Title

Distributed scheduling policy to coordinate activities of companies in a port

Abstract

Nowadays, organizations understand the value of the relations between different supply chain entities and focus on integration and coordination of business process. Finding a coordination system to achieve better alignment is a complex task, particularly when there is no trusted authoritative entity. One of the coordination problems in logistic area is scheduling the dock-derricks service, provided by terminal companies in the port, to service the barge companies. The aim of the thesis is to estimate the efficiency of various decentralized scheduling strategies by means of average waiting time to achieve better coordination and association among barges and terminals. To coordinate the process of loading/unloading cargoes, different scheduling policies are evaluated through utilizing the agent-based modeling and simulation. The conceptual model is designed through literature review. Then the model is implemented in Java code using Repast platform. The model includes three types of agents namely terminal, port, and barge agents. These agents interact with each other to simulate the business processes of a port. The simulation program is implemented by considering stochastic (i.e. interruption is assumed) and deterministic (i.e. no interruption) modeling of the activities. This thesis compares two approaches to schedule the dock-derrick services, namely cooperative and non-cooperative approaches. Different experimental settings are considered using multilevel factorial design. The significant difference between these settings is tested statistically using ANOVA and Univariate test. The result of simulation shows that in deterministic model the cooperative policy with ‘no’ gap time may reduce the average waiting time significantly under different levels of crowd. In stochastic model, when there is high arrival rate, two settings showed same level of efficiency. First ‘no’ gap time with non-cooperative policy and second half an hour gap with cooperative policy. However, with half an hour time gap, barge can be planned more efficiently as it is more probable to be departed earlier than planned time. Moreover, in stochastic model when the arrival rate is medium/low, result of data analysis suggested cooperative policy with ‘no’ gap time is an efficient setting. However, at this setting the average amount of delay and variation from the planned departure time is higher. Increasing the amount of gap time may results in better planning at the expense of more waiting time.

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1 Introduction

During the past, organizations used to put their effort to optimize their internal business process. Nowadays, organizations understand the value of the relations between different supply chain entities. Therefore, they focused on integration and coordination of business process amongst supply chain entities. Nevertheless, alignment of organizations business process involves information exchange or resigning governance over some of the internal processes. This makes alignment not an easy decision as mistreatment can risk companies' competitiveness in market place (Chaib-draa & Muller, 2006).

Entities in a supply chain have to reach an acceptable level of alignment. Finding a coordination system to achieve alignment of the operations is a complex task for the supply chain entities, particularly when there is no trusted authoritative entity. The coordination should enable collaboration and guaranty the interest of each independent entity (Kanda & Deshmukh, 2008). Traditional way of optimizing business processes concerned improving particular objective. This is also referred as centralized optimization, which involves combining objectives of all entities into one objective. This become more complex as all members of supply chain should reach a consensus about the degree of equilibrium and the influence of centralized optimization on their interests (Sadeh, et al., 1998). Moreover, the entities in the supply chain usually refuse centralized coordination system, through trusted authoritative entity, as it may risk their competitiveness in the market (Sadeh, et al., 1998). As a result, introduction of a distributed coordination system can be an alternative solution.

As introduction of multi-agent based modeling, study on distributed coordination system has increased. Multi-agent modeling can facilitate distributed planning and coordination in various fields of study. However, little effort has been put on multi-agent based modeling of business processes and comparing its performance with traditional mathematical modeling and optimization (Chaib-draa & Muller, 2006).

1.1 Background

According to the WorldBank, over the past few years port's traffic has increased from 200 million to 600 million containers per year. This obligates terminal operators in the port and container ships to focus on efficiency and cost effectiveness (Stahlbock & Voß, 2008). Currently, Mathematical models are employed to evaluate efficiency of different scheduling policies and rules.

One of the problems in logistic area is scheduling the dock-derrick service, provided by terminals in the port, to service the barges. The giant container ships, which are loaded with almost 18000 containers, cannot pass the canals. They have to find a port close to the hinterland to unload their cargoes. From there barges take cargoes to the final destination (Schuur, et al., 2009). As the use of barges is cost-efficient and environmental friendly, ports start to use them more and more (Port-of-victoria, 2015). However, the barges have to spend lots of time in port, as the scheduling policy is not preeminent (Miller, et al., 2004). Efficient handling of the barges needs better coordination between barge and terminal companies (Konings, 2007).

As it stated earlier, to align the activities of companies in the port, barges need to book time slots in advance. However, terminals do not have integrated information system to share and coordinate their schedules. Moreover, several companies own the barges. Unfortunately, booking time slots is only possible through direct personal contact, which causes inefficiency and lots of waiting time. The barge starts to call each terminal, which want to stopover, to find the best order of visit with smaller waiting time. This way of working requires making appointment at least one day before entering the port (Kentrop, et al., 2003). However, this way of making appointments can cause uncertainty, increase of idle time and unproductive utilization of resources (Hillegersberg, et al., 2005; Kentrop, et al., 2003).

Moreover, such uncertainty can cause some unacceptable behavior. Barges may book more time slots than they need, so if they missed first appointment, they will have a second chance. Sometimes barges declare less number of containers to book appointment that is more suitable. To deal with such unacceptable behaviors, terminals make waiting line to avoid inactive times. Such issues cause more complex alignment and conflict (Kentrop, et al., 2003).

This brief overview illustrates incompetent and disorganized alignment process. Kentrop, et al. (2003) argue about centralized coordination system through an authorized party to harmonize operations of independent companies. The authors believe that the centralized solution failed as companies are hesitant for information sharing and losing their independence (Kentrop, et al., 2003). Kentrop, et al. (2003) provide an example to centralized coordination system in which terminals make their timetable available via internet. Kentrop, et al. (2003) argue that the barge companies were satisfied with the solution, however, terminal companies complained about the solution as it brought more cost than value added.

Study conducted in 2004 suggests decentralized coordination mechanism instead of centralized one (Miller, et al., 2004). Miller, et al. (2004) use multi agent technology to enable booking of time slots with shortest queuing time prior to the actual arrival. Such decentralized approach shown improvement in planning and coordinating operation of companies.

This thesis focus on coordination and harmonization of the barges and terminals business process in a situation that actors will collaborate only if certain conditions are met to guaranty the interest of each independent company.

1.2 Problem

Efficient handling of the barges needs better coordination between barge and terminal companies (Konings, 2007). To align and coordinate the activities of companies in the port, they need to agree upon possible service time in advance. This requires establishment of an integrated information system to share and coordinate their schedules (Kentrop, et al., 2003). Current approaches to coordinate the activities of companies in the port include direct personal contact, web-based scheduling, authorized party, and multiagent system.

Some problems make these approaches inefficient. Direct personal contact is proven inefficient due to human error, lots of waiting time, and possibility of strategic behavior

(Hillegersberg, et al., 2005; Kentrop, et al., 2003). Centralized coordination system through an authorized party failed as companies are hesitant for information sharing and losing their independence (Kentrop, et al., 2003). Moreover, web-based scheduling and making terminals timetable available via internet brought more cost than value added (Kentrop, et al., 2003). Miller, et al. (2004) provide decentralized coordination mechanism and used multi agent technology to enable booking of time slots with shortest queuing time prior to the actual arrival. However, the system does not allow for real time update if any changes in the plan happen during arrival to the port. Lack of support for real time operation made system incapable of dealing with dynamism in the system (Delfmann & Koster, 2007).

The system proposed by Miller, et al. (2004) has following drawbacks; first, Miller, et al. (2004) focus is just to design a practical planning system, but not optimal one. Second, the system does not allow for real time update if any changes in the plan happen during arrival to the port. Third, negotiation protocol is not efficient, as agents need to exchange large number of message. Forth, any mechanism against strategic behaviors is not introduced. Finally, there is no simulation and experimental result about the performance of the system. More detail about Miller, et al. (2004) system can be found in *section 2.4*.

Schuur, et al. (2009) introduce a multi agent solution that seems considering and solving the problems of Miller, et al. (2004) decentralized coordination mechanism. However Schuur, et al. (2009) do not considered possibility of the interruption in service that may occur due to technical problem in derrick, delay in providing cargos documentations, late arrival of deep see container-ships, delay in releasing cargos from customs (Kentrop, et al., 2003). In addition, Schuur, et al. (2009) do not provide any inferential statistic analysis to test the significance difference between various experimental settings.

Section 1.2 was a brief overview on the coordination problem and drawback of proposed ways to improve the performance. The players mostly due to losing autonomy reject a centralized coordination system. On the other hand, decentralized solution suggests much better and feasible way to work out the problem. However, it failed to deal with real time demand, dynamic nature of the problem, possibility of the interruption, and possible strategic behaviors. Low level of alignment can lead to inefficiency and increase in total cost of the business. This in turn can cause losing attractiveness of barges as an alternative transportation solution, which is more environmental friendly. Considering the problem of finding decentralized and efficient solution to schedule and coordinate the business process of companies in the port (i.e. efficient scheduling policies to load/unload containers with less queuing time) and current achievement in solving the coordination problem among the companies in a port, the research question is formulated as follow:

What is an efficient distributed scheduling policy considering dynamism and possibility of the interruption?

The efficiency can be estimated based on number of barge that has been serviced during a specific period as well as total time of inactivity in simulated environment.

1.3 Purpose

The purpose of this thesis is to present a multiagent scheduling system for the container port and to assess various decentralized scheduling strategies to achieve better coordination and association among barges and terminals.

Moreover, the purpose is to present an efficient decentralized solution to schedule and coordinate the business process of the companies in a port. Real time processing, minimum number of message exchange between agent, and reducing the inactivity time can be described as efficiency of the system.

In other word, the aim of thesis is to evaluate performance of different queuing policy and time gap. The goal of queuing policy is to reduce the waiting time, and including extra time gap in timetable aim to make the timetable more flexible in case of unpredicted incidents. However, more flexibility may increase the waiting time. This necessitates finding a trade-off between flexibility and waiting time.

1.4 Goal

The goal is to achieve better coordination and association among barges and terminals by suggesting efficient scheduling approach so to make marine transportation more organized and attractive option. The barges companies are regarded as a customer of the terminal companies. Dissatisfied barges, due to the long idle time, will seek other terminals with better service quality (Vollmann & Davis, 1990). Moreover, considering barges as cost-efficient and environmental friendly way of transportation, it may become less attractive due to lots of delay and misalignment. The goal of this thesis is to help companies in a port to improve their utilization degree by reducing the queuing time.

1.4.1 Ethics and sustainability

The ethic corresponds to a set of codes of right behavior during the research process. It provides a guideline to judge the righteousness or immorality of researchers' action (Gregory, 2003).

During the research, the attempt is to represent data without any manipulation and misrepresentation. False justification to impose the desired result is absolutely avoided and objectivity in the experiment is the main concern. Throughout the whole research process, the aim is to provide a truthful report of the results so it can be used by stakeholders to make informed decision on how to the coordinate activities among the companies in a port. Moreover, every part of the research that are from others work is referenced explicitly. To assure the quality of the research, all assumptions, used methodology, data collection procedure, and data analysis method is discussed in detail along with discussion about validity and reliability of the research. These can help readers to judge the reliability of the report. Finally, to ensure correct choice of methodologies, and reduce the bias in data collection and interpretation critical review of examiner, supervisor, and other students are considered carefully.

The other ethical issue concerns companies that may want to implement the solution that is presented in this thesis. Implementing a multiagent system to perform scheduling may cause unemployment of human operators. To deal with this issue companies need to consider training of the human operators so they can work in other position.

The other important issue is sustainability. Sustainability is responsibility to make future of business and society safe. Efficient alignment of business processes of companies that involve transportation of goods can reduce the logistic costs. The cost reduction and economical sustainability can be achieved through efficient scheduling of the container ships, which in turn can result in improving the utilization degree, less waiting time, and less full consumption. On the other hand finding solution to improve coordination of companies in a port can make the waterway transportation more popular. Shipping goods through the waterway is an environmental friendly and a green solution as the ships can transport large amount of products with lower full consumption and total carbon footprint. The water transportation does not need construction of roads, which mostly involves destroying the nature. The waterway logistic can also improve the safety in society as it can reduce the probability of the massive accidents caused by trucks. Therefore, the result of this thesis can help to optimize and organize the activities of companies in a port or other companies with similar problem and make this kind of transportation more efficient, which in turn can improve societal, economical, and environmental sustainability of the logistic.

1.5 Methodology

Research can be considered as systematic and scientific way of investigation to gain knowledge on a certain area. Research involves clarifying problem, formulation of hypothesis, data collection, and analysis to test the hypothesis, and finally reporting the result. Following these steps, the research can contribute to existing body of knowledge (Kothari, 2004). In conclusion, the research can be seen as systematic method of looking for information to solve a defined problem (Kothari, 2004). Research methods comprise techniques for carrying out research operations and research methodology is about systematical problem solving thorough following various steps. Therefore, it is essential to be familiar with both research techniques and the scientific approaches, which is known as methodology (Kothari, 2004).

Two general choices in doing research are quantitative and qualitative methods (Cresswell, 1994). In the quantitative research methods, which are originated from natural science, the aim is to collect data objectively through, for example, experiment, or mathematical modeling (Cresswell, 1994). Qualitative research methods, on the other hand, concerns study of complex social phenomena to gain a holistic view that is formed with words. Qualitative data can be collected through, for example, observation, interview, or documents (Cresswell, 1994). Saunders, et al. (2012) also introduce a mixed methods approach, in which both quantitative and qualitative data collection and analysis techniques can be adopted in the research in parallel or sequential to get benefit of both approaches.

This thesis benefits from mixed approach by collecting qualitative data about the current business processes and requirements to determine the basic for multi agent based modeling and defining the appropriate behavior of the agents. This helps to model the system and define different settings and assumptions that are close to the real world situation. In this step, data collection solely relies on secondary data collection and critical reviewing of existing documents to get an in-depth view about the situation under the study. After designing the model the performance of the proposed multi-agent model is evaluated under different settings and scheduling policies. In this step, quantitative data, which is generated through simulation, is analyzed by using inferential statistics methods to deduce the result about efficiency of different policies.

1.5.1 Research approach

Every research engages using theory that can be made either explicitly or implicitly in the research design. The extent of theory clarity at the beginning of the research indicates whether the study should follow deductive or inductive approach (Saunders, et al., 2012). Deductive reasoning starts with a theory, then narrowing it down to an operationalizable and testable hypothesis. In final step researcher needs to test the operational hypothesis using appropriate research strategy such as experiment, action research, case study. After testing the hypothesis, it may be necessary to modify the theory based on the obtained results (Saunders, et al., 2012). On the other hand, in the inductive reasoning researcher starts from collecting data and trying to find a pattern in data through carefully analyzing data in order to develop a theory (Robson, 2002).

The other way of doing research is abductive approach (Saunders, et al., 2012). Deductive reasoning starts from theory to data and inductive reasoning starts from data to theory, whereas abductive reasoning moves back and forth. In fact, abductive approach is combination of inductive and deductive approaches. Abductive reasoning starts with observing facts then finding out reasonable theory about how the observed fact may have taken place (Saunders, et al., 2012).

Axelrod (2003) considers simulation as an alternative way of doing science in contrast with deduction and induction. The simulation approach that is adopted in this thesis starts like a deductive reasoning by considering set of assumption in terms of agent rules and behaviors. However, simulation does not aim to confirm and test the theory. A simulation produces data that can be analyzed by researcher inductively. However, it differs from inductive reasoning as data comes from set of predefined rules for the agents (i.e. scheduling policies) rather than observation of real world. Simulation helps to find the pattern in the data, which is produced under different assumptions and settings, inductively. Afterwards effect of each setting on the efficient planning and coordination of activities among the companies in a port can be deduced.

The business process in a port is complex to be studied analytically through mathematical modeling due to heterogeneous behavior in the system. Multi-agent based modeling allows modeling such behaviors (Axelrod, 1987). It is also impossible to perform field experiment due to ethical issues as the experiment may risk the companies' interest. In such situation, the simulation and especially agent-based modeling can be seen as an aid intuition to realize and explain real world situation (Dinther, 2008). The simulation allows having control over the variables to reproduce different situations (Dinther, 2008). Variables such as busy/quiet port, interruption in process of moving containers, etc can be controlled in order to study and describe variation in total inactivity time of the barges by comparing different scheduling policies.

1.6 Delimitation

Some issues are not subject matter of this thesis and can be investigated in another research. To have a steady system the agents must be monitored and prevented for showing strategic behaviors. This requires investigating of probable strategic behaviors and suggesting a way to detect occurrence of such behavior. Moreover, after detecting occurrence of the strategic behavior it is necessary to introduce a fair and feasible fining system.

When an autonomous agent decides to perform an action on behalf of human operator, then the operator should have trust and confidence on agent's action and be convinced that what is done is the best option and could not be performed in a better way. This thesis does not aim to prove that suggested solution is the best possible one. There is always possibility of finding another way of scheduling that is more efficient.

Another issue that is not addressed in this thesis is degree of customizability of the agents. This is the case when companies would like to have more power over their agent and add some more functionality such as giving highest priority to load/unload containers' that belong to a certain customer. This necessitates defining extent of liberty that could be given for customizing the agent design. The extent of autonomy can vary from no customization, custom configuration, or full customization of agent's functionalities. When investigating the degree of

1.7 Outline

The summary of each section can be described as follow. Section 2 describes business situation, requirements, and objective of the companies. Sections 2.3 through 2.5 studies problem of centralized planning and then two different decentralized systems are discussed. Section 2.5 also includes detailed discussion about the agents' objectives and mathematical model that is applied for the purpose of this thesis. Section 2.6 describes algorithm that is used to find the shortest traveling path for the barges. Section 3 gives a theoretical discussion about the multi-agents characteristics and properties. Section 4 is discussion about the research method that is applied to the thesis. It includes the modeling process of the simulation, data collection and data analysis methods, as well as discussion about the applied research strategy. This section ends with discussion about quality assurance of the thesis. Section 5 describes interaction protocol among the agents along with difficulties to realize some of the agent's properties (section 5.3). Section 5.4 is reflection about the proposed interaction protocol among the agents. Section 6 describes implemented agent model along with the flowchart of the agents' activities. This section also contains assumptions and settings that are used to run the simulation. Section 7 represents the outcome of the simulation and result of the data analysis. Finally, section 8 is end of the report, which includes answer to the research question, discussion about the limitations and suggestions for further work.

