships while all the costs related with the fleet were included. In the solution of the model a variety of routing algorithms compared in order to assign shipments to ships in a spectrum of realistic situations.

An interactive support system known as MOPASS[4] was presented by *Stott and Douglas* (*1981*). MOPASS developed as a support decision system appropriate for the planning and scheduling of bulk shipping. Through a medium term linear programming model ships can be assigned to voyages under the condition that voyages specification must be know in advance. The objective of the model was to find the minimum operating costs in order to meet the quantities that the ship has to load.

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[4] Marine Operation Planning and Scheduling System.

From the literature modeling presented in the section above we can infer the complexity of the maritime transportation and the difficulties that a planner has to overcome for the generation of a quality schedule. Albeit the interest of the researchers to investigate the problem more in depth have generated models were most of them have not found any application in real worlds problems. Either due to the number of assumptions that must be made in order to improve the validity of their models or because of the complexity that these models involve in their development are some of the major factors that repel managers to employ them. Thus it is no provocative to postulate that the majority of the published works and the effort of most of the researchers is still on a experimental and theoretical base having found accreditation only in academic level. In addition researchers have mainly concentrated on the field to produce optimal routes and schedule while the concept of robustness has not been explicit discussed

3.3 Difference between Shipping Scheduling Problems and other Modes of Transportation

In this chapter we will also try to address the difference between the problem of shipping routing and scheduling in comparison with the other modes of transportation such as rail, air and truck. The purpose of drawing a demarcation line among the modes of transportation on the field of scheduling and routing problems is first to substantiate the argument that shipping operations involve more complexity and secondly to illustrate the uncertainty occurs in the environment that shipping is functioning,

The class of scheduling and routing problems in the maritime transportation system differs in many aspects with the other modes of transportation. It is apparent that the space where air, truck and train freight transportation are taking place is fairly straightforward to define. Whilst their operating characteristics create a more agile framework under which the scheduling and planning decisions are taking. On the contrary maritime transportation system due to the dynamic and complex environment that its events are taking place, scheduling routing and related problems are more difficult to be analyzed. In addition the uncertainty within the maritime transportation system in conjunction with the long term planning and scheduling this mode involves designate the lack of versatility of the maritime transportation system to mitigate the impact of unforeseen events. In the following Table 3.1 we plot some of the operating characteristics among different modes of transportation namely, maritime, aviation, road and train.

Table 3.1 Operational Characteristics of the Modes of Transportation

Operational Characteristics	*Mode of Transportation*			
	SHIP	***AIRCRAFT***	***TRUCK***	***TRAIN***
Barriers to entry	Small	Medium	Small	Large
Industry concentration	High	Medium	Low	High
Fleet variety (physical & economic)	Large	Small	Small	Small
Power unit is an integral part of the transportation unit	Yes	Yes	Often	No
Transportation unit size	Fixed	Fixed	Usually Fixed	Variable
Operating around the clock	Usually	Seldom	Seldom	Usually
Trip (or voyage) length	Days-Weeks	Hours-days	Hours-days	Hours-days
Operational uncertainty	Larger	Larger	Smaller	Smaller
Right of way	Shared	Shared	Shared	Dedicated
Pays port fees	Yes	Yes	No	No
Route Tolls	Possible	None	Possible	Possible
Destination change while underway	Possible	No	No	No
Port period spans multiple operational time window	Yes	No	No	Yes
Vessel-port compatibility depends on load weight	Yes	No	No	No
Multiple products shipped together	Yes	Seldom	No	Yes
Returns to origin	No	No	Yes	No

Source: Ronen et al (2004)

According to the above Table 2.3 we can deduce the complexity of maritime transportation regarding scheduling problems. Whilst we can explicit point out some operating characteristics of shipping in comparison with air, truck and rail in order to elucidate some of the aspects that have to be considered when maritime scheduling system is examined:

- Fleets do not always consist of homogeneous ships. On the contrary, ships are different to each other, in terms of capacity, speed and generally on their operating and design characteristics. Correspondingly, these dissimilarities crop up further diversity in their cost structure. However diversity in the cost structure may occur also among two identical ships due the fact that maritime industry is a high volatile one engendering frequent fluctuations. We can quote for example the capital costs that are associated to the price for which a vessel is acquired. Owning to the fact that vessel prices, either in the second or new market, are fluctuating according to the market cycles the capital cost is also fluctuate according to these cycles. Therefore the cost structure among two identical ships may be different since capital costs, as a component of the cost structure, oscillated between high and low values depending on the cycles that the ship has been acquired.

- The scheduling environment upon which shipping companies design their services depends to a large extend on the mode operation of the ship. As we have already mention above its mode of operation is determined by a number of different characteristics that a planner must take into account. Therefore a proper planning must comply with these features creating different operational decisions on routing and scheduling problems for each one of the modes of operations.

- It is not a requisite for a ship to return to its origin. Especially in tramp shipping for a ship not to return to its origin is a common phenomenon as tramp shipping operates within the framework of a taxicab i.e. follows the available cargoes.

- The degree of uncertainty involved in shipping scheduling is higher than any other mode of transportation. Disruptions related with unforeseen events such as severe weather conditions are sources of uncertainty and delay beyond any proper planning. Incontrovertible, disruptions may occur also in other modes of transportation. However, the fact that in maritime transportation the voyage as a function of time is comparatively longer than other modes, hence the exposure of ships in uncertainties is much higher escalating the probability of vessels being out of schedule.

- Maritime transportation is characterized by a round the clock operation. Antithetically, in vehicles transportation operations during night are not taking action with the exception of the road transportation. Hence shipping schedule is blueprinting under the scheme that there are no idle times during the planning horizon. As a result the absence of planned idle times implies that unpredicted delays can not be absorbed and consequently operations in order to meet the pro-forma schedule in the case of delay have only the alternative to utilize the available idle time known in advance.

- Destinations of ships are not fixed. There is always the possibility of destinations to be changed during the voyage. This may happen in the tramp shipping where the ship follows the cargo or in the case that severe weather condition does not allow the ship to reach its destination and find another water corridor to deliver the cargo.

Moreover maritime transportation involves in the majority of the cases transportation of cargoes between different continents. Apparently, aviation can be appointed in this respect similar to maritime transportation. However aviation is mainly referred to the transportation of passenger. On the other hand maritime is mainly referred as freight transportation. Albeit airplanes may carry cargo in the form of packaged good, vessels are transporting also liquid cargoes and dry bulk cargoes. Thus the vessels design varies according to the cargo whilst in aviation aircrafts are either small or large in size. Correspondingly there is burden of designing and scheduling a fleet in maritime transportation rather than in aviation. In addition as we have already mentioned vessel are operating around the clock and thus continuously. In aviation passenger are prefer to flight early in the morning in intercontinental flights and during night in continental flights. However in both cases the planner has the ability to plan a buffer time as the aircraft stays idle during the night or day that can absorb delays while in shipping that is not possible.

Chapter IV - Operation Planning and the Concept of Robustness in Maritime transportation

This chapter commences with a brief overview of some of the aspects of the operational level of planning that have to be considered as threshold for of the generation of more quality schedules. In the following section the concept of robustness and the need of its incorporation in the different levels of planning is addressed. The last section of the chapter explicit discusses sources of disturbances that may curb the smooth functioning during the schedule execution in the maritime transportation system.

4.1 Operation Planning

The high level of uncertainty involved in the environment that shipping operations take place stimulates a dynamic rather than a static approach of the way planners must take decisions. Hence a range of factors on the nucleus of operational planning must be considered and configured on the scope of curbing exogenous disturbances that will turbulently affect any proper planning and scheduling. Towards this direction factors such as operational scheduling, environmental routing, and speed selection are discussed on the following section.

4.1.1 Problems in the level of Operational Scheduling

In principal, it is not feasible in the planning horizon of a ship to be scheduled for more than one voyage. Usually the above constraint corresponds to the condition where either the supply of the commodity to be transported or the demand for the commodity to be delivered in the target markets cannot be accurately estimated. Synchronous to the nature (usually agricultural products) of the commodity may be such that weather conditions can propagate demand and supply variations. Hence an uncertainty, positively correlated with such factors, proliferate the complexity involved in the process of creating robust shipping schedules. Within this framework we can derive from the real world an example such as the transportation of fruits to illustrate the above limitations. Usually the transportation of fruits varies due to the facts that are seasonal commodities while their high degree of deterioration imposes the deployment of refrigerated ships. However the shipping company is not aware in advance of the amount of the cargo, the exact time as well as the destinations that these fruits have to be shipped. On the contrary an adequate capacity must be scheduled for the specific season that the fruits are traded. Furthermore, the producer that hires the shipping company for the transportation of his production does not have any cargo that have to be shipped back to him and thus the ship to return in the loading port to reload with cargo. Instead the carrier owes, under a contract of affreightment that usually these actions are taking place, to assure available shipping capacity in the loading port.

Moreover, a number of parameters such as, inventory policy of the supplier, the time needed for the logistical function for the physical distribution of the product i.e the time needed for the product to be shipped from the producer to the supplier, demand projections as well as availability of the product are interrelated in any planning scheme. Therefore the carrier has to alter the planning horizon every week with the objective to minimize the costs related to the fleet subject to the above constraints. Normally when a single voyage is assigned to a ship, the ship has to call a specified number of ports for unloading the cargo. However in daily operations there are many cases in which the ship has to call more than one ports for unloading which means that the capacity of the ship as it has been planned in advance may not be the adequate one and thus the deployment of more ships for splitting the cargo may be needed.

By the same token, the above example demonstrates the uncertainty and complexity involved in the level of operational scheduling and some of the features that a planner has to take into account when scheduling a ship.

4.1.2 The concept of the Environmental Routing

The term of environmental routing, as it is referred in the literature and explicit analyzed in the paper by *Ronen (2004)* corresponds to the environmental conditions that a ship is exposed during its voyage from one point to the next. Usually such environmental condition can be delineated in characteristics as winds, waves, currents, tides that the body of water entails. Correspondingly the incorporation of such factors on decisions for selecting the optimal route may have a great impact on the efficient performance of the ship in terms of delays. In other words, as soon as these factors are taken into account in the design of the route that the ship must follow, the punctuality of the ship schedule or even more the opportunity of reducing the en route time and thus the cost can be achieved by mitigating or taking advantage of the effects that these factors involve. It will be also worthwhile to make a distinction between the environmental and weather routing. Generally these two terms are used in an interchangeably manner. Albeit the latter one can be considered as a subgroup of the environmental routing due to the fact that the weight at which tides, waves and winds can influence the selection of the optimal route may vary as a function of the weather condition that a ship has to encounter. In the following section we proceed with a more in depth analysis of the environmental routing components.

4.1.2.1 The impact of Waves in the Scheduling Process

Decisions on the selection of the optimal route are strongly correlated with the waves that a ship may accidentally meet during the voyage. Knowing the height as well as the direction of waves on a route it is feasible to estimate the proper speed that a ship has to attain in order to find the minimum transition time from an origin to a destination. The knowledge of such factors provides the ability to the planner to tackle with scheduling and routing problems with more flexibility and thus to improve the punctuality and reliability of the service provision. Albeit in the daily operation the height and the direction of the waves cannot remain static but they may vary over the time.

Towards this direction *Perakis and Papadakis (1989)* have discussed the problem of finding the minimum sailing time in a route taking into account the wave's height and direction. Based on their analysis given that the weather conditions remain static we can determine the height and direction of the waves as a function of the geographical coordinates x,y. Therefore under this assumption we can select-while design the route and the schedule of the ship-the routes that will enable the vessel to traverse a distance in the minimal possible time. However, in the daily operation the height and the direction of the waves cannot remain static but on the contrary they may vary over the time. It will be also worthwhile to mention that in spite of the fact that *Perakis and Papadakis* didn't succeed to provide sufficient estimation of any potential time savings through their study they proved that *"Is never optimal to wait for a storm, instead one should go ahead under the maximum permissible power setting".*

4.1.2.2 Ship Scheduling –Routing selection and Ocean Currents

A significant environmental variable on the selection of the optimal routing is the ocean currents. A related study of *Lo Mcord & Wallhas (1991)* show that the exploitation of the ocean currents can lead to a reduction of the annual fuel costs of the vessels up to 65-70 million dollars. In the daily operation scheme it is a common practice, as far it concern speed selection policies, the ship to speed up after its departure from the point of origin and after it has been assured that enough time has been saved in order to be on time in the destination point the ship slow down to reduce the fuel consumption. However if we assume that no environmental forces are occurring or even more that we are able to estimate the ocean currents among a number of routes and thus select the *"noncurrent route"* the application of the speed up and slow down strategy cannot be ratified as the optimal one. On the contrary *Lo Mcord & Wallhas(1991)*.proved that *"in the absence of environmental forces and given a fixed passage time, fuel consumption is minimized by traveling in a constant velocity".* Correspondingly the above statement implies that if we can predict the ocean currents of a route we can save a significant proportion of the fuel costs.

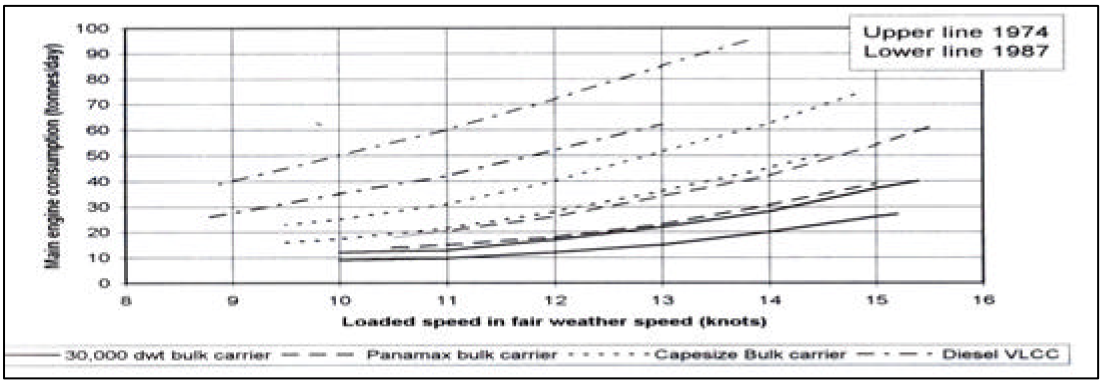
By the same token the above approach gives us the flexibility to generate more robust schedules and improve the reliability and punctuality of the service provision. As soon as the ship has to call at a number of different ports on global scale, the planner can design the network of the candidate calling ports in such way that the savings of the fuel costs gained among two ports given the absence of environmental forces to be exploited in the next pairs of ports. In other words, the planner has the flexibility to adjust the speed up to extend of the gained fuel savings from the exploitation of the ocean currents and thus to mitigate delays occurred form disturbances in the next voyage by speeding up. Thus by increasing the speed without affecting the costs the planner can ensure a more flexible reliable and punctual planning horizon.

However ocean currents, as the other components of the environmental routing, are not static but change over time indicating the complexity of the routing and scheduling decisions as well as the dynamic environment under which shipping operations are taking place.

4.1.3 Ship Scheduling and Speed Selection Issues

Fuel costs accounts for 50% of the total voyage costs. However, fuel consumption of a vessel is related to a number of factors such as the ship size, the laden condition (full or ballast), weather conditions, efficiency of the engines and speed. Among these factors the speed that the ship will attain during the voyage is the most important. Figure 4.1 displays the relationship between fuel consumption and speed for a number of different ship designs

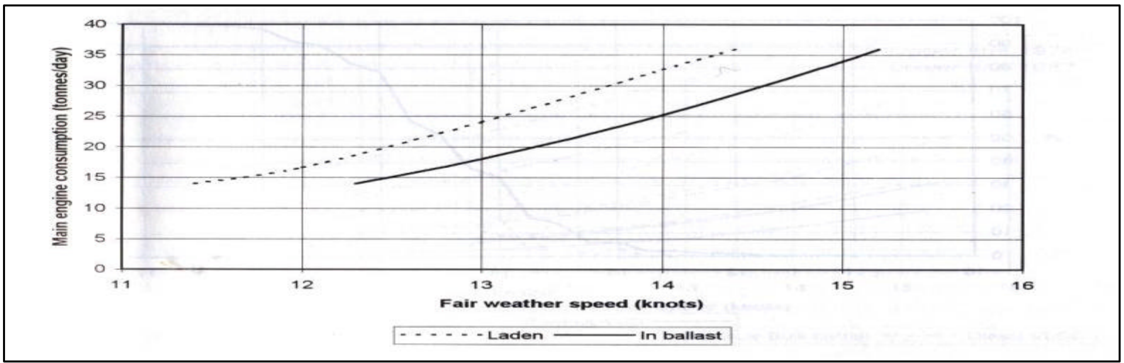
Figure 4.1 Relation Fuel Consumption & Speed between Different Vessels Design



Source: Waals (2005)

From figure 4.1-2, we can also infer that the relationship among the two variables is described by a non linear function. Further it has been approximately estimated that the fuel consumption of a vessel is proportional to the third power of the sailing speed (Figure 4.2) In other words, this can be translated to a saving up to 30% in the fuel consumption per time unit with a reduction of the vessels speed at about 10%.

Figure 4.2 Relation Fuel Consumption & Speed



Source: Waals (2005)

Hence, steaming at slower speed accompanied by the potential gains that such a policy incorporates, gives hope for higher profit margins. However, slower speed implies additional sailing days and possible loss of the cost reduction earned in sea due to delays that may occur. As a result, one should indicate a speed as an optimal one providing that this speed ensure the minimum total economic cost of a voyage. Moreover, assigning an optimal speed that the vessel has to attain during the voyage may not reflect the reality and lead to delays due to the uncertainty involved in shipping operations. Thus, recalculation of the optimal speed during the voyage in order the ship to meet the schedule for the remaining part may be required.

Therefore, implementing an optimal speed must not be consider as a variable depending only on the economic cost of a voyage but also as a function of the transit times. Specified dates that have been determine from the pro-forma schedule that a ship has to meet in the planning horizon for loading-unloading the cargoes limits the ability of the ship to maintain a constant velocity. As a consequence in avoidance of disrupting any existing schedule, deviations of optimal speed would have been more optimal providing the flexibility of adjusting the speed during the voyage, subject to the circumstances and uncertainties that the ship has to encounter. By not being on time, it may entail a big loss for the shipping company in terms of losing a significant number of customers due to the lack of the reliability or the need of deploying another ship.

For that a reason a trade off between optimal speed and reliability of the service provision exists. As the daily rate of the marine bunker fuel consumption of a vessel accounts for some thousands of dollars, allocating the optimum speed at which as ship has to sail it may lead to significant cost reductions and thus ensure the survival of the company especially during peaks of the oil prices. On the other hand, the challenge of the shipping companies to achieve high punctuality figures fulfilling not only their contracts but also attracting more customers insinuates the ability of the company to find alternatives for improving the reliability of the services and to avoid delays. On that quest, speed selection can be used from the shipping companies as a tool to improve the reliability but accompanied with the cost that such strategy incorporates.

4.3 The Concept of Robustness in the Planning Process of the Maritime Transportation System

In the daily shipping operations, there is an apodictic law regarding the deficiency of the shipping industry to successfully accomplish a high level of service provision in terms of reliability and punctuality within the time frame decided on the planning horizon. A number of uncertain factors that usually planners are unable to predict or they do not consider in the planning process strengthen this verity. Accordingly, in order to aggrandize the validity of shipping operations and limited the effect of uncertainty it may be worthwhile to reckon with the concept of robustness in the planning process. As we have described in Chapter II, in the literature modeling the majority of the models that have discussed the problem of routing and scheduling in maritime transportation have not taken into account this aspect.

In the following section a number of different factors that may affect the reliability of the service provision in all levels of planning in the shipping operations is presented.

4.3.1 Robustness Issues in the level of the Strategic Planning.

On a strategic planning level, decisions regarding the size and mix of the fleet constitute the main problem one has to confront. Nevertheless, a spectrum of uncertainties inherent to such decisions leads to a poorer quality of planning outcomes. Parameters associated with such uncertainties can be described as follow:

- The time frame under which these decisions are taking covers a long term period. Decisions on enlargements of the fleet or replacement of the assets are planned in long term span as the shipbuilding industry is a very complicated and time consuming manufacturing process from order to deliver. Moreover maritime industry is a volatile market characterized by cyclicality underlying the complexity involved in the fleet design in terms of the capacity as it is difficult one to forecast the exact time when the market will reach the peak or the low stage of the cycle. Similar it is very perplexed for the planner to estimate the size of the fleet in order to generate profits during peaks and to avoid losses when the market is low in terms of capacity utilization.

- The demand for shipping services derives from demand for trade. Generally shipping services are not used on their own but with conjunction with other products or services. It is thus a derived demand and is heavily depending on freight rates, cargo flows, trade, economic activity and the factors that affect them. Therefore estimating the demand for shipping services we have to consider all the direct demand functions of the products –services that the demand for shipping services is derived from.

- In correlation with the above argument the responsiveness of the supply of shipping services in demand changes is not prompt as a time lag between changes in demand and modification of the fleet size capacity exists.

- Another baffling aspect that the planner has to deal with is the decision of the shipping company to undertake a long term period contract of carrying specified quantities of cargoes, usually fairly distributed throughout the contracted period. However, there is a trade off between the decision of the company to undertake such contracts and to secure revenue per unit cargo handled or to operate in the spot market and design the fleet according to the market direction. Speculation of the future market performance is essential as if the market experiences a boost during the contracted period, the shipping company lacks the flexibility to deploy ships in the spot market and benefit from the soared freight rates to generate higher profit margins. Antithetically if the freight rates shift downwards, deploying the vessels under a long term contract will guarantee steady revenue and favorable capacity utilization unaffected from fluctuations in the level of the freight rates.

Thus, unpredictable fluctuations in both sides of the market forces underpin the difficulty of the planner to assess the marginal value of fleet decisions adjustments and allocate the optimum capacity. The disturbances inherently form such unpredictable fluctuations has a sound effect on scheduling and routing decision as the planning process accounts for a long term period and hence changes in the fleet size and mix may require cancellation or rescheduling of the predetermined schedule.

4.3.2 Operational and Tactical Planning and the Issue of Robustness

Robustness issues may be posed also on the operational and tactical level of the network design. The robustness of a maritime transportation system depends on the degree of the influence on the systems in a number of disturbances that may occur. The function of the system under difficult situations will determine its robustness. On the contrary a system that is vulnerable to external influences can easily be disoriented from the original plan leading to delays that can be propagated rapidly throughout the whole network. Towards to this direction a number of factors as sources of such delays must be considered in the planning process in order to isolate them and mitigate their influence. Among these factors we can address as the most important ones:

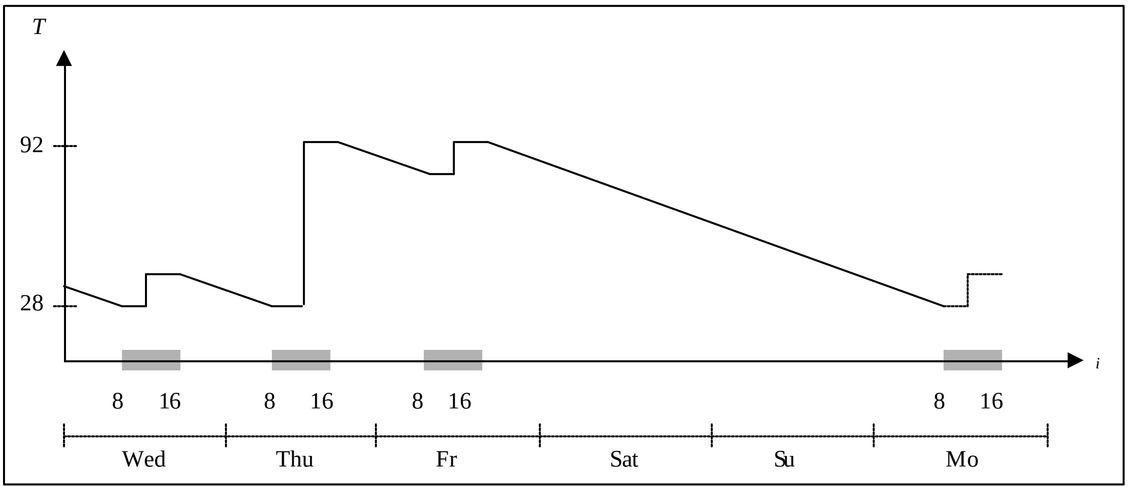
- Severe weather conditions that can have a direct impact on the scheduled sailing time a vessel needs from an origin to a destination.
- Port time delays originated mainly in the lack of port infrastructure and the conditions that prevailing during the visit period of the ship in the port.

Sailing in slow speed due to unforeseen weather conditions that a ship may encounter during the steaming period results in an out of schedule arrival in the destination point. However as a ship rotates through the interchange points of the geographical areas that have to be served, non scheduled arrival or departure in one point are causing delay propagation as the delay spreads throughout the whole network. Hence cancellation or rescheduling decisions may be required. However if in the planning horizon a buffer time has been considered to avoid uncertainties, the planned scheduled will not be disturbed under the condition that the buffer time is enough to absorb the time lost in sea or in port. On the contrary as ships involve high operating costs while a ship generates profit when it is at sea, usually the planners are shrink the buffer time to the minimum possible point to avoid any idleness of the ship.

Furthermore, in some ports, terminal operators are not operating during nights or in other cases cargo handling operations are not conducted during weekends. In other words failure of the ship to arrive on time and thus loss of the time slot agreed with the terminal operator for the stevedoring process implies that the ship will stay idle in the port. Whereas if we consider the above cargo handling operating hours of the terminals the time the ship will stay idle in the port may extend a day or even more several days.

Let’s consider for example the case where a vessel, as it has been determine form the schedule during its rotation, has to call a port i that operates under the above condition. The port is operating during the week from Monday to Friday while during the weekend the port remains closed. The shift for the cargo handling during the working days starts at 8:00am and ends at 16:00pm. The time needed for the ship to unload the cargo that has to be delivered in the port i, is estimated as function of the volume of the cargo and the cargo handling productivity the port can achieve to be 12 hours. Under this scheme if the vessel arrive in the port at 8:00 on Monday the discharging process to be completed needs 8 working hours during Monday and 4 working hours during Tuesday. However the total time that the ship has to stay in the port i and then continue to hit for the next port j is 28 hours. By the same token, the time the ship has to stay in port may experience an exponential growth if for example we consider the case where the vessel arrive in the port i on Thursday at 15:00 in the afternoon. In this situation the unloading process will start at 15:00pm until 16:00pm when the cargo handling operation will stop. The vessel must stay idle for 16 hours until Friday morning when the operation will start again. However, during Thursday and Friday the unloading process records 9 hours while 3 hours still remain in order the ship to be ready to hit for the port j. Thus the ship has to stay idle 64 hours, from Friday afternoon 16:00pm until Monday 8:00am when the operations starts again and at 11:00am on Monday when the cargo will be discharged the ship will be free to departure. Hence the total idle time will be 80 hours whereas adding the 12 hours time the ship needs to unload give us a total time spend in port i of 92 hours.

Figure 4.3: Time spent in port as a function of the arrival time



Source: Fagerholt (2002)

Figure 4.3 illustrate us the time the ship spends in the port i as a function of the time the ship arrives in the port. In the example we consider as the arrival time the time that the discharging process starts. From the graph, we can depict an interval between [28, 92] hours that the ship has to stay in port with 28 hours the minimum and 92 hours the maximum. However in the daily operation scheme shipping companies in order to avoid idleness during the weekend they may extend the cargo handling operation paying an extra fee to the terminal operator.

In addition, by considering unforeseen weather conditions, a vessel may encounter during the steaming time, the probability the ship staying idle longer than it has been estimated in the planning horizon increases.

Moreover another problem that may lead to disruption in the initial schedule is related with the inability of a fully loaded ship to enter in a port when the tide is low. On the contrary on high tide difficulties may occur in the short-sea shipping operations and inland waterways, as feeders and barges would not be in position to pass under a bridge creating significant delays and scheduling problems on that field of operations

As a result, the planner during the planning process has to consider a spectrum of different factors in order to improve the robustness of the schedule and increase the reliability and punctuality of the service provision for greater customer satisfaction. Towards this direction, meticulous examination of every any external factors that may disturb a schedule accompanied with a recovery strategy is essential. Therefore speed adjustments, increase of the loading rate, or rescheduling and cancellation may be required. However, changes in an already announced schedule in one vessel must diametrically not affect the schedule of other vessels. Instead, elaborated revision and modifications of the initial plan that will amplify the robustness of the planning process must be incorporated.

4.4 Main Sources of Delay in the Maritime Transportation System

Sequentially, a more comprehensive insight of the origin of the disturbances within the maritime transportation system or its environment that inhibit or significantly delay the mobility in maritime transportation in the following section is presented.

We can broadly categorize the delays into terminal delays that incur during the interval between the arrival and departure of a vessel to/from a port and in en route delays occurring during the sailing time from an origin to a destination. In both cases the main sources of disturbances than can provoke malfunctions and deviating conditions on the planning process of the maritime transportation are environmental constraints i.e. weather conditions as well as port condition and infrastructure constraints

The existence of adverse weather conditions such as rain, snow, winds, low visibility, tornado, hurricane, and thunderstorm that can affect the operations can result in significant weather-related disruption in shipping services provision. For example we can refer to a hurricane hammered the Suez Canal where winds blowing in a speed up to 40 knots/mile created major delays for 90 vessels waiting for the weather to calm down and cross the canal (*Containerization International*). Furthermore the hurricane *Glaudete* that hit ports in Texas where more than 15 vessels have been delayed whilst other heating to these ports asked to seek for alternatives routes *(Containerization International)*. Irrefutably an interaction between weather and maritime transportation exists. Delays can be caused because of the need of the vessel to reduce the sailing speed from the optimum speed to the safe speed while sailing with severe weather conditions. On the contrary, mitigation of the weather conditions impacts are limited due to the uncertainty involved as weather conditions are determined by natural dynamics whilst the use of past data for future predictions has a limited capacity that comes from the inability to factually quantify the past. However uncertainty exists also in the maritime system as the decision process consist of the involvement of many people with the interaction of atmospheric, surface and vessel condition parameters. Therefore, due to the interdependence between weather and maritime transportation, the planning process on the latter deals with a decision-making that is based on uncertainty not only on a prospective point of view but also with uncertainty on a retrospective point of view because we cannot easily evaluate the impact of one decision on the final outcome considering experience from the past.

Albeit weather conditions cannot be changed, planners have three alternatives to ameliorate the results of bad weather conditions during the decisions process. Thus they can treat the unexpected weather conditions by for example increasing speed on the next destination to keep up with the schedule, respond by rescheduling and cancellations on the initial plan and finally they can project additional buffer time beforehand, during the design of the schedule.

Zero delays in maritime transportation constitute an ideal situation whereas the current situation in terms of reliability and punctuality of the mode is saturated. Disruptions disturb the system behavior whereas further to the uncertainties originated from the weather conditions, port infrastructure and conditions constrains expand the range of the disturbances that may curb the smooth functioning of the planned itineraries of the shipping companies. Inasmuch as, uncertainty inherent with the lack of infrastructure or adverse port conditions can be described a follow:

Port Infrastructure. Inadequate port infrastructure in terms of maritime infrastructure access such as access channels, approximation zones, signaling (buoys, lights) sea defense (break waters) may increase the time that the ship needs to access the port. Under such conditions delays may occur as the maneuvering time increases either for safety matters or lack of navigation experience of the ship master and his inability to navigate efficient the vessel.

Lack of service provision. Ports are providing a wide range of services to the shipping companies that allow the cargo to reach its destination. Depending on the efficiency and quality of such services disturbances may occur regarding the schedule of a ship leading to important delays and inability of the vessel to hit for the next destination within the planning horizon. Such services can be summarized as follows:

- **Berthing services.** Efficient berth planning and schedule of the port operator in order to provide prompt berthing of the vessels upon arrival is essential for a shipping company on the endeavor to keep up with the schedule within the planning horizon. On antithesis insufficient berth planning system incapable to allocate berthing space to the vessel has as a result congestion in the port and increase in the time the vessel has to remain in port.
- **Pilotage**. Pilotage is a highly specialized service that requires special skills and knowledge of the port characteristics. Absence of qualified pilots to guide the ship into our out of the port fast and safe may cause delays in extend of the port time estimated in the planning horizon.

- **Tugging**. Tugging services may also constitute a source of delay. Delays may occur due to the fact that tugs needed to escort the ship in or out the port are not conveniently available to furnish the required service in the scheduled time as it has been schedule with the port operator or the private company that facilitates such services on behalf of the port.

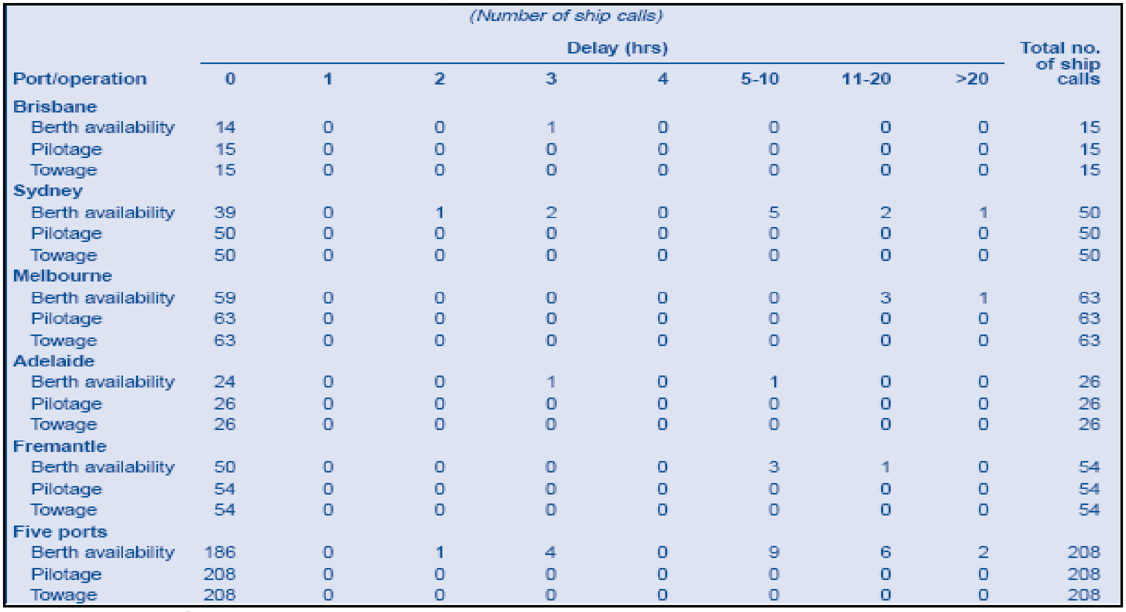
- **Cargo handling.** The major factors of delays in discharging cargoes are portainer crane breakdowns. Lack of the terminals operators to upgrade their equipments as some of them are more than 30 years old while lack of the appropriate and regular maintenance of the electro-mechanical parts are some of the reasons that may cause unpredictable delays. Moreover sometimes ports are placed in such way that in the case of misplacement of containers their location does not allow them to be discharged without having to move others cargoes. In addition other factors that may cause delays but in less significance level are high winds, transfer vehicles breakdowns, yard congestion. However delays may occur not only in the unloading process but also during the time the ship waits to be loaded and proceed to the next destination. Such delays are related with:

    - **Custom delays.** Bureaucratic structures, that the public governance under which most of the ports are operating, are usually unsuitable for the effective function of the customs in ports preventing the free flow of cargoes can be considered as a source of delay.
    - **Wrong working paper and typing errors** either form the shipper or the port authority may stonewall the loading/unloading process and lead to an unpredictable delay and an increase of the port time
    - **Terminal operators.** Apart from equipment breakdowns the productivity in a terminal may be influenced to the reluctance of the terminal operators to hire extra dock workers during peak periods that can have significant impacts on the efficient function of the terminal and thus to the port time a vessel spends in the port.
    - **EDI system breakdowns** that can prevent the flow of information and create a significant malfunction in the port operation.

Needless to say that either lack of port infrastructure or lack in services provision is significant factors for the creation of bottlenecks in ports. Genesis of delays due to heavily congested ports account for a large amount of hours that a ship has to remain trapped in the port, waiting to be served. In addition locks exist in many ports may also be considered as a definite factor for the propagation of bottlenecks. This can also be justified from many shipping companies intention to avoid during the planning process to incorporate ports with such geographical characteristics in the list of the candidate calling ports.

Regarding delays originated from inadequate port conditions/infrastructure and insufficient port services data compiled from *Waterline (1997)* in five ports in Australia are illustrated in the following table.

Table 4.4 Delays due to Port Service Operations



(Number of ship calls)

Port/operation	Delay (hrs) 0	1	2	3	4	5-10	11-20	>20	Total no. of ship calls
Brisbane									
Berth availability	14	0	0	1	0	0	0	0	15
Pilotage	15	0	0	0	0	0	0	0	15
Towage	15	0	0	0	0	0	0	0	15
Sydney									
Berth availability	39	0	1	2	0	5	2	1	50
Pilotage	50	0	0	0	0	0	0	0	50
Towage	50	0	0	0	0	0	0	0	50
Melbourne									
Berth availability	59	0	0	0	0	0	3	1	63
Pilotage	63	0	0	0	0	0	0	0	63
Towage	63	0	0	0	0	0	0	0	63
Adelaide									
Berth availability	24	0	0	1	0	1	0	0	26
Pilotage	26	0	0	0	0	0	0	0	26
Towage	26	0	0	0	0	0	0	0	26
Fremantle									
Berth availability	50	0	0	0	0	3	1	0	54
Pilotage	54	0	0	0	0	0	0	0	54
Towage	54	0	0	0	0	0	0	0	54
Five ports									
Berth availability	186	0	1	4	0	9	6	2	208
Pilotage	208	0	0	0	0	0	0	0	208
Towage	208	0	0	0	0	0	0	0	208

Source: Waterline 1997

From the above table we can infer that the shipping companies have to bear a delay caused from insufficiency in port infrastructure and port service provision that ranges from 1 up to 20 hours. According to these statistics congestion-berth availability can be ascribed as a dominant factor leading to delays varies from 5-20 hours. On a second level towage is also a significant source of delay whilst pilotage services have a less detrimental impact in terms of delays.

A strike in ports is a usual phenomenon and significant source of delay. Ports as mentioned above are usually operate under public administration. However the powerful labor unions in ports are always in conflict with the port authority, while unions are using strikes as an instrument to create pressures We can refer for example in the Durban port where a strike caused an average delay for the vessels up to 120 hours forcing the shipping companies to deploy supplementary ships in the SA route in order to confront with the expensive delays *(Containerization International)* Furthermore strikes in Canadian ports had significant impacts in vessels delay where they were unable to discharge perishable goods leading to major loss of cargoes. (*Containerization International)*. Nevertheless among these factors we must also add and with a less probability to occur delays from fire, earthquakes riots of the dock labor and etc.

Chapter V - Liner Shipping Scheduling System

In this chapter we concentrate on the Liner Shipping Scheduling and Routing System. By investigating first the environment under which liner shipping mode is operating, schedule and route planning issues are presented in the following section In sequence cost analysis of the route-schedule planning is discussed. All of the above aspects are addressed on the endeavor to facilitate the development of the simulation model on a liner shipping schedule in the following chapter.

5.1 Space of the Liner Shipping Operations.

In the growing shipping community, as consolidation continues in all channels of distribution, a new operational framework underpins the propensity for strategic choices relating to the way a carrier wants to maintain a global service. Such decisions are induced by substantial changes in the market environment under which liner shipping operates. The large adoption of the container, the context of world trade nowadays which is facilitated through the elimination of trade barriers as a result of the interaction between micro-macro economic and policy oriented factors, horizontal integration of the liner shipping companies via trade and operational agreements (liner conferences, consortia, alliances), constitutes some of the main driving forces of an ever-changing environment that the liner mode of operation is confronted with.

In this context, strategic decisions triggered by fierce competition utilize the fundamental tools to curb the demise of a company invigorating any potential growth and expansion of the market share. Accordingly, globalization, logistics integration and containerization have reshaped and redefined the shipping industry in terms of its functional role in the value chain. Whilst the provision of more sophisticated services for the sake of creating customer value along the supply chain is imperative. In the strife for greater efficiency and effectiveness in the liner shipping operations specialization, differentiation and diversification into inland transportation are generic tactics that are pursued to attain better positioning in the market. Moreover, the deployment of larger vessels and a more economic consumption of fuel in an endeavor to exploit the economies of scale to a further cost reduction subject to profitability, necessitates the design of new route networks to avoid the diseconomies of scale that mainly originate in malfunctions and deficiencies in port operations. In other words the planning process of the liner operation involves the design of more integrated route networks in terms of punctuality reliability and geographical coverage.

However, liner shipping networks in juxtaposition with other network industries are characterized by a number of technical features *(Veentsra 2002)*:

- Indivisibilities fountainhead from its factors of production i.e ships

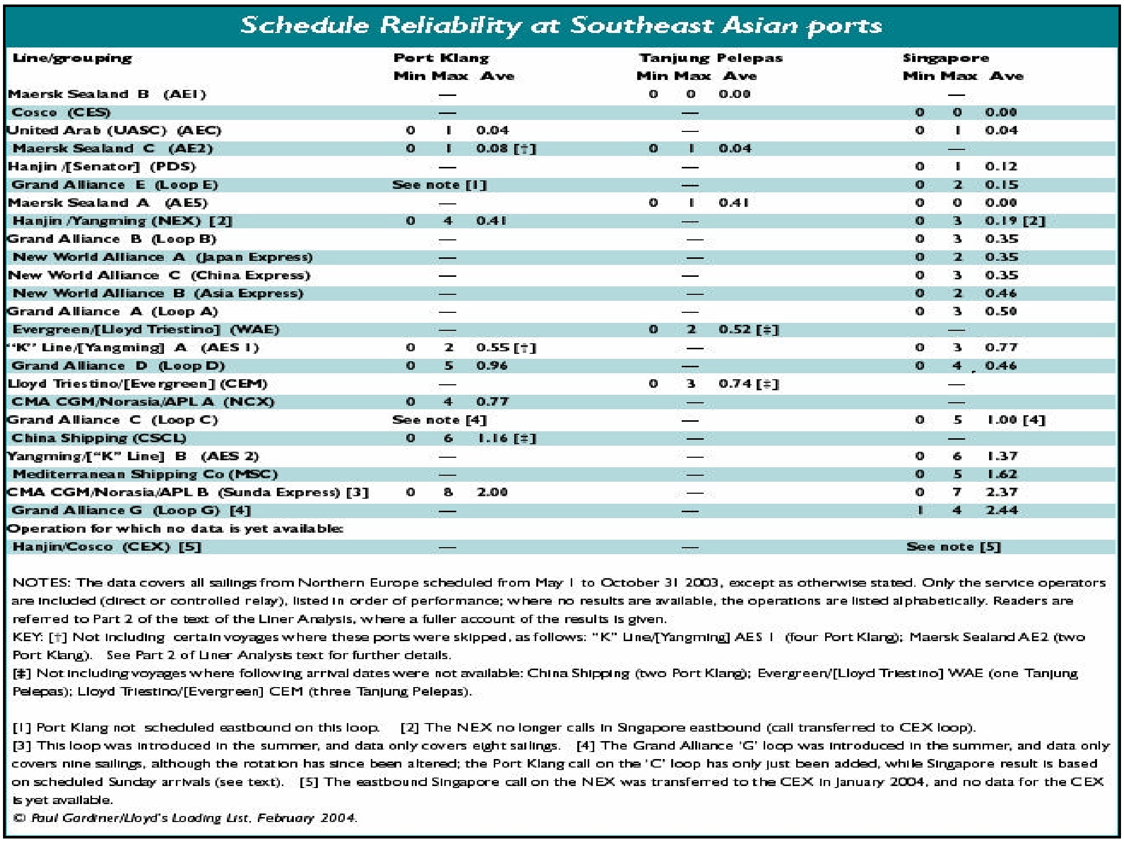
- Interconnectedness with the other parties involved in the production chain as a perquisite for its technical performance

- Advantages derived either from the suppliers or the users of the services are strongly correlated with the presence of other users/suppliers (network externalities).

According to the above technical features, the planning process of liner shipping operations calibrates the interplay of a number of different participants for achieving a favorable level of horizontal and vertical integration as the new era of liner operations are compelled by. Towards this direction, proper scheduling and routing yield an inherent drive for the restoration of confidence in terms of the robustness of the network design and consequently to obtain stability and integration amongst the respective parties. Furthermore, the concept of interconnectivity is introduced, considering that the enlargement of the network dimensions is facilitated by co-operation agreements among operators through alliances, in the virtue of the tendency to expand the geographic coverage of the services provision. However, interconnectivity, as a notion to nurture such an endeavor in conjunction with the need to overcome the physical capacity constraints that the design of such network are subject to, implies the formation of multiple sub-networks interconnected with each other where the user of one network are able to access to the facilities/services of another network. Hence, a higher degree of co-ordination among the nodes of the network i.e. ports, the users and the strings through which ports are connected is essential.

Therefore, decisions within the framework of the network regarding internal parameters such as route and candidate calling ports selection, optimum fleet deployment, rotation among the ports and scheduling of the fleet ought to align with a number of external factors such as other parties or terminal operators along with the logistic chain. Standardization may imply a tool to mitigate the complexity of the transportation system and improve the co-ordination among the parties involve. However, since liner shipping companies provide their services under fixed frequencies, fixed capacities as well as fixed berth time windows the vulnerability to malfunctions, mistakes and uncertainty involved in shipping operations, is much higher pursued by disruptions throughout the whole network. Through this approach the reliability of shipping schedule constitute a critical ingredient for the improvement of the network co-ordination. However this concept strays in the daily operations. Data compiled from *Containerization International* depicts the reliability of the shipping schedules of liner companies (Figure 5.1)

Figure 51 Schedule Reliability of Liner Shipping Companies



Schedule Reliability at Southeast Asian ports

Line/grouping	Port Klang			Tanjung Pelepas			Singapore		
	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
Maersk Sealand B (AE1)		—		0	0	0.00		—	
Cosco (CES)		—			—		0	0	0.00
United Arab (UASC) (AEC)	0	1	0.04		—		0	1	0.04
Maersk Sealand C (AE2)	0	1	0.08 [†]	0	1	0.04		—	
Hanjin /[Senator] (PDS)		—			—		0	1	0.12
Grand Alliance E (Loop E)	See note [1]				—		0	2	0.15
Maersk Sealand A (AE5)		—		0	1	0.41	0	0	0.00
Hanjin /Yangming (NEX) [2]	0	4	0.41		—		0	3	0.19 [2]
Grand Alliance B (Loop B)		—			—		0	3	0.35
New World Alliance A (Japan Express)		—			—		0	2	0.35
New World Alliance C (China Express)		—			—		0	3	0.35
New World Alliance B (Asia Express)		—			—		0	2	0.46
Grand Alliance A (Loop A)		—			—		0	3	0.50
Evergreen/[Lloyd Triestino] (WAE)		—		0	2	0.52 [‡]		—	
"K" Line/[Yangming] A (AES 1)	0	2	0.55 [†]		—		0	3	0.77
Grand Alliance D (Loop D)	0	5	0.96		—		0	4	0.46
Lloyd Triestino/[Evergreen] (CEM)		—		0	3	0.74 [‡]		—	
CMA CGM/Norasia/APL A (NCX)	0	4	0.77		—			—	
Grand Alliance C (Loop C)	See note [4]				—		0	5	1.00 [4]
China Shipping (CSCL)	0	6	1.16 [‡]		—			—	
Yangming/["K" Line] B (AES 2)		—			—		0	6	1.37
Mediterranean Shipping Co (MSC)		—			—		0	5	1.62
CMA CGM/Norasia/APL B (Sunda Express) [3]	0	8	2.00		—		0	7	2.37
Grand Alliance G (Loop G) [4]		—			—		1	4	2.44
Operation for which no data is yet available:									
Hanjin/Cosco (CEX) [5]		—			—		See note [5]		

NOTES: The data covers all sailings from Northern Europe scheduled from May 1 to October 31 2003, except as otherwise stated. Only the service operators are included (direct or controlled relay), listed in order of performance; where no results are available, the operations are listed alphabetically. Readers are referred to Part 2 of the text of the Liner Analysis, where a fuller account of the results is given.
KEY: [†] Not including certain voyages where these ports were skipped, as follows: "K" Line/[Yangming] AES 1 (four Port Klang); Maersk Sealand AE2 (two Port Klang). See Part 2 of Liner Analysis text for further details.
[‡] Not including voyages where following arrival dates were not available: China Shipping (two Port Klang); Evergreen/[Lloyd Triestino] WAE (one Tanjung Pelepas); Lloyd Triestino/[Evergreen] CEM (three Tanjung Pelepas).

[1] Port Klang not scheduled eastbound on this loop. [2] The NEX no longer calls in Singapore eastbound (call transferred to CEX loop).
[3] This loop was introduced in the summer, and data only covers eight sailings. [4] The Grand Alliance 'G' loop was introduced in the summer, and data only covers nine sailings, although the rotation has since been altered; the Port Klang call on the 'C' loop has only just been added, while Singapore result is based on scheduled Sunday arrivals (see text). [5] The eastbound Singapore call on the NEX was transferred to the CEX in January 2004, and no data for the CEX is yet available.
© Paul Gardiner/Lloyd's Loading List, February 2004.