2 Design choices and analysis

To model the system it is essential to develop understanding about the business situation. This section provides brief overview about the hinterland shipment problem as well as the business environment and activities of companies in a port. This section also explains business objective of the companies, key performance indicators that must be assessed as well as describing indicators that is used in this thesis. Then some of the related articles in area of decentralized scheduling are reviewed critically. This will help to design a conceptual model that is close to real world context. Moreover, Time dependent vehicle routing problems (TDVRP) is introduced as an algorithm to find the shortest traveling route.

2.1 Overview of the business operation

One of the operations in logistic area is scheduling the dock-derrick service, provided by terminals in the port, to service the barges. The giant container ships, which are loaded with almost 18000 containers, cannot pass the canals. They have to find a port close to the hinterland to unload their cargoes. From there barges take cargoes to the final destination (Schuur, et al., 2009). However, the barges have to spend lots of time in port, as the scheduling policy is not preeminent (Miller, et al., 2004).

Efficient handling of the barges needs better coordination between barge and terminal companies. Upon arrival of barges to a port, they need to book time slots with several terminals to load/unload the containers. The available time slots are based on serviceability of the terminals. The serviceability relies on number of waiting cargo ships, available resources in the terminal, and efficient employment of existing resources (Konings, 2007).

As it stated earlier, to align the activities of companies in the port, barges need to book time slots in advance. It must be consider that several companies own the barges. Unfortunately, booking time slots is only possible through direct personal contact, which causes inefficiency and lots of waiting time. The barge starts to call each terminal, which want to stopover, to find the best order of visit with smaller waiting time. This way of working requires making appointment at least one day before entering the port

(Kentrop, et al., 2003). However, the appointments cannot be always guaranteed as (Hillegersberg, et al., 2005; Kentrop, et al., 2003):

- Workers mistake and assigning the same time for different barges
- As barges book time slots at a number of terminals, any problem, such as late arrival, lack of enough labor, or downtime of a derrick, can affect the timetable of others.
- Arrival time is not always accurate so terminals have to keep their derrick booked, while they could serve other customer in the waiting queue.

These issues can cause uncertainty and increase of idle time and unproductive utilization of resources (Kentrop, et al., 2003). Moreover, such uncertainty can cause some unacceptable behavior. Barges may book more time slots than they need, so if they missed first appointment, they will have a second chance. Sometimes barges declare less number of containers to book appointment that is more suitable. To deal with such unacceptable behaviors, terminals make waiting line to avoid inactive times. Such issues cause complexity in alignment and possibility of conflict (Kentrop, et al., 2003).

One of the performance criteria for the barges is to have less and steady idle time. The main causes of increase in idle time are non-stationary waiting time and service time. To reduce the effect of such ambiguity, barges have to position shipments with same delivery destination side by side. This, on the other hand, reduces the efficiency and necessitates more slack in timetable as it may become necessary to reposition the cargoes. All these together at the end will cause reduction in number of trips and so increase of tariff (Konings, 2007).

The performance criteria for the terminals can describe as improvement in the efficiency of resources allocation and exploitation. The ambiguity and volatility in barges' timetable cause inefficient planning and more inactive time in the terminals. Inefficient planning leads to ambiguity in the other processes such as piling containers at the terminal dockside (Konings, 2007). For example, think about a situation in which barge had to change its visiting order. Sometimes this leads to lack of space to load containers from one of the terminals. Now terminal is in trouble of figuring out how to ship these containers on time (Konings, 2007).

2.1.1 Barge companies: objective and concerns

The key objective of barge companies is to reduce the risk of interruption in each round trip and leave the port in earliest possible time (Kentrop, et al., 2003). There are different reasons that may cause interruption in the planned timetable, as follow (Kentrop, et al., 2003):

- Impractical timetable: for example duplication in the booking times, two visits at the same time, or lack of enough slack in the terminals' schedule. These in addition to other problem during the round trip (e.g. technical problem) can cause unsteady arrival/departure times to/from terminals.

- The speed of loading/unloading containers is directly depends on speed and number of available dock-derricks. Moreover, the speed of derricks varies and it is not possible to guarantee full speed all the time. This will lead to ambiguity in both amount of time, which is required to load/unload certain number of containers and estimation of exact waiting time in the queue.

- As any barge need to stopover at a number of terminals, so any disruption in a terminal will affect other terminals and makes planned timetable even more unsteady.

The barge companies may decide to perform some of the actions described below to reduce the effect of mentioned problem (Kentrop, et al., 2003):

- Increasing speed to recover from the delay: This has very little advantage especially in a short traveling distance. On the other hand, increasing the speed can increase the fuel consumption up to 2 times more the fuel consumption with normal speed.

- Positioning shipments with same delivery destination side by side: This solution, on the other hand, can reduce the productivity, as more barges will be needed to carry same amount of containers.

- Adding slack to the timetable: it adds flexibility to the plan, so it is possible to back to the plan in case of occurrence of any interruption. This also has its own disadvantage, as more slack will result in more waiting time.

To realize the purpose of barge companies Hillegersberg, et al. (2005) recommend following indicators to be assessed:

1. To maximize $\frac{number\ of\ batge\ exits\ the\ port\ on\ time}{number\ of\ barge\ exits\ the\ port}$

2. To minimize $avrage\ delay = \frac{total\ delays\ in\ arraival}{number\ of\ barges\ entered\ the\ port}$

3. To minimize Maximum amount of delay

4. To minimize Extra expenses due to late arrival

2.1.2 Terminal companies: objective and concerns

The key purpose of terminal is to improve efficiency of available resources such as dock, derrick, and employees (Kentrop, et al., 2003). Inefficiency can be result of following issues (Kentrop, et al., 2003):

- Barge companies declare quantity of containers either wrong or very late so terminals cannot be well prepared at the time of arrival.

- Technical problem in derrick, delay in providing cargos documentations, late arrival of deep see container-ships, delay in releasing cargos from customs, etc.

To improve the efficiency and deal with mentioned problems terminals may decide to (Kentrop, et al., 2003):

- To make barges waiting in line to reduce their inactivity and so increase the productivity.

- Sometimes they can speed up the derrick movement to improve the productivity.

- In each port, there is a worker pool that allows terminals to hire daily (temporary) labor in case of increase in workload.

To realize the purpose of terminal companies Hillegersberg, et al. (2005) recommend following indicators to be assessed:

1. To increase the periodical turnover
2. To increase number of movement of containers by derrick
3. To trim down average inactive time for the barges
4. To reduce upper limit of barges' inactive time when they are in line

Unexpectedly, the level of productivity and exploitation of available resources is not considered as a performance indicator

The center of attention in this thesis is on average performance of whole system but not a single company. The efficiency of the terminals relies on enhancing the quality of the services given to the barges and reducing their average time of standing in line and so average time that they should spend at the port. The capacity of the terminal is considered constant. Otherwise, we will never know that if changes in productivity were because of variability in capacity or some other dependent variable. For that reason, considering only the barges' performance will also involves the terminals performance.

2.1.3 Important issues in coordination of activities

To figure out a way for coordinating business processes of companies in a port some issues must be considered. These issues include (Kentrop, et al., 2003; Guan & Cheung, 2004; Konings, 2007; Miller, et al., 2004):

- Independency: every company wants to have governance over its business processes.
- Lack of formal liaison: there is no formal written contract among the companies to be used as a leverage to make it compulsory delivering of definite level of service quality.

- Imperfect information exchange: Due to competitive nature of the companies, they are not eager to exchange information that may risk their interest and competitiveness in the marketplace.

- Inconsistence and contradictory business objectives: different independent companies have their own objectives and business strategies that best suits their individual interests. Therefore, an effective and acceptable design can only be achieved by considering each individuals objective.

- Distributed structure: each company has little or no knowledge about business operation of other companies in the port and they can leave or join the system whenever they want. Because of this, the entities in the system can be different companies at any time.

- Affiliation of business processes: Each barge needs to stopover at several terminals at each round trip. Therefore, any interruption and postponement in activities of a certain terminal can negatively influence the activities of other terminals. This may become worse if a barge arrange a timetable in which stop times are too close to each other. Example of probable interruptions include, technical problems, blocked canal due to accident, lack of sufficient labors, missing or delay in preparation of custom documentation, etc.

- Dynamic nature of the problem: the information is not known in advance and turns out to be visible as time goes. Arranging the to-do list of the dock and the barge's round trip in the port need to be prepared with no information about upcoming situation.

- Some of the cargoes must be delivered by barges at an exact time, as they need to be loaded into giant ships for intercontinental transportation.

- Domination: the terminal companies are the one who govern the business environment. They are the one who have agreement with liners to transport cargoes. Therefore, barge companies cannot oblige them for convinced level of service quality. This is allied to Lack of formal liaison as discussed earlier.

These issues must be considered for developing an effective and acceptable solution. When it comes to business environments, effectiveness of the solution seems to be more vital than its efficiency and optimality. However, efficiency itself is difficult to achieve as companies have diverse objectives and are required to decide in a dynamic situation.

2.2 Applied scheduling policies in similar problems

Some of the study areas, which can be applied to the barge scheduling, are dock allocation (Guan & Cheung, 2004; Wang & Lim, 2007), and vessel scheduling (Halvorsen-Weare & Fagerholt, 2010; Siswanto, et al., 2011). However, these studies cannot cover all aspects of barge scheduling and servicing dilemma.

Dock allocation studies consider the problem of optimal assigning of available dock space to vessels with the objective of minimizing total waiting time. However, dock allocation problem cannot be appropriate as:

- Guan & Cheung (2004) and Wang & Lim (2007) assume known arrival and processing time before creating the plan. In this thesis, the arrival time is not always correct. This obligates terminals to consider potential arrivals when planning dock and resource allocation.
- Guan & Cheung (2004) and Wang & Lim (2007) aim to solve the problem in one terminal. However, in this thesis coordination between several terminals must be considered. Business processes of Terminals are co-dependent, since barges need to stopover at a number of terminals.

Researches in area of vessel scheduling problem are also applicable to other logistic problem such as tuck or train scheduling (Halvorsen-Weare & Fagerholt, 2010; Siswanto, et al., 2011). The concern of vessel scheduling is to find optimal solution for assigning cargoes to available vessels that minimize the cost of transportation. It requires satisfying constraint such as, different destinations of each cargo, limited capacity of each vessel, promised delivery time, and servicing all customers in a reasonable time (Halvorsen-Weare & Fagerholt, 2010; Siswanto, et al., 2011). However, the problem addressed in this thesis differs from current articles about vessel scheduling problem.

- The scheduling of the vessels concerns round trip to ports rather than terminals owned by a specific port. At the first look, it may appear related to this work, however, the order in which vessels visit ports mostly depend on geographical location of ports. For planning the barges visiting order, it is essential to consider the availability of docks. However, in case of the vessels scheduling it is assumed that dockside is free for mooring and handling the ship upon its arrival.
- Such studies also assumed static situation and known information prior to planning.

Another related area is attended home delivery problem (Golden, et al., 2008). In home delivery problem, the aim is to improve the service quality by finding the best delivery route and schedule as well as reducing the probability of delivery failure (Golden, et al., 2008). Delivery failure may happen if customer is not at home at the time of delivery. To optimize the situation delivery company must consider a planning that captures preferred delivery time of the customers (Golden, et al., 2008). This can be used for the purpose of this thesis by allowing for many delivery companies as barges and many customers as terminals. Here the aim of customers is to plan delivery time of different carriers as close as possible to each other, so they do not have to stay at home for long time.

Hospital patient scheduling is another research area that is close to our problem. The patients normally need to book appointment at different section of a hospital. These appointments must be made concerning the available time slots at different section of the hospital and trying to reduce the time that patient need to stay at hospital in waiting room (Decker & Li, 1998). The situation seems to be similar to problem area of this thesis; although, there is dissimilarity regarding to the arrival time. The patients' appointment can be variable and delayed to book most suitable time with lower waiting time for them. However, this is not achievable solution, as the barges never agree to wait for days to have a trip in a day with less inactive time.

2.3 Centralized planning

The need for developing information system that enables the alignment and coordination of business processes of different entities in supply chain has became more vital as strategic value of collaboration between companies has been realized (Miller, et al., 2004). Centralized approaches, which concern single objective optimization, normally cannot accomplish a suitable and satisfactory solution. Inefficiency of the centralized approaches can be described as follow (Miller, et al., 2004):

- They have shortage in considering the contradictory interests of independent companies.
- Companies' disapproval to share information, even with an authorized party, as it may risk their competitiveness.
- The environment is not static and the information becomes available dynamically during the process.
- The centralized approach is less efficient and impractical as the problem turn out to be outsized.

On the other hand, a multi-agent system (MAS), which is made of several interrelated agents, aim to solve local or global objectives in distributed manner. It can be used to work out problems that are complicated or unfeasible for an individual agent to solve (Wooldridge, 2009).

2.4 Approach 1: a decentralized planning system

Study conducted in 2004 suggests decentralized coordination mechanism, which is called approach 1, instead of centralized one (Miller, et al., 2004). Miller, et al. (2004) use multi-agent technology to enable booking of time slots with shortest queuing time a day prior to the actual arrival. Such decentralized approach shown improvement in planning and coordinating operation of companies. However, the system does not allow for real time update if any changes in the plan happen during arrival to the port. Lack of support for real time operation made system incapable of dealing with dynamism in the system (Delfmann & Koster, 2007).

Miller, et al. (2004) propos a system in which scheduling begin every day at a certain time for the day after. At that time, the communication protocol is as follow:

1. Barge starts by making set of potential visiting orders and related arrival times (called scenario). However, the algorithm of creating these scenarios is not explained clearly. It is unclear based on what criteria or information the algorithm decides to change the requested timeslot or order of visit to create set of potential plans. As Miller, et al. (2004) mention, planning system need to be run one day in advance and the plan can never be changed afterward (real-time planning if interruption happens just before the booked timeslot) it can be assumed that they implement a search algorithm for a giant search space. Therefore, they need a long time to run the algorithm and no change will be accepted afterward as applying any changes need another day of planning.
2. Then it prioritizes the scenarios. Even though there is no explanation about the prioritization criteria, it seems that a scenario with a smaller interval of start and finish time has a higher priority.
3. After that, it selects a scenario with highest priority and sends booking request along with the estimated arrival time to all terminals in the scenario.
4. Now each terminal checks to see if requested timeslot is available and sending reply to the barge by saying available or unavailable.
5. If any of the terminals sends unavailable message remove the current scenario and back to step three. However, they did not describe what happens if all the scenarios fail. In other word there is no prove of liveness of the scenario creation algorithm and if it eventually succeeds.
6. If all requested timeslots is available end of the planning.

Also instead of numerical experiment and evaluation of the system performance Miller, et al. (2004) just compared the efficiency of planning that is done by agents versus the one performed manually by humans. The human planning resulted in number of mistakes such as, impossible booking time, or late arrival due to incorrect calculation of mooring, handling, and sailing time. The agent system could create a remarkable and practical planning that surprised everyone in test room. However, some mistakes and irrationalities were found in the planning made by agents. The visiting order was in a way that required long time of sailing and lots of fuel consumption that is not acceptable for companies. In addition, some of the participants became worried about their career and possibility of losing their job by introduction of the system. Finally, the participant of the experiment asked for a planning system that allows prioritization of the visiting order so they can give higher priority to load/unload containers that belongs to a certain company.

The result of Miller, et al. (2004) study have shown enhancement in the situation by employing agents to perform distributed planning. Moreover, the companies were interested in implementation of the system in practice.

As it also mentioned before the system is static and not capable of handling dynamic situation. It means that all information requires being static and known one day prior to start of the planning. Although, in the real situation the information becomes available over the time and complete information about the future may not be always available (Delfmann & Koster, 2007). Moreover, the system aims to achieve a practical scheduling instead of the best possible schedule. This not acceptable by stakeholder as they may be able to create a better planning without using the approach 1 system (e.g. the proposed visiting order by the system was in a way that required long time of sailing and lots of fuel consumption). Finally, in the proposed system no synchronization mechanism is introduced. According to the Miller, et al. (2004) report, barge can start to send their scenarios concurrently. For that reason, the terminal has to send reply to the proposals of multiple barges simultaneously. This may leads to a state that all barges must propose next scenario with lower precedence. Sending scenarios simultaneously may lead to a situation that a timeslot ts1, in which an 'unavailable' reply was sent by terminal t1 to barge b2, become available again as the barge agent b1 who made temporary booking of ts1 revoked it.

2.5 Waiting profiles: a multi-agent based scheduling system

To synchronize the business processes of the companies in a port Schuur, et al. (2009) suggest a protocol called waiting profile. Through this protocol, terminals create upper limit of waiting, upon demand from the barge, for each potential entrance time of the barge. By using the upper limit of waiting, the barge can settle on the route with shortest waiting time. In order to add more flexibility to the system Schuur, et al. (2009) suggest adding extra gap between each visit. Schuur, et al. (2009) assume that sailing time between two subsequent terminals and the time that takes to load/unload containers are deterministic. In other word, they did not considered possible interruption during these activities. Through the rest of this section, the model of Schuur, et al. (2009) will be discussed further and example of their model's application will be presented. The model suggested by Schuur, et al. (2009) is also used for the purpose of this thesis.

2.5.1 Model

Schuur, et al. (2009) employ the agent based modeling, which consist of agents that functions on behalf of barge companies (we refer to this agent as BA) and terminal companies (we refer to this agent as TA). Schuur, et al. (2009) model is the one that is used in this thesis. The model includes waiting profile that provides information about upper limit of waiting, upon demand from the BA, for all likely entry time of the barge. The TA is considered as an agent with reactive property that only reacts to the BA request of issuing upper limit of waiting. On the other hand, the BA is considered as an agent with proactive property that can calculate the best route of visit with shortest possible inactivity time. The outcome of the communication protocol is settlement of an appointment that both parties have agreed upon it. The chain of events can be summarized as follow:

1. The BA asks for the upper limit of waiting from all of the terminals it needs to stopover at them to load/unload cargoes.
2. The TA replies by sending the upper limit of waiting, for all likely entry time of the barge.
3. Based on received information from step 2 the BA calculates the best route of visit with shortest possible inactivity time.

4. The BA sends the request to each of the terminals to book a timeslot regarding to the result of the calculation from step 3. The end of this step means that both parties agreed upon:
   4.1. The BA declares to show up at the specified time, which is called expected arrival (EA).
   4.2. The TA declares that the cargoes will be loaded/unloaded no later than the arranged time, which is called, expected service time (EST).