Source: Containerization International

By the same token, avoidance of delays through more robust planning process in terms of scheduling of the fleet able to function adequately under deviating conditions within the liner shipping system and its environment will reassure a more effective and efficiency service provisions. Under this scheme, absence of delays that may occur due to the lack of efficacy in the planning process along with the inability of the planner to take into consideration disturbances and other external parameters. These parameters may direct or indirect influence the performance of the whole cycle of the service provision-especially on the level of door-to-door service as the new era of liner shipping stipulates- will prolong the reliability and improve the punctuality of the network. Through this notion liner shipping companies will not only to be able to fulfill their contracts but also to achieve a competitive advantage and better positioning in the market. Needless to say, the cogency of the liner shipping networks design to fulfill its expectations in terms of coherence and efficiency and in perception with the ability of the network to converge with the customer needs is fundamental for improving competitiveness, retention of the company's position and basis for attraction of new customers. Hence specialization, diversification, differentiation, standardization aligned with reliability, punctuality, robustness of the shipping schedules, are generic strategies for the nowadays liner shipping operations.

5.2 Issues in Liner shipping Scheduling & Routing System

The frame under which liner shipping operations are conducting, pose the provisions of services at regular intervals based on timetables advertised in advance among specified nodes of the network i.e. ports and to serve specific trade routes (connections of the network) either on a global, regional or local dimension *(Ilmer 2005*). Despite that, building up an extensive network to fulfill the globalization process and production fragmentation where the dispersion of manufacture and assembly of a product entails the movement of different components and parts between continents, implies the incurrence of high fixed costs due to the extensive infrastructure i.e. vessels, containers, agents that are required to facilitate such networks. Nevertheless the planning process of liner shipping in terms of routing and scheduling decisions must cautiously appraise all the variables that may influence and disturb its coherence as alterations of scheduling and routing decisions are not feasible during the short run process of operations.

5.2.1 Levels of the Liner Shipping Planning

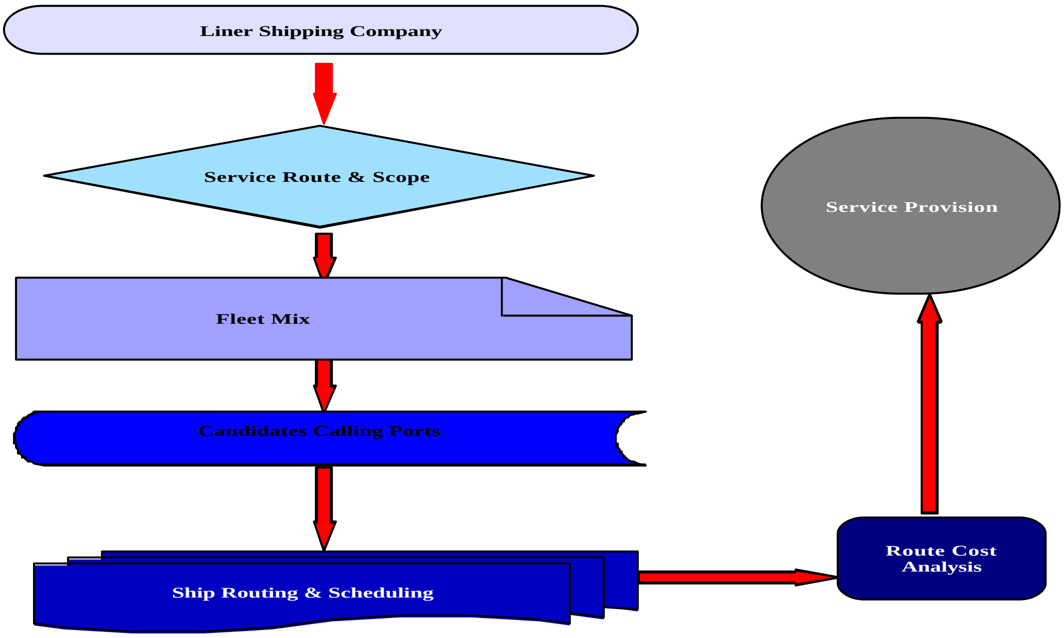
The course of action that liner shipping companies are adopting to plan their services encompass the interplay of a number of factors such as:

- the relationship of the company with its clients,
- market scanning and scrutiny for potential expansion,
- cost analysis of the service provision,
- selection of the trade route and
- Fleet scheduling (*Shih-Chan Ting (2003))*.

Among these functions, routing and scheduling decisions constitute the most elaborative process as it incorporates the amalgamation of the above elements to perform an outcome that will support and corroborate the company decisions on the endeavor to integrate, upgrade or update an ongoing service route as well as on the process to introduce a new one.

As we have mentioned above, liner shipping is one of the most competitive markets. Hence the blueprint of sophisticated analytical and systematic tools to be enhanced in the planning process of every liner shipping company is vital as a prerequisite for integrated operations. Correspondingly the design of the services provision of a liner can be analyzed and segregated into five sub-categories where the outcome of each one will determine the decisions for the next stage. Figure 5.2 illustrates the different levels that a liner has to encompass in the initiative of a trade route in order to converge with the requirements of the market as well as to reassure reliable and punctual services.

Figure 5.2 Liner Shipping Service Route & Scheduling



Source: Shih-Chan Ting (2003)

5.2.2 Issues in the Service Route and Scope of the Liner Shipping System.

On the outset of the introduction of a new liner shipping service the first concern of the company is to configure the scope and the type of the route. In the present climate, due to the intensive competition that liner shipping companies are confronting with, induces not only the provision of high quality services among the different trading regions but also it is vital of importance to achieve a high degree of fleet utilization. Ergo shipping companies with regard to such pressures developed new operating patterns namely multi route services. Through the application of pendulum, round the world, end-to end services as the context of the new service patterns that liner shipping companies adopted, enabled them to enhance the fleet productivity in terms of fleet deployment as well as slot utilization.

The general options *(Lim 1996)* and their main features open to a global carrier in regard of the way a planner will decide to design the service network can be summarized as follows:

End-to-End Services. The shipping company operates in the trade routes between two major continents. In the Transatlantic trade the vessel is scheduled to sail from USA to Europe and then back to USA whereas in the Transpacific the regions that the vessel is scheduled to sail are from Asia to US in the west coast and return back to Asia.

Pendulum Services. In a pendulum routing the carrier operates between three continents. The services offered cover all or some parts of the route which links the East Coast of U.S.A through Europe and Asia and then to West Coast of U.S.A returning back via the same route (*Keith).* One of the main advantages of operating in a pendulum routing is that the company can achieve significant savings in terms of the number of the ships needed to be deployed. However the deployment of Post Panamax vessels restricts the scope of the service provision either to North Atlantic or Transpacific routes as the transit through the Panama Canal is not possible. Moreover, although the company extends the geographical coverage whereas a larger number of ports can be called, the probability of delays and out of schedule arrivals may occur as the ship is exposed to disturbances due to the length of the voyage and the greater number of ports to be called.

Round the World Services. In principal round the world services involve the separation of the fleet into two parts. Each part of the fleet is assigned to follow a different string. A round the world service links North America, Europe, Asia, where a number of the vessels of the fleet offer services in the westbound while the rest on the eastbound. Trade imbalances are more possible to occur in such service patterns. Hence sailing frequency together with the capacity of the vessels in each one of the legs is adjusted according to the traffic volume. However port congestion may lead to significant disruptions in the pro-forma schedules *(Ilmer 2005*).

5.2.3 Liner Shipping Fleet Deployment

Once the scope of the service and also the type of the route has been decided the next level of the liner planning route and schedule process concern decisions on the size and the number of the ships to be deployed. Demand projections regarding the candidate trade routes and sailing frequency will determine the appropriate capacity and number of the vessels required. With regard to the available capacity that the company either owns or has chartered, this stage incorporates also decisions on what and how many ships to be built or chartered in the spot market in order the company to meet the demand requirements of the new market. Moreover cooperative agreements in liner shipping through alliances pose new criteria to take into consideration on fleet deployment decisions. Such criteria include slot exchange, slot chartering, vessel sharing, joint ownership/ or utilization of terminal equipment. *(Haralambides 2000)*

5.2.4 Factors for the Selection of Ports

A number of factors are interacting with each other in order the liner shipping company to select the ports that will call at. We can elucidate these factors as follows:

- **Geographical position:** Refers to the geographical position of the port with regard to the overseas market links as well as the accessibility in hinterland
- **Port infrastructure:** Draught restrictions, port access, berth length
- **Quality of Service Provision:** Terminal productivity, absence of congestion, nautical services such as pilotage, mooring, port working hours.

- **Costs:** Cost of maritime-nautical services, port dues and taxes, cargo handling costs.*(Ilmer 2005)*

5.3 Liner Shipping Scheduling System & Cost Analysis of the Route

In principal the cost structure of shipping company can be perceived into two major categories: fixed and variable costs while these two sections can be breakdown into capital, operating, commercial, maritime, direct and indirect costs (*UNCTAD 2004)*. In order to conduct a cost analysis in shipping we can divide the costs into three main categories:

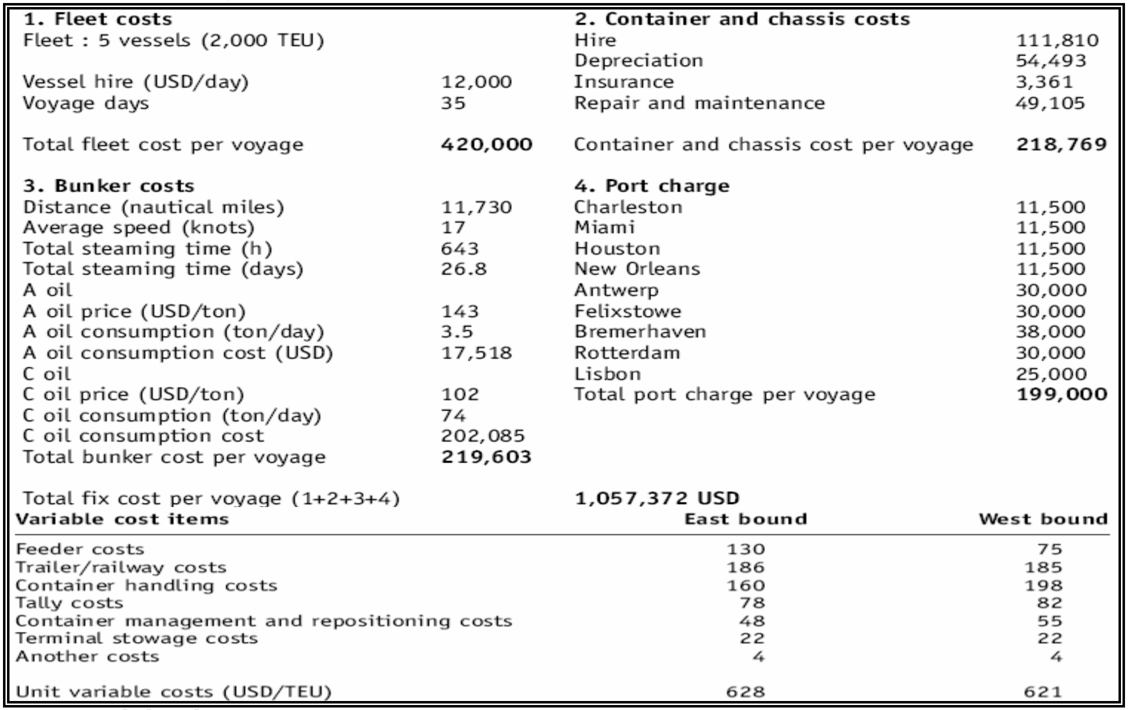
- **Voyage cots**: Variable costs which change directly with the specific voyage subject to fuel consumption, oil prices, port dues, cargo handling.
- **Operating costs**: Variable costs that are normally related with the daily operation of the ship regarding crew costs, insurance costs, maintenance, and management costs.
- **Capital costs**: Fixed costs associated with the capital invested for the acquisition of ship either from the new or second hand market in conjunction with interest rate and depreciation. *(Haralambides 2005)*.

However when we referred to liner shipping and especially on the cost analysis of a route the above index of costs has a different profile. The main characteristic of liner shipping cost structure is the high portion of invariant costs. Once the route, the fleet mix, the ports, the schedule of the ship has been defined upon during the planning process operating costs tend to lay on the boundary of fixed costs. Accordingly crew costs, maintenance, insurance costs, management costs due to the nature of scheduled liner shipping services are becoming constant in the short run.

Moreover considering that bunkering costs and fuel consumption can be fairly estimated on a fixed itinerary along with port and canal dues, voyage costs variations are associated with the volume of the cargo to be shipped. Thus, feeder cots, stowage costs, cargo handling costs are those to be confined and determine the voyage costs. However due to the trade imbalances in some routes whereas transportation of empty containers for repositioning can result in a fully capacity utilization of the vessel, the above costs subject to the cargo volume may also become fixed.

Figure 5.3 illustrates the variable and fixed costs to be considered in a cost route analysis.

Figure 5.3 Fixed and Variable Cost in Cost Route Analysis



1. Fleet costs		**2. Container and chassis costs**	
Fleet : 5 vessels (2,000 TEU)		Hire	111,810
		Depreciation	54,493
Vessel hire (USD/day)	12,000	Insurance	3,361
Voyage days	35	Repair and maintenance	49,105
Total fleet cost per voyage	**420,000**	Container and chassis cost per voyage	**218,769**
3. Bunker costs		**4. Port charge**	
Distance (nautical miles)	11,730	Charleston	11,500
Average speed (knots)	17	Miami	11,500
Total steaming time (h)	643	Houston	11,500
Total steaming time (days)	26.8	New Orleans	11,500
A oil		Antwerp	30,000
A oil price (USD/ton)	143	Felixstowe	30,000
A oil consumption (ton/day)	3.5	Bremerhaven	38,000
A oil consumption cost (USD)	17,518	Rotterdam	30,000
C oil		Lisbon	25,000
C oil price (USD/ton)	102	Total port charge per voyage	**199,000**
C oil consumption (ton/day)	74		
C oil consumption cost	202,085		
Total bunker cost per voyage	**219,603**		
Total fix cost per voyage (1+2+3+4)		**1,057,372 USD**	

Variable cost items	**East bound**	**West bound**
Feeder costs	130	75
Trailer/railway costs	186	185
Container handling costs	160	198
Tally costs	78	82
Container management and repositioning costs	48	55
Terminal stowage costs	22	22
Another costs	4	4
Unit variable costs (USD/TEU)	628	621

Source: Shih-Chan Ting (2003)

Further a cost that we have to comprise corresponds to an amount that the company has to bear in accordance with non on schedule arrivals in the selected ports. As vessels follow fixed itineraries published in advance, the berth time windows provided by the terminal operator have also been scheduled in compliance with the vessel schedule. Therefore delay penalty fees may be embodied in the voyage costs in the case where the vessel fails to meet the time slot agreed with the time operator. Also surcharges may incur if the actual arrival time of the vessel prolongs the initial fixed time for the provision of maritime services such as pilotage and mooring. Thus a surplus of charges will increase the beforehand costs of the route that the shipping company projected during the planning process. Penalty fees are also probably to ensue when shipper have posed time clauses of the delivered cargo.

In addition, another cost to be considered is also related with the occurrence of unforeseen events that will impede the smooth function of the fixed schedule. However its nature is more stochastic rather than deterministic. The inability of the shipping company to perform its required functions due to the lack of robustness in the planning horizon will make the schedule to deviate from its initial course or even worst to make it infeasible. As a result a significant cost in terms of customer dissatisfaction may occur. Slow transit times and absence of means to mitigate the uncertainties generate time variability through the supply chain. Thus customer reliance on the shipping companies is fading and hence they have to carry large inventory due to the long lead times. However such cost for the shipping company cannot be quantified at least in the short time. On the contrary in the long run unreliable services are translated into customer loss.

Therefore a new element must be introduced in the design of the cost structure of a route which can be described as the value of time.

5.3.1 Time and its Value

The era where price was the main criterion for the assessment of the liner shipping service performance does not exist anymore. On the contrary recent technological developments in other transportation modes as well as the introduction of new concepts in the whole cycle of the commodities flow have emerged a high competitive environment within the transportation industry. Just in time deliveries and supply chain management applications stimulated by the customer needs for a wider array of global and integrated services have redefine the criteria either on an economic or commercial basis for the demand of liner shipping services. The inception of such tools makes imperative the synchronization of all the parties involved as the insufficient performance of one link of the chain directly affect all the others. Hence the necessity of the liner shipping companies to achieve a more agile structure able to respond to changes in customers preferences is essential.

However a critical issue permeating the above changes in the liner shipping environment refers to the question what is the value of time. As the efficient performance of liner shipping services through the supply chain can be assessed as a function of time the key question is in what extend the shipping company can bear an additional cost for the improvement of its reliability. Through a number of alternatives such as steaming in a higher speed or reducing the nodes of the network, liner shipping companies have to evaluate the trade off between the time profit its one of the these actions is pursued by versus the costs of arriving at ports with delays and disrupting the whole cycle of the cargoes flow. Presumably the repercussions in the operational and voyage costs of the decision to follow one of the above strategies can be fairly estimated. On antithesis an insurmountable problem refers on the forecast of the customer willingness to pay for securing a reliable service. In other words what is the function that can estimate the value of time in terms of reliability and punctuality in order the company be able to deduct it in the price of the services offered?

Correspondingly a balance between the cost of employing more robust networks and shipping schedules as well as the estimation of customer’s inventory costs has to be struck. Under this notion the company will be able to asses the value of time and thus determine the margin to improve the reliability of its service on a justified price that the customers are willing to pay.

Chapter VI.-.Model Formulation

Having laid the ground through the analysis that has been conducted in the previous chapters on scheduling related issues, in this chapter we proceed to the model formulation on a liner shipping schedule.

6.1 Analysis of the Problem Space and Considerations for the Model Formulation

Liner shipping mode of operations presents an interesting case of transportation system. Similar to the public transportation fixed itineraries published in advance underline its nature. Moreover a number of ports have to be called at in order to ensure that the containership have achieved a high portion of capacity utilization as an indicator to determine the profit of the company in conjunction with the costs. At the calling ports in the frame of the stevedoring process the vessel will load/unload the containers and will hit for the next ports until the ship complete a whole rotation of the designed route and continue for the next rotation. Under this notion the fixed itinerary will determine the arrival times in its destination. Given these information the company will contract with the terminal operators the time slot for the ship to berth and a productivity ratio for the stevedoring process to be achieved.

However extensions in the network and the necessity for a vessel in a one rotation to deal with more ports as a prerequisite to tackle the high competitive environment within the liner shipping industry requires an exhaustive scheduling planning. The most elaborative part of such planning process is to make a solid schedule taking into considerations external disturbances that may curb the smooth function of the schedule. Severe weather condition that the ship may encounter, congestion in the calling port, mechanical breakdowns, lack of infrastructure in the calling ports that a vessel is exposed to during a journey will provoke significant delays and failure of the ship to meet the pro-forma schedule.

As we have already mentioned selecting a solid route encompass the interrelation of a number of factors such as the potential capacity utilization of the ship, the cost of the route as well as the potential profits. However another concept to take into consideration refers to the robustness of the schedule. The potential profits for a company increase as the capacity utilization increases or with the ability of the vessel to visit more ports in one rotation as the probability of sailing fully loaded becomes higher. On the contrary if the robustness of the schedule is low the shipping company may undergo revenue losses.

Hence, it is imperative for the shipping company to explore all the alternatives to be exploited into the quest of constructing quality schedules. Thus a satisfactory operational level can be achieved leading to a high level of customer's satisfaction and reduce the cost of the route. The robustness of a shipping schedule can be considered as an indicating measurement to evaluate the performance of the schedule and thus the performance of the service provision of the company. A robust planning gives the ability of the shipping company to cope with unanticipated disturbances during the daily operations. Correspondingly, operational deviations interpreted as alterations of the original shipping schedule may be required.

As a result, increase of speed further to the predetermine one in the planning process enables the vessel to reduce the time needed to cover a distance. Moreover increase of the cargo handling rate to confront with the port time delays and he decision of skipping a port in correlation with the time profit that the vessel will save for the consecutive ports are some of the generic strategies that we can map in order to furnish the endeavor for the generation of more robust shipping schedules.

However the decision to undertake its one of the above actions is pursued by a respective cost. This cost can be attributed as an additional cost above the cost that had been determine in the beforehand cost analysis of the route. By the same token additional knots in the steaming speed induce an upward shift of the fuel consumption. Taking the decision of omitting a port in the occurrence of delays has also a sound effect in the costs of the company. Alike, penalties fees posed by the customers for non delivery of the cargo as well as the cost for the terminal operator without utilizing its services in the case where the de jure cancellation of the reserved slot extends the agreed time. Parallel skipping a port in order to improve the punctuality of the service provision for a customer equilibrates with an analogous marketing cost delineated by the loss of other prospective customers

Conceptually, the liner shipping transportation system comprise the synthesis of a network where a number of factors are interacting with each other while entities attached to this network are abiding entities that follow the routes adhere to an array of rules that will decode their behavior. Vessels constitute these entities carrying out the fixed published in advance itineraries. Under this scheme developing and designing a simulation model to examine the behavior and evaluate the functioning of such a system is the main concern of the thesis.

All the characteristics of the liner shipping transportation system described above, furnish the difficulty in the endeavor to understand and specify the problem. Under this scheme in order to deliver a valid identification of the space that labels the problem as well as methodically model it a number of considerations have to be taken into account:

- Identification of the events and the factors that affect a liner shipping schedule.
- Acclimatization with the different parties involved and their influence in the functioning and execution of the liner shipping schedule.
- Instruments to convey practicable and viable interventions.
- Elements to evaluate such interventions (Table 6.1)

Table 6.1 Modeling Considerations

Factors	Parties	Interventions
Weather Problems	Planner	Increase Speed
Port Problems	Shipping Company	Omit a Port
Routes	Terminal Operators	Increase Cargo Handling Rate
Itineraries	Customers	
Arrival/Departure Times		
Ship Parameters		
Loading /Unloading Time		

Considering the features portrayed above a "what if" simulation model is developed. The employment of a simulation model in the context of "what if" analysis aims to generate scientifically and statistically based evidence that will deliver a supplementary real time decision tool for the scheduling process through a scenario evaluation approach. Apparently due the dynamic environment that the liner shipping mode operates as well as due to the nature of the problem the interaction of many factors cannot be accommodated in the model. Accordingly it is imperative to introduce a number of assumptions to facilitate our approach.

6.2 Assumptions Made and Simulation Events.

The model is formulated on the foundation of the following assumptions:

1. During the planning horizon ships are following the same sequence of the candidate calling ports.
2. Berth time windows available in each candidate port are provided by the terminal operator.
3. Vessel speed is determined by the design and the characteristics of the vessel and can be adjusted to a certain extend
4. Volumes of cargo for loading/unloading in each port are predetermined.
5. Loading/unloading time is depending on the cargo handling productivity of the terminal operator.
6. Cargo handling productivity at each port can be fairly estimated. Cargo handling productivity it is also adjustable to a certain extend depending on carrier's request.
7. We do not take into account the influence of weather forecasts in the vessel's departure from a port. A ship will depart from the port without being influenced from the weather forecast in the case where bad weather conditions are predicted. Therefore the ship will not remain idle in the port waiting for better weather forecast.
8. Buffer time has been predetermined in the planning horizon.
9. In the case where the vessel does not call a port the containers to be discharged are transferred to the consecutive port where the terminal assign extra cranes in order the port in time in the consecutive port not to extend to the one that has been predetermined in the planning horizon. The containers are transferred to another vessel of the fleet in order to reach their destination.

10. Terminal operators provide a slot for the vessel to berth independently of the amount of the vessel's delay in the arrival time.

6.2.1 Problem Formulation

We assume a number of candidate calling ports i where $i = 1,2,3\ldots\ldots n$. The journey of the ship from the initial port to its final destination is divided into stages. The rotation of the vessel between two ports is consisting of two stages:

- **Sailing Time:** (*The time that the ship needs to sail from port i to port j, from the departure port i to the arrival port j*). Sailing time describes the section of the journey where the ship is sailing from port i to port j with either its predetermined speed or maximum speed. The time that ship has to sail from one port to the other is a function of the sailing speed the distance and the bad weather condition that the ship may encounter

- **Port Time** : (*The time that the ship spends in the port from its arrival time until the departure).* Port time describes the section of the journey where the ship arrives in the port and stays until the ship will departure for the next destination. This sections is a function of the cargo handling productivity, the cargo of the volume to be loaded/unloaded and a port conditions delay that may increase the port time

For the first section the variables that will determine the size of the sailing time are as follows:

1. **Sailing Time (ST):** The variables to determine the Sailing time between Port i and Port j are:

- **Speed (S)**, the speed of the ship depending on its design and S ? [min,max] (*unit knots/hour*).
- **Distance (D),** the distance between two pairs of ports. *(unit: Nautical Miles)*
- **Weather Condition Delay (W)**, the additional time that the ship needs to sail from port i to port j as an increase in the initial time due to weather conditions. In principal a ship may be affected above a force wind 6 and even the vessel attaining the same speed due to the environmental forces an additional time is needed for the completion of the voyage between Port i to Port j. We describe this additional time as Weather Condition Delay. We also include in this additional time delays that may occur due to mechanical problems or other external disturbances during the journey. However as weather conditions delays affect in a higher degree the time the vessel needs to sail from Port i to Port j we donate such delays as *Weather Conditions Delays.* *(unit: Hours*)

Hence the Sailing Time will be equal to:

$$SailingTime_{i,j} = \left(Distance_{i,j} / Speed_{i,j}\right) + WeatherConditionsDelay_{i.j}$$

$$ST_{i,j} = (D_{i,j} / S_{i,j}) + W_{i,j}$$

Therefore if for example the distance between Port i and Port j is 500 nautical miles and the vessels speed is 20 Knots/hour, the vessel to cover this distance needs a nominal time of:

500/20=25 hours

Ergo, if the vessel will start its journey from Port i at time 0 the arrival time of the vessel in Port j will be at the 25 hour. However due to weather conditions or other delays an additional time is needed in order the vessel to cover the distance. If the additional time is for example W=2 hours then the ship will arrive at the Port j at time:

25+2=27 hour

Henceforth the time that the ship will cover the distance sailing at a speed S determined by the schedule and an additional time because of delays that may occur will give us the actual arrival time of the ship.

2. **Time in Port (TP):** The variable that will determine the Port Time are:

- **Cargo handling Productivity (C):** The productivity that the terminal operator can achieve in the calling Port j expressed by *moves/hour.*
- **Cargo Volume (V):** The volume of the cargo that the ship has to load unload in the calling Port j *(unit TEU)*
- **Port Time Delay (P):** Delays that may occur during the time that the vessel spends in the port and will increase that time.*(unit hours)*

Henceforth the Port Time in the Port j will be equal to:

Port Time j= (Cargo Volume j/Cargo handling Productivity j)+ Port Time Delay j

$$TP_j = (V_j / C_j) + P_j$$

Let's assume for example that the ship arrives in the Port j at time 0 while the cargo volume to be unloaded in the Port j is 600 TEUs. The cargo handling productivity that the terminal operator can achieve is 60moves/hour. Then the time that the ship needs to unload is

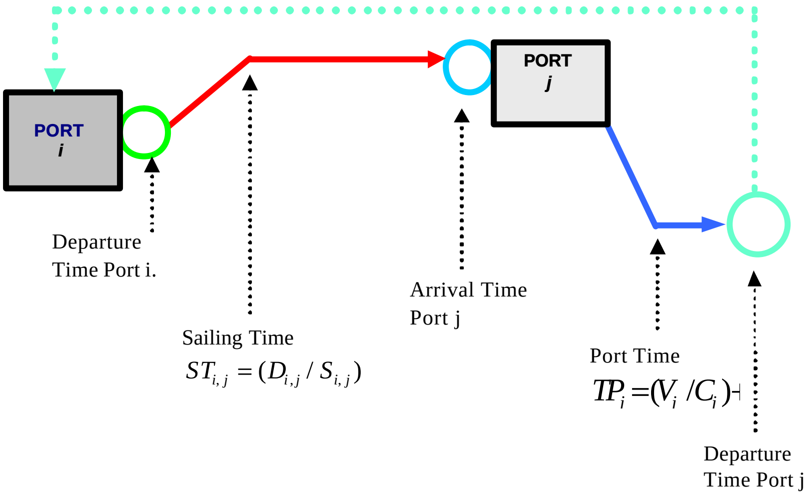
600/60=10 hours

However if delays occur during the process from the arrival time of the vessel until the time that the vessel will be ready to hit for the next port implies that the vessel needs to stay more time in the port j. Let's present this time as Pj (Port Time Delay in Port j) and assume that the Pj is equal to 2 hours. Hence the time that the vessel has to stay in the port is:

TPj=10+2=12

As a result the vessel will be ready to hit for the next port (actual departure time) at 12 hour instead of the hour 10 which is the nominal time estimated in the planning process. The sequence of events in the voyage of a vessel between Port i and the Port j until the departure of the vessel for the next destination i.e. Sailing Time, Voyage Time as we have described them above can be portrayed as follow (Figure 6.1)

Figure 6.1 Simulation Events



6.2.2 Cost Penalty Function

In an endeavor to look through all the possible alternatives to construct more robust shipping schedules as well as to evaluate them we introduce a *Cost Penalty Function*. This cost penalty function is modeled as a tool to evaluate the decisions of the planner either to omit a port or to increase the nominal speed to the extend that is feasible in order to avoid delays that may occur during the voyage of the ship from an origin to a destination. Also it can be considered as an additional cost that a shipping company has to bear in the case of alterations in the fixed-planned schedule. One should expect that the cost penalty function can estimate the exact cost. However total costs are not related only with one stage of the vessel‘s voyage. Hence the calculation of the *Cost Penalty Function* in one stage for which alterations in the fixed schedule have been undertaken cannot give us the total cost. Instead costs are related with the whole activity of the vessel and also with the period that is remaining for the vessel to complete its rotation through the candidate calling ports. Therefore our vision is not to construct a tool in the form of a function s that can estimate the accurate costs and penalties of schedule alterations in a journey rather than to develop a tool that will help us to evaluate the profile of any decision alternative in order to construct more robust shipping schedule.

Therefore in our approach the components of such *Cost Penalty Function* that we are taking into account are as follows:

Marketing Penalty Cost Factor: We introduce a marketing penalty cost factor that varies between [0, 1]. This factor reflects the significance of the decision not calling a port. Considering the relationship management of a company there are some customers that are more important than others for a number of reasons such as personal-long term relationships, marketing factors etc. Moreover some markets are more weightier in comparison with others either because a market is new for the shipping company as it has just penetrated and wants to establish a good name in the market or for other competition reasons. Hence canceling a port due to delays in a voyage may have greater impact rather than another one in the rotation of the ship. Thus assigning a marketing penalty factor equal to 1 the planner shows the significance of the customer whilst in the case where this factor is equal to 0 reflects the non significance of the customer and parallel shows also the potentiality of not calling a port to serve this customer. The weight that the planner will assign to each port depends on his perception of the market. However a way to quantify such a factor apart from the company's perception for its customers will be also the load factor and marketing research outcomes. Depending on the load factor the company can construct an index indicating the share of each customer in the company expressed in percentage. In sequence through marketing research can clarify the importance of each customer from 0 to 1.Multiply those two factors we can derive an amount lying between [0, 1] describing the marketing penalty factor not serving a customer and thus not a calling a port where the customer is located to. The introduction of such factor aims to provide a more general profile to the cost penalty function as well as to make it more flexible.

Cost of omitting a port: We consider as "Cost of Omitting a Port" all the costs that are related with the action of not a calling a port. Such costs include the penalties that the company has to bear as it is liable for untimely deliveries of cargo, according to the claims the customer can assert as it has been agreed in the contract upon. The weight of such cost in the *Cost Penalty Function* is determined by the contracts of the company with each individual customer with respect to the agreed stipulated time limitation for the delivery of the cargo. Another cost also to be considered when canceling a port refers to the cost of unloading the containers in another consecutive port as well as assigning barges in order the containers to reach their destination.

Cost Savings of Omitting a Port: The pro-forma schedule as it has been formulated in the planning process imposes the vessel to call a number of consecutive ports. However alterations of the original schedule regarding the decision not to call a port imply a portion of cost savings. Such costs savings mainly refer to the avoidance of the port charges as well as the cost savings in fuel consumption. Correspondingly the vessel will hit directly to the port that is consecutive to the skipped port. Therefore the distance between the last in call port and the port that is consecutive to the skipped one is shorter. Hence a saving in the fuel consumption is occurring in comparison with the fuels costs determined in the planning process. The level of the savings costs in the *Cost Penalty Function* is a function of the individual port charges the vessel will not call and the fuel consumption savings.

Cost of Increasing the Nominal Speed: Similarly in the planning process one of the most important components of the route cost analysis is the fuel consumption of the vessel as a function of the speed that the vessel will attain during its rotation through the candidate calling ports. Alterations in the nominal speed directly implies increases in the fuel consumption and hence in the costs of the company. The weight of these costs in the *Cost Penalty Function* depends on the marine fuel prices, the laden condition of the ship ballast or full, the ship type and design. The design of the ship as well as the efficiency of the main engine is essential. Depending on the age of the ship it is evident that newly build ship can perform relatively more economically in terms of fuel consumption in high speed due to the efficiency of their engines. On the contrary in old buildings the fuel consumption in high speeds increases in a higher rate.

Cost of Increasing the Cargo Handling Rate: Such costs are referring to alterations in the cargo handling productivity of the terminal operator with the one agreed in the planning process. Thus the assign of an extra crane to speed up the stevedoring process is pursued by a respective cost. The portion of the cost to assign an extra(s) crane(s) in the *Cost Penalty Function* varies depending on the individual terminal operator and the way the terminal is pricing the utilization of its equipment by the vessel. (In our case we do not examine the case of increasing the cargo handling productivity however we have included it as an alternative for upgrading the robustness of a schedule)

Penalty Fees: Penalties posed by the terminal operator or any other party responsible for the provision of maritime services to the vessel either to berth or departure from the candidate calling port. Usually a time interval is assigned that the vessel has to abide for its arrival time. In the case of non-adherence to the time limit the shipping company has to bear a surcharge contingent to the amount of delays. In order to address an example of such costs we can refer to the Port Of Vigo in Spain for the provision of mooring services. In the incidence of a delayed arrival of the vessel rather than the agreed time for the provision of mooring services a surcharge is adding to the initial fee. Thus according to Port of Vigo mooring rates, there is no surcharge for the first 30 minutes while when the delay of the vessel lies between [30min,1hour] a 20% surplus of the initial tariff is charged and when the delays lies between [1,2] hours a 50% tariff surplus is charged.

According to the above parameters/components of additional costs as well as cost savings of the company's decision to alter the original schedule in order to mitigate the occurrence of delays the *Cost Penalty Function* that we address as an evaluate indicator of such alterations is formulated as follows:

$$CPF_i = MPF_i \times (COP_i - CSO_i) + PF_i + CS_{i,j} + CHR_i$$

where:

CPFi= Cost Penalty Function
PFi=Marketing Penalty Factor Port i
COPi=Cost Of Omitting Port i
CSOi=Cost Savings of Omitting Port i
PFi=Penalty Fees in Port i
CSi,j=Cost of Increase the Speed during the voyage from Port i to Port j
CHRi=Cost of Cargo Handling Rate Increase in Port i

6.3 Simulation Process

In order to achieve our goal i.e. the generation of more robust shipping schedules we develop a simulation model. Through this approach we succeed to model a system as it evolves over time by representation in which the state variable are change instantaneously over time (*Averill M. Law 2000)*. In other words regarding our study we can infer that we develop a simulation model through which we can examine the operation of the liner shipping scheduling system over time. Simulation as a quantitative approach entails the generation of an artificial history of the liner shipping scheduling system and through the observation of that artificial history our objective is to draw and derive logical inferences vis-a-vis to the operational characteristics of the real liner shipping scheduling system. Moreover for the construction of the model we utilize Excel spreadsheets. A simulation process driven by the utilization of spreadsheets allows the easiness for the conceptual format of the problem. Whilst enables more users to tinker with the inputs of the model and explore alternatives through the "what if" approach in order to facilitate the process of finding a solution in a problem.

Accordingly, with the adaptation of a simulation approach we module the liner shipping schedule model as a sequence of events. Therefore in order to model such a system we have to identify the processes, the constant parameters and the probability inputs that these events involve.

By the same token in a liner shipping schedule the voyage constitutes the principal process in order the vessel to execute a whole rotation and head directly for the next one whilst a second process refers to the stevedoring operation in the calling ports. Such processes are considered as endogenous one in the perception that can be controlled by the decision maker. In addition, in these processes the sequence of events are describing by the fixed schedule that the vessel follows. Constant parameters in the simulation process are the route and the fixed schedule. The route can be considered as the description of the sequence of the nodes in the network i.e. ports and their specific characteristics. The fixed schedule depicts the features that are essential for the execution of the rotation in a route by the vessel indicating the time and the date that the vessel has to arrive in a destination and departure for the consecutive one. In the processes the vessel and the ports are constitute the means for accomplishing the goal i.e. the rotation.

Probabilistic inputs in the simulation process are the delays that the may occur during the voyage and during the time that the vessel spend in the port for the stevedoring process. Thus we consider two probabilistic inputs, the weather conditions delay, and the port time delay. Such processes are considered as exogenous one as they are out of the control of the decision maker. In the following Table 6.2 we describe the controllable and probability inputs in the simulation process.

Table 6.2 Simulation Inputs

Controllable Inputs					
Processes/Endogenous Processes		**Constant Parameters**		**Means**	
Voyage	***Stevedoring Operation***	***Route***	***Fixed schedule***	***Vessel***	***Ports***
		Number of Ports	*Arrival Time*	*Type*	*Name*
		Distances	*Departure Time*	*Speed*	*Cargo handling Productivity*
		Sequence of Ports		*Capacity*	
				Cargo Volume	

Probability Inputs/Exogenous Processes	
Weather Condition Delay	**Port Time Delay**
Statistical distribution	*Statistical distribution*

The sequence of the events to be considered in the simulation process have already mentioned in the section 6.2.1. Every individual event triggers the consecutive one leading to a simulation of the liner shipping schedule. In addition, each leg of the shipping schedule can be broken down to the events below :(Figure 6.1, Section 6.2.1)

- Departure event; the vessel departures from an origin to a destination.
- Steaming event; the vessel sails from an origin to a destination
- Arrival event; the vessel arrives in the destination port
- Port event; the vessel has berthed in the port and the loading/unloading process starts.
- Departure event for the next destination; the vessel departures from the last destination and hit for the consecutive one.

Weather conditions event- an event that changes the steaming event is simulated. This event changes the duration of the sailing time. Port conditions event-an event that changes the duration the vessel spends in the port for the loading/unloading process-is simulated. For the generation of the weather and port time conditions we use random time delays based on a statistical distribution that describe those two variables.

Given the nominal arrival times in each consecutive port according to the fixed schedule we derive the delays in each event in comparison with the actual arrival times that entail the generation of the weather and port conditions delay that may occur. Moreover as most of the liner shipping services are offered on a weekly basis, the nominal departure time for the next rotation is fixed and in comparison with the actual departure time from the last destination we derive the delay that the ship will convey for the next rotation.

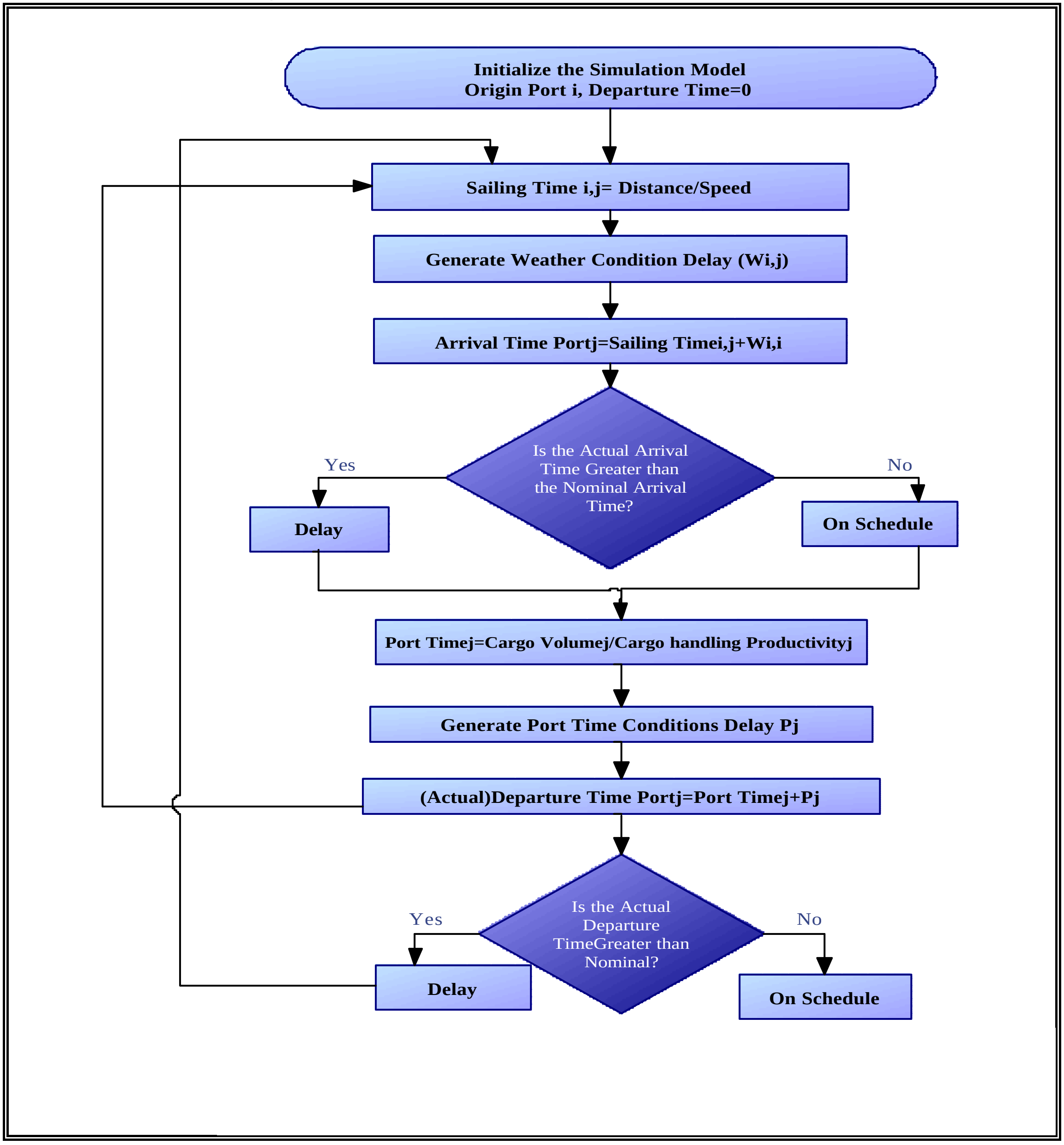
The performance metrics of the simulation model are consisting of:

- Average and maximum delays
- Number of delays; the number of times that the vessel will not arrive on the scheduled time in the calling port.
- Probabilities of delays, the probability that the vessel will not arrive on the scheduled time

- The number of the delays that are above the buffer time that the planner has assigned in each leg of the schedule.
- Probability of delays above the buffer time.

In the following Figure 6.2 we illustrate the chart flow of the simulation process:

Figure 6.2 Flow Chart of the Simulation Process



6.4 Model Application in an Explanatory Case Study

Due to the lack of the various types of data required in order to apply the simulation model in real-time situation problem, we report on a liner shipping schedule case study that was carried out by *Shih-Chan Ting et al (2003)*. This case study was concerned with the utilization of a dynamic programming method for the design of an optimal liner shipping schedule under berth time window constraints entailing vessel speed, cargo handling productivity and schedule arrangements. However from the above case study we are borrowing the data regarding the cruising speed of the vessel, the cargo handling productivity in the candidates calling ports, the cargo volumes the vessel has to load/unload, the available berth time windows in the calling ports, the buffer times, and the pro-forma schedule that *Shih-Chan Ting et al (2003)* produced.

In their study they used a weekly Trans-Atlantic service offered by a Taiwanese liner shipping company. The data concerning the service of the company and the pro-forma schedule that the vessel has to follow for the completion of a weekly rotation through the calling ports is presenting in the following Table 6.3.

Table 6.3 Data of the Explanatory Case Study

Calling Ports	**Distance (D)**	**Speed (S)**	**Cargo**	**Port Productivity (P)**	**Buffer Time**	
	Nautical Miles	**Knots**	**TEUs**	**Moves/hour**	**Voyage (BV)**	**Port (BP)**
Charleston (CH)				60	0	3
	435	19	468			
Miami (MIA)				60	2	3
	970	19	421			
Houston (HST)				60	3	1
	433	19	702			
New Orleans				60	2	2
	4859	19	468			
Antwerp				65	2	1
	141	19	655			
Felixstowe				55	1	1
	311	19	515			
Bremenhaven				65	1	1
	255	19	655			
Rotterdam				60	1	1
	1086	19	468			
Lisbon				55	1	2
	3385	19	328			
Charleston					4	0
Vessel 2000 TEU				***Total Buffer Time***	***32 Hours***	
				Average Buffer Time	***3.6 Hours***	
				Maximum Buffer Time Both Port &Voyage	***6 Hours***	

Source: Shih-Chan Ting (2003)

6.4.1 Model Application

The first step in order to apply the model in the case study we report is to convert the pro-forma schedule into hours. In our model the simulation clock starts to count at time 0 and thus we assume that the departure time from the initial port is time 0. Hence, given the data from Table 6.3, assigning as initial port the port of Charleston we find the nominal arrival time of the vessel in the consecutive port as follows:

$$\textit{Nominal Arrival Time MIA} = \textit{Departure Time CH} + \textit{Steaming Time } (D/S_{CH-MIA}{}^{5}) + \textit{BufferV}_{CH-MIA}{}^{6}$$

$$\Rightarrow \quad \textit{Nominal Arrival Time MIA} = 0 + 435/19 + 3 = 24.9 \textit{ Hour}$$

Henceforth the nominal arrival time for the vessel to berth in port Miami is at the time ***24.9 Hour***. For the consecutive Port Houston the arrival time will be as follows:

$$\textit{Nominal Arrival Time HST} = \textit{Nominal Arrival Time MIA} + \textit{Working Time MIA}^{7} + \textit{BufferP}_{MIA}{}^{8} + \textit{Steaming Time } (D/S_{MIA-HST}) + \textit{BufferV}_{MIA-HST}$$

$$\Rightarrow \quad \textit{Nominal Arrival Time HST} = 24.9 + 421/60 + 3 + 970/19 + 3 = 89.3 \textit{ Hour}$$

Consequently the nominal arrival time in Houston will be at time ***89.3 Hour***. Following the same procedure for the consecutive ports we find the nominal arrival times expressed in hours for each port of the rotation. As the service is offered on a weekly basis after the calculation of the arrival time in the initial port Charleston we find the departure time for the next rotation if we add the working time in CH and the buffer time in Port CH. A summary of all the nominal arrival times is presented below in the following table.

Table 6.4. Nominal Arrival Times

Calling Port	**Nominal Arrival Time**
	Hour
MIA	***24,9***
HST	***89,3***
NEO	***126,8***
ANR	***393,6***
FXT	***413,1***
BRV	***440,8***
RTM	***466,3***
LIS	***533,2***
CHS	***722,3***
Next Rotation Start	***733,2***

Apparently all the above information listed in Tables 6.3-6.4 represent the endogenous attributes of the simulation model. The weather conditions delay and the port time delay

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[5] Distance/Speed between Charleston -Miami

[6] Buffer Time for the Voyage Charleston Miami

[7] Working Time Miami= Cargo Miami/ Cargo Handling Productivity Miami

[8] Buffer Time in the Port Miami

that constitute the probabilistic-exogenous attributes of the simulation model are described by a probability distribution (See Table 6.5)

Table 6.5 Probability Distribution Weather/Port Conditions Delay

Weather Conditions Delay		*Port Time Condition Delay*	
Hours	***Probability***	***Hours***	***Probability***
0	*0,02*	*0*	*0,05*
1	*0,05*	*1*	*0,30*
2	*0,24*	*1,5*	*0,10*
3	*0,20*	*3*	*0,20*
3,5	*0,12*	*4*	*0,35*
4	*0,15*		***1***
4,5	*0,14*		
10	*0,08*		
	1		
Expected Value	***3,58***	***Expected Value***	***2,45***
Expected Values(Sum)			***6,03***

Due to the lack of weather delays as well port time delays data in order to sample an empirical distribution estimated on the basis of such data, the probability distribution that describes each one of the uncontrollable inputs of the model is assigned by experimental judgment. Therefore to assign the above probability distributions we report on the buffer time the planner has included in the pro-forma schedule. Regarding the pro-forma schedule of the Trans-Atlantic service the total buffer time that the planner has assigned in the vision of a successful on time completion of a whole rotation is 32 hours. Since in our schedule the ship rotates through 9 ports we conclude that an average of 3.6 hours has been assigned to facilitate the process consist of the vessel to sail from an origin to a destination, complete the loading/unloading process in the destination port and departure for the next destination. The maximum buffer time the planner has assigned for the above process corresponds to an amount of 6 hours.

Conceptually estimating the expected value of the probability distributions of the weather conditions delay that we have assumed and respectively the expected value of the port time delay the sum of them give us an expected value of 6.03 hours. The planner has decided a buffer time to mitigate disturbances that may occur during the rotation. Moreover planers usually try not include enough buffer time in the schedule to avoid idleness of the vessel. Thus we decide a probability distributions of which the sum of their expected value is above the average 3.6 and close to the maximum 6 hours buffer time. Through this approach we try to give a general impression of the behavior of the weather and port conditions delay close to the buffer time the planner has assigned.