The EST is the due time of the arrival. Therefore, the agreement is only valid if the barge show up no later than EST. Otherwise, the appointment will be revoked and the barge is obliged to book new timeslot. Schuur, et al. (2009) assume no interruption in activities and sailing time between two subsequent terminals and the time that takes to load/unload containers are deterministic, so the BA can plan arrival accurately and without delay.

To test the proposed model, Schuur, et al. (2009) consider three modes of information sharing. In the first mode, no agreement will be established among the agents about the EST and EA. Therefore, the BA only relies on calculating shortest route to reach all terminals. In the second mode, the BA asks from TA if a specific timeslot is free. In the third mode, the BA asks for the upper limit of waiting as described above. The evaluation of these there modes of information sharing proved that the third mode is the most optimal mode of communication. Therefore, this thesis sticks to that mode.

Schuur, et al. (2009) describe waiting profile as $(t, ULW_{terminal})$, which means upper limit of waiting at the specific terminal for each possible entry time t.

2.5.2 Agents objectives and decision making process

The objective of BA is to define in which order and in which time it should stopover at terminals to have shortest possible inactive time.

Let us have a look at Schuur, et al. (2009) mathematical model. Assume that T terminals should be appointed where $T \subset$ All terminal. The BA has following information:

- For all T the load/unload time LT and sailing time ST are known and are deterministic.
- Upper limit of waiting ULW at the specific terminal for each possible entry time t

Therefore, the total time of journey TJ between two terminals x and y can be calculated as the sum of LT, ST, and ULW.

As it is mentioned before, the objective of BA is to reduce $\sum TJ$. The outline of the model is shown below:

T: subset of terminals that is supposed to be dropped by

LT_x: Load/unload time at x, where $x \in T$

ST_{xy}: Sailing time from x to y, where $(x, y) \in T$

$ULW_{x,t}$: Upper limit of waiting at x, where $x \in T$, at time t

DT_x: Departure time from x, where $x \in T$

ET_y: Entry time at y, where $y \in T$, and $ET_y = DT_x + ST_{xy}$

$TJ_{x,y}$: The time of journey from x to y, where $(x, y) \in T$, and $TJ_{x,y} = ST_{xy} + ULW_{y, ET_y} + LT_y$

As it is illustrated in the mathematical model, the BA trusts the obtained waiting profiles to work out best route with shortest inactivity time.

The TA pursues following procedure to agree upon a timeslot that should be booked for a specific barge. Let D be set of available dockside derrick. Every derrick can service to a barge at a time and has a fixed capacity. Schuur, et al. (2009) assume the time that takes to move a container by derrick is deterministic.

The objective of TA is to come up with an agreement with BA about the possible service time and guarantee the availability of that time.

The reserved time can be seen as a contract that both parties must stick on it. According to the contract, the BA declares to show up at the specified time, which is called expected arrival (EA). The TA defines the upper limit of waiting ULWs from this EA until the last planned activity and declares that the cargoes will be loaded/ unloaded no later than the arranged time, which is called, expected service time (EST). The expected service time is total of expected arrival and upper limit of waiting EST=EA+ULW. After reserving a time slot, the TA arranges its to-do-list in a way that no other reservations are contravened. The to-do-list includes intended start time IST and the expected finish time EFT for all barges. Expected finish time is the total of intended service time and Load/unload time LT, EFT=IST+LT. intended

The TA must guarantee to start load/unload containers at any time before EST. although rearrangement in timetable is allowed under certain condition. If a barge enters before its EA time, the TA checks to see if it can finish the servicing process prior the promised time to the barge, which is next in to-do-list. This will help the terminal to get most of its resources and reduce the inactivity time.

The waiting profile is produced by TA to communicate upper limit of waiting for each potential entry time. To produce the waiting profile several phase must be followed.

The first phase is to find possible start periods, which are periods where the loading/unloading container can be started right away without any waiting. These periods are established by taking into account potential entry rows r in the to-do list. Entry row r implies entry after the r^{th} barge. This requires that after each entry, all barge prior to the recent entry to be rearranged and serviced as soon as possible, and servicing the barges after the entry row to be postponed as much as possible. Each start period p can be defined as $[s_p, e_p]$ which is calculated as follow.

- The s_p = EFT of the barge p
- $e_p = IST_{p+1} - LT$
- When p is zero then s_p= current time
- if p=last barge then $e_p = \infty$
- ignore the period If $s_p < e_p$

- If $e_p > s_{p+1}$ then $e_p = s_{p+1}$

Table 2.2 represent an example of constructed start periods based on the to-do list represented in table 2.1.

Table 2.1: an example of to-do list of a terminal

	Agreed time slot		Actual to-do list		
	EA	EST	IST	LT	EFT
Barge1	13	23	13	5	18
Barge2	32	42	32	5	37

Table 2.2: the start period

Start period	Start (s)	End (e)	Entry row number (to the table 2.1)
1	0	8	0
2	18	27	1
3	37	∞	2

Now is time to produce the waiting profile, which includes corresponding upper limit of waiting for all potential entry times between present time and ∞. The procedure is described as follow (Schuur, et al., 2009):

- If entry time ET of the barge is within a start periods p from table 2.2 then $ULW \quad = 0$
- Else ULW = $s_{closest\ start\ period\ after\ ET} -$ ET

Table 2.3 illustrates an example of waiting profile with respect to the data from table 2.1 and 2.2. Figure 2.1 also shows ULWs as linear equation.

Table 2.3: waiting profile

Potential entry time	ULW	Entry row
0	0	0
8	10	1
27	10	2

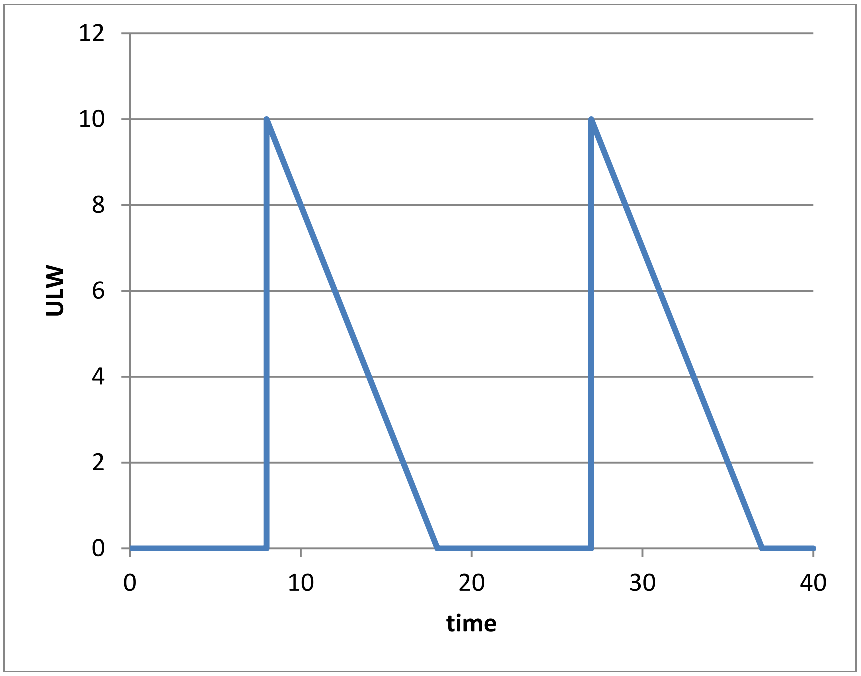


Figure 2.1: waiting profile corresponding to the data from table 2.1 and 2.2

The current version of waiting profile has no flexibility to deal with interruptions that may occur. Therefore, the process must start and finish exactly according to the agreed time. To add more flexibility (Schuur, et al., 2009) proposed to add extra time to the upper limit of waiting in table 2.3.

2.6 The time dependent vehicle routing problem

One of the ways that BA can use to work out best route with shortest waiting time is to solve time dependent vehicle routing problem (TDVRP). Finding an optimal algorithm to solve TDVRP needs a comprehensive research and comparing the result of new algorithm with existing one to prove it optimality and efficiency. Therefore, this thesis relies on offered solution devised by (Ehmke, 2012).

Ehmke (2012) specifies algorithm based on digraph G (V, E) in which V represent vertices and E represents edges. Each edge is defined as (s, e) where s stands for starting point and e stands for end of the edge. The digraph is complete and matrix $[c_{se}(d_s)]$ identifies the journey time from s to e given start time of travel d_s.

The algorithm to find shortest trip time is defined as follow.

- m-*1* vertices need to be stopped over
- Vertex 0 corresponds to the start and end of the trip after passing m-*1* vertices (circular trip).
- $J\ (V,\ e)$: minimum time of journey from vertex 0 passing all vertices in set V until arriving to vertex e.
- c_{xy} = time that it takes to move from point x to y
- w_x = waiting time at node x; if x=0 or x=n+1 then $w_x = 0$
- s =the starting time from entry point 0
- d_x = leaving time from x
- The costs of moving from a vertex to other one are given by journey times. The minimum cost for entire journey with m vertices is described as a recursive function by $J^* = min_{n\in(1\ldots m-1)}[J(\{1,\ldots,m-1\},n) + w_n + c_{n0}(d_n)]$. This represents the earliest time of coming back to origin point 0 given start time d_0.
- J^* can be calculated based on moving costs of prior states. For $|V|$>*1* and e as last visited vertex $J\ (V,\ e) = min_{n\in V-\{e\}}[J(V-\{e\},n) + w_n + c_{ne}(d_n)]$ for all $e \in V$ and $d_n = J(V-\{e\},n) + w_n$ which corresponds to moving costs of visiting e directly after partial journey n
- The first decision after leaving the vertex 0 is defined by $|V|$= *1*, $J\ (\{e\},\ e) = s + w_0 + c_{0e}(s)$ for all e=1... m-1. This corresponds to time of reaching destination vertex e.

The pseudo code is provided in algorithm 1. First, J ({e}, e) is estimated, which represents entrance times N_e^{arr} for all journey N_k that leave the origin vertex 0 at time s toward the first vertex e. Each partial journey N_e is extended to include one more unvisited vertex until no more vertices left to be added. When the journey is completed, save the total cost. After exploring whole search space sort the solutions based on cost and the one with lowest cost (J^*) is the optimal solution, which has earliest arrival time to the origin point 0.

Algorithm 1

Input:

G (V, E)

S= start time from origin vertex 0

Start:

J=J-0rigin vertex 0

For each $e \in J$ do

$N_e = \{0, e\}$;

$N_e^{arr} = c_{0e}(s)$; // J ({e}, e)

$L = L \cup N_e$;

Processing:

For each $e \in |J|$ do

For each $N_e \in L$ do // J (V, e)

$l = last\ vertex\ of\ N_e$;

$n = n | \min\{c_{ln}(N_y^{arr})\}\ for\ all\ n \in V - N_y$;

$N_y = \{0, \ldots., l, n\}$;

$N_y^{arr} = c_{ln}(N_y^{arr})$;

Result:

For each $N_y \in L$ do

$N_y = \{0, \ldots., l, 0\}$;

Sort N according to N_y^{arr};

Return first cell of L // J^*

At each phase, it is necessary to store some information regarding partial journey, which include, set *V*, the last visited vertex in *V* (vertex *e*), and arrival time at *e*. The arrival time is considered as cost that needs to be stored in an array. The values of *V* and *e* should be stored in an array as bits. The five first bits represent the value of *e* and the remaining represent the set *V*. For example if there are 10 vertices need to be visited include start point (*m*=10), *V*= {3, 5, 9} and *e*=5 so the binary representation is 0100010100<u>00101</u> (the underlined five bits correspond to *e*) (Ehmke, 2012).

3 Overview of Multi-agent system

In a multi-agent system, global efficiency cannot be achieved directly as every agent is autonomous and has its own goal. In other word the overall efficiency of the system, depend on action of individual autonomous agent. The users' satisfaction and acceptance of the system depends on users feeling about the ability of the system to benefit them and that the conditions of using the system not to risk their interests (Weiss, 2013).

In this part of the literature review we talk about issues that must be concerned to design an optimal (i.e. efficient) and acceptable (i.e. effective) multi-agent system. A system that is efficient but fail to satisfy the users' requirement will encounter user resistance to change and so it is not effective.

In centralized system, single authorized entity is responsible to control and coordinate the activities of other entities to improve the system performance (Miller, et al., 2004). Alternatively, decentralized system aim to coordinate several autonomous entities that have their own goal and the overall performance the system depends on action of each individual and independent entity. The decentralized system also called Multi-agent system (Sadeh, et al., 1998).

The communication protocol among the agents and the choice of appropriate strategy are the vital aspects of multi-agent design. The protocol specifies the content and outcome of the communication among the agents. The strategy defines the approach taken by agent to exploit provided information. The communication protocol and the strategy are mutually dependent. A self-interest agent will choose a strategy that has better outcome for itself. Because of selected strategy the agent may decide to provide low quality information (e.g. deficient or erroneous information), which is unpleasant from system perception (Wooldridge, 2009). This implies that design of multi-agent system must be in a way that prevents opportunistic behavior. The outcome of the designed communication protocol should guaranty that self-interested agent will prefer the strategy that is pleasant from system perception. Set of rules can be established through defined communication protocol, so even opportunistic agent will perform desirable action (Zambonelli, et al., 2002). Therefore, the communication protocol is an important aspect of the design as it can affect sustainability of the system.

3.1 Agent's properties

Wooldridge & Jennings (1995) define the agent as a hardware or software-based system that enjoys the following properties:

- Autonomy: agents ability to have control over its action without any direct external intervention;
- Pro-activeness and reactivity: agent not only has ability to observe its environment and react to the changes but also it can take initiative and act according to its goal.
- Social ability: agent can interact with other agents or humans.

Moreover, some authors in area of artificial intelligent provide stronger definition for agent. Shoham (1993) describe agent as a system that not only has the above properties but also implemented using *mentalistic* notions, such as knowledge, belief, intention, and obligation. Other properties of agents, which are defined by different authors include:

- Mobility: capability to move around an network (White, 1994)
- Veracity: Not intentionally communicate incorrect information (Galliers, 1988)
- Benevolence: not to have conflicting goals, and agent will always try to do what is asked of it (Rosenschein & Genesereth, 1985)
- Rationality: agent will behave to realize its goals, and avoids kind of behaviors that prevent its goals being realized (Galliers, 1988)

Jennings, et al. (1998) describe multi-agent system as a network of problem solvers that collaborate to solve a problem that cannot be solved individually due to partial view of the environment, asynchronous computation, no universal control mechanism, and distributed data. Even though, agents have their individual preferences, the interaction among them should be in a way that leads to achieving coherent global properties.

Multi-agent system is appropriate for the problems with such characteristics (Sadeh, et al., 1998):

- Modularity of the problem: possibility of dividing problem into sub-problems that have their own set of distinctive state variables.
- Decentralization of the problem: possibility of breaking down the problem into independent and autonomous processes.
- Variability and dynamism: The problem configuration may vary repeatedly.
- Synthetic complexity

Examples of such problems are supply chain management, logistics and transportation, and smart grid. Problems with mentioned characteristics require more adjustable and powerful solution. Multi-agent system is one of the proposed solutions to solve these kinds of problems.

3.2 Properties of the communication protocol

To design an optimal and acceptable system (i.e. efficient and effective system), it is important to consider set of preferred properties of the communication protocol. The properties that are applicable and considered in this thesis, according to the Wooldridge (2009) include:

- Individual sensibleness: the design of the system must be in a way that encourages parties to employ it in practice. It means that the pay off from utilizing the system must be more than rejecting it.

- Consistency: the communication protocol must be designed in a way that is steady, consistent, and non-manipulatable to prompt agents to act as it is supposed.

- Assurance of success: the protocol must be designed in a way to ensure certainty of reaching an agreement.

- Fast and distributed: no single point of failure, reaching agreement in a reasonable and short time, and reducing the number of message passing as much as possible to achieve efficient communication (i.e. to reduce the network traffic).

- Computationally efficient: to reach an agreement in a timely manner it is important that the communication protocol use as little computational power as possible, particularly in case of real-time decision making.

- Comprehensible and simple: the negotiation strategy of the agent must be straightforward and easy to understand.

- Sustainable: the multi-agent system should provide a solution, which is feasible and implementable from both logical point of view and underlying organization procedure. For instance, reasonable distribution of gain/loss among entities. Even though the system shows a good performance logically, the companies may stop using it if the distribution of gains is unreasonable. Unfairness can risk their interests and competitiveness in the market.

4 Methods

This part illustrates system definition of the simulation model and method for collecting independent and unbiased data. The data analysis method and research strategy is discussed in detail. Finally, there is discussion about the processes that are followed for modeling of the simulation.

4.1 System definition of simulation model and data collection

In this thesis discrete event simulation (DES) is used to model the operation of the system. This means that the system function is modeled as distinct series of events, which takes place at a certain time and cause state transition in the system. It is assumed that no state transition happens between two successive events; therefore, the simulation can move in time from an event to the subsequent event (MacDougall, 1987). Considering the problem under the study, the system entities include queue of barges and terminals. The system events are arrival, starting service, and departure. The system states include length of the queue and the terminal status that can be either active or inactive. The random variables, which are necessary to model a stochastic system, are arrival rate and the service time in the terminal.

The implemented simulation is non-terminating, also known as steady-state, and there is no certain event to determine the exact duration of the simulation. Therefore, it is the modeler’s decision to determine the length of the simulation. In other word, in this thesis the steady-state properties of the system, which are not biased by the initial states, are interested and evaluated. To produce meaningful statistic for a steady state simulation two criteria must be taken into account. First, identifying the transient state and then deciding number of replications and run length.

Steady state simulation starts from empty states (i.e. no queue barges exist at the start). Therefore, it takes for a while until arriving to a state with meaningful statistics. The transient state of a simulation can cause initial bias in the result of the study. To eliminate the influence of such bias on the analysis, heuristic proposed by White, et al. (2000), which is called ‘*Marginal Standard Error Rules*’ (MSER) is employed. The heuristic finds the truncation point by considering the observations that not only are away from the sample mean but also have significant effect on estimation of confidence interval. The author also proved that the heuristic with batch size of length five (MSER-5) is extremely accurate in finding the truncation point.