Both the weather and port conditions delays are simulated. By utilizing the generation of random numbers for each simulation run we derive representative values of the probabilistic inputs. We generate a random number between 0 and 0.02. If the random number is 0.0 but less than 0.02 we set the weather condition delay 0 hours. If the random number is 0.02 but less than 0.05 we set the weather condition delay 1 hour and so on. We apply the same procedure for the port conditions delay.

6.4.2 Costs of Alterations in the Initial Schedule.

The additional cots that we consider in the case of alterations in the initial schedule are described as follows:

- Bunkering costs. We derive the data regarding the fuel consumption and the fuel costs from Table 5.3 (section 5.3) where a route cost analysis is illustrated and refers to our case study. Further in the case of speed interventions in the schedule we assume a maximum speed of 23 knots. Thus the additional cost in each voyage steaming with maximum speed will be.

Table 6.6 Cost of Speed Increase

Bunker Cost Speed 19 Knots										
Voyage distance	**NM**	**435**	**970**	**433**	**4859**	**141**	**311**	**255**	**1086**	**3385**
Speed	**19**	**19**	**19**	**19**	**19,0**	**19,0**	**19,0**	**19,0**	**19**	**19**
Voyage days	**Days**	**1,0**	**2,1**	**0,9**	**10,7**	**0,3**	**0,7**	**0,6**	**2,4**	**7,4**
IFO Consumption per day	MT	74,0	74,0	74,0	74,0	74,0	74,0	74,0	74,0	74,0
MDO Consumption / Port	MT	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5
Price IFO	USD	102								
Price MDO	USD	143								
Bunker costs	**USD**	**7700,9**	**16556,6**	**7667,8**	**80929,7**	**2834,4**	**5648,4**	**4721,4**	**18476,7**	**56531,2**
Bunker Cost Speed 23 Knots										
Voyage distance	**NM**	**435**	**970**	**433,0**	**4859**	**141**	**311**	**255**	**1086**	**3385**
Speed	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**
Voyage days	**Days**	**0,8**	**1,8**	**0,8**	**8,8**	**0,3**	**0,6**	**0,5**	**2,0**	**6,1**
IFO Consumption per day	MT	74,0	74,0	74,0	74,0	74,0	74,0	74,0	74,0	74,0
MDO Consumption / Port	MT	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5
Price IFO	USD	102								
Price MDO	USD	143								
Bunker costs	**USD**	**6448,7**	**13764,2**	**6421,3**	**66942,0**	**2428,5**	**4753,1**	**3987,3**	**15350,4**	**46786,7**
Extra $ Cost at Speed 23 Knots		**1252,2**	**2792,4**	**1246,5**	**13987,7**	**405,9**	**895,3**	**734,1**	**3126,3**	**9744,5**

Due to the lack of data for the cost of omitting a port, the penalty marketing factor, the cost of savings not calling a port and the delay penalty fees, as we have define them, we assume the following:

- Cost of omitting a port 300($) per TEU: This cost includes the penalty fees posed by the customer and also the roll on cost of the containers.
- Cost Penalty Marketing Factor[9], for each port is assumed as follows:

MIA	HST	NEO	ANR	FXT	BRV	RTM	LIS	CHS
0,3	0,6	0,3	0,6	0,5	0,6	0,4	0,2	0,3

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[9] Assumptions made based on the cargo volume in its port.

- Delay Penalty Fees that the Terminal Operators will pose for failure of the vessel to berth on schedule are assumed as follows:

The First Hour Of Delay	**0**
Second Hour of Delay	**$500**
Past the Second Hour	**$1000**

- Cost Savings by Skipping a Port: For thhe costs that the company will save by skipping a port we assume that correspond only to the port charges of the skipped port. Recalling the Table 5.3 with the cost route analysis the port charges in each port are:

MIA	HST	NEO	ANR	FXT	BRV	RTM	LIS	CHS
$11500	$11500	$11500	$30000	$30000	$38000	$30000	$25000	$11500

6.5 Simulation Process in the Explanatory Case Study

Using an Excel spreadsheet we simulate the events of the shipping schedule of the Trans-Atlantic service for 100 consecutive rotations. The spreadsheet carries out the simulation process shown in Figure 6.2

Referring to the Figure 6.2 which represents the flow chart of the simulation process the simulation is initialized in the first initial port, *Charleston*. Then a new rotation for the vessel starts. A weather condition delay is generated. The actual arrival time of the vessel in the second port, *Miami* is then computed by adding the weather condition delays to the sailing time ($Dist._{Miami-Houston} / Speed_{Miami-Houston.}$). The actual arrival time of the vessel is compared with the nominal arrival time indicated by the pro-forma schedule. If the actual arrival time is greater than the nominal arrival time then a delay is recorded. In sequence the vessel berths and the stevedoring process starts. A port conditions delay is generated. The port time ($CargoVol._{Miami} / CargoHanRate_{Miami}$) that the vessel spends in the port until the completion of the stevedoring process where the ship will departure for the next destination is then computed by adding the port conditions delay. The actual departure time of the vessel for the next port, *Houston*, is computed by adding the actual arrival time and the port time. In the case where the vessel is earlier than the scheduled time to berth we assume that the ship stays idle until the scheduled time.

For the next port, *Houston*, the actual arrival time is computed by adding in the sailing time ($Dist._{Miami-Houston} / Speed_{Miami-Houston.}$), the weather conditions delays generated for the voyage *Miami-Houston*, and the actual departure time from *Miami*. Then the actual arrival time in *Houston* is compared with the nominal arrival time indicated by the pro-forma schedule. A delay is recorder if the actual arrival time is greater than the nominal arrival time. We continue the same procedure for the next port recording the delays in each voyage. In the last calling port of the rotation *Charleston*, which is our initial port, after the completion of the stevedoring process in *Charleston* the actual departure time from Charleston represents the actual departure time for the next rotation.

As the service offered by the Taiwanese is a weekly service, the pro-forma schedule also indicates the nominal departure time from *Charleston* for the next rotation. This nominal departure time is compared with the actual departure from *Charleston* for the next rotation. If the actual is greater than the nominal departure time for the next rotation a delay is recorded. This delay is transferred in the next simulation run which represents the next rotation of the vessel through the calling ports. Hence the actual arrival time in *Miami* (next rotation) is computed by adding the weather condition delays generated to the sailing time ($Dist._{Miami-Houston} / Speed_{Miami-Houston.}$) and the delay from the previous rotation. Through this procedure the simulation runs are not independent.

6.5.1 Results of the Simulation Process in the Initial Schedule

Using the Excel spreadsheet we simulate the shipping schedule of our case study for 100 consecutive rotations of the vessel through the calling ports. Ultimately summary of the performance metrics are collected describing the results of 100 consecutive rotations. The summary statistics of the simulation process are showed in the following table:

Table 67 Summary Statistics of the Simulation

VOYAGE	CHS-MIA	MIA-HST	HST-NEO	NEO-ANR	ANR-FXT	FXT-BRV	BRV-RTM	RTM-LIS	LIS-CHS	Next rotation
Number of Delay	91	88	87	87	90	90	91	93	95	88
Probability of Delay	0,91	0,88	0,87	0,87	0,9	0,9	0,9	0,9	0,95	0,88
Average Delay (hours)	**40,6**	**37,4**	**37,6**	**38,1**	**39,4**	**42,2**	**40,5**	**42,3**	**43,9**	**40,6**
MAX Delay (hours)	94,2	87,8	86,2	86,1	72,8	95,8	87,3	89,8	94,3	94,2
Number of Delay>3.6 hours	84	82	81	82	84	86	86	87	90	85
Probability of Delay>3.6	0,84	0,82	0,81	0,82	0,84	0,86	0,86	0,87	0,9	0,85

Interpreting the above summary statistics we can infer that for the first voyage from Charleston to Miami the vessel in 91 out of 100 consecutive rotations will fail to arrive on schedule in the port Miami. This result provide us an 91/100=0.91 probability of the vessel's failure to arrive on schedule. Or in other words approximately 91% of the rotations the vessel will be out of schedule in port Miami. The average delay is 40.6 hours per rotation for the first voyage where at least in one rotation the maximum delay is 94.2 hours. The times that the vessel will exceed the average buffer time assigned by the planner (3.6 hours) is 84 times out of the 100 rotation giving us a probability of 0.84 that the vessel will extend the average planned buffer time for the first voyage. The above interpretation stands also for the consecutive ports.

The section of the table referring to the Next Rotation summarizes the statistics regarding the delay that the vessel will convey in the next rotation from the previous one or the positive difference between the actual departure time for the next rotation and the scheduled one. Hence 88 out of the 100 rotations the vessel will departure for the next rotation with a delay. This result gives us a probability of 0.88 that the vessel will fail to start on schedule for the next rotation. Moreover the average delay is 40.6 hours per rotation where at least once the vessel will start the next rotation with a maximum delay of 94,2 hours. The times that the delay for the next rotation will extend the average planned buffer time is 85 out of 100 rotations with a probability of 0.85. However the statistics referring to the next rotation are significant as they can be considered as an indicator of the delay propagation in the system due to the inability of the vessel to recover the occurrence of delays in the sequence of the events in the schedule.

The results regarding the cost penalty function are referring only to penalties fees that the company has to bear due to delays in the slot time agreed with the terminal operators(Table 6.7).

Table 6.7 Cost Penalty Function Initial Schedule

Cost Penalty Function	
Penalty Marketing factor	0
Cost omitting a port	0
Cost saving omitting a port	0
Cost increase the speed	0
Cost Increase Cargo Handling Productivity	0
Average Penalty Fee	**17950**
Decisions Costs	**17950**

Recalculating the simulation process 25 times while keeping steady the results of the summary statistics we draw a sample of 25 observations regarding the average delay. Through this approach we sample an empirical distribution of the average delay. Accordingly we calculate the mean of the sample ($\overline{X}$) the standard deviation and with a confidence level a=95% we estimate the population mean (μ) of the average delay by constructing the confidence interval estimator of the μ[10]. (Table 6.8)

Table 6.8 Confidence Intervals of the Average Delay Initial Schedule

VOYAGE	**Mean (hours)**	**Standard Deviation**	**LCL**	**UCL**
CHS-MIA	40,3	25,6	**30,3**	**50,4**
MIA-HST	37,2	25,5	**27,3**	**47,2**
HST-NEO	37,7	25,5	**27,3**	**47,2**
NEO-ANR	37,8	25,5	**27,8**	**47,8**
ANR-FXT	39,1	25,7	**29,1**	**49,2**
FXT-BRV	41,9	26,1	**31,7**	**52,1**
BRV-RTM	40,5	25,9	**30,3**	**50,6**
RTM-LIS	41,9	26,0	**31,7**	**52,0**
LIS-CH	43,3	26,1	**33,1**	**53,5**
NEXT ROTATION	40,3	26,0	**30,1**	**50,5**

---

[10] $\overline{X}(n) \pm z_{1-a/2}\sqrt{\frac{S^2(n)}{n}}$

Interpreting the above table we can infer for example for the voyage between CHS-MIA that the population mean of the average delay is estimated to lie between 30.3 and 50.4 hours with a confidence level 95%. The same stands for the consecutive voyages. From the statistics above we observe that the vessel in the first voyage has a mean ($\overline{X}$) average delay of approximately 40 hours. This can be attributed mainly to the fact that the vessel starts the next rotation with a mean average delay of 40.3 hours and thus the vessel fails to recover the delay from the previous rotation. However in the consecutive ports the mean average delay falls due to the buffer time that the planner has incorporated in the schedule. Whereas in the second part of the rotation when the vessel call at ports in Europe the vessel builds up a delay. The imbalance occurring is associated with the buffer time that the planner has assigned in the two part of the rotation. Recalling the Table 6.3 we can observe that in the first part (Ports in USA) the buffer time incorporated in the schedule is higher than the buffer time in the second part (Ports in Europe). Although the distances between the consecutive ports in Europe are shorter weather conditions delays and port time delays in conjunction with a small amount of planned buffer time lead to significant delays.

From the results above we can depict that the schedule in not feasible without any intervention in the pro-forma schedule. Moreover we can conclude that the robustness of the schedule is very low under adverse weather and port conditions showing a high degree of influenceability in external influences whilst the fastness of the system to damped out deviations in the schedule is very low. Moreover the buffer times in the different stages of the rotation are fixed as well as the scheduled times for the vessel to berth does not allow changes in the buffer time. As a result increase of the buffer time action rescheduling and new agreements with the terminal operators. Therefore we proceed with the examination of alteration in the initial schedule.

6.6 Scenario 1: Increase of the Nominal Speed.

The first scenario examines the intervention in the nominal speed that the vessel has been decided to attain in the planning process during the voyage from an origin to a destination. However alterations in the nominal speed and thus steaming at higher speed implies higher fuel consumption and increase in the shipping companies costs. Hence to evaluate the decision of the planner to increase the speed we make use of the cost penalty function parallel to the time profits gained.

Regarding the decision in which voyage between two pairs of ports we must increase the speed our decision rule relies on the distance. Hence we decide to increase the speed in a voyage where the distance is long. The intention to adopt the above decision rule is two folded. First we want to illustrate the role of the cost penalty function. Steaming at higher speed for a longer distance means the impact in costs is more palpable. On a second basis it contributes to better results in terms of time savings. For that reason we select to change the speed in the voyage from *Lisbon to Charleston*. This voyage represents the second longer distance with 3859 Nautical miles. Moreover we select this part of the rotation in order the vessel to mitigate delays occurred during the whole rotation and thus to start the next rotation with less/no delay. The vessel that we deploy is a containership

2000 TEUs. Usually the maximum service speed in complement that a vessel of this capacity can achieve is 23 knots *(Waals 2005)*. Hence in the simulation model we adjust the speed for the voyage from *Lisbon Charleston* to 23 knots. We also select the vessel to steam at high speed first because the planned speed is close to the maximum speed and also to mitigate the high delays the performance metrics of the simulation process in the initial schedule have indicated. Thus we want to achieve the highest possible time profits by undertaken this action. The adjustment of the speed is applied to all the simulation runs that each one represents one rotation of the ship.

6.6.1 Results of the simulation Process in the Scenario 1

In the Excel spreadsheet we simulate the shipping scheduling while we have adjusted the speed for 100 consecutive rotations of the vessel.

From the summary statistics following the same procedure that we have described in the simulation process we recalculate the simulation process 25 time and we draw a sample of 25 observations for the average delay. With a confidence level a=95% we construct the confidence intervals estimator of the mean (μ) of the average delay (Table 6.9).

Table 6.9 Confidence Intervals-Scenario 1 Increase of Nominal Speed

VOYAGE	**Mean (hours)**	**Standard Deviation**	**LCL**	**UCL**
CHS-MIA	0,8	0,1	0,7	0,8
MIA-HST	0,6	0,2	0,5	0,7
HST-NEO	1,0	0,2	0,9	1,1
NEO-ANR	1,2	0,2	1,1	1,3
ANR-FXT	1,9	0,3	1,7	2,0
FXT-BRV	2,7	0,4	2,5	2,8
BRV-RTM	3,6	0,5	3,4	3,8
RTM-LIS	4,7	0,5	4,5	4,9
LIS-CH	0,0	0,0	0,0	0,0
NEXT ROTATION	0,0	0,0	0,0	0,0

Interpreting the confidence intervals estimator of the mean (μ) of the average delay we can deduce that with a confidence level 95% in the first voyage for example the average delay falls between [0.7,0.8] hours. Overall the Table 6.9 depicts that the average delay in all parts of the rotation has been improved while in the last voyage that we intervened in the nominal speed we achieved a zero delay situation enabling the vessel to start the next rotation on schedule. Moreover from the mean ($\overline{X}$) of the average delay that we sampled we can infer that a delay is building up with lower rate in the first part of the voyage (Ports USA) and with higher rate in the second part (Ports Europe) until the vessel to attain maximum speed and recover the delays occurred . Again as in the main simulation process of the initial a priori schedule without interventions this phenomenon can be attributed to the higher amount of buffer time in the first part of the rotation in comparison with the second part. Finally we can conclude that the robustness of the schedule has vertically improved as the schedule seems to perform fairly well under adverse weather and port time conditions

The results that we derive from the cost penalty function are illustrated in the following Table 6.10:

Table 6.10 Costs in Alterations of the Schedule Scenario 1

Cost Penalty Function	
Penalty Marketing factor	0
Cost omitting a port	0
Cost saving omitting a port	0
Cost increase the speed	**9744**
Cost Increase Cargo Handling Productivity	0
Average Penalty Fee	**4990**
Decisions Costs	**14734**

An additional cost $9744 that represents the cost of increasing the speed is indicated. This cost refers to one rotation of the vessel. In other words portrays the additional cost the company must consider in the cost route analysis in order the vessel to execute the schedule by attaining in the last voyage a speed of 23 Knots/hour. The average penalty fees that represents the penalties that the company has to bear from the terminal operators due to extensions in the slot time agreed upon give us an amount of $4990 per rotation. However in comparison with the main simulation process we can infer a reduction in the penalty fees approximately up to 35% (17950/4990**).** The overall cost of the company to undertake such decision is considered to be $14734.

6.7 Scenario 2: Omit a Port.

For the second scenario we examine the case of the decision maker to omit a port of the vessel's rotation through the calling ports. In order to take a decision which one of the ports we have to omit we assign intervals of delays that varies from [3, 24] hours and. [24, +∞) hours. We connect the above intervals with the average delay in the arrivals time that the simulation process indicates in the performance metrics. Every time that we recalculate the simulation process and the average delay of the vessel's arrival time in each ports falls in the second interval [24, +∞) we recorded it as 0 indicating as potential port to be omitted while when it falls in the interval [3.24] we recorded as 1 indicating not to omit this port. Our intention to assign these intervals lies behind the concept that if the average delay of the vessel's arrival time in a port extends an amount of 24 hours implies a delay of a day. However the average buffer time that has been incorporated in the planning horizon is 3.6 hours with a max value of 6 hours. Obviously if the vessel's delay is almost a day or more in one port then there is no possibility of the vessel to recover such delay in the consecutives ports. Moreover due the knock off effect, delay propagation will occur throughout the whole network. These intervals can be also considered as indicators of the delay that set in risk the robustness of the schedule. The first interval show a low amount of risk while the second a high amount of risk to disturb the functioning of the schedule.

For the next step of the procedure to ascertain which port we have to omit we recalculate the simulation run 10 times. In its recalculation we record the average delay of the vessel in the calling ports that falls in the interval $[24,+\infty)$. From the sample that we draw from the 10 observations we conclude that 7/10 and 6/10 the actual arrival times in ports Houston and Felixstowe respectively, have a high risk average delay in comparison with the other ports. Hence the intervention in the initial schedule to omit a port is designated by omitting the ports Houston and Felixstowe.

In addition by omitting a port we have to consider that the distance is not any more the same. As the vessel does not call at Houston but head directly from Miami to New Orleans the distance that describes the two pairs of ports is shorter than in the case where the vessel rotates from Miami to Houston and then to New Orleans. However, the Excel spreadsheet has been constructed in such way that permits those updates. Hence by external calculations that are connected with a control table in the main spreadsheet that we conduct the simulation run, by assigning in the section of the control table *Exclude/ Include Port* 1(Not omit) or 0 (Omit) we update the distances among the calling ports depending on the action we undertake. Further this updates are applied to the simulation process.

6.7.1 Results of Simulation Process Scenario 2

We simulate the shipping schedule with the intervention of the vessel to skip ports for 100 consecutive rotations. The performance metrics that are collected are illustrated in the following table:

Table 6.11 Performance Metrics Simulation Process Scenario 2 Omit a Port

VOYAGE	CHS-MIA	HST	MIA-NEO	NEO-ANR	FXT	ANR-BRV	BRV-RTM	RTM-LIS	LIS-CHS	Next rotation
Number of Delay	29		0	0		0	0	0	0,	0
Probability of Delay	0,3		0	0		0	0	0	0	0
Average Delay (hours)	0,6		0	0		0	0	0	0	0
MAX Delay (hours)	8,0		0	0		0	0	0	0	0
Number of Delay>3.6 hours	6,0		0	0		0	0	0	0	0
Probability of Delay>3.6	0,1		0	0		0	0	0	0	0

Interpreting the summary statistics of the simulation we can infer that by omitting two ports we succeed to achieve a zero delay condition in almost the whole rotation. The only part of the rotation that delays have been recorded corresponds to the first voyage of the vessel from CHS-MIA. These delays can be attributed to the fact that the buffer time that has been included in the voyage between CHS-MIA recalling the Table 6.3 is 2 hours.

Hence the vessel as it starts the next rotation on schedule, adverse weather condition or other unforeseen events during the steaming time lead to a delay of 0.6 hours per rotation However due to the fact that the ports Houston and Felixostowe are not calling at, enables the vessel to recover the delays occurred in the first voyage. Moreover for the ports left to call at the performance of the schedule in terms of punctuality is ideal as the vessel is always on time. Ergo based on the simulation results we can support that omitting the above two ports with the buffer time that the planner incorporated in the planning process, the robustness of the schedule has been improved verifying that the schedule can function fairly well under the occurrence of unforeseen events. Moreover the amount of the average delay in the arrival time in the first voyage is not that high instead it can be considered as ordinary delay.

However to undertake such decision the extra cost that the company has to bear is analogous to an amount of ($) 356980 per rotation.

Table 6.12 Costs of Omitting a Port

Cost Penalty Function	
Penalty Marketing factor	**1,1 (0,6+0,5)**
Cost omitting a port	**365100**
Cost saving omitting a port	**41500**
Cost increase the speed	0
Cost Increase Cargo Handling Productivity	0
Average Penalty Fee	**370**
Decisions Costs	**356980**

Another significant observation refers to the fact that the penalties fees in comparison with the simulation process without intervention and the scenario of increasing the speed record a reduction of 500% and 13% respectively.

6.8 Scenario 3: Omit a Port under a Decision Rule.

For the above two scenarios presented we can surmise that their application is inherently allusive on a static application of the model. Interventions in the two previous scenarios are applied in all the simulation runs while alterations of the schedule are not adaptive during the execution of the schedule. Ergo we can consider that the interventions are applied on a static way.

However it would be interesting to debate the already mentioned scenarios with the daily operation scheme. In other words to examine the robustness of the pro-forma schedule during its implementation and under this concept on a dynamic application of the model. Justifiably we proceed with the construction of two new scenarios utilizing the same simulation model whereas a decision rule is applied in the simulation process in order to determine under which condition the vessel will skip a port or in which stage will of the rotation will increase the speed.

The first scenario refers to the examination of the case where under a decision rule the simulation process decides to omit or not a port as the vessel executes the schedule. Recalling the central assumptions of the simulation model, the simulation process was executed under the hypothesis that the terminal operator can offer a slot independently of the amount of the vessels delay in its arrival time. However for the implementation of this scenario we withdraw the hypothesis of the terminal operator availability to offer a slot further to the agreed time due to the fact that the credibility of such an assumption is invalid during the daily operations. Moreover a vessel may encounter the situation of a heavily congested port during its arrival time. Congestion parallel with the fact that the vessel did not succeed to arrive in the port at the scheduled time augur a failure of the vessel's ability to recover the previous delay. Whilst constitute a concrete proof that in the consecutives ports the vessel's delay will deteriorate attributable to the knock off effect.

On the other hand the difference between the actual arrival time and the nominal arrival time in a port may record a high amount of delay. Such a delay may be prohibitive for the vessel to call at this port. As the high amount of delay will spread throughout the whole schedule and thus the arrival times in the consecutives ports will also be disturbed it is validly for the vessel to skip the port and head for the next destination.

Under these considerations we assume that the vessel has already reached the port and depending on the amount of delay we decide either to enter in the port and load/unload or to skip the port. However in this case we do not have changes in the distances between the ports as the decision is taking after we have reached the port.

From the abovementioned in the simulation process we apply a decision rule. This decision rule refers to the situation where if the positive difference between the actual arrival and the nominal time (delay) in a port is larger than 7 hours then the vessel does not call the port and head directly for the next one. Hence the vessel will not unload/load cargo in the skipped port and will continue its journey to next destination. We decide as a threshold for the vessel to skip a port a delay of more than 7 hours as the planner in the case study has incorporated an average buffer time 3.6 hours. Thus if the actual arrival time of the vessel extends the nominal arrival time more than 7 hours indicates that the vessel has already consumed the buffer time assigned for the next voyage. Hence it would be advisable for the vessel to continue its journey in order to recover the previous delay by saving the port time and any delays that may occur during this time.

We apply the decision rule in each individual port and for 50 runs in the simulation process which represent 50 consecutive rotations of the vessel. Every time that the vessel skip a port we record which port, while in the spreadsheet we have connected with external calculation the costs of skipping the specific port in order to automatically derive the costs of such actions. The costs are the same as we have assigned them in the initial a priori schedule.

6.8.1 Results of the Simulation Process Scenario 3

We simulate the shipping schedule for 50 consecutive rotations. The summary statistics collected from the simulation process are presented in the next table:

Table 6.13 Performance Metrics Scenario 3

VOYAGE	CHS-MIA	MIA-HST	HST-NEO	NEO-ANR	ANR-FXT	FXT-BRV	BRV-RTM	RTM-LIS	LIS-CHS	Next rotation
Number of Delay	29	14	22	18	27	29	35	37	25	13,0
Probability of Delay	0,58	0,28	0,44	0,36	0,54	0,58	0,7	0,74	0,5	0,26
Average Delay (hours)	**1,4**	**0,6**	**1,2**	**1,4**	**1,9**	**2,2**	**3,1**	**3,7**	**1,3**	**0,5**
Number of Omit a Port	2	0	2	2	3	2	5	8	0	🟥
Probability Omit a Port	0,04	0,0	0,04	0,04	0,06	0,04	0,1	0,16	0	🟥

The performance metrics in this scenario avail the interpretation of a number of different factors related with the case we examine in this section. Henceforth, the summary statistics show the number of times that the vessel will fail to arrive on schedule in the calling ports which for example for the first port in call after the departure from the initial port, the vessel 29 time out of 50 will reach the port with a delay. This result gives us a probability of 0.6 (29/50) that the vessel will be out of schedule. The average delay is 1.4 hours per rotation for the first voyage. Moreover the times that the vessel will omit the first port i.e the vessel will arrive but will not load/unload, instead will continue in the next destination is 2 times out of 50 consecutive rotation. Therefore a probability of 0.04 describes the possibility of the first port to be omitted by the vessel. The same interpretation stands for the consecutive ports.

Note that as we have defined in the section referred in the Keywords and Terminology the starting point of a voyage in liner shipping can be assigned by the planner. Therefore considering that the vessel can skip the initial port Charleston we consider as the initial port, to record the delay for the next rotation, the consecutive one and so on.

With a confidence level a=95% and a sample of 25 observations that we draw by recalculating the simulation process 25 times while keeping steady the summary statistics we calculate the confidence interval estimator of the mean (μ) regarding the average delay, and the confidence interval for the probability of omitting a port. The results are presented in the following Table 6.13:

Table 6.13 Confidence Intervals Scenario 3

	Average Delay				*Probability of Omit a Port*			
VOYAGE	**Mean (hours)**	**Standard Deviation**	**LCL**	**UCL**	**Mean**	**Standard Deviation**	**LCL**	**UCL**
CHS-MIA	1,388	0,274	1,280	1,495	0,027	0,022	0,019	0,036
MIA-HST	0,657	0,214	0,572	0,741	0,005	0,009	0,001	0,008
HST-NEO	0,985	0,310	0,864	1,107	0,025	0,020	0,017	0,033
NEO-ANR	1,090	0,321	0,965	1,216	0,033	0,030	0,021	0,045
ANR-FXT	1,559	0,278	1,450	1,668	0,054	0,031	0,042	0,066
FXT-BRV	1,942	0,392	1,788	2,096	0,074	0,041	0,058	0,090
BRV-RTM	2,238	0,433	2,068	2,408	0,079	0,039	0,064	0,094
RTM-LIS	2,644	0,456	2,465	2,823	0,097	0,042	0,080	0,113
LIS-CH	1,357	0,275	1,249	1,465	0,028	0,020	0,020	0,036
NEXT ROTATION	0,562	0,183	0,490	0,634				

Form the above table we can infer that the behavior of the system is similar to the simulation process with interventions, Scenario 1 Increase of Nominal Speed. In other words from the mean ($\overline{X}$) of the average delay we can depict that in the first voyage a delay occurred is mitigated in the consecutive ports (Port of USA) showing that the buffer time assigned in the planning horizon can respond in the occurrence of unforeseen events. On the other hand in the second part (Ports in Europe) a delay is building up until the vessel head for the last voyage back to the initial port where delays are mitigated because the buffer time incorporated in this final stage of the rotation is 4 hours (Table 6.3). However the robustness of the schedule has been improved. Thus the decision of the system to skip a port in the situation where an occurrence of delay extends the threshold of 7 hours leads to significant time profits.

However it is significant to observe that the mean ($\overline{X}$) of the probability of skipping a port follows the same direction of the mean($\overline{X}$) of the average delay. As the average delay increases the probability also to skip a port increases showing a positive relationship among the two factors. Furthermore due to the fact that the rate of the mean ($\overline{X}$) of the average delay follows an opposite direction of the buffer time assigned in the planning process, the transitivity relation indicates that the probability to skip a port follows an opposite direction of the planned buffer time. For example the highest mean ($\overline{X}$) of the probability (0,097) to skip a port is concentrated in the port of Lisbon. This is a result of the interaction of two factors. First the delay that is building up in the ports of Europe and secondly because the buffer time assigned in the voyage RTM-LIS is only 1 hour.

The results from the cost penalty function show the average cost of 50 consecutive rotation that the company has to bear by undertaken the decision to skip ports depending on the delay in the arrival time.

Table 6.14 Alteration Cost Scenario 3

Cost Penalty Function	
Average Penalty Marketing factor	**28441**
Average Cost omitting a port	
Average Cost saving omitting a port	
Cost increase the speed	
Cost Increase Cargo Handling Productivity	
Average Penalty Fee	**7400**
Decisions Costs	**35841**

Therefore a cost of $28441 per rotation for the decision to skip a port with an additional cost of penalties fees 7400 per rotation gives us a total of $35841 per rotation. However we can see that the average penalties fees are not improving significantly in comparison with the two previous scenarios where the initial schedule has been altered. This can be attributed to the fact that the decision to skip a port is undertaken after the seventh hour of delay in the arrival time. Thus the vessel with a delay that lies between [1,7] call the port and bears the penalty fees from the terminal operators.

6.9 Scenario 4: Increase of the Nominal Speed under a Decision Rule

In this scenario we examine the case where we apply a decision rule relevant to the previous scenario regarding the nominal speed. Henceforth if the vessel's actual arrival time in a port extends the nominal time more than 7 hours the vessel instead of skipping the port call the port to load/unload the cargo but in the next voyage the vessel attain maximum speed in order to avoid delays in the next destination. In other words the vessel has already failure to arrive on schedule and synchronous encounters the probability of delays during the port time in the calling port. Therefore if the delay of the arrival time is more than 7 hours, in the next destination the vessel steams with high speed of 23 Knots.

The decision rule is applied on a dynamic basis in each port and each individual run in the simulation process.

6.9.1 Results of the Simulation Process Scenario 4

In the Excel spreadsheet we simulate the shipping scheduling for 100 consecutive rotations while the model according to the decision rule decides the vessel to increase the nominal speed or not in the different stages of the rotation.

The performance metrics of the simulation process are presented in the following Table (6.15):

Table 6.15 Performance Metrics Scenario 4 Increase of the Nominal Speed

VOYAGE	CHS-MIA	MIA-HST	HST-NEO	NEO-ANR	ANR-FXT	FXT-BRV	BRV-RTM	RTM-LIS	LIS-CHS	Next rotation
Number of Delay	35	14	21	12	19	23	25	27	27	23
Probability of Delay	0,7	0,3	0,4	0,24	0,38	0,46	0,5	0,54	0,54	0,46
Average Delay (hours)	**3,4**	**0,8**	**1,5**	**0,7**	**1,2**	**1,9**	**2,9**	**3,6**	**3,2**	**2,5**
Number Increase Speed	7,0	11	0	5	1	1	3	0	0	🟥
Probability Increase Speed	0,14	0,22	0	0,1	0,02	0,02	0,06	0	0	🟥

The performance metrics illustrate the number of times the vessel will be out of schedule in each port, the probability of not arriving on schedule and the average delay in each voyage. Further show the number of the times the vessel will have to increase the speed in each voyage given that the delay in the previous port at call extended the threshold of 7 hours. From the number of times the vessel increases the nominal speed we derive the probability that describes this decision.

Drawing a sample of 25 observations from the results of the summary statistics after the recalculation of the simulation process 25 times while keep steady the results we construct the confidence interval of the population mean (μ) of the average delay and the probability the vessel increase the nominal speed with a confidence level a=95%. The results are showed in the following table:

Table 6.16 Confidence Interval Scenario 4

	Average Delay				**Probability Of Increase Speed**			
VOYAGE	**Mean (hours)**	**Standard Deviation**	**LCL**	**UCL**	**Mean**	**Standard Deviation**	**LCL**	**UCL**
CHS-MIA	3,263	0,593	3,031	3,495	0,184	0,057	0,162	0,206
MIA-HST	0,619	0,267	0,515	0,724	0,013	0,017	0,006	0,020
HST-NEO	1,045	0,328	0,916	1,174	0,029	0,027	0,018	0,039
NEO-ANR	1,043	0,396	0,888	1,198	0,026	0,026	0,016	0,036
ANR-FXT	1,808	0,476	1,621	1,994	0,068	0,030	0,056	0,080
FXT-BRV	2,538	0,603	2,301	2,774	0,121	0,060	0,097	0,144
BRV-RTM	3,333	0,530	3,125	3,541	0,000	0,000	0,000	0,000
RTM-LIS	4,509	0,656	4,252	4,766	0,000	0,000	0,000	0,000
LIS-CH	3,722	0,728	3,437	4,008	0,138	0,047	0,119	0,156
NEXT ROTATION	2,702	0,550	2,486	2,917				

Interpreting the statistics above we can infer with a confidence level 95% that the population mean(μ) of the average delay that lies between the confidence interval with the higher amount of delay is located in the port of Lisbon where in the second position in terms of the average delay the vessel fails to arrive on schedule in port of Charleston. For that reason the probability the vessel to increase the speed between the voyage from Lisbon to Charleston is higher with comparison with the other voyages. However the vessel does not seem to recover the delay that is building up in the ports of Europe. Thus the vessel starts the next rotation with a mean ($\bar{X}$) average delay of approximately 3 hours. Correspondingly we observe a higher probability of the vessel to increase the speed in the voyage between Charleston to Miami. In the consecutive ports the vessel recovers the delay until the ports of Europe.

In addition another factor to consider in this case apart from the imbalances in the buffer time between the two parts of the rotation refers to the cargo volume. The cargo volumes in Europe are slightly higher than in USA. Furthermore a high volume of cargo is concentrated (Table 6.3) in ANT-FXT-BRV, where also a delay is building up. However in these consecutive ports the vessel does not increase the speed. Instead the delay is aggregating from these three ports and after the vessel arrives with a delay in Lisbon the decision to increase the speed in the voyage from Lisbon to Charleston. is undertaken

Albeit the occurrence of delay, the schedule seems to perform well under the dynamic decision to increase the speed in the next destination when the arrival time in the previous port extends the threshold of 7 hours delay. Therefore we can support that the robustness of the schedule is improved.

The results of the cost penalty function are showed below:

Table 6.17 Alteration Costs Scenario 4

Cost Penalty Function	
Average Penalty Marketing factor	0
Average Cost omitting a port	0
Average Cost saving omitting a port	0
Average Cost increase the speed	**1107**
Cost Increase Cargo Handling Productivity	*0*
Average Penalty Fee	**4010**
Decisions Costs	**5117**

As a result the company has to bear an additional cost of $5117 per rotation by undertaken this strategy to avoid delays. The result of the cost penalty function in this section in comparison with the scenario of omitting a port under a decision rule gives us a more economically alternative to avoid delays.

6.10 Results and Discussion.

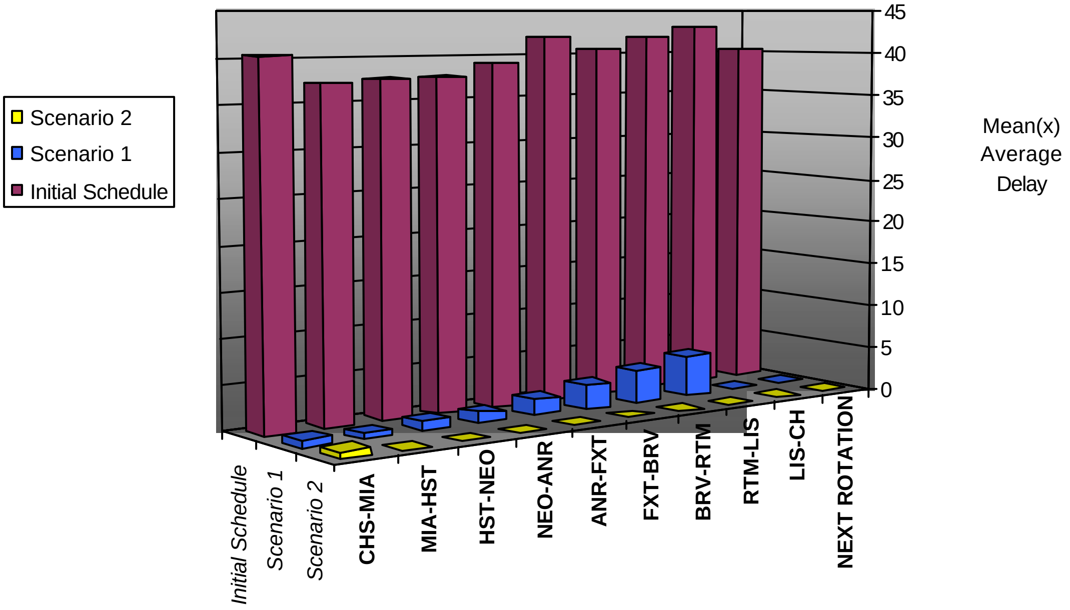
This section presents the results of the simulation process for the four different scenarios where interventions in the initial schedule have been undertaken. These results are compared with the simulation process of the initial schedule. It is should be emphasized that the results of the model are aim to evaluate and thus to improve the robustness of one vessel following its rotation through the calling ports .

Table 6.17 shows the results for the first two scenarios in comparison with the initial a priori schedule regarding the mean ($\bar{X}$) average delay in the arrival times in each port.

Table 6.17 Comparison Scenario 1 & 2

	Initial Schedule	**Scenario 1 Increase Speed**	**Scenario 2 Omit Port**	
	Average Delay	**Average Delay**	**Average Delay**	
VOYAGE	**Mean (hours)**	**Mean(hours)**	**Mean(hours)**	
CHS-MIA	40,3	0,8	0,752	CHS-MIA
MIA-HST	37,2	0,6	0	HST
HST-NEO	37,7	1,0	0	MIA-NEO
NEO-ANR	37,8	1,2	0	NEO-ANR
ANR-FXT	39,1	1,9	0	FXT
FXT-BRV	41,9	2,7	0	ANR-BRV
BRV-RTM	40,5	3,6	0	BRV-RTM
RTM-LIS	41,9	4,7	0	RTM-LIS
LIS-CH	43,3	0,0	0	LIS-CHS
NEXT ROTATION	40,3	0,0	0	Next Rotation
Average Penalty Fees	17950	4990	*370*	
Decision Costs	**17950**	**14734**	**356980**	

Figure 6.3 Average Delay Initial Schedule, Scenario 1-2



Therefore the scenario referring to the decision of the planner not to call two ports gives us the more robust solution. The schedule of the vessel can perform fairly well under the occurrence of external influences whilst the fastness of the system to respond in deviating conditions and damped them out is relatively high. However this solution leads to a higher value of the cost penalty function. In the scenario where the interventions in the nominal speed have been undertaken has also a significant impact in the schedule robustness. However delays still occur. Correspondingly, a delay is building up in the

second part of the voyage due to the imbalances of the buffer time assigned in the planning process. Moreover the value of the cost penalty function is relatively small. As a result the higher the value of the cost penalty function the higher the degree of the schedule robustness leading to an extra cost the company that has to bear and via versa.
Moreover the results of the decision to increase the speed are positively correlated with the planned buffer time. The higher the buffer time the higher the robustness of the schedule under these decisions. In addition another significant observation corresponds to the fact that the buffer time is less between voyages where the distances are not so long. Thus for the ports in Europe that are close to each other, the planner has incorporated less buffer time. However under adverse weather and port conditions the influnceability of the system is higher and more vulnerable resulting to delays. Apparently the decision maker in relatively close distances is trying to push further down the buffer time to avoid idleness of the ship. However this logic seems not to function fairly well.

On the contrary given the time slots in different ports an increase in the buffer time in order to improve the performance of the schedule directly implies the need of reduction in the network nodes. This also has been proved from the second scenario by omitting ports. On the other hand the planner utilizing the simulation model can make adjustments in the nominal speed in different stage of the rotation without interventions in the buffer time for the seek of the optimal or close to optimality robust solution. In our case we have just examined the scenario of increasing the maximum speed the vessel can attain in one stage of the rotation. The intention was to illustrate the functioning of the simulation model. Depending on the companies objectives further adjustments can be made of the speed and in different rates leading to better results.

Accordingly in the scenario of omitting a port the penalty marketing factors that have been assigned is relatively high rather than in other ports. Thus lead us to the conclusion that the higher the penalty marketing factor the higher the value of the cost penalty function and correspondingly higher level of the schedule robustness. Also in the decision to omit a port depending on the low risk and high risk intervals of delays that we have assigned it is evident that ports close to each other constitute better solution as potential ports to be omitted. This can be attributed to the fact that the buffer time in close to each other ports are less. As a result this solution seems to deliver fairly well the objective of increasing the robustness of the schedule considering that the roll on cost of the non delivered containers can be reduced in comparison with the opposite case.

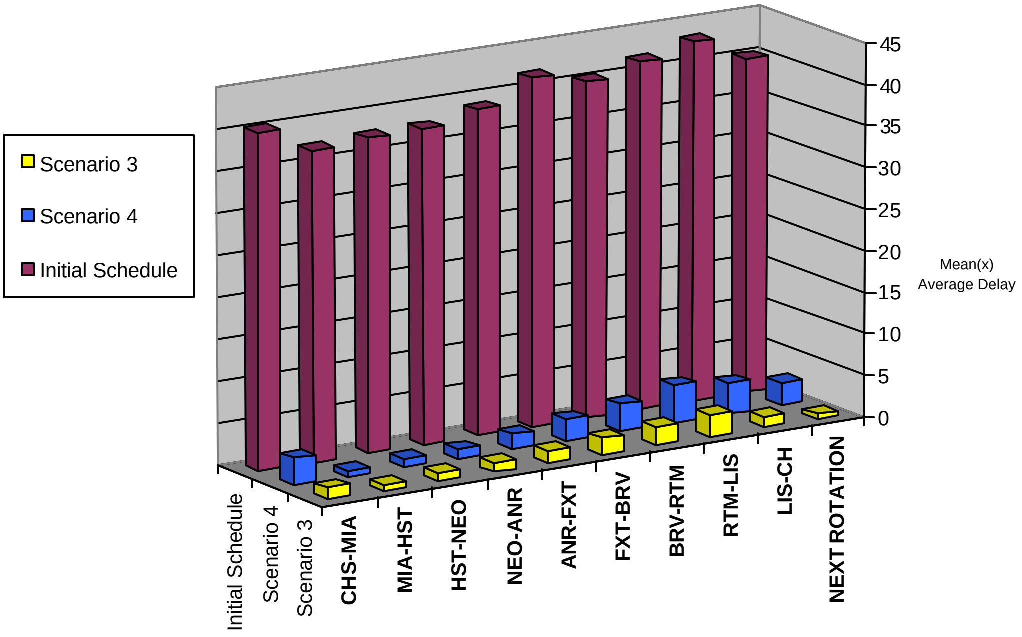
Finally we can observe a reduction in the average penalty fees in comparison with the base case simulation process where the second scenario results prevails the results of the first scenario. Moreover we conclude in a significant observation that a schedule that considered being optimal without taking into consideration the aftermath of adverse weather and port conditions does not mean that is less costly or more profitable than a robust one. This can easily proved by the fact that the cost of increasing the speed which also improves the robustness of the schedule is less costly than the initial schedule. The penalty fees the company has to pay in the terminal operators per rotation is slightly higher than the decision to increase the speed in order to improve the robustness.

Regarding the scenarios developed under a decision rule where a threshold amount of delays determine whether to increase speed/omit a port are presented in the following table.

Table 6.18 Comparison of the Initial Schedule with Scenario 3-4

	Initial Schedule	**Scenario 3 Omit Port**		**Scenario 4 Increase Speed**	
	Average Delay	Average Delay	Probability Omit Port	Average Delay	Probability Increase Speed
VOYAGE	**Mean(Hours)**	**Mean(hours)**	**Mean**	**Mean(hours)**	**Mean**
CHS-MIA	40,3	1,388	0,027	3,263	0,184
MIA-HST	37,2	0,657	0,005	0,619	0,013
HST-NEO	37,7	0,985	0,025	1,045	0,029
NEO-ANR	37,8	1,090	0,033	1,043	0,026
ANR-FXT	39,1	1,559	0,054	1,808	0,068
FXT-BRV	41,9	1,942	0,074	2,538	0,121
BRV-RTM	40,5	2,238	0,079	3,333	0,000
RTM-LIS	41,9	2,644	0,097	4,509	0,000
LIS-CH	43,3	1,357	0,028	3,722	0,138
NEXT ROTATION	40,3	0,562		2,702	
Average Penalty Fees	17950		7400	4010	
Decision Co.	**17950**		**35841**	**5117**	

Figure 6.4 Average Delay Initial Schedule, Scenario 3-4



Interpreting the statistics above we can infer that the scenario of skipping a port in a dynamic way leads to a relatively higher degree of the schedule's robustness in comparison with the scenario increasing the speed. Whereas the value of the cost penalty function per rotation is much higher than the later scenario. However in both scenarios we cannot achieve the situation of zero delays due to the threshold of delay that we applied in the simulation run. Moreover we can also observe as in the case of the two previous scenarios that the buffer time assigned in the different stage of the rotation is positively related with the robustness of the schedule. Thus the both scenarios are following the same direction in terms of robustness where imbalances of the a priori buffer time influences the robustness level of the schedule. The higher the buffer time the higher the robustness of the schedule.

In addition we can postulate that the best results in the scenario of skipping a port are attributed to the fact that the port does not call the port and thus avoids first the loading/unloading process and second the port conditions delays that may occur in the skipped port. In the central assumption we have assumed that the cargoes will be transferred in the consecutive ports while the terminal operator will assign extra cranes to speed up and have no impact in the port with the respect costs, which we have take into account as roll non cost of the containers. Thus the time profits are much higher than increasing the speed where the vessel has to load/unload in each consecutive port.

Due this situation in the scenario of increasing the speed under a decision rule we can observe that the vessel after it calls at the port of ANR where the cargo is second in volume, the average delay is building up with a higher grade rather than case of omitting a port. In other words as the vessel the will skip the above port in some of the 50 consecutive rotation avoiding also possible delays that may occur in this port can achieve higher robustness of schedule .

Comparing the two sets of scenarios of skipping a port in dynamically and statically way a contradiction exists on the decision which port to skip. Based on the statistical results, the dynamically scenario indicates the port of LIS and the Port of RTM as the ones to be omitted or the ones that in 50 consecutive rotations congregate the higher probability to be skipped. On the contrary we have suggested in the static application of the model the ports HST and FXT. However this difference is attributed to the fact that the distances in the dynamic scenario does not change as the vessel take the decision to skip the port after the arrival time. Moreover the approach by assigning low and high amount of risk intervals to make inferences based on the average delay which port to omit, takes into account the performance of the schedule without interventions where a delay propagates in a higher degree as the vessel executes the schedule. For that reasons we avoid to go through this comparison.

Chapter VII - Concluding Remarks and Future Research

The expansion of international trade over the last few years through the globalization process has triggered the demand for more efficient maritime services. Into this quest new challenges have to be met by the shipping companies in terms of efficient schedules and routes of the vessels. However maritime transportation and especially liner shipping mode of operation constitute distinctive transportation systems dominated by a number of features different form the other transportation systems. Correspondingly modeling such a system in order to develop a decision aiding tool requires the consideration of the specific factors that this mode involves.

Towards this direction a simulation model of a liner shipping schedule has been developed. The objective of such model is to evaluate the robustness of a schedule and provide alternatives that will enhance the ability of the schedule to perform fairly well in the event of unforeseen deviating conditions. Although the space that describes the problem of the liner shipping schedule may be straightforward clarified instead it is an evident truth that involves a high degree of complexity.

Designing a shipping schedule designated by solidness and fastness with which can response and damped out schedule deviations is a multifarious problem. Hence by imitating the operation of the schedule process in order to estimate the effect of changes in the parameters that influence the performance of the schedule is imperative to understand how the system behaves. As a result the simulation model was developed to facilitate this purpose by simulating a liner shipping operations and evaluating the performance metrics of the schedule. Through this approach decision makers can test the robustness of a shipping schedule and achieve a feasible one under the occurrence of external disruptions.

The results obtained from the model application in an explanatory case study provide an indication of the simulation model potentiality to be developed as an efficacious and supplementary tool for the designing of more quality shipping schedules. As such, by intervening in the initial schedule through alternatives namely, skip a port of the vessel's rotation and increase in the nominal speed four scenarios was constructed juxtaposed with the initial planned schedule.