The next step after defining the transient state of the data set is to decide number of replications and run length. In a terminating simulation, in which there is a natural event to define the end of simulation, researchers need to run several replication to achieve an independent data set. However, in non-terminating simulation, the model should be run for a long period and then dividing the run into separate batches. Each batch can be considered as a replication. This method is called batch method (Chung, 2004). Implementing batch method includes (Chung, 2004):

- Identifying non-significant correlation lags size: In this step, the idea is to find the lag size. The lag size is intervals in observations that have non-significant correlation with each other. When there is a slight correlation ($Correlation\ coefficient\ \rho \cong 0$), then autocorrelation is not an issue.

- Identifying batch size and batch time: after finding non-significant correlation lags size, the batch size can be calculated as

$$batch\ size = 10 * non - significant\ lag\ size$$

The batch size then needs to be translated into batch time:

$$batch\ time = \frac{runtime\ length}{number\ of\ observation} * batch\ size$$

- Identifying run length: the run length must be extended enough so it is possible to have at least ten batches (replication) after truncation of the transient state.

$$run\ length = length\ of\ transientstate + 10 * batch\ time$$

4.2 Data analysis

Every research based on the simulation can be categorized in to two groups. First group includes simple simulations with only two different treatments. Each model or treatment corresponds to a specific operating policy. Second group includes simulations that are more complicated and involve examining more than two treatments. For the simple simulation researcher can use confidence interval or hypothesis testing. Two well-known approaches to analyze the simple simulations include Welch and paired t-test approach (Chung, 2004).

In case of this thesis, there are more than two models to be compared. Considering $mixed\ level\ full\ factorial\ design$ there exist four factors include

- two levels cooperation factor (cooperative, and non-cooperative)
- three levels gap (no gap, medium, and high)
- two levels sailing and service time (deterministic, and stochastic)
- three levels arrival rate (low, medium, and high)

In full factorial design, number of treatments equals

$$number\ of\ levels^{number\ of\ factors}$$

Since there are two factors with two levels and two factors with three levels, thus total number of treatments is 36

$$alternatives = 2^2 * 3^2 = 36$$

Comparing these alternatives involve a two-step procedure. The first step is to analyze the variance (ANOVA) to verify significant difference between means of alternative treatments. In other word, the null hypothesis is that all means are equal and alternative hypothesis is that not all three means are equal. If ANOVA test leads to acceptance of null hypothesis, there is no mean to continue the analysis. However, if null hypothesis is rejected it is valuable to know which model had a better performance. The ANOVA test cannot provide such information. Therefore, as a second step, to find out which means is significantly different, it is essential to run Univariate test and Pairwise comparison. To perform the ANOVA test it is essential to ensure the normality of dependent variable and homogeneity of the variances before doing the test. The Q-Q plot method is used to test the normality and Levene's test is used to test homogeneity of variances.

4.3 Research strategy

The research strategies are methodologies to manage, plan, design, and carry out research. The most common strategies for conducting quantitative studies include, ex post facto, survey, case study, and experiment (Håkansson, 2013).

In experimental design, the practitioner moves from cause to effect by applying different treatments to similar groups that are selected randomly. However, in ex post facto the researcher needs to deduce the causes by looking back at the facts. This is a type of research in a situation when it is impossibility to control independent variables due to ethical or physical constraints. Moreover, unlike the experimental research, in ex post facto research, the practitioner cannot assign subjects randomly as the facts and data already exists that cannot be reproduced through experiment (Goddard & Melville, 2007).

The survey is another possible research design that enables research to collect data from a large population effectively with lower possible cost. The survey strategy normally uses questionnaire, structured observation/ interviews to collect data from a representative sample of the population (Saunders, et al., 2012).

The case study is an ideal choice when practitioner needs to get rich understanding about the context under the study. The case studies generally aim to answer ‘how’ and ‘why’ questions when the focus is on contemporary events and there is no control over the variables and the context under the study (Yin, 2003).

The other research methodology concerns experimental design. The experimental study aims to study the relationship between variables through manipulating independent variables and looking at variation in dependent variable (Håkansson, 2013). It is more common to conduct the experiment in laboratory settings to have more control over different aspects of research like sampling, variables, and context (Saunders, et al., 2012). Although such control can improve the internal validity of the research but due to such manipulation the external validity of the research, become difficult to establish (Saunders, et al., 2012). The other problem in experimental design that risks the external validity of the research is obligation to select a small sample due to cost and complexity of the sampling. Small sample may not be a representative sample. Moreover, due to ethical issues is not possible to conduct an experimental design in some cases (Saunders, et al., 2012).

Simulation and especially multi-agent based modeling as a new way of study can be a solution to the sampling and ethical issues of experimental research (Kothari, 2004). In case of this thesis, it is not ethical and possible to ask companies to risk their business and implement different scheduling policy to investigate the performance of different strategies. On the other hand, establishing a representative sample of companies to participate in the experiment as control group and treatment group is extremely expensive. Therefore, this thesis utilizes the simulation as an alternative way of doing experiment to evaluate the efficiency of the multiagent system. The simulation approach involves constructing an artificial environment of a port to schedule loading/unloading containers. This allows observing the dynamic behavior of system under different conditions (e.g. busy/quite port and interruption in loading/unloading containers) and scheduling policies. According to (Kothari, 2004) given the initial condition (same as treatment in experiment) a simulation run to signify the property of the process over time. In other word, unlike other research designs the simulation looks for data from the future, instead of contemporary or historical data, to better understand the future conditions. When it is come to coordination of activities among the companies in a port, modeling of the environment through agent-based modeling helps to define a simple set of rules and behavior for each agents and study the dynamism of the system under settings such as various scheduling policy, possibility of interruption, and different arrival rate.

4.4 Modeling processes of simulation

The process of modeling and simulation study described below is based on the work presented by (Robinson, 2004). Figure 4.1 summarizes key processes of a simulation study. The rectangles are the key phases in a simulation study and correspond to the main deliverables (Robinson, 2004):

- *Conceptual model*: is an explanation of the model to be developed.
- *Computer model*: is implementation of the conceptual model on a computer.
- Solutions/ understanding: is drawn from the outcomes of the experiments.
- An improvement in the real world: is derived from implementing the obtained solutions/understanding from previous step.

The arrows in figure 4.1 represent the procedures that allow progress from a phase to next one. Each step is described below with detailed discussions.

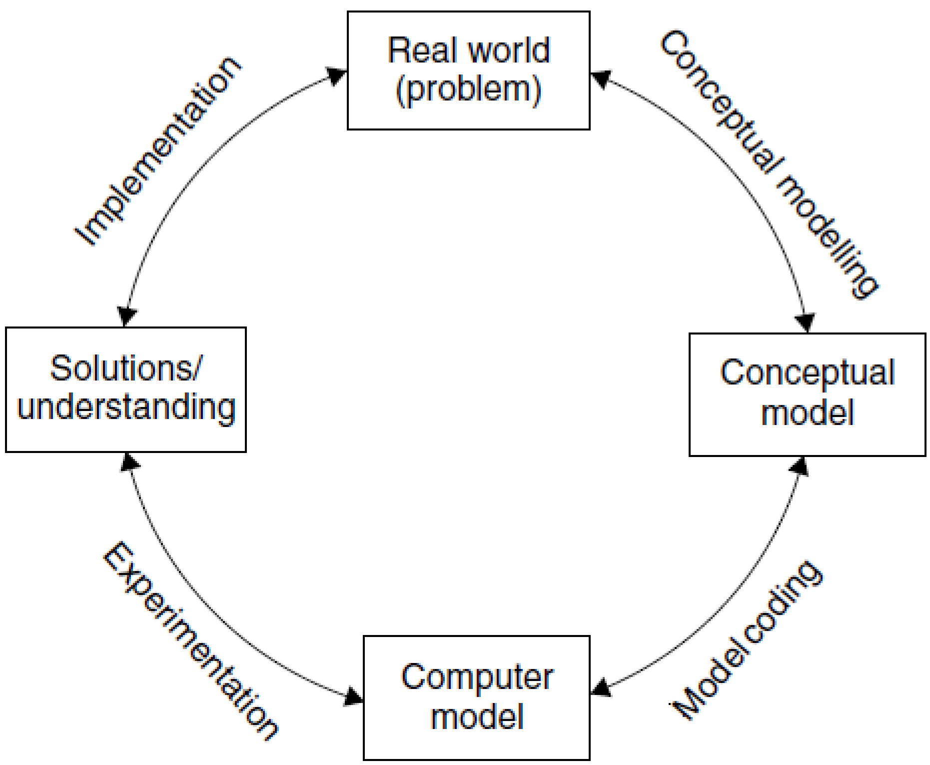


Figure 4.1: key processes of simulation study (Robinson, 2004).

- **Conceptual modeling and simplifications:**

The thesis is initiated by recognition and formulation of the problem, which exists in the real world. The aim of 'problem formulation' is to realize the problem and to plan a model that is appropriate for dealing with the problem (see section 1). Conceptual modeling includes the following course of actions (Robinson, 2004):

- Understanding of the problem situation
- Establishing the objectives
- Design the conceptual model
- Collect the data essential for developing the model

- **Understanding of the problem situation:**

The first step in conceptual modeling is to understand the problem situation. This helps to develop a model that is close to real world context. This thesis benefits from theoretical study for understanding the problem situation. Studies conducted by Hillegersberg, et al. (2005), Kentrop, et al.(2003), Konings (2007), Miller, et al. (2004), Schuur, et al.(2009), and Stahlbock & Voß (2008) provided valuable insight about the business process in a port to load/unload containers and they are used throughout the modeling process.

- **Establishing the objectives:**

The second step is to define the objective of modeling. Defining the objective is a vital issue in modeling process as it provides guidance for experiment and helps to define appropriate input, output, and content for conceptual model designing (Robinson, 2004). The purpose of this thesis is to present a multiagent scheduling system for the container port and to assess various decentralized scheduling strategies to achieve better coordination and association among barges and terminals.

- **Design the conceptual model:**

After understanding the problem situation and define the objective, the third step is to design the conceptual model by identifying its, input, output and content. The experimental factors are inputs to the model (Robinson, 2004). The experimental factors are defined in a way to achieve the objective of the modeling. Multi-level factorial design is used to define the factors and associated levels, in which each factor has to be varied (*see section 3.2*). It is useful to conduct experiments with factors that are not possible to have control over them in real world and to have better internal validity. Such factors include arrival rate, and possibility of interruption in process of loading/unloading cargoes. Moreover, amount of gap time and scheduling policies are the factors that are possible to have control over them in real world. These factors are varied during the experiment to find the most efficient scheduling policy.

The output of the model aims to identify whether the objective of the model is achieved (Robinson, 2004). To evaluate the efficiency of the proposed scheduling policies two outputs are defined and considered during the data analysis. These outputs include, average writing time in the queue and difference between planned and actual departure time.

- **Collect the data essential for developing the model**

The final step in designing the conceptual model is data collection. These data are required to develop the computer model (Robinson, 2004). Information, which is presented in *section 2*, provides the basis for designing the content of the model. The contents of the model enable the model to accept the input and provide the output. In other word, content of the model includes what component must be integrated in the model to transfer the input to an output and what is the critical process and interconnection between these components. The component of the model and the involved processes are discussed in *section 6*.

The level of details in the model needs to be reduced to keep the focus of modeling on the defined objectives. Considering all components in the model can add unnecessary complexity to the model, which cannot even improve the accuracy of the model (Robinson, 2004). For example, a dock-derrick component can be put in a black box and be represented as a time delay to simulate the time that it takes to move the containers. The other example is arrival rate that is replaced by random variable. In addition, some components do not need to be considered, as their exclusion from the model has no effect on accuracy of the result. The examples of such components include availability of labors, or working shift pattern (for more details see *section 6.2*).

❖ **Computer model**

After designing the conceptual model, it needs to be implementation of as computer model. To achieve this Repast tool kit is used so the simulation can be build and performed on a computer. Repast provides fully synchronized simulation environment to implement the agents and required interconnection among them.

❖ **Experimentation**

This step involves the process of designing the experiments and deciding about the method data analysis. The aim is to obtain accurate result and performing sensitivity analysis of output data (see *sections 4.1, 4.2, 6.2, and 7* for more detail)

❖ **Implementation**

This step involves implementation of the solution, which is obtained from analysis of simulation data, in real world. This is up to decision makers in companies to decide whether the reported result in this thesis is valid and reliable enough to be implemented as multi-agent scheduling system. The likelihood of implementation could be increased if the stakeholders were involved during the modeling process.

As it is obvious in figure 4.1, the process of simulation modeling is an iterative process. This iteration must be done to until achieving desired improvement. This issue is considered and discussed in *section 8*.

4.5 Verification and validation

Verification is the course of actions to make sure that the conceptual model has been translated to computer model with enough precision and accuracy. However, validation is the courses of actions to make sure that conceptual model is sufficiently precise and correct for the purpose at hand (Davis, 1992). The methods of verification and validation, which is used in this thesis, follow the processes defined by (Robinson, 2004).

Conceptual model validation: the specification and assumptions that is made in the model should be discussed among people who have comprehensive knowledge about the system under the study. Their feedback can be used to see if the model is appropriate. However, in case of this thesis the comprehensive literature review on similar research is performed to specify a model that is close to real world situation. The assumption and simplifications in the model is assessed according to the studies that are performed in real world cases.

Verification: verification is carried out by comparing the implemented model with specifications defined in conceptual model. It is done continuous by during the coding and implementation. Different characteristic of the conceptual model is verified during the coding such as timing of events, calculation of the path, calculation of upper limit of waiting and timetable generation, as well as controlling the logic of cooperative and non-cooperative policy. The simulation codes is checked and debugged to ensure right logic. The logic of the different policies is discussed in a non-technical format so everyone can test the logic. A visual check is also performed by looking at the log file of the events and stepping event by event to find any abnormal behavior. The output data from simulation is checked against any inconsistency data. For example, the waiting time and difference between planned and actual departure time are inspected to see if the model performs logically. In addition, the expected behavior of each method is calculated manually and it is checked to see if the method behaves as it is expected.

Black-box validation: this method of validation concerns validating the behavior of model through comparing the simulation with either real world or another model. Since there is no real world data available, the model is compared with another model provided by Schuur, et al. (2009).

Experimentation validation: accuracy of the experiments depends on defining the warm-up period, run length, number of replications and data analysis. All these steps are discussed in detail in *sections 3.1 and 3.2*. This makes it easy for readers to judge validity of the experiment.

However, it must be noticed that it is not feasible to confirm absolute correctness of the model. The verification and validation process aim to increase the confidence about the correctness and acceptability level of the result. The general rule is to perform as much as testing as possible to improve the validity and reliability. Moreover, the acceptance of the study is not just depending on the validity. Validation and verification only concerns the quality of the model and accuracy of the result; it does not concern if the result of the study meets the exact expectation of the stakeholders (Robinson, 2004).

5 Designed interaction protocol among agents in the port

The first issue that must be considered during design of the communication protocol is to facilitate real time scheduling. The protocol is required to handle a non-stationary situation, in which barges come into the port one after the other and they need to book timeslots to deliver/pickup their cargoes. The communication protocol also needs to satisfy properties in *section 3.2*, and business requirement in *section 2.1*. Figure 5.1 illustrates the proposed communication protocol.

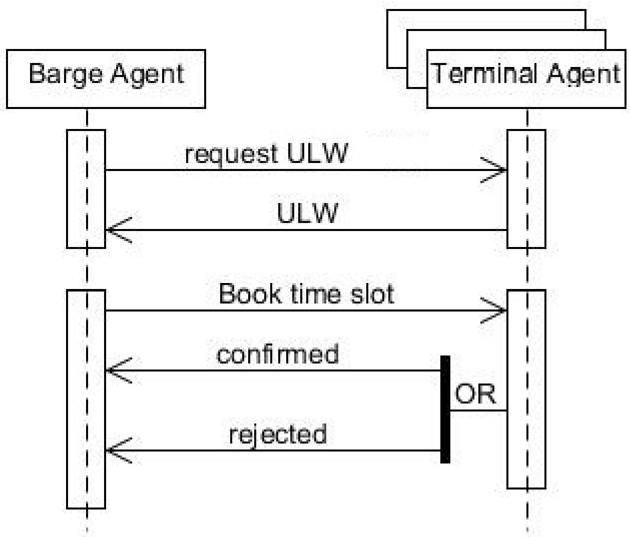


Figure 5.1: Communication protocol

The communication protocol includes two components that is the information that should be shared and the outcome of the protocol.

5.1 The outcome of the interaction protocol

The outcome of the protocol is to enable barge and terminal agent to arrange a deal about the viable and most appropriate time of anchoring. When they arranged the deal, the barge assures to stopover at the terminal's dock at that time and the terminal declares the earliest time to start lading cargoes. The barge uses the declared earliest time of lading to estimate the proper timeslot that need to be booked on subsequent terminal. If for any reason the barge fails to show up on time, it needs to book another timeslot.

5.2 The information that need to be shared

The communication protocol has two steps. First barge send a request to all terminals, that it needs to stopover, to get vacant timeslots so it can realize the best route (i.e. the best time to stopover at each terminal with shortest waiting time). Then, the barge demands the favored timeslots, from previous step, to be booked.

In the first step the idea introduced by Schuur, et al. (2009) is used. Their method for finding the best route is described in *section 2.5*. Certain Upper limit of waiting (ULW) for each potential arrival time is created and sent by terminal. The ULW is created upon the barge request and it is specific for the requester.

The barge demands for the ULW from all terminals that should stopover. After collecting the upper limits, it can decide about the best route with minimal idle time, using the TDVRP algorithm (see *section 2.6*), so it can leave the port sooner.

In second step, the barge agent declares favored timeslots, from previous step, to be booked and receive the confirmation from corresponding terminals. These steps are supposed to happen in real time. If the barge agent does not come to a decision in a timely fashion, it is more probable that issued upper limit of waiting to be revoked as others can take required timeslot. The duration of interaction protocol is about 100 ms with Intel core i3 CPU and 4GB of RAM, so the probability of revocation is very low and ignorable. However, if revocation happens, the barge needs to execute the protocol again.

5.3 Obstacles and contradictions in the realization of the agents properties

The design objective of communication protocol is to design a protocol in a way that if self-interested and autonomous agents follow the protocol the overall activities be reasonable and agreeable for the involving business entities (Weiss, 2013). The communication protocol is a critical aspect in realizing the properties, which are mentioned in *section 3.2*, and has an effect on acceptance of the system by stakeholders.

Applying the properties, which are mentioned in *section 3.2*, in design of the communication protocol seems to be an easy task at first look. However, in practice conflicts between some of these properties are realized. In this part, such conflicts and their effects on implementation of the system are discussed.

One of the problems is conflict between Individual sensibility and sustainability properties. Assume that a barge planned to stopover at a terminal at 12 pm and with estimation of one-hour handling and sailing time. If the barge's timetable to stop in next terminal be so tight, e.g. at 13 pm, any interruption can have an effect on the working plan of that terminal and barges that booked a time with second terminal. This makes the design subject to any small interruption. On the other hand, considering some flexibility between two consecutive visits, to reduce probability of expansion of interruption, is against the objective of the barge, which is to depart from the port sooner.

5.3.1 Monitoring agents activities

To design a steady system it is important to have a mechanism to prevent agents from showing strategic behavior by giving wrong and deficient information to other agents (Helbing, 2012). It is essential to introduce some control over the agents' action. This is can be achieved through either exterior control or instruction or self- regulation mechanism. Exterior control requires introduction of an independent and authorized party to watch and control the action of each agent and punish them for any action that is against the defined regulation. On the other hand, with self-regulation mechanism agents correct each other with no exterior controller agent (Helbing, 2012).

Moreover, introduction of exterior controller requires decision about kind of punishment. On the other hand, exterior controller is in contradiction with agents' automaticity. For that reasons, self-regulation mechanism is favored over exterior control.

5.3.2 Distribution of gain/loss

Distribution of gains/losses is a difficult and critical issue that is linked to the game theory. It is beneficial to stay away from such distribution in the design of the system due to following reasons (McCain, 2009):

- Justice in certain distribution of losses/benefits is more often subject to argument among entities. This becomes more challenging when there are many entities with different interest.
- It is challenging to establish a distribution that seems to be fair and acceptable by every individual in the system. Something that is fair from game theory point of view is not considered as fairness by individuals.

Moreover, in our case, recording all behaviors, mapping out the causes of disturbance and delay, as well as calculating amount of loss due to any interruption requires huge amount of work to be done, which give rise to expenditures of the system.

Even if we find a way to calculate the amount of loss/gain for each entity, the next problem is to share it among the entities in a way that is reasonable, and satisfactory from their pint of view. This is so challenging as for example, how to map out the causes of disturbance and delay, considering that, the root cause of disturbance can be opaque. Moreover, the contribution of each cause on disturbance should be clarified and quantified. An additional example is the involvement of each entity on the performance of the system. The question is, if the way an entity acts has a negative impact on the performance of the system, can others decide to stop giving service to that company?

5.3.3 Trust on agents performance

When an autonomous agent decides to perform an action on behalf of human operator, then the operator should have trust and confidence on agent's action and be convinced that what is done is the best option and could not be performed in a better way.

5.3.4 Fast decisions making

In a system that needs to make decision in real time it is essential to take action in a timely manner. However, the question is how much fast should be the decision-making?

If a barge need to stopover at *t* terminal the search space for finding the best order with minimal waiting time is *t!*, which is quite a big search space. Therefore, finding the best and optimal solution may take some times. As barge agent searching the space for the best solution, it is apparent that a requested time being taken by other agent and so requirement to search for the new solution. This has a negative influence on efficiency of the communication. Therefore, it is important to make a fast decision before any changes, in current timetable of the terminal, happen.

5.3.5 Customizability of the agent

Another issue that must be bear in mind during the design of the multi agent system is companies' liberty to customize their agent. this is the case when companies would like to have more power over their agent and add some more functionality such as giving highest priority to load/unload containers' that belong to a certain customer. This necessitates defining extent of liberty that could be given for customizing the agent design. The extent of autonomy can vary from no customization, custom configuration, or full customization of agent's functionalities.

To have a clearer image, assume that a terminal company implements a customized agent. This agent should operate according to the defined rule so the state of the system does not transit to an undesired state. For example if agent work in a way that lead to unrealistic scheduling of the barges, then must be a way to obligate the terminal company to modify the action of its agent. If they refuse to regulate their agent or there is no way to obligate them to do, then the whole system will observe devaluation in expected service quality.

5.4 Reflection on the proposed interaction protocol

This part aim to evaluate the suggested communication protocol by considering the properties, which are discussed in *section 3* and difficulties specified in *section 5.3*. In addition, considering the business objectives, which are mentioned in *section 2.1*, it is believed that agents are self interested and opportunistic.

Individual sensibleness: considering that agents are self-interested and make decision in a way that allow them to meet their own objective make the system

Individual sensibleness given that the overall performance of system is satisfactory and acceptable by all entities.

Consistency: to assure consistency of the system any manipulation must be prevented through a self-regulatory system. This requires introducing of a 'reputation evaluation' mechanism. To evaluate the reputation of each entity in the system it is necessary to reach an agreement among the companies in the port about how much and how many times of delay is tolerable and what is the possible punishment for company with a bad reputation, which should be also fair. On the other hand, the dominant position of the companies is another important issue. A company that has a dominant position can force others to behave in desired way. However, it is hard to control and regulate the actions of dominant companies. Moreover, to have a fair 'reputation evaluation' mechanism it is crucial to have a comprehensive system of to generate cause and effect tree to find the entity that was the main cause of trouble. The cause and effect tree is important as it can help us to achieve a fair a 'reputation evaluation' mechanism. As we discussed before, it is hard to establish such system as the causes of delay are transitive and can be transparent. Therefore, we suggest establishment of self-regulatory system as a further research.

Assurance of success: to assure the end result of communication protocol is successful the 'upper limit of waiting', which is generated by terminal must be long enough. It means that it should be no less than the time necessary for a barge to carry out its job in the port. However, the amount of time that a barge needs to carry out its job is unidentified. Therefore, the terminal should generate the 'upper limit of waiting' until the end of last scheduled task in the terminal.

Fast and distributed: using the generated 'upper limit of waiting' and the 'Time dependent vehicle routing problems (TDVRP)' algorithm can facilitate rapid success in finding the route with shortest idle time. The duration of interaction protocol is about 100 ms with Intel core i3 CPU and 4GB of RAM.

Computationally efficient: as the system is distributed, agents communicate with each other directly, and few number of messages should be passed among agent to accomplish their task, so it is efficient and there is no single point of failure.

Comprehensible and simple: The routine of barge agent to choose the order of visit with least inactive time is simple, straightforward, and comprehensible for the companies that employ the agent.

Sustainable: First, considering the example, which is discussed in *section 5.3*, the barge is accountable to arrive on time and to recover from any probable interruption. Because of this, even though the barge's purpose is to trim down its stay time in the port as much as possible, it is more probable that the barge add some additional gap between every stop. Such extra gap enables to separate the activities of terminals and to some extent prevent dissemination of interruption in activity of an entity to others. Secondly, as it is argued before (*see section 5.3.2*) the share of gains and losses is not considered in the design of system. Regarding to these issues the system is liable to be sustainable.

5.4.1 Advantages and disadvantages of proposed protocol

In previous part the characteristics of designed communication protocol is discussed. However, it is important to consider the weak and strong points of the proposed communication protocol with respect to information that need to be shared and the outcome of the protocol.

According to the Jennings, et al. (1998) direct communication among the agents is one of the strong points of the design especially in a case of coordinating activities of set of self-interested agents. As the communication, protocol mimics the routine of the companies in the port; it is more liable to be sustained and accepted by the player. It also allows avoiding problem of sharing gains/losses, which can make the design more complicated unreasonably.

The generated upper limit of waiting by terminal enables the barge to calculate the arrival to other subsequent terminals correctly. Moreover, 'upper limit of waiting' can be generated in a way that allow terminals to have more flexibility in their schedule and to improve their productivity, for example by increasing the upper limit of waiting during estimated rush hours. This is one of the main difference between 'upper limit of waiting' and 'approach 1', which only specifies if a certain time is available or not.

Lack of some regulatory mechanism to control behavior of the agents and to prevent any strategic behavior is one of the weaknesses of the system. As it is discussed before currently, it is hard to establish such self-regulatory mechanism based on the reputation of the agents. This must be considered in further research to improve the robustness of the system

The proposed way of making appointment and considering that both parties will stick to the established agreement and be on time can make the system more robust. However, lack of any regulatory mechanism to punish the barges, which have been repeated late, can persuade them to show some strategic behavior. For example, they may reduce the extra gap between two subsequent visits. This can happen, as there is no fine for being late. Such undesired behavior can diminish the system robustness. Therefore, we should hope that everyone would play fairly according to the rules. On the other hand, if you are a skeptical person you may see this unrealistic that every one follows the rules. With such a view that entities are not eager to make honest agreements so in advance scheduling does not seem sensible. In this case, it can be a good idea to design a system in which no agreement about the possible handling time is required in advance.

6 Simulation model

In this thesis, the problem is break down physically so that each agent corresponds to a company in a port. There are various ways to design multi-agent system, which are handy in case of large number of agents with flexibility in allocation of responsibilities and tasks. Here tasks and responsibilities of agents are defined according to the business situation, which is described in *section 2*.

Moreover, to improve effectiveness of the system, in the modeling of the system the attempt is to impersonate the business structure as it is defined in *section 2* so it is more probable that the entities accept the solution.

The proposed system can improve the situation in two areas:

- It facilitates more rapidly and consistently communication among the entities. It also eases the duty of the human operators who are responsible of scheduling.
- Multi-agent system can to some extent outreach limited rationality of the humans as the agents can use techniques to search for the best solution in a bulky search space.

The multi agent based modeling which is talked about in *section 2.5* is used to evaluate different circumstances in the port. The multi agent model along with waiting profile theory is used as it includes basic requirement for conducting the thesis, which is set of agents with appropriate behavior rules. The agents and the way they interact with each other are represented in figure 6.1.

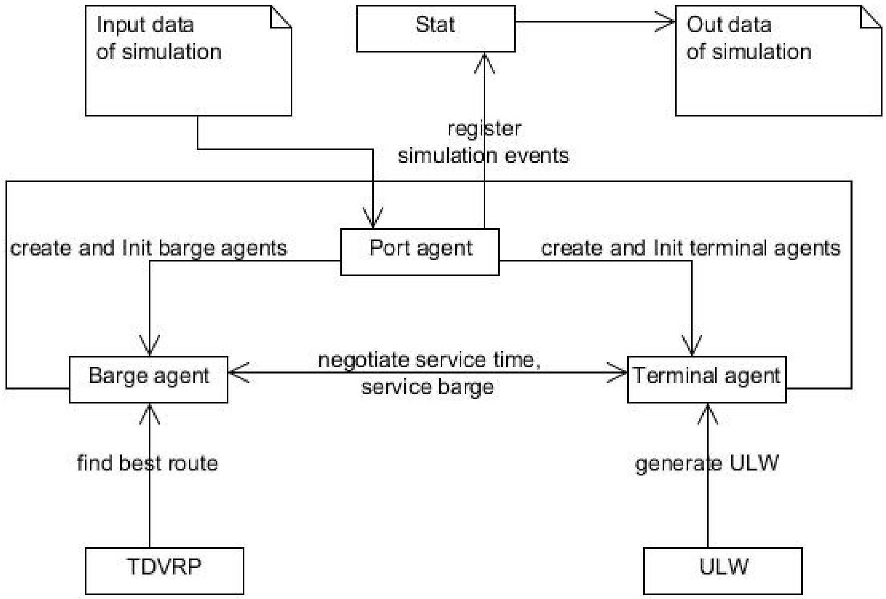


Figure 6.1: general architecture of the simulation model

Port agent: This agent is responsible to create the context by implementing the ContextBuilder of Repast. The context allows adding agent to the environment so they can interact with each other. After creating the context, port agent gets the input data of the simulation, which is defined by user, from an xml file. These parameters include, gap time, scheduling policy, arrival pattern, and certainty in model. This agent creates 15 terminal agents and adds them to the context. It also creates and initializes barge agents during runtime using the Poisson arrival pattern.

Barge agent: This agent is responsible to contact with defined terminal agents to book appropriate time slot by following communication protocol described in *section 5* (figure 5.1). Terminals create upper limit of waiting, upon demand from the barge, for each potential entrance time. By using the upper limit of waiting, the barge can settle on the route with shortest waiting time by using TDVRP class. This agent is considered as a proactive agent that can calculate the best route of visit with shortest possible inactivity time. The outcome of the communication protocol (figure 5.1) is settlement of an appointment that both parties have agreed upon it. The agreement is only valid if the barge show up no later agreed time. Otherwise, the appointment will be revoked and the barge is obliged to book new timeslot. The flowchart of the barge events is represented in figure 6.2.

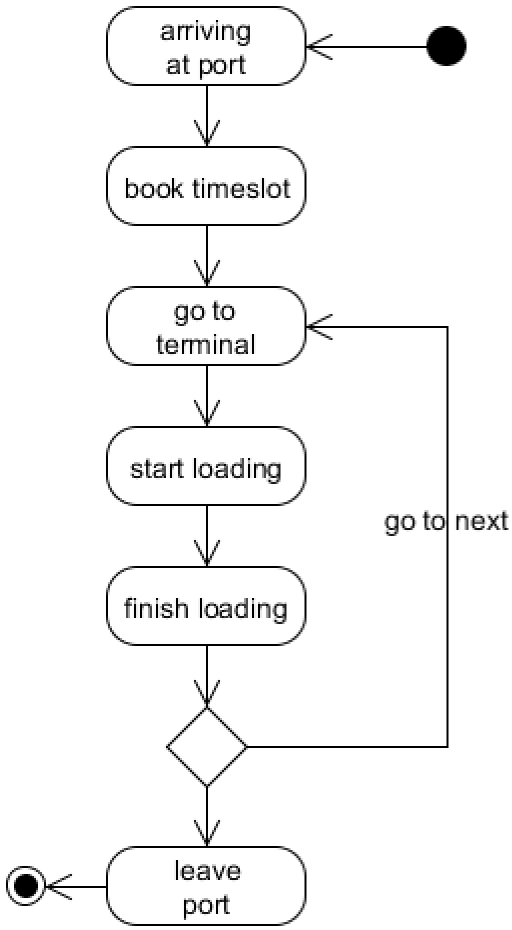


Figure 6.2: flow chart of the barge events

Terminal agent: This agent replies to the barge demand of issuing upper limit of waiting by using ULW class. It is also responsible to schedule and service barges. It maintains a queue of barges that need to load/unload their cargoes. The barges will be selected from the queue according to the chosen scheduling policy. When a barge comes in front of the terminal, the terminal makes decision whether to start the job based on its scheduling procedure, which is either cooperative (figure 6.4) or non-cooperative (figure 6.5). Terminal continuously withdraw barges from the waiting line based on its scheduling procedure, begin the service and then schedule the end time of the operation using the simulator's event scheduler. The sequence of events is shown in figure 6.3.

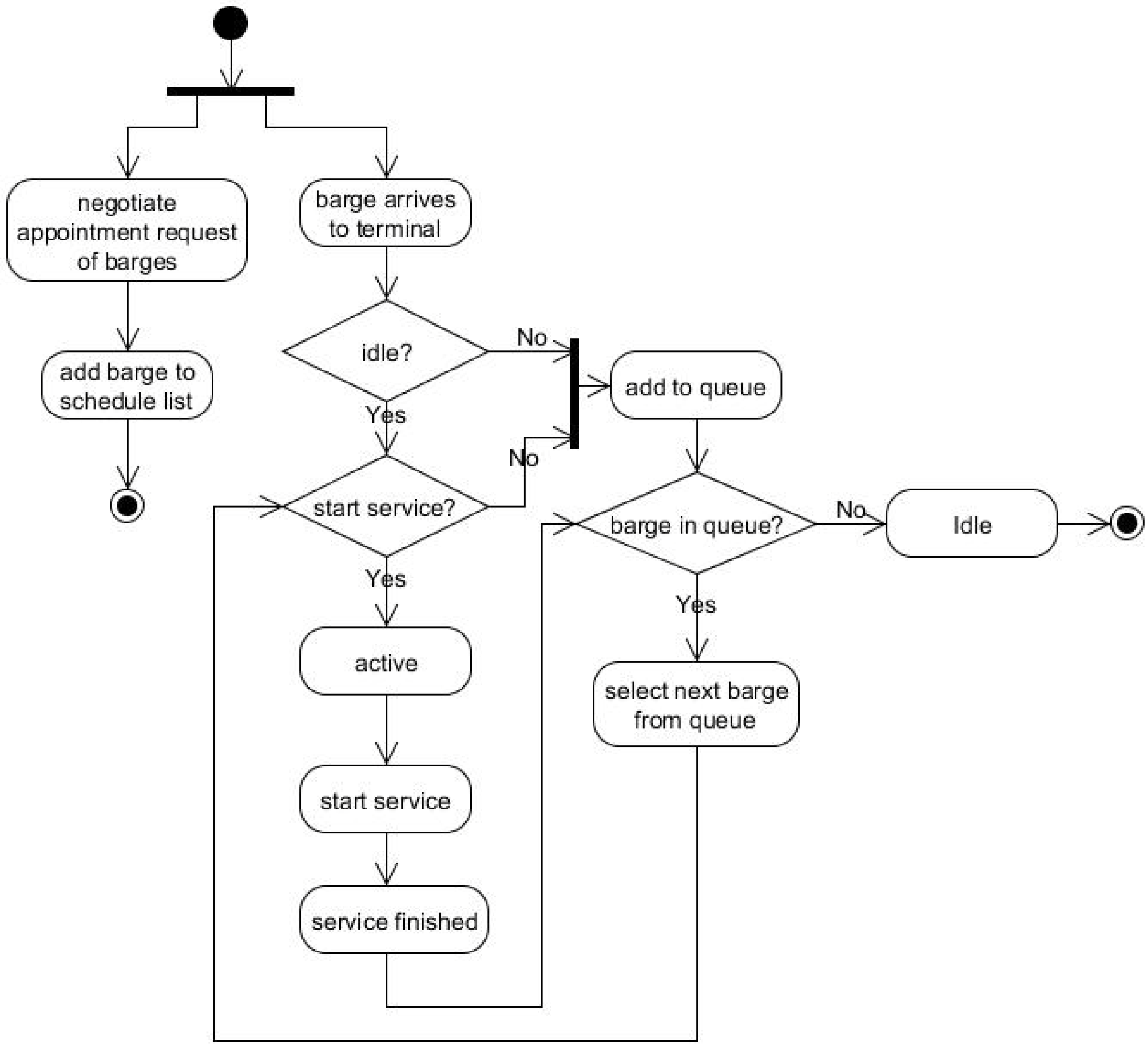


Figure 6.3: flow chart of the terminal events

ULW: this class provides information about upper limit of waiting, upon demand, for all likely entry time. The mathematical model is described in *section 2.5*.