The four scenarios can be divided into two sets where the first two refer to a static application of the model as interventions applied in all simulations runs. In the second set the last two scenarios illustrate a dynamic application of the model in the concept that the model decides during the executions of the rotation either to skip or not a port or to increase or not the speed

Both of the two sets of scenarios can be used in interchangeable manner. The planner can test the robustness of the schedule by intervening in static way and compare them with the dynamic application of the model and via versa. However this comparison must incorporate also the objective the company wants to achieve in order to derive the optimal or close to optimality feasible schedule in the event of adverse weather and port conditions.

In addition intervention must be undertaken considering the view push or pull of the service provision execution of the company. Therefore depending on the way-reactive or speculative of the customers demand-the company provides services, the planner will decide which alternative will be undertaken. Therefore for example as soon as demand is known in advance the decision of skipping a port in order to improve the reliability of the schedule to catch the "profitable" customer is more justifiable and effortlessness. On the other hand on a speculative view of the customers demand, increasing the speed, in order to offer services in greater geographical coverage, is more supportable approach.

Moreover a cost penalty function is introduced in order to develop an evaluation tool of the alternatives examined in the four scenarios. Without having in mind to construct an appropriate tool for the total cost computation of the route, the cost penalty function and its components aims to deliver a view of the trade-off amongst the total cost of a route and alterations of the schedule in order to enhance its robustness.

Given the planned buffer time, from the computational results a positive correlation has been detected among the interventions and the planned buffer time. On the other hand a critical point observed refers to the fact that a planner's intention to assign the minimum buffer time in ports located close to each other is not the advisable one. Disruptions that may occur during these stages of the rotation reduce the robustness of the schedule even when interventions in the initial schedule have been made.

In addition the results obtained showed that the robustness of the schedule can be improved achieving the condition of zero or close to zero delays by skipping a port. Similarly the robustness of the schedule has been improved while increase in the nominal speed has been decided. Albeit the first case may give us better results in terms of robustness the value of the cost penalty function designates more economically the application of the later case. However an additional cost the company has to bear for the improvement of the schedule robustness does not mean that this schedule will lead to lower profitability in comparison with the optimal one. Albeit a schedule that is considered as optimal but does not take into account the shipping schedule performance in the event of disturbances may result to lower profits rather than a robust schedule. In principal the conclusions that can be made from the results of the four scenarios are as such:

- The robustness of the schedule improved vertically by skipping ports in comparison with the initial a priori schedule describing that the buffer time is not adequate. However increase of the planned buffer time directly implies reduction in the size of the network which is also the case of a skipping a port justifies. Ports close to each other are the main source of delay as the buffer time calculated in the planning process does not enables the schedule to damp out disturbances that may occur. The decision to skip port dynamically and randomly during the execution of the schedule improves the robustness of the schedule but in a less degree rather than applying a static alteration of schedule in the concept that the alteration is applied in all simulation runs.

- Increasing the speed as an alternative also improves the robustness of the schedule. Less expensive but with more influenceability to external distributions. Positive relation has been detected through this intervention between robustness and the assigned buffer time. Thus redistribution of the planned buffer time in the stages where inadequate buffer time enables delays to build up is required.
- The value of cost penalty function is positively correlated with the robustness of the schedule. However the initial schedule seems to be less profitable regarding the penalties fees due to delays rather than undertaken the decision to increase the speed.
- The higher the marketing penalty factor in the port we skipped the higher the robustness. This is justifiable in our case as the penalty factor has been assumed regarding the cargo volumes. Thus cargo volumes and robustness are positively correlated. The higher the cargo volumes in a port we skip the higher the robustness of a schedule. Therefore in order to serve a customer with a high cargo volume (which may also be a profitable customer) it is more advisable to skip two ports with low volume cargoes.
- A schedule that is considered as optimal without taking into account the aftermath of adverse weather and port conditions may be less profitable than a robust one.

Regarding which alternative can be considered as the optimal one, simulation as a tool is not an optimization technique. Instead is a facsimile of a real situation where an experiment in different configurations of this situation is conducted in order to find a solution close to the optimal one. Therefore depending on the company's perception a close to optimality solution is the one that corresponds to the company's aims. In addition our approach delivers the performance and evaluation of a schedule believed to be optimal under the occurrence of disturbances. Through this concept shipping companies can apply our approach for evaluating the robustness of a perspective schedule and thus to incorporate this technique to confront with external disturbances into the strategic level of planning.

Problems of the Model and Future Enhancements

Apparently one on the major drawbacks of the developed simulation model is the assignment by experimental judgment of the probability distributions that describe the weather and port time conditions delays. Moreover we have considered as processes only the voyage and port time whereas the pilotage time the vessel needs to enter and departure of the port has not been explicit analyzed. Those events in the daily operation constitute significant sources of delay. In our model we assumed their impact in the probability distribution but we have not knowledge of their real impact. In addition the costs of the different interventions have been also assumed. This as a result reduces the validity of the cost penalty function.

In the dynamic application of the interventions we considered that the decision of the vessel to skip a port is taken after the vessel has arrived in the calling port and depending on the delay the vessel skips or not the port. Therefore questions can be posed regarding the fact that the vessel can change direction in the middle of the voyage and head for the consecutive one where savings can be aroused due to shorter distances. On the other hand we assume as an intervention in the nominal speed the maximum speed. Robustness can also be achieved by increasing the speed in different stages and with different rate.

However one of the significant advantages of the model is that has been constructed in an Excel spreadsheet where its simplicity enables the use of the model by more people. Moreover the simulation process is controlled by a table which contains all the required data for the model implementation. This control table is connected with other external calculation regarding alterations in distances and speed as well as the cost that these actions involve. Therefore updates in the control table automatically update the simulation run and the value of the cost penalty function. As a result an inbuilt flexibility to accommodate additional endogenous and exogenous processes characterizes the model whilst regarding the data availability different course of events can be examined Thus standardization has been achieved permitting the general use of the model in the evaluation of other schedules.

However future enhancements must be incorporated for a more integrate and validate development of the model. Under this notion an explicit analysis of the simulation events and their impact constitute a prerequisite for the model improvement. Weather condition delays and port conditions delay to be detailed researched and the real probability distribution of those events to be found. Whilst the impact of correlation has to be contemplated. As the vessel may encounter a storm in the space of an ocean there is high probability that the vessel floating in the same ocean/or body of water to call a consecutive port to encounter the same bad weather conditions. In addition another suggestion is to divide the voyage from an origin to a destination into stages. Through this approach and regarding the results of delays in each stage it will enable decisions to be taken for alterations of the nominal speed in the next stage of the voyage or decisions to the skip consecutive port the vessel is heading to. Thus potential savings of shorter distances as well as of fuel consumption can improve the results of the cost penalty function suggesting a more economically robust scheduling approach.

A further suggestion refers to development of a decision rule where depending on the amount of delay, the model can decide the appropriate additional knots in the nominal speed the vessel must attain in the next stage and thus to be on schedule in the next destination. This approach will also indicate the need for the deployment or not of faster vessels. Also as we have developed two sets of scenario it will be appealing to demonstrate a hypothesis test for making inferences about the population mean of the average delay between the interventions in a static and dynamic approach that the scenarios suggest in order to make inference about the validity of the interventions that we undertake in the static approach.

In addition it will be interesting to model the schedule of the whole fleet. This will give us the flexibility to skip ports without bearing high costs by assigning the cancelled task to another vessel of the fleet. In addition this triggers the research of the new trends in liner shipping such as mergers and alliances that upshot to enormous fleets generating the need for the design of new networks. Further will be worthwhile to investigate the ramification of the nowadays extensive order books of new buildings and analyze in the scheduling process the impact of the situations where new vessels are added once in a while in the fleet. And if we considered also the deployment of large containerships, bunkering and other scheduled task such as security process of the containers, maintenance and etc and their impact are some further thoughts that have to be incorporated in the generation of quality schedule.

Finally a more elaborative extension of the model is to take decisions aligned with the schedule of the ports, terminal operators and other parties involved. Thus modeling the whole network it will give us the flexibility to rifle through all the alternatives of available berth time windows in cases of delays and through the appropriate interventions to achieve higher degree of robustness with less costs effects. Through this approach will be also justifiable to make adjustments in the planned buffer in order to find the optimal one as the flexible berth time windows will permit increases of the buffer time without the need of reducing the size of the network.

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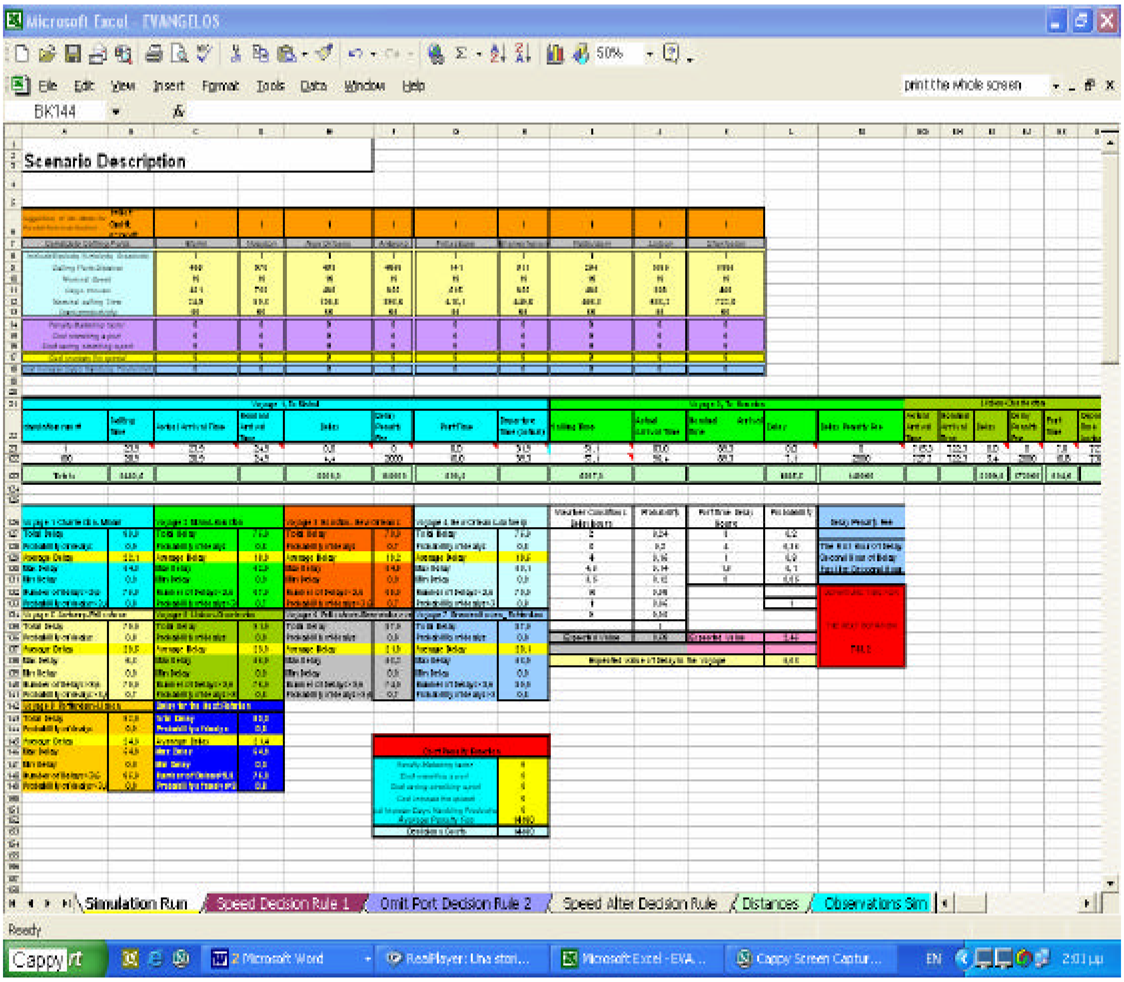
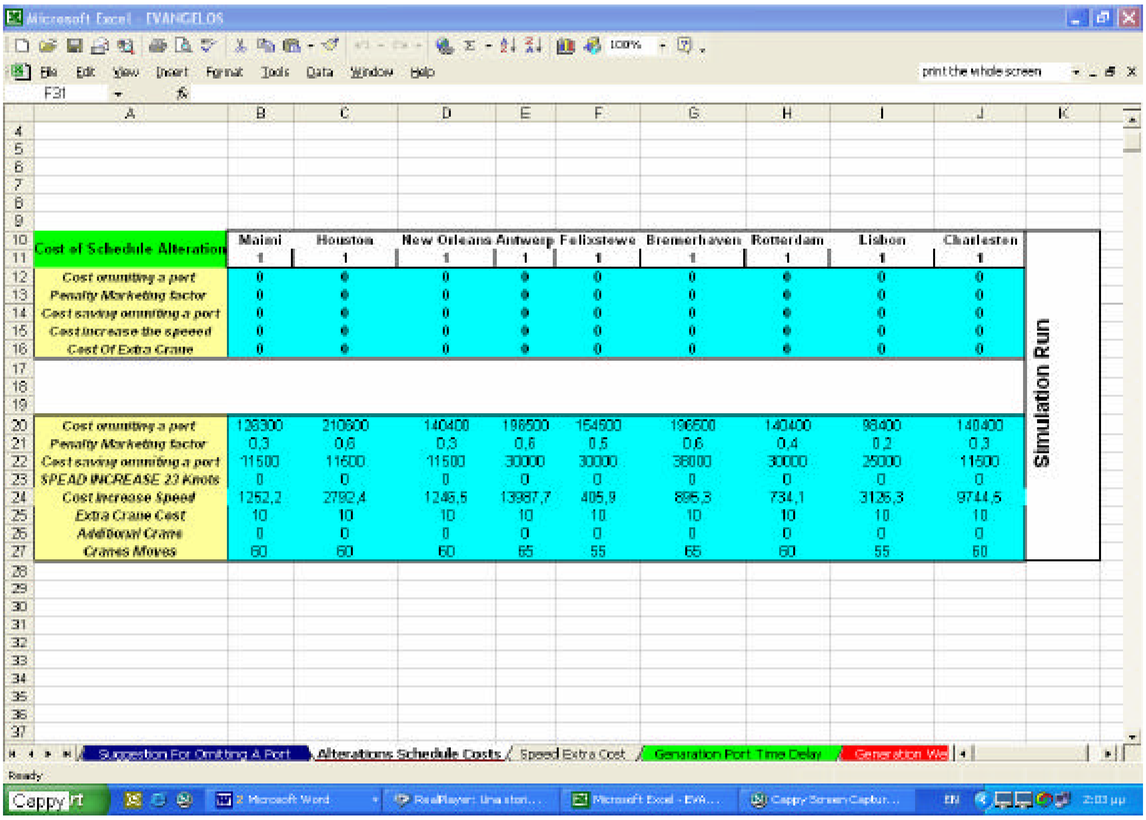
Appendix 1

In the following figure the Excel Spreadsheet of the Simulation process is presented:



The data are presented in the control table in the first rows of the spreadsheet. In the following rows the simulation run are presented. Note that the simulation trials and some of the voyages the vessel executes as part of the rotation are hidden so that the spreadsheet can be shown in a reasonable size. Then the performance metrics of the simulation runs for each individual port and for the next rotation are shown. There also we can find the results of the cost penalty function, the probability distribution of the weather conditions and port conditions delay. The control table is connected with other external calculation regarding the distances , the speed and the cost of alterations in speed in order every time we apply any intervention in the initial schedule to update the control table and the cost penalty function while this updates are applied in the simulation runs. The external calculations the control table is connected to are shown below:

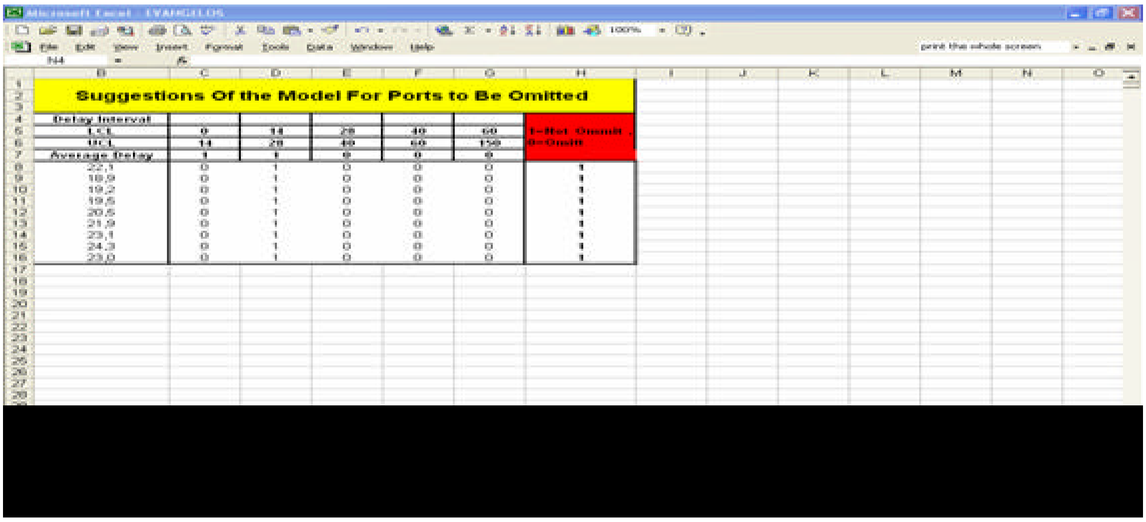
The spreadsheet that refers to the costs of alterations in the initial schedule is showed below: This spreadsheet is connected with the control table in the main spreadsheet where if we enter 0(omit port) this spreadsheet calculates the costs and updates the control table. The same stands also for the speed and the cargo handling productivity



Cost of Schedule Alteration	Maimi	Houston	New Orleans	Antwerp	Felixstewe	Bremerhaven	Rotterdam	Lisbon	Charleston
	1	1	1	1	1	1	1	1	1
Cost ommiting a port	0	0	0	0	0	0	0	0	0
Penalty Marketing factor	0	0	0	0	0	0	0	0	0
Cost saving ommiting a port	0	0	0	0	0	0	0	0	0
Cost increase the speeed	0	0	0	0	0	0	0	0	0
Cost Of Extra Crane	0	0	0	0	0	0	0	0	0

Cost ommiting a port	128300	210800	140400	196500	154500	196500	140400	98400	140400
Penalty Marketing factor	0,3	0,6	0,3	0,6	0,5	0,6	0,4	0,2	0,3
Cost saving ommiting a port	11500	11600	11500	30000	30000	38000	30000	25000	11500
SPEAD INCREASE 23 Knots	0	0	0	0	0	0	0	0	0
Cost increase Speed	1252,2	2792,4	1246,5	13987,7	405,9	895,3	734,1	3126,3	9744,5
Extra Crane Cost	10	10	10	10	10	10	10	10	10
Additional Crane	0	0	0	0	0	0	0	0	0
Cranes Moves	60	60	60	65	55	65	60	55	60

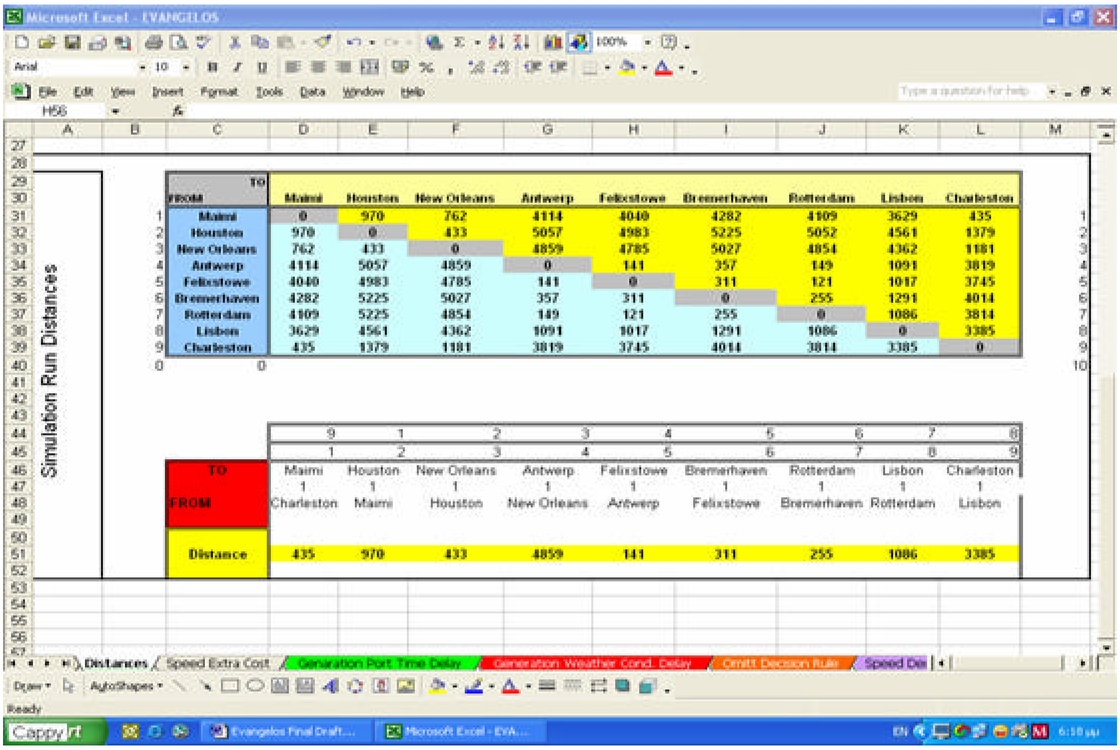
The following spreadsheet is connected with the average delay of the performance metrics of the simulation runs. Every time that the average delay falls in the interval with high risk amount of delay is recorder as potential port to be omitted and updates the table in the first row in the main spreadsheet of the simulation run as a suggestion of the model for port to be omitted.