TDVRP: This class provides the route with shortest waiting time by implementing the algorithm described in *section 2.6*.

Stat: this class is used by all agents to register the events such as arrival/departure time to and from port/terminal, as well as start/finish time of service at each terminal. These events are written to an Excel file and can be used for debugging purpose. This class also registers the total waiting time and difference between actual and planned departure time as output of the simulation for analysis purpose.

6.1 Scheduling procedure

Different scheduling procedures are defined by considering the extent to which parties stick to the agreed time slot and amount of extra gap included in the waiting profile. In the following part, these strategies will be discussed comprehensively. Terminals' approach to arrange and service the barges can be categorized as cooperative or non-cooperative.

6.1.1 Cooperative approach

Under the cooperative approach, both parties agree upon a certain time to start (un)loading of the cargoes and they are supposed to stick to the agreed timeslot. Figure 6.4 illustrates the flow chart of the system under the cooperative approach.

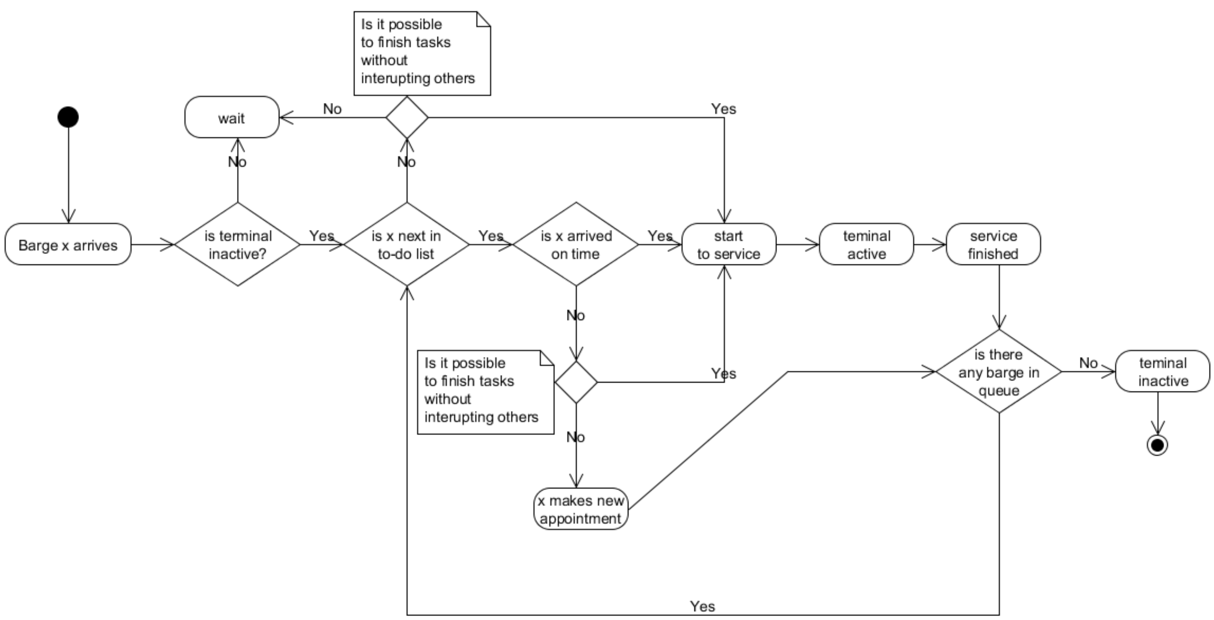


Figure 6.4: flow chart of the system under the cooperative approach

This approach may work well when there is no uncertainty and interruption assumed in the model. Such model is called deterministic throughout the paper. Under deterministic model, using cooperative approach means that both parties have exact information about the arrival and service time. On the other hand, it may diminish the efficiency, as the barge may have to wait in line even if the terminal is inactive. This is due to possibility of overlapping with the time that is arranged for other barge as it is shown in flow chart diagram figure 6.4.

Under the stochastic model when there is uncertainty and possible interruption in process of servicing and sailing, the parties may not always stick to the agreed timeslot. If a barge is late and the estimated time of finishing the loading of cargoes is larger than the time that is arranged for other barge so it has to book another timeslot to prevent propagation of interruption. This is the same approach as described in (Schuur, et al., 2009).

6.1.2 Non-cooperative approach

The proposed way of making appointment and considering that both parties will stick to the established agreement and be on time can make the system more robust. However, lack of any regulatory mechanism to punish the barges, which have been repeated late, can persuade them to show some strategic behavior. For example, they may reduce the extra gap between two subsequent visits. This can happen, as there is no fine for being late. Such undesired behavior can diminish the system robustness. Therefore, we should hope that everyone would play fairly according to the rules. On the other hand, if you are a skeptical person you may see this unrealistic that every one follows the rules. With such a view that entities are not eager to make honest agreements so in advance scheduling does not seem sensible. Moreover, in real situation it is always possible that some interruption occur during the process, for example due to technical problem or missing custom documents. Also due to governing position of terminals, they rather prefer to reduce the inactivity time as much as possible by ignoring the overlap condition that is obligatory condition in cooperative approach. In this case, it can be a good idea to design a system in which no agreement about the possible service time is required in advance.

The non-cooperative approach is derived from combination of first-in first-out and the waiting profile methods. This involves servicing the barges according to their position in the queue. However, the waiting profile is still used to find the shortest journey time. In this approach, the waiting profile can be seen as an approximation tool to find the shortest path. Like cooperative approach, both parties need to agree upon a timeslot but there is no obligation to stick to the agreement. The position in the waiting line is the only criteria to decide whether to start servicing. Figure 6.5 illustrates the flow chart of the system under the non-cooperative approach.

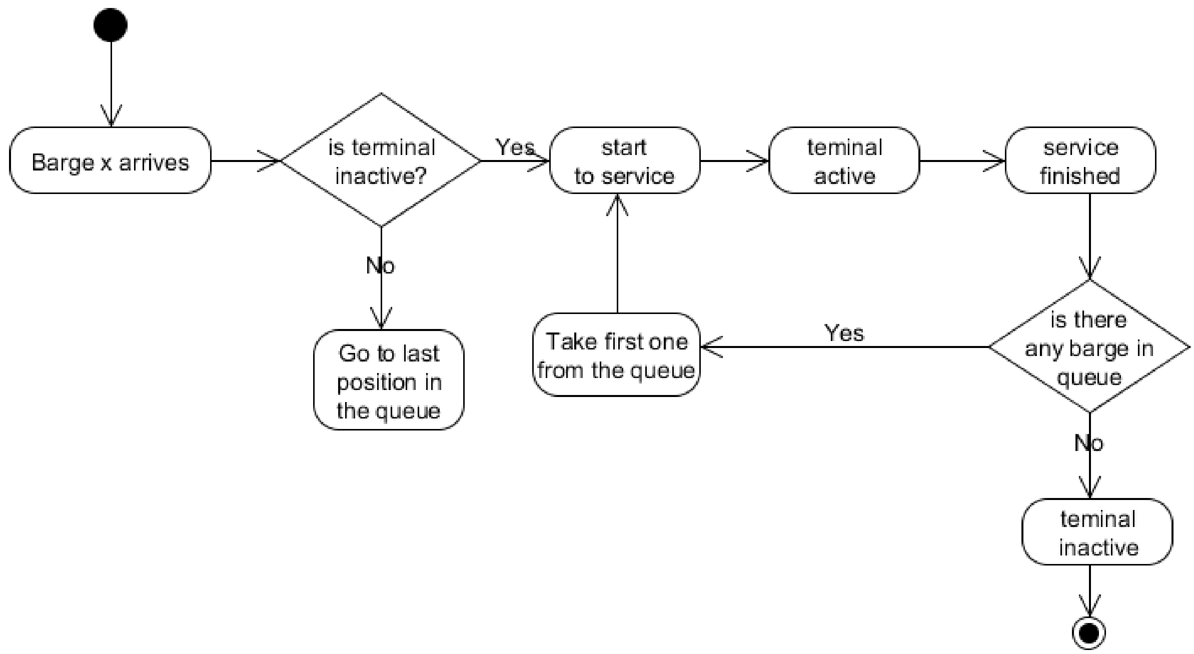


Figure 6.5: flow chart of the system under the non-cooperative approach

6.1.3 Extra time gap

The terminal should make a decision about amount of extra time that need to be added to the estimated upper limit of waiting. The purpose of adding extra time is to make the timetable more flexible and resistant against possible interruptions. This extra time may provide enough time to recover from possible interruption and back to schedule without propagating the delay to other entities in the port. Three levels of gap are defined as no gap, medium gap (half an hour), and high gap (one hour).

6.2 Simulation assumptions and simplifications

In this thesis, it is assumed the agents are self-interested and may show strategic behavior, without any care about other agents in the system. It is also assumed that similar agents have similar algorithm and intelligent.

The cooperative and non-cooperative approach is assessed under both deterministic and stochastic setups. The service time and the traveling time variables are definite under the deterministic setup and never change during the run time. It means no interruption assumed during the process and the value of these variables would stay the same as the one that is used to calculate the shortest path and making appointment. Schuur, et al. (2009) have defined the realist setting for the service time and number of the terminals to stopover as follow:

- Service time is normally distributed random number with mean 30 and variance 10 which is discretized by rounding it and setting the min value to 10
- Number of the terminals to stopover is triangularly distributed with min 2, max 8, and mode 5. The total number of terminals are 15 include the port gateway.

However, to simulate the possible interruption, under the stochastic setup the value of these variables during the actual process may differ from the one that is used to calculate the shortest path and making appointment. During the actual process the determined value for travelling time and service time is replaced by a normally distributed random numbers where the mean is the value that is used to calculate the shortest path and making appointment and variance is three. The variance can be set to other values to simulate different degree of chaos in the port. However considering the factorial design of experiment this will increase the number of experiment exponentially. Evaluating efficiency of the scheduling approach under different level of chaos can be considered in further research.

The approach used to model arrival pattern of the barges is Poisson process, which is a common way that is used in most models. If number of arrival per unit of time is exponentially distributed the interarrival rate has a Poisson distribution (Banks, 1998).

The aim of modeling arrival pattern as exponentially distributed is to simulate different level of workload and crowdedness.

To estimate the level of crowdedness it is necessary to have estimation on maximum possible utilization degree. Considering average service time and mode of number of the terminals to stopover, each barge needs 150 ticks of service in average, thus:

$$total\ available\ time\ to\ service\ = No\ of\ terminals * runlength$$

$$14 * 65120 = 911680$$

$$total\ No\ of\ barges\ to\ service = \frac{total\ available\ time\ to\ service}{avrage\ service\ time}$$

$$\frac{911680}{150} \approx 6077$$

$$arrival\ rate = \frac{runlength}{total\ No\ of\ barges\ to\ service}$$

$$\frac{65120}{6077} \approx 11$$

Therefore, by allowing for the traveling time and queuing time arrival pattern of one barge per 11 ticks means high crowdedness. Considering three level factorial design high, medium and low arrival pattern is experimented. The arrival rates are high=13, medium=15, and low=20. Exponentially distributed random number with arrival rate of λ means that the probability of selecting interarrival time of greater than x is $e^{-\frac{1}{\lambda}*x}$. Therefore, there is higher probability of selecting an interarrival time of less λ.

6.2.1 Run length

The run length and transient state is calculated according to the methods introduced in *section 3.1*. The model is run under different condition and longest run length and transient state is considered for all settings. Consider that overestimating these values improve the validity of the result while it may increase the computation cost. The transient state of 1440 ticks and run length of 65120 ticks is estimated to have a valid result.

6.2.2 Randomness in the model

When there is randomness in the model, it is important to initialize the random number generator with same seed so the output of simulation would be always same despite existing of random element in the model. Therefore, a consistence comparison between different experimental settings can be made. Moreover, to prevent correlation among random element each element uses different stream of random number with different seed (Robinson, 2004). The random elements in this thesis include, interarrival pattern, traveling time, service time, number of terminals to stopover, and deviation between expected and actual traveling/service time when adding uncertainty to the model.

6.3 Implementation

The model contains agents that each of them embodies an individual barge/terminal company and it has dynamic and decentralized attributes. In addition, the interaction is only between dissimilar agents not between two identical agents such as terminals. All the agents in the system use identical communication protocol and can decide on behalf of human operator in the corresponding company. For the purpose of this thesis, three different types of agents are developed in JAVA, which are barge, port, and terminal agents. Moreover, there are two classes called ULW and TDVRP, which are used by agents to find shortest path and create upper limit of waiting at each possible entry time.

The agents are coded in Repast platform using JAVA programming language. The Repast Suite allows creating agent-based simulation. It is fully object oriented, has notion of clock, supports concurrent discrete event scheduling, and provides libraries for developing and running agents. It also provides GUI for entering specific value for each experimental factor. This GUI must be configured according to the need of modeler by writing an xml file. Repast reads from the xml file to create data entry fields in the GUI.

To model the business activities in a port, discrete event simulation (DES) is used. Repast provides fully concurrent DES scheduler. The implemented model in this thesis uses event scheduler of Repast (IScheduler class) that is responsible to schedule occurrence of certain event at certain time. Each event in the simulation is coded as a

JAVA method and embodied in corresponding class. Each method includes set of activities that must be done during particular event. The examples of such events include arrival/departure event to and from port/terminal, as well as start/finish service at each terminal. The repast provides notion of clock, which is called tick. IScheduler allows scheduling a certain event to happen at specific tick count. In essence, IScheduler object invoke method of an object (e.g. barge object) at certain tick count.

Moreover, The Repast scheduling allows for dynamic scheduling such that the completing of an event can itself schedule other events to be started in a certain time in future. For example, the “arrival to terminal” event may schedule the “start service” event, which in turn schedule “finish service” event.

7 Result

This section demonstrates the outcome of the simulation under different settings. To find an answer to the research question different scheduling policies with various amount of time gap, which is added to the waiting profile, are evaluated to find the best setting. The aim is to find out the effect of different settings on waiting time.

Using mixed level full factorial design, 36 experiments are performed considering different possible settings. These settings are represented in table 7.1. The experiments are aim to discover appropriate settings under two different conditions. These conditions include deterministic and stochastic model.

Table 7.1: mixed level full factorial design of simulation

Factors	levels
Scheduling policy	Cooperative, non-cooperative
Extra Time gap	No gap, half an hour, one hour
Certainty in model	Deterministic, stochastic
Arrival pattern	13, 15, 20
Total number of simulations	36

Moreover, before conducting ANOVA test it is essential to consider normality and homogeneity of variances in data. Consequence of violating these assumptions is discussed by some Authors (McDonald, 2015; Glass, et al., 1972; Rutherford, 2011; Maxwell & Delaney, 2004; Lix, et al., 1996). Carefully reviewing mentioned literatures data analysis is performed as follow:

Since ANOVA is not so sensitive to deviation from normality, visual inspection of normality is performed using histogram and Q-Q plot. In case of sever skewness; data transformation is performed to make data look more normal. The homogeneity of variances is tested using Levene's test. In case of heterogeneity of variance, both Welch’s anova and ANOVA test is used to ensure correctness of the test. Since number of observation in each group is large, balanced and there is no big variation of standard deviation, the probability of ‘*type I*’ error is still 0.05 and there is no difference between correctness of ANOVA and Welch test. Finally, whenever there is heterogeneity of variance Games-Howell is used as post hoc test instead of Duncan and Tukey test.

7.1 Deterministic model with cooperative policy

Under deterministic model, no interruption during the process is assumed. As it mentioned before extra time gap can be add to the upper limit of waiting time to generate more flexible timetable. The result of simulation shows that there is relation between time gap and difference between intended and actual departure time of the barge (figures 7.1 through 7.3). As time gap increases, the departure time is earlier than the intended time. This result is identical for different level of crowd in the port.

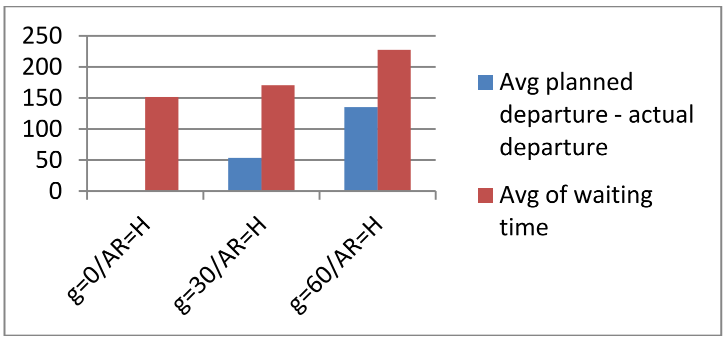


Figure 7.1: Average of waiting time and difference between planned and actual departure time during high arrival rate (AR=H) with different amount of time gap (g).

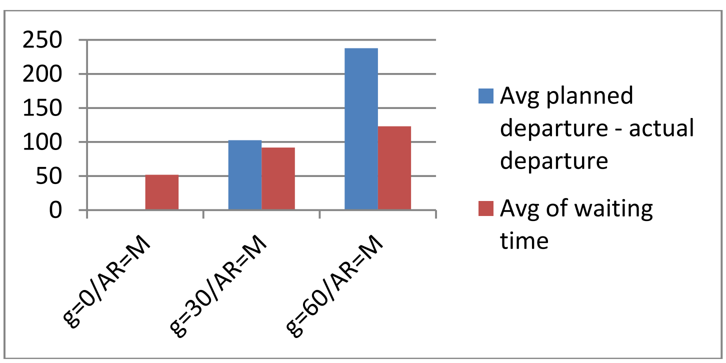


Figure 7.2: Average of waiting time and difference between planned and actual departure time during medium arrival rate (AR=M) with different amount of time gap (g).

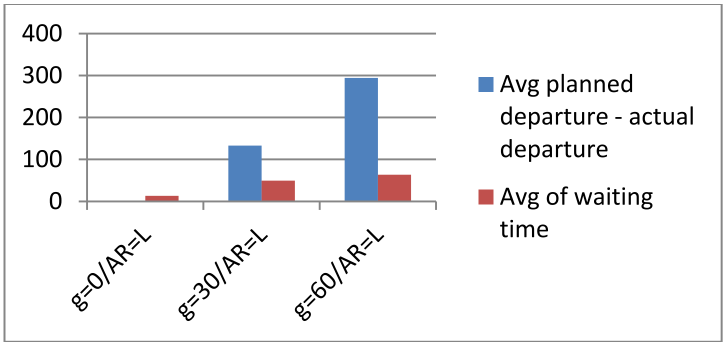


Figure 7.3: Average of waiting time and difference between planned and actual departure time during low arrival rate (AR=L) with different amount of time gap (g).

The result of simulation (figures 7.1 through 7.3) is also identical to the result presented by Schuur, et al. (2009) and shows that the model implemented for the purpose of this thesis is valid and correct.

The reason of adding extra time gap is to make the timetable more flexible. This causes adding extra time to the upper limit of waiting which in turn results in calculating longer expected staying time in the port. However, when there is no interruption during the process, this time gap will never comes handy and barges can leave earlier than the intended time. Customers may become more satisfied if their job finishes earlier than their expectation; the extra time gap can help to achieve such satisfaction. However, the purpose here is to reduce the waiting time not providing artificial satisfaction. Considering this issue the significance difference of average waiting time is analyzed using Welch test with confidence level of 95% (α=0.05). Different amount of gap are compared considering different level of arrival rate.

For the high arrival rate (figure 7.1) the result of Welch test reported as $F(2, 9560) = 391.69$, $\rho < 0.001$, $\rho < \alpha$. It can be concluded that at the busiest time of the port at least two of the three level of time gap differ significantly on their average waiting time. Post hoc comparison using Games-Howell indicated all three levels of gaps are significantly differing from each other. However, estimating the effect size by adjusted omega squared[1] it can be concluded that approximately 5% of the total variance in average of waiting time is accounted for by amount of extra time gap.

[1] $est.\omega^2 = \frac{df_{bet}(F-1)}{df_{bet}(F-1)+N_r}$

For the medium arrival rate (figure 7.2) the result of Welch test reported as $F(2, 8270) = 1250.9$, $\rho < 0.001$, $\rho < \alpha$. It can be concluded that at the medium level of crowd in the port at least two of the three level of time gap differ significantly on their average waiting time. Post hoc comparison using Games-Howell indicated all three levels of gaps are significantly differing from each other. However, estimating the effect size by adjusted omega squared it can be concluded that approximately 17% of the total variance in average of waiting time is accounted for by amount of extra time gap.

For the low arrival rate (figure 7.3) the result of Welch test reported as $F(2, 6086) = 2091.11$, $\rho < 0.001$, $\rho < \alpha$. It can be concluded that during quiet time of the port at least two of the three level of time gap differ significantly on their average waiting time. Post hoc comparison using Games-Howell indicated all three levels of gaps are significantly differing from each other. However, estimating the effect size by adjusted omega squared it can be concluded that approximately 31% of the total variance in average of waiting time is accounted for by amount of extra time gap.

From data analysis, it seems that under deterministic model, in which there is no interruption during the process, as the port becomes more quiet the amount of extra gap has more effect on increasing the average of waiting time. In all three level of crowd, adding no extra time gap shows better result in reducing the average of waiting time. The negative effect of extra time gap on waiting time is because of changes in calculation of shortest path using TDVRP. The shortest path is calculated using the upper limit of waiting on each specific time. Adding different amount of extra time to the upper limit of waiting can cause different calculation of path. When there is no interruption in the model, making the schedule flexible and robust to possible disruption does not make sense. Such flexibility can be considered as wrong upper limit of waiting, which in turn cause miscalculation of shortest path and increase in average of waiting time.

7.2 Comparing non-cooperative and cooperative policy under deterministic model

The previous section was mainly aim to ensure validity of model by comparing the result of experiment with the result obtained by Schuur, et al. (2009). As it is discussed before, the implemented model provided the same result as Schuur, et al. (2009); however, different interpretation is made.

This section intends to compare efficiency of non-cooperative and cooperative policy during different levels of crowd in the port.

High arrival rate:

To compare the non-cooperative and cooperative scheduling policy under busiest time of the port a two-way analysis of variance is performed. The means and standard deviations are presented in Table 7.2.

Table 7.2: Descriptive statistic, considering different policy and gap time under high arrival rate

Dependent Variable: Waiting time

gap	policy	Mean	Std. Deviation	N
0	cooperative	11.0549	5.39998	4806
	non-cooperative	12.0084	4.56602	4803
	Total	11.5315	5.02296	9609
30	cooperative	12.1814	4.70067	4804
	non-cooperative	12.6836	4.91128	4804
	Total	12.4325	4.81343	9608
60	cooperative	14.0939	5.38377	4799
	non-cooperative	13.4366	4.74195	4804
	Total	13.7651	5.08323	9603
Total	cooperative	12.4426	5.32130	14409
	non-cooperative	12.7096	4.77728	14411
	Total	12.5761	5.05827	28820

A two-factor analysis of variance at $\alpha=0.05$ showed a significant effect of extra time gap on average waiting time, $F(2, 28814) = 492.78$, $p < 0.05$. As amount of time gap increases the waiting time increases. The effect of scheduling policy was significant $F(1, 28814) = 20.73$, $p < 0.05$. Cooperative policy was perceived to be more efficient than non-cooperative policy. There was significant interaction between extra time gap and scheduling policy, F (2, 28814) = 1658.05, p <. 05. Figure 7.4 illustrate the estimated marginal means considering different amount of gap and policy. Even though Levene's test reject the hypothesis of homogeneity of variance across groups, the result of test is still significant as the p value is much smaller than 0.001. Therefore the probability of type I error due to heterogeneity of variance is low and the result is still reliable with 95% confidence level. The output of ANOVA test is available in appendix A.

The result of analysis indicates that cooperative policy without adding extra time gap significantly increases the efficiency by reducing the average waiting time. The reason of negative effect of time gap is already discussed. Regarding to the scheduling policy, non-cooperative approach does not seem to be efficient except in case of high level of time gap. In other word, non-cooperative policy can mitigate the negative effect of high time gap. Under the deterministic model and rush time of the port, sticking to the plan seems to be better strategy. Non-cooperative policy that follows first-come-first-serve strategy causes barge 'A' that came earlier than estimated time to be served right away and departed earlier. However, the other barge that was on time and first one in the list may have to stop longer since it showed up after barge A. From the data analysis it seems that the number of barges who are departed earlier is much less than the number of barges who are late due to first-come-first-serve strategy.

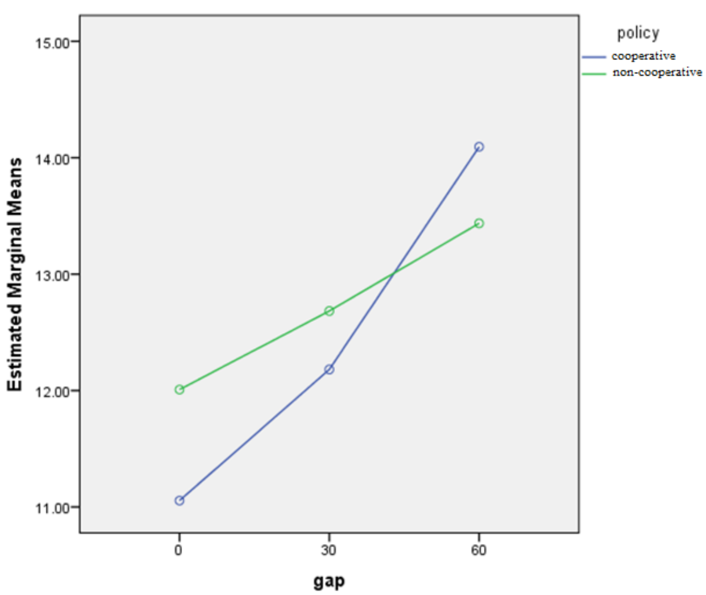


Figure 7.4: Estimated marginal means under High arrival rate

Medium arrival rate:

To compare the non-cooperative and cooperative scheduling policy under medium level of crowd in the port a two-way analysis of variance is performed. The means and standard deviations are presented in Table 7.3.

Table 7.3: Descriptive statistic, considering different policy and gap time under medium arrival rate

Descriptive Statistics

Dependent Variable: waiting time

gap	policy	Mean	Std. Deviation	N
0	cooperative	6.0135	3.97588	4169
	non-cooperative	8.1209	3.85628	4168
	Total	7.0670	4.05560	8337
30	cooperative	8.9547	3.41390	4164
	non-cooperative	9.1843	3.43404	4165
	Total	9.0695	3.42570	8329
60	cooperative	10.3048	4.11670	4164
	non-cooperative	10.1147	3.91747	4169
	Total	10.2097	4.01914	8333
Total	cooperative	8.4234	4.24411	12497
	non-cooperative	9.1400	3.82956	12502
	Total	8.7818	4.05788	24999

A two-factor analysis of variance at $\alpha=0.05$ showed a significant effect of extra time gap on average waiting time, $F (2, 24993) = 1464.61$, $p <. 05$. As amount of time gap increases the waiting time increases. The effect of scheduling policy was significant $F (1, 24993) = 222.21$, $p <. 05$. Cooperative policy was perceived to be more efficient than non-cooperative policy. There was significant interaction between extra time gap and scheduling policy, $F (2, 24993) = 216.55$, $p <. 05$. The partial eta squared test showed that 10% of variation in waiting time is because of extra time gap. The Pairwise comparison and Univariate test (table 7.4 and 7.5) confirmed significance difference between no gap time, $p<0.001$, and one hour of gap time, $p=0.02$. This can be seen in figure 7.5, which illustrates the estimated marginal means considering different amount of gap and policy.

Table 7.4:Pairwise Comparisons policy*gap

Dependent Variable: waiting time

gap	(I) policy	(J) policy	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
0	cooperative	non-cooperative	-2.107*	.083	.000	-2.270	-1.944
	non-cooperative	cooperative	2.107*	.083	.000	1.944	2.270
30	cooperative	non-cooperative	-.230*	.083	.006	-.393	-.067
	non-cooperative	cooperative	.230*	.083	.006	.067	.393
60	cooperative	non-cooperative	.190*	.083	.022	.027	.353
	non-cooperative	cooperative	-.190*	.083	.022	-.353	-.027

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 7.5: Univariate Tests policy*gap

Dependent Variable: waiting time

gap		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
0	Contrast	9256.550	1	9256.550	642.650	.000	.025
	Error	359992.008	24993	14.404			
30	Contrast	109.789	1	109.789	7.622	.006	.000
	Error	359992.008	24993	14.404			
60	Contrast	75.322	1	75.322	5.229	.022	.000
	Error	359992.008	24993	14.404			

Each F tests the simple effects of policy within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

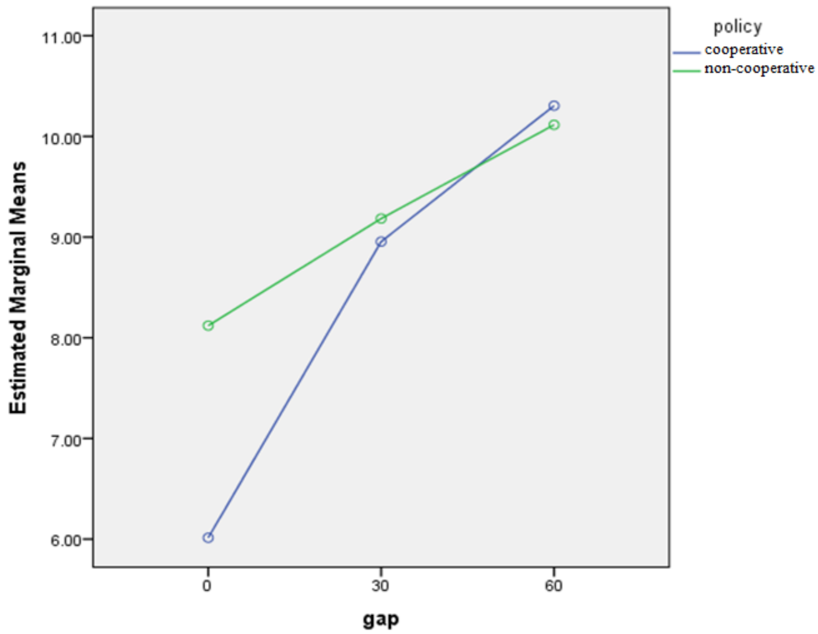


Figure 7.5: Estimated marginal means under medium arrival rate

As can be seen in figure 7.5 and tables 7.4-7.5 the cooperative policy with no gap time shows significantly better result in reducing the average of waiting time compare to other settings. It is obvious that as time gap increases the waiting time increases sharply.

Low arrival rate:

To compare the efficiency of the different setting under the Low arrival rate a two-way analysis of variance is performed on output data of the simulation. The mean, standard deviation and sample size is presented in table 7.6.

Table 7.6: Descriptive Statistics

Dependent Variable: waiting time

gap	policy	Mean	Std. Deviation	N
0	cooperative	2.3752	2.73269	3095
	non-cooperative	3.4323	3.14776	3097
	Total	2.9039	2.99439	6192
30	cooperative	6.2430	3.26553	3094
	non-cooperative	6.3881	3.28707	3094
	Total	6.3155	3.27685	6188
60	cooperative	7.0625	3.71236	3092
	non-cooperative	6.9192	3.58027	3094
	Total	6.9908	3.64730	6186
Total	cooperative	5.2262	3.84880	9281
	non-cooperative	5.5792	3.67810	9285
	Total	5.4027	3.76843	18566

A two-factor analysis of variance at $\alpha=0.05$ showed a significant effect of extra time gap on average waiting time, $F(2, 18560) = 2724.26$, $p <. 05$. As amount of time gap increases the waiting time increases. The effect of scheduling policy was significant $F(1, 18560) = 53.02$, $p <. 05$. Cooperative policy was perceived to be more efficient than non-cooperative policy. There was significant interaction between extra time gap and scheduling policy, $F(2, 18560) = 55.7$, $p <. 05$. The partial eta squared test showed that 23% of variation in waiting time is because of extra time gap. The Pairwise comparison and Univariate test (table 7.7 and 7.8) confirmed no significance difference between two different scheduling policies when gap time is half an hour, $p=0.08$, or one hour $p=0.09$. However, adding no gap time showed significant effect on reducing waiting time under both cooperative and non-cooperative setting. Moreover, the cooperative policy with no gap showed to be most efficient strategy. This can be seen in figure 7.6, which illustrates the estimated marginal means considering different amount of gap and policy.

Table 7.7: Pairwise Comparisons

Dependent Variable: waiting time

gap	(I) policy	(J) policy	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
0	cooperative	non-cooperative	-1.057*	.084	.000	-1.222	-.893
	non-cooperative	cooperative	1.057*	.084	.000	.893	1.222
30	cooperative	non-cooperative	-.145	.084	.084	-.310	.020
	non-cooperative	cooperative	.145	.084	.084	-.020	.310
60	cooperative	non-cooperative	.143	.084	.088	-.021	.308
	non-cooperative	cooperative	-.143	.084	.088	-.308	.021

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 7.8: Univariate Tests

Dependent Variable: waiting time

gap		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
0	Contrast	1729.685	1	1729.685	158.589	.000	.008
	Error	202429.279	18560	10.907			
30	Contrast	32.558	1	32.558	2.985	.084	.000
	Error	202429.279	18560	10.907			
60	Contrast	31.723	1	31.723	2.909	.088	.000
	Error	202429.279	18560	10.907			

Each F tests the simple effects of policy within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

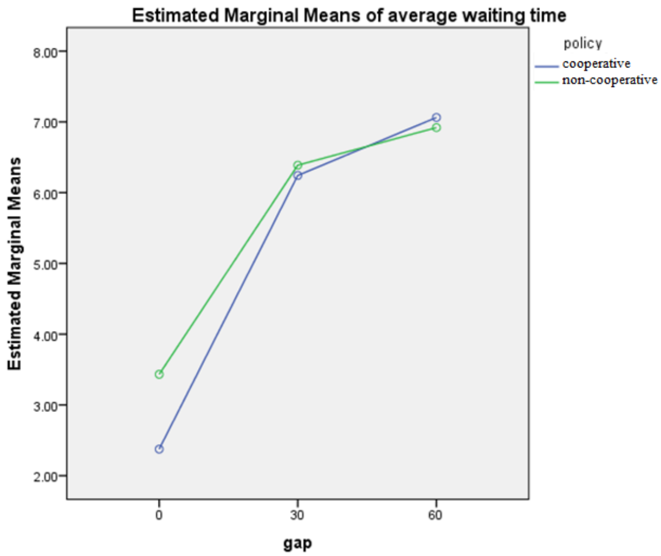


Figure 7.6: Estimated marginal means under Low arrival rate

The result of data analysis confirmed that when there is no interruption in the work process the cooperative approach with no extra time gap is the most efficient option compares to other settings. It is proven that amount of time gap has more significant effect on variation of average waiting time than the scheduling policy. The amount of time gap causes more variation in waiting time as port become quieter. As it is discussed before adding different amount of time gap to the timetable causes calculation of the different route. When there is no interruption in the model, making the schedule flexible and robust to possible disruption does not make sense. Such flexibility can be considered as wrong upper limit of waiting, which in turn cause miscalculation of shortest path and increase in average of waiting time.

Regarding to the scheduling policy, non-cooperative approach does not seem to be efficient policy. Under the deterministic model and different level of crowd in the port, sticking to the plan seems to be better strategy. Non-cooperative policy that follows first-come-first-serve strategy causes barge 'A' that came earlier than estimated time to be served right away and departed earlier. However, the other barge that was on time and first one in the list may have to stop longer since it showed up after barge A. From the data analysis it seems that the number of barges who were departed earlier and benefited from non-cooperative policy are much less than the number of barges who were late due to this policy.

7.3 Comparing non-cooperative and cooperative policy under stochastic model

To compare the non-cooperative and cooperative scheduling policy under stochastic model a two-way analysis of variance is performed. The results are interpreted by grouping them according to the level of crowd in the port.

High Arrival rate:

A two-factor analysis of variance at $\alpha=0.05$ showed a significant effect of extra time gap on average waiting time, $F(2, 28808) = 220.84$, $p <. 05$. The effect of scheduling policy was not significant $F(1, 28808) = 1.84$, $p >. 05$. There was significant interaction between extra time gap and scheduling policy, $F(2, 28808) = 55.63$, $p <. 05$. The result of post hoc test proved no significant difference between 'no' and half an hour gap as p=0.09 time (table 7.9 and Figure 7.7).

Table 7.9: Tukey HSD

gap	N	Subset	
		1	2
0	9608	12.6041	
30	9608	12.7562	
60	9598		13.9976
Sig.		.092	1.000

The error term is Mean Square(Error) = 25.414.

a. Uses Harmonic Mean Sample Size = 9604.664.

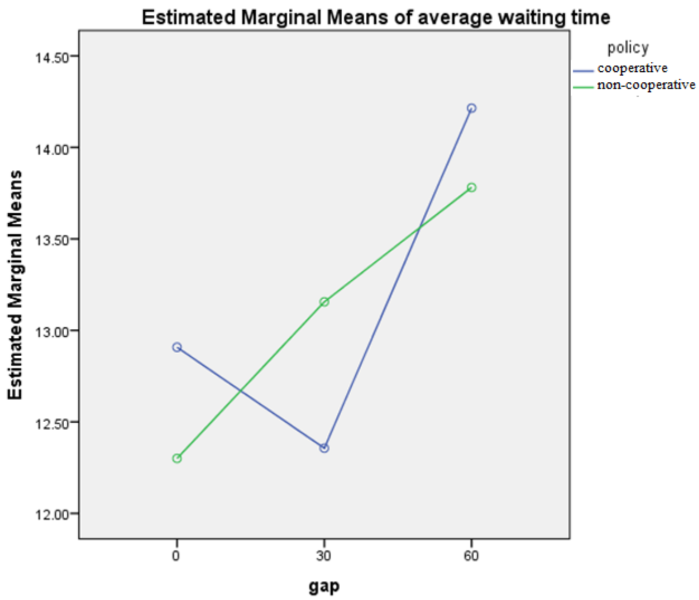


Figure 7.7: Estimated marginal means under high arrival rate

Considering the result there are two options that proved to be at the same level of efficiency. First, one is ‘no’ time gap with non-cooperative policy and second one is half an hour gap with cooperative policy. By looking at the average of difference between planned and actual departure time (figure 7.8) it can be seen that with half an hour of extra time gap barge can be planned more efficiently as it is more probable to be departed earlier than planned time. However, adding no gap can cause more delay since the timetable was not flexible enough to mitigate the consequence of interruption in process. Therefore, when there is possibility of interruption and during the rush hours cooperative approach with half an hour time gap is most efficient option.

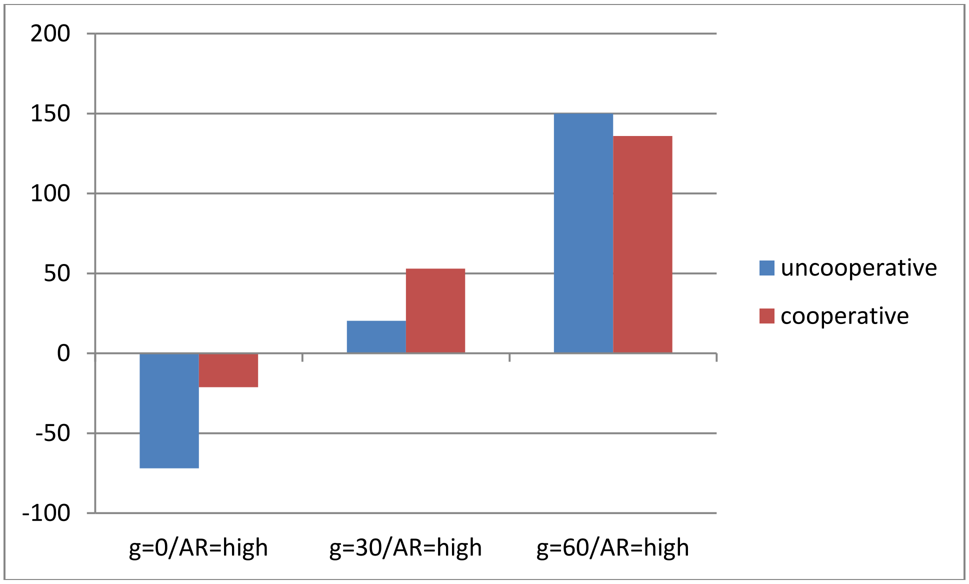


Figure 7.8: average of difference between planned and actual departure time

Medium arrival rate:

A two-factor analysis of variance at α=0.05 showed a significant effect of extra time gap on average waiting time, $F (2, 24987) = 699.92$, $p <. 05$. The effect of scheduling policy was significant $F (1, 24987) = 39.9$, $p <. 05$. There was significant interaction between extra time gap and scheduling policy, $F (2, 24987) = 13.552$, $p <. 05$. The Pairwise comparison and Univariate test (table 7.10 and 7.11) confirmed no significance difference between two different scheduling policies when gap time is half an hour, p=0.04, or one hour p=0.3. However, no gap time showed significantly different result under different policies p<0.001.

Table 7.10: Pairwise Comparisons

Dependent Variable: waiting time

gap	(I) policy	(J) policy	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
0	cooperative	non-cooperative	-.671*	.085	.000	-.838	-.504
	non-cooperative	cooperative	.671*	.085	.000	.504	.838
30	cooperative	non-cooperative	-.173*	.085	.042	-.341	-.006
	non-cooperative	cooperative	.173*	.085	.042	.006	.341
60	cooperative	non-cooperative	-.090	.085	.294	-.257	.078
	non-cooperative	cooperative	.090	.085	.294	-.078	.257

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 7.11: Univariate Tests

Dependent Variable: waiting time

gap		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
0	Contrast	937.726	1	937.726	61.800	.000	.002
	Error	379142.649	24987	15.174			
30	Contrast	62.566	1	62.566	4.123	.042	.000
	Error	379142.649	24987	15.174			
60	Contrast	16.729	1	16.729	1.103	.294	.000
	Error	379142.649	24987	15.174			

Each F tests the simple effects of policy within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Even though the p value for half an hour extra time gap is smaller than α=0.05, it is better to reject the assumption of significance deference since data failed to meet the assumption of homogeneity of variance and p value is close to the α. This is mainly because of possibility of type I error due to heterogeneity.

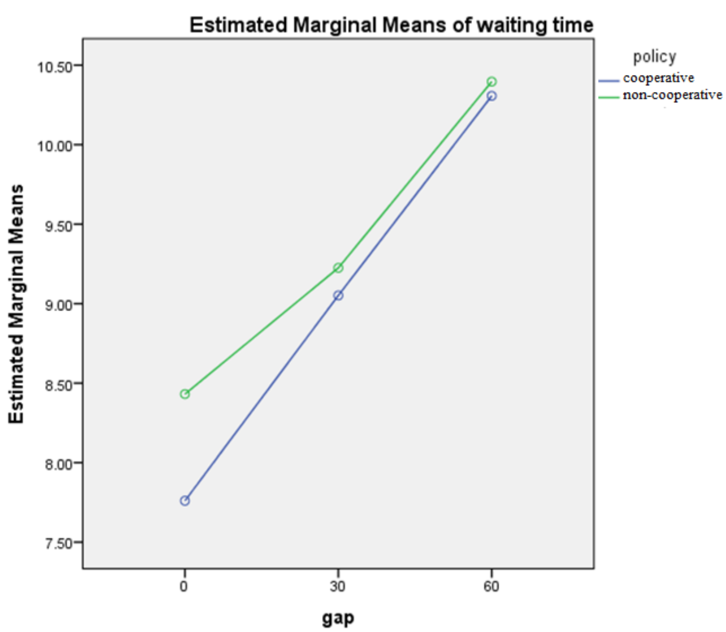


Figure 7.9: Estimated marginal means under medium arrival rate

Figure 7.9 and result of data analysis suggested no gap time and cooperative policy as an efficient setting when the arrival rate is medium and there is possibility of interruption.

However looking at the figure 7.10 it can be seen that the average amount of delay and variation from the planned departure time is higher when there is no gap time and so the timetable is not flexible. As can be seen adding more gap time results in better planning but more waiting time. Therefore, this must be decided by stakeholders to decide for either more accurate planning of the departure time or reducing the waiting time.

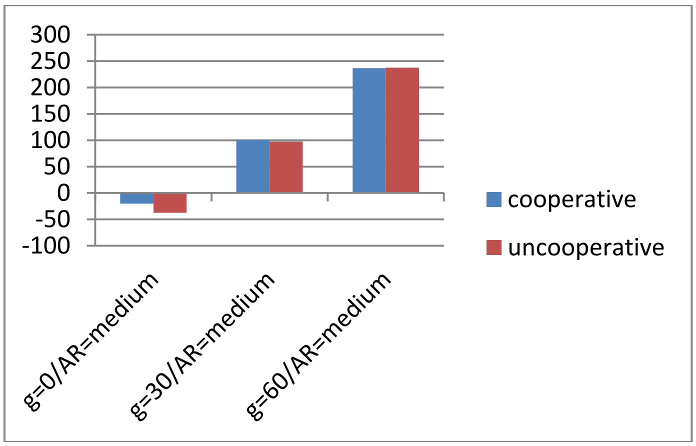


Figure 7.10: average of difference between planned and actual departure time

Low arrival rate:

A two-factor analysis of variance at $\alpha=0.05$ showed a significant effect of extra time gap on average waiting time, $F(2, 18554) = 1354.4$, $p <. 05$. The effect of scheduling policy was significant $F(1, 18554) = 12.3$, $p <. 05$. There was significant interaction between extra time gap and scheduling policy, $F(2, 18554) = 8.15$, $p <. 05$. The Pairwise comparison and Univariate test (table 7.12 and 7.13) confirmed no significance difference between two different scheduling policies when gap time is half an hour, $p=0.2$, or one hour $p=0.7$. However, no gap time showed significantly different result under different policies $p<0.001$.

Table 7.12: Pairwise Comparisons

Dependent Variable: waiting time

gap	(I) policy	(J) policy	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
0	cooperative	non-cooperative	-.455*	.088	.000	-.627	-.282
	non-cooperative	cooperative	.455*	.088	.000	.282	.627
30	cooperative	non-cooperative	-.114	.088	.196	-.286	.059
	non-cooperative	cooperative	.114	.088	.196	-.059	.286
60	cooperative	non-cooperative	.034	.088	.695	-.138	.207
	non-cooperative	cooperative	-.034	.088	.695	-.207	.138

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Table 7.13: Univariate Tests

Dependent Variable: waiting time

gap		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
0	Contrast	319.853	1	319.853	26.772	.000	.001
	Error	221670.245	18554	11.947			
30	Contrast	19.981	1	19.981	1.672	.196	.000
	Error	221670.245	18554	11.947			
60	Contrast	1.839	1	1.839	.154	.695	.000
	Error	221670.245	18554	11.947			

Each F tests the simple effects of policy within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Figure 7.11 and result of data analysis suggested no gap time and cooperative policy as an efficient setting when the arrival rate is low and there is possibility of interruption.

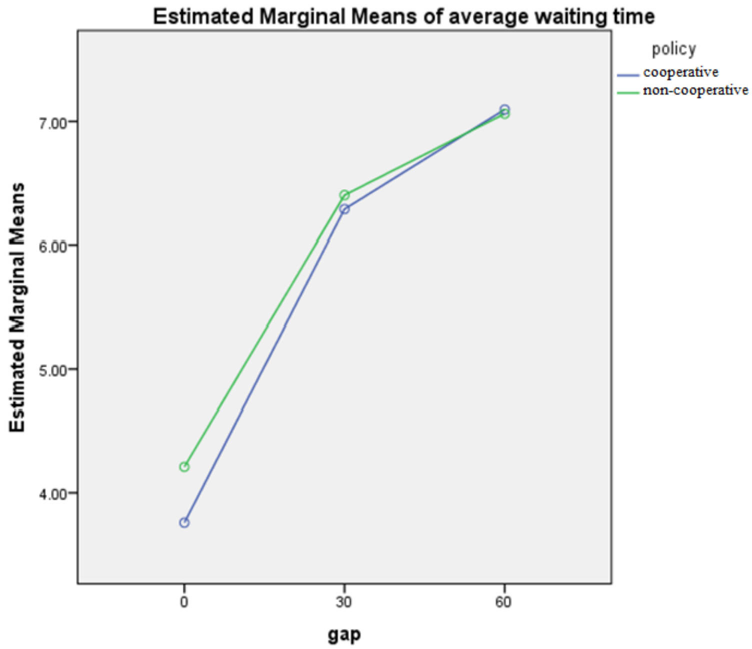


Figure 7.11: Estimated marginal means under Low arrival rate

However looking at the figure 7.12 it can be seen that the average amount of delay and variation from the planned departure time is higher when there is no gap time and so the timetable is not flexible. Adding more gap results to have better planning but it will increase the average of waiting time. Moreover, the non-cooperative strategy showed better planning of departure time when the gap time is zero. Therefore, this must be decided by stakeholders to decide for either more accurate planning of the departure time or reducing the waiting time.

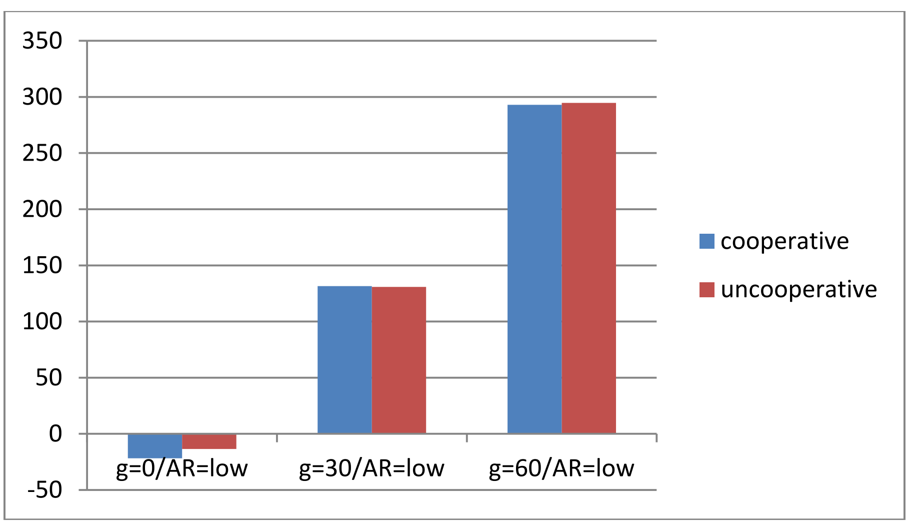


Figure 7.12: average of difference between planned and actual departure time

However, it must be consider that in this thesis only one level of interruption is assumed and it seems that the assumed amount of interruption does not requires flexibility in the timetable through adding more time gap. Adding more gap time may become more useful when amount interruption increases in the port. This issue must be considered in further study.

8 Conclusion

This thesis presents a multiagent scheduling system for the container port to achieve better coordination and association among barges and terminals. The performance of proposed multiagent system and various decentralized scheduling strategies are evaluated through simulation. Real time processing, minimum number of message exchange between agent, and reducing the inactivity time is considered to achieve efficient solution.

In this thesis different queuing policy and different amount of time gap is considered using factorial experiment design. The goal of queuing policy is to reduce the waiting time, and including extra time gap in timetable aim to make the timetable more flexible in case of unpredicted incidents. Each autonomous agent in the model is representative of a company in the port. The behavior and objective of the agents is defined based on relevant study. The interaction protocol among the agents is designed in a way to achieve real time and fast processing, as well as minimum number of message passing among agents.

The efficiency of two different scheduling policies is evaluated by means of simulation. The result of simulation shows when no interruption is assumed in the model the cooperative policy with zero gap time may reduce the average of waiting time significantly under different level of crowd.

When there is possibility of interruption and during the rush hours cooperative approach with half an hour time gap is efficient option. Result of data analysis suggested no gap time and cooperative policy as an efficient setting when the arrival rate is low or medium and there is possibility of interruption.

8.1 Discussion

The simulation is run under different setting. The cooperative and non-cooperative policies are compared with each other under different level of crowd as well as existence of interruption during the process. The result of simulation shows that when there is no interruption in the model the cooperative policy with zero gap time might reduce the average of waiting time significantly under different level of crowd. Considering the defined assumption and settings it seems that amount of time gap has more significant effect on variation of average waiting time than the scheduling policy. The amount of time gap causes more variation in waiting time as port become quieter. When there is no interruption in the model, making the schedule flexible and robust to possible disruption does not make sense. Such flexibility can be considered as false upper limit of waiting, which in turn cause miscalculation of shortest path and increase in average of waiting time. Under the deterministic model and different level of crowd in the port, sticking to the plan seems to be better strategy when there is no interruption. Non-cooperative policy that follows first-come-first-serve strategy causes barge ‘A’ that came earlier than estimated time to be served right away and departed earlier. However, the other barge that was on time and first one in the list may have to stop longer since it showed up after barge A. From the data analysis it seems that the number of barges who were departed earlier and benefited from non-cooperative policy are much less than the number of barges who were late due to this policy.

When there is high arrival rate and possibility of interruption is assumed, two options proved to be at the same level of efficiency. First, one is ‘no’ time gap with non-cooperative policy and second one is half an hour gap with cooperative policy. By looking at the average of difference between planned and actual departure time (figure 7.8) it can be seen that with half an hour of extra time gap, barge can be planned more efficiently as it is more probable to be departed earlier than planned time. However, adding no gap can cause more delay since the timetable was not flexible enough to mitigate the consequence of interruption in process. Therefore, when there is possibility of interruption and during the rush hours cooperative approach with half an hour time gap is efficient option.

Under the medium and low arrival rate, the situation is slightly different and need more consideration. Result of data analysis suggested no gap time and cooperative policy as an efficient setting when the arrival rate is low or medium and there is possibility of interruption. However, at this setting the average amount of delay and variation from the planned departure time is higher (figure 7.10). Increasing the amount of gap time may results in better planning at the expense of more waiting time. Therefore, this must be decided by stakeholders to decide for either more accurate planning of the departure time or reducing the waiting time.

It must be considered that these result achieved under defined assumptions and settings. The experimental method has better internal validity since it is possible to have control over independent variable. However, better external validity can be achieved through the field experiment, which is not possible due to ethical issue. Of course, the setting and assumptions that is made in this thesis has effect on the obtained result. It is probable that other set of setting and assumption produce different result. To improve the validity of this thesis, it is necessary to make the conceptual model closer to real world situation as much as possible. For example, the stochastic model only assumes one level of interruption that is relatively at low level. Different level of interruption must be defined carefully to have a result that is more valid. It is probable that various level of interruption may have effect on selection of most efficient scheduling policy. In design of the model, the closing time of the port is not considered and agents work 24/7. It