Suggestions Of the Model For Ports to Be Omitted

Delay Interval						1=Not Omit , 0=Omit
LCL	0	14	28	40	60	
UCL	14	28	40	60	150	
Average Delay	1	1	0	0	0	
22,1	0	1	0	0	0	1
18,9	0	1	0	0	0	1
19,2	0	1	0	0	0	1
19,5	0	1	0	0	0	1
20,5	0	1	0	0	0	1
21,9	0	1	0	0	0	1
23,1	0	1	0	0	0	1
24,3	0	1	0	0	0	1
23,0	0	1	0	0	0	1

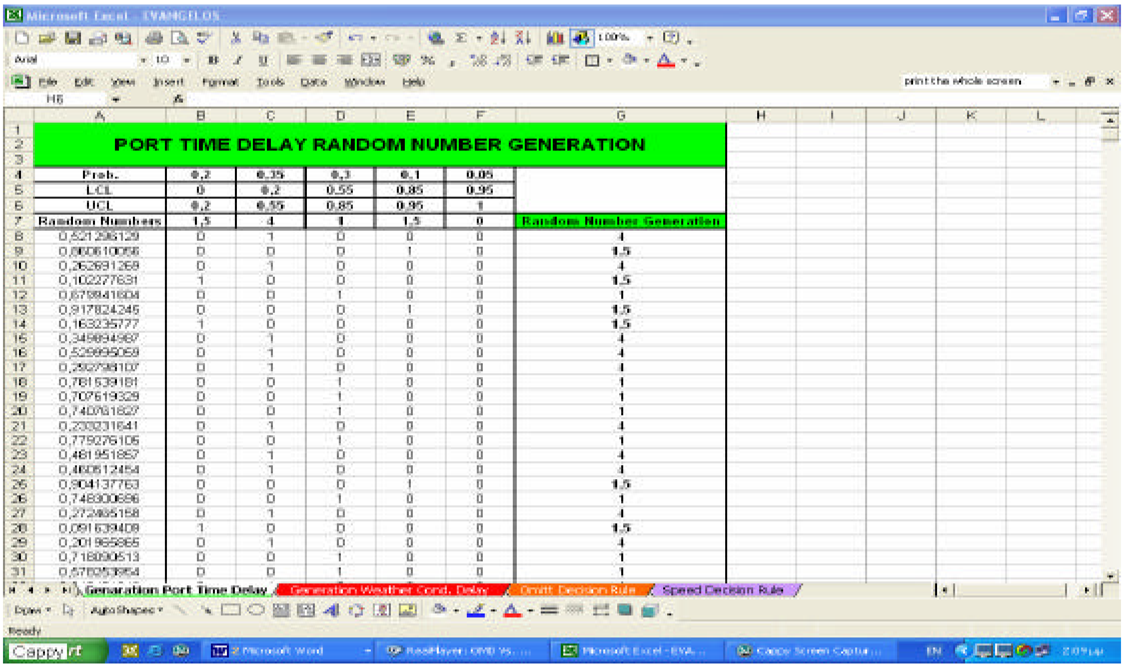
In the following spreadsheet we have calculated the distances between the ports so every time that we skip a port by the assigning 0 in the control table in the main spreadsheet this spreadsheet updates the control table with the new distance and so the simulation runs are executed with the new distances:



	FROM \ TO	Maimi	Houston	New Orleans	Antwerp	Felixstowe	Bremerhaven	Rotterdam	Lisbon	Charleston	
1	Maimi	0	970	762	4114	4040	4282	4109	3629	435	1
2	Houston	970	0	433	5057	4983	5225	5052	4561	1379	2
3	New Orleans	762	433	0	4859	4785	5027	4854	4362	1181	3
4	Antwerp	4114	5057	4859	0	141	357	149	1091	3819	4
5	Felixstowe	4040	4983	4785	141	0	311	121	1017	3745	5
6	Bremerhaven	4282	5225	5027	357	311	0	255	1291	4014	6
7	Rotterdam	4109	5225	4854	149	121	255	0	1086	3814	7
8	Lisbon	3629	4561	4362	1091	1017	1291	1086	0	3385	8
9	Charleston	435	1379	1181	3819	3745	4014	3814	3385	0	9
0	0										10

	9	1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8	9
TO	Maimi	Houston	New Orleans	Antwerp	Felixstowe	Bremerhaven	Rotterdam	Lisbon	Charleston
	1	1	1	1	1	1	1	1	1
FROM	Charleston	Maimi	Houston	New Orleans	Antwerp	Felixstowe	Bremerhaven	Rotterdam	Lisbon
Distance	435	970	433	4859	141	311	255	1086	3385

The spreadsheet below presents the random number generation of port conditions delays:

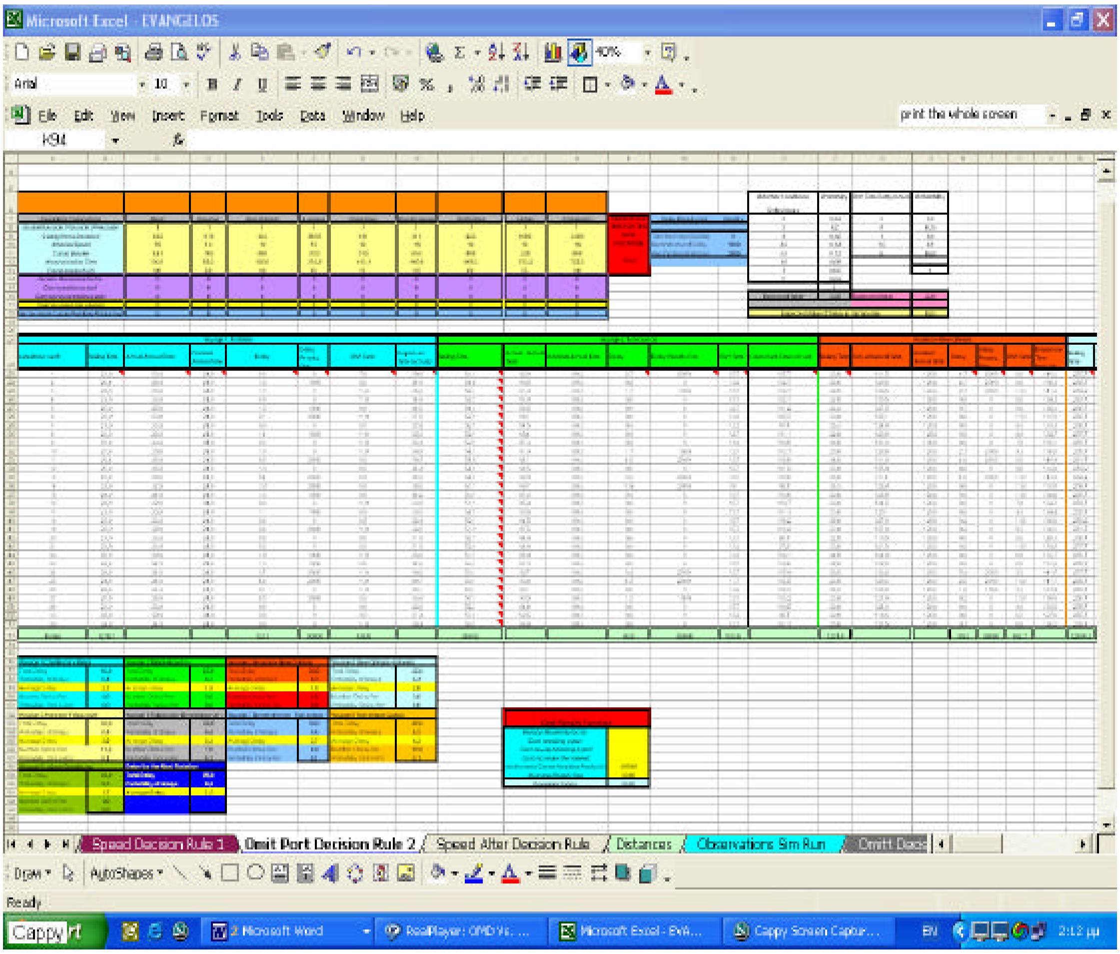


PORT TIME DELAY RANDOM NUMBER GENERATION

Prob.	0,2	0,35	0,3	0,1	0,05	
LCL	0	0,2	0,55	0,85	0,95	
UCL	0,2	0,55	0,85	0,95	1	
Random Numbers	1,5	4	1	1,5	0	Random Number Generation
0,521296129	0	1	0	0	0	4
0,860610056	0	0	0	1	0	1,5
0,262691268	0	1	0	0	0	4
0,102277631	1	0	0	0	0	1,5
0,679941604	0	0	1	0	0	1
0,917824245	0	0	0	1	0	1,5
0,163235777	1	0	0	0	0	1,5
0,345894987	0	1	0	0	0	4
0,529995059	0	1	0	0	0	4
0,292798107	0	1	0	0	0	4
0,781539181	0	0	1	0	0	1
0,707619329	0	0	1	0	0	1
0,740761827	0	0	1	0	0	1
0,230231641	0	1	0	0	0	4
0,779276106	0	0	1	0	0	1
0,481951857	0	1	0	0	0	4
0,460612454	0	1	0	0	0	4
0,904137763	0	0	0	1	0	1,5
0,748300696	0	0	1	0	0	1
0,272465158	0	1	0	0	0	4
0,091639408	1	0	0	0	0	1,5
0,201965865	0	1	0	0	0	4
0,718090513	0	0	1	0	0	1
0,578053954	0	0	1	0	0	1

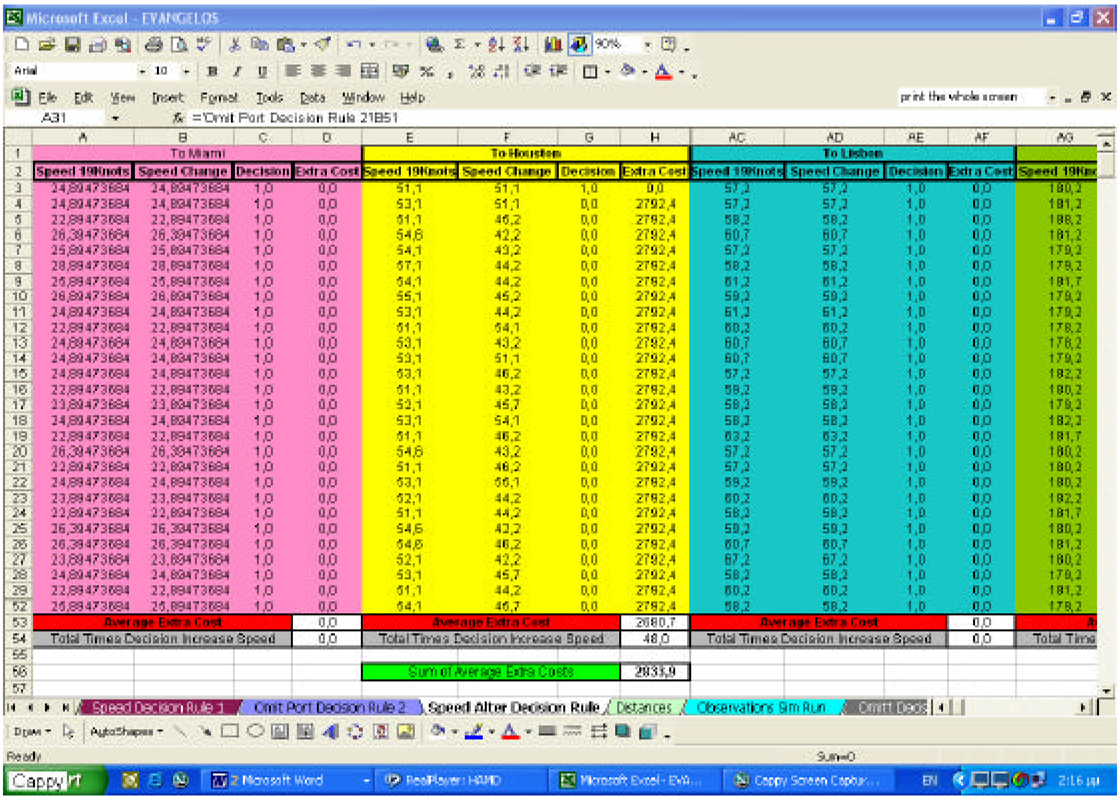
In the first column we have the generation of random number from 0 to 1 and depending in which interval the random number falls in, give us the hours of delays due to port time conditions. This port delay is transferred in the simulation run while each simulation run is connected with a different random number that the Excel spreadsheet generates. Note that these intervals represent t the probability distributions that we have assign for the port time delays. We have also constructed a same spreadsheet for the weather conditions delay.

The following spreadsheet represents the scenario for omitting a port under a decision rule. A same spreadsheet has been constructed for the scenario increase speed under a decision rule. It is the same spreadsheet as the one for the initial schedule but in the simulation runs we have applied the decision rule.



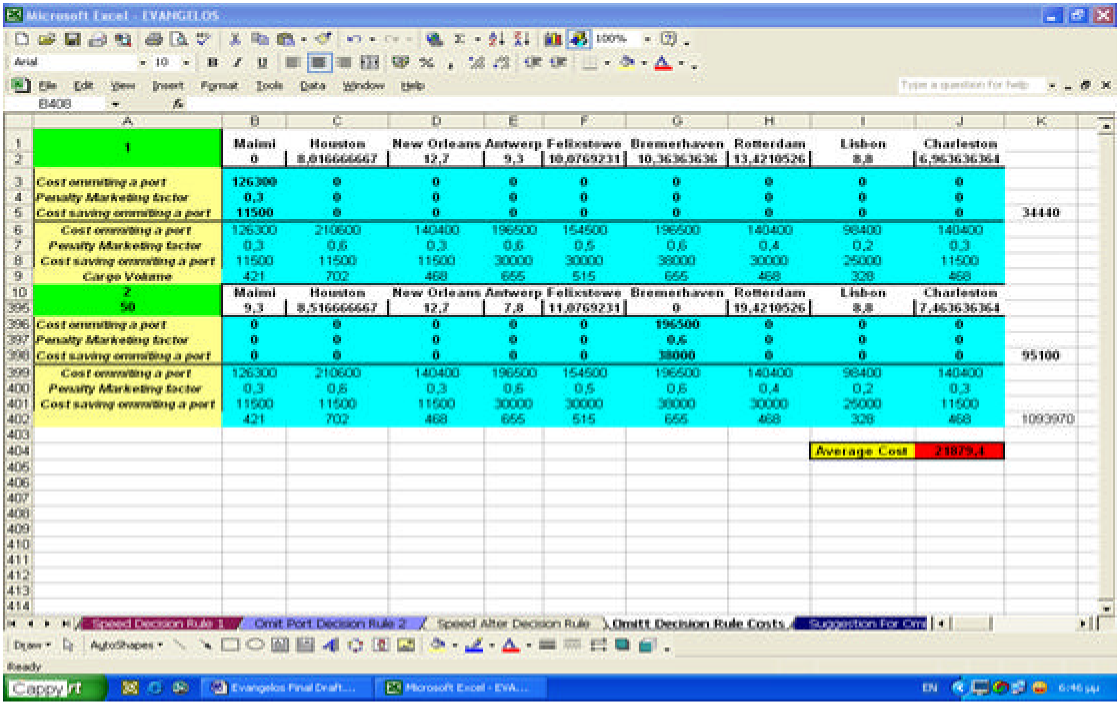
This spreadsheet is also connected with the spreadsheet showing below in order to calculate the costs every time the vessel skips a port or increases the speed.

The following spreadsheet represents the calculations of the costs for increasing the speed of the vessel in dynamic way. This spreadsheet is connected with the simulation runs and every time that the vessel increases the speed directly gives us the costs. In sequence This spreadsheet is connected with in the main spreadsheet of the simulation run under a decision rule to update the cost penalty function. Note that some of the simulation trials have been hidden.



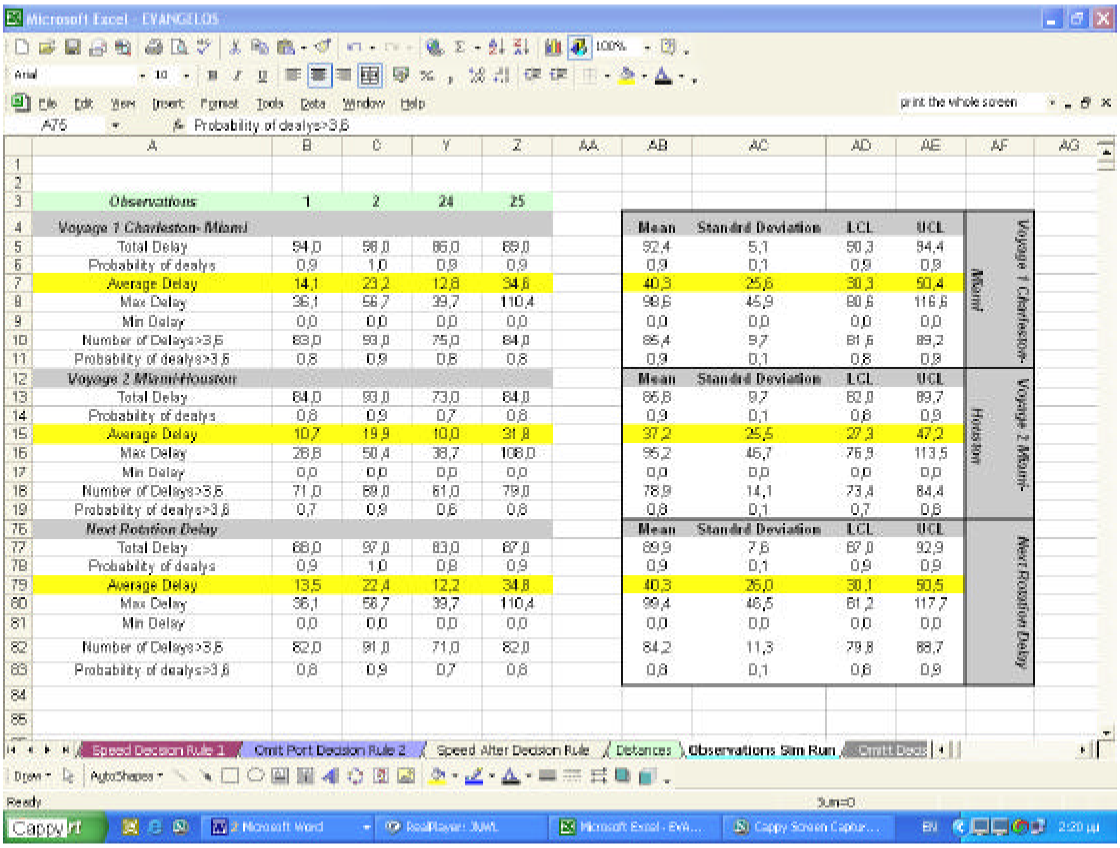
	A	B	C	D	E	F	G	H	AC	AD	AE	AF	AG
1	To Miami				To Houston				To Lisbon				
2	Speed 19Knots	Speed Change	Decision	Extra Cost	Speed 19Knots	Speed Change	Decision	Extra Cost	Speed 19Knots	Speed Change	Decision	Extra Cost	Speed 19Kn
3	24,89473684	24,89473684	1,0	0,0	51,1	51,1	1,0	0,0	57,2	57,2	1,0	0,0	180,2
4	24,89473684	24,89473684	1,0	0,0	53,1	51,1	0,0	2792,4	57,2	57,2	1,0	0,0	181,2
5	22,89473684	22,89473684	1,0	0,0	61,1	46,2	0,0	2792,4	58,2	58,2	1,0	0,0	188,2
6	26,39473684	26,39473684	1,0	0,0	54,6	42,2	0,0	2792,4	60,7	60,7	1,0	0,0	181,2
7	25,89473684	25,89473684	1,0	0,0	54,1	43,2	0,0	2792,4	57,2	57,2	1,0	0,0	179,2
8	28,89473684	28,89473684	1,0	0,0	57,1	44,2	0,0	2792,4	58,2	58,2	1,0	0,0	179,2
9	25,89473684	25,89473684	1,0	0,0	54,1	44,2	0,0	2792,4	61,2	61,2	1,0	0,0	181,7
10	26,89473684	26,89473684	1,0	0,0	55,1	45,2	0,0	2792,4	59,2	59,2	1,0	0,0	179,2
11	24,89473684	24,89473684	1,0	0,0	53,1	44,2	0,0	2792,4	61,2	61,2	1,0	0,0	179,2
12	22,89473684	22,89473684	1,0	0,0	61,1	54,1	0,0	2792,4	60,2	60,2	1,0	0,0	178,2
13	24,89473684	24,89473684	1,0	0,0	53,1	43,2	0,0	2792,4	60,7	60,7	1,0	0,0	178,2
14	24,89473684	24,89473684	1,0	0,0	53,1	51,1	0,0	2792,4	60,7	60,7	1,0	0,0	179,2
15	24,89473684	24,89473684	1,0	0,0	63,1	46,2	0,0	2792,4	57,2	57,2	1,0	0,0	182,2
16	22,89473684	22,89473684	1,0	0,0	61,1	43,2	0,0	2792,4	59,2	59,2	1,0	0,0	180,2
17	23,89473684	23,89473684	1,0	0,0	52,1	45,7	0,0	2792,4	58,2	58,2	1,0	0,0	179,2
18	24,89473684	24,89473684	1,0	0,0	53,1	54,1	0,0	2792,4	58,2	58,2	1,0	0,0	182,2
19	22,89473684	22,89473684	1,0	0,0	61,1	46,2	0,0	2792,4	63,2	63,2	1,0	0,0	181,7
20	26,39473684	26,39473684	1,0	0,0	54,6	43,2	0,0	2792,4	57,2	57,2	1,0	0,0	180,2
21	22,89473684	22,89473684	1,0	0,0	51,1	46,2	0,0	2792,4	57,2	57,2	1,0	0,0	180,2
22	24,89473684	24,89473684	1,0	0,0	63,1	56,1	0,0	2792,4	59,2	59,2	1,0	0,0	180,2
23	23,89473684	23,89473684	1,0	0,0	52,1	44,2	0,0	2792,4	60,2	60,2	1,0	0,0	182,2
24	22,89473684	22,89473684	1,0	0,0	51,1	44,2	0,0	2792,4	58,2	58,2	1,0	0,0	181,7
25	26,39473684	26,39473684	1,0	0,0	54,6	42,2	0,0	2792,4	59,2	59,2	1,0	0,0	180,2
26	26,39473684	26,39473684	1,0	0,0	54,6	46,2	0,0	2792,4	60,7	60,7	1,0	0,0	181,2
27	23,89473684	23,89473684	1,0	0,0	52,1	42,2	0,0	2792,4	67,2	67,2	1,0	0,0	180,2
28	24,89473684	24,89473684	1,0	0,0	53,1	45,7	0,0	2792,4	58,2	58,2	1,0	0,0	179,2
29	22,89473684	22,89473684	1,0	0,0	51,1	44,2	0,0	2792,4	60,2	60,2	1,0	0,0	181,2
52	26,89473684	26,89473684	1,0	0,0	54,1	46,7	0,0	2792,4	58,2	58,2	1,0	0,0	178,2
53	Average Extra Cost			0,0	Average Extra Cost			2880,7	Average Extra Cost			0,0	A
54	Total Times Decision Increase Speed			0,0	Total Times Decision Increase Speed			48,0	Total Times Decision Increase Speed			0,0	Total Time
55													
56					Sum of Average Extra Costs			2833,9					
57													

In the following spreadsheet we have the cost for the case that the vessel skips a port under a decision rule. Each trial in the main spreadsheet is and each port is connected with this spreadsheet and in the case in the case of a skipping calculates the cost and updates the cost penalty function in the main spreadsheet



	A	B	C	D	E	F	G	H	I	J	K
1	1	Malmi	Houston	New Orleans	Antwerp	Felixstowe	Bremerhaven	Rotterdam	Lisbon	Charleston	
2		0	8,016666667	12,7	9,3	10,0769231	10,36363636	13,4210526	8,8	6,963636364	
3	*Cost ommiting a port*	126300	0	0	0	0	0	0	0	0	
4	*Penalty Marketing factor*	0,3	0	0	0	0	0	0	0	0	
5	*Cost saving ommiting a port*	11500	0	0	0	0	0	0	0	0	34440
6	*Cost ommiting a port*	126300	210600	140400	196500	154500	196500	140400	98400	140400	
7	*Penalty Marketing factor*	0,3	0,6	0,3	0,6	0,5	0,6	0,4	0,2	0,3	
8	*Cost saving ommiting a port*	11500	11500	11500	30000	30000	38000	30000	25000	11500	
9	*Cargo Volume*	421	702	468	655	515	655	468	328	468	
10	2	Malmi	Houston	New Orleans	Antwerp	Felixstowe	Bremerhaven	Rotterdam	Lisbon	Charleston	
395	50	9,3	8,516666667	12,7	7,8	11,0769231	0	19,4210526	8,8	7,463636364	
396	*Cost ommiting a port*	0	0	0	0	0	196500	0	0	0	
397	*Penalty Marketing factor*	0	0	0	0	0	0,6	0	0	0	
398	*Cost saving ommiting a port*	0	0	0	0	0	38000	0	0	0	95100
399	*Cost ommiting a port*	126300	210600	140400	196500	154500	196500	140400	98400	140400	
400	*Penalty Marketing factor*	0,3	0,6	0,3	0,6	0,5	0,6	0,4	0,2	0,3	
401	*Cost saving ommiting a port*	11500	11500	11500	30000	30000	38000	30000	25000	11500	
402		421	702	468	655	515	655	468	328	468	1093970
403											
404									Average Cost	21879,4	
405											
406											
407											
408											
409											
410											
411											
412											
413											
414											

In the following spreadsheet the observations and the calculations for the confidence interval estimator of the population mean of the average delay are presented:



	A	B	C	Y	Z	AA	AB	AC	AD	AE	AF
1											
2											
3	*Observations*	1	2	24	25						
4	***Voyage 1 Charleston- Miami***						**Mean**	**Standard Deviation**	**LCL**	**UCL**	Voyage 1 Charleston- Miami
5	Total Delay	94,0	98,0	86,0	89,0		92,4	5,1	90,3	94,4	
6	Probability of dealys	0,9	1,0	0,9	0,9		0,9	0,1	0,9	0,9	
7	Average Delay	14,1	23,2	12,8	34,6		40,3	25,6	30,3	50,4	
8	Max Delay	36,1	56,7	39,7	110,4		98,6	45,9	80,6	116,6	
9	Min Delay	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	
10	Number of Delays>3,6	83,0	93,0	75,0	84,0		85,4	9,7	81,6	89,2	
11	Probability of dealys>3,6	0,8	0,9	0,8	0,8		0,9	0,1	0,8	0,9	
12	***Voyage 2 Miami-Houston***						**Mean**	**Standard Deviation**	**LCL**	**UCL**	Voyage 2 Miami- Houston
13	Total Delay	84,0	93,0	73,0	84,0		85,8	9,7	82,0	89,7	
14	Probability of dealys	0,8	0,9	0,7	0,8		0,9	0,1	0,8	0,9	
15	Average Delay	10,7	19,9	10,0	31,8		37,2	25,5	27,3	47,2	
16	Max Delay	28,8	50,4	38,7	108,0		95,2	46,7	76,9	113,5	
17	Min Delay	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	
18	Number of Delays>3,6	71,0	89,0	61,0	79,0		78,9	14,1	73,4	84,4	
19	Probability of dealys>3,6	0,7	0,9	0,6	0,8		0,8	0,1	0,7	0,8	
76	***Next Rotation Delay***						**Mean**	**Standard Deviation**	**LCL**	**UCL**	Next Rotation Delay
77	Total Delay	88,0	97,0	83,0	87,0		89,9	7,6	87,0	92,9	
78	Probability of dealys	0,9	1,0	0,8	0,9		0,9	0,1	0,9	0,9	
79	Average Delay	13,5	22,4	12,2	34,8		40,3	26,0	30,1	50,5	
80	Max Delay	36,1	56,7	39,7	110,4		99,4	46,5	81,2	117,7	
81	Min Delay	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	
82	Number of Delays>3,6	82,0	91,0	71,0	82,0		84,2	11,3	79,8	88,7	
83	Probability of dealys>3,6	0,8	0,9	0,7	0,8		0,8	0,1	0,8	0,9	
84											
85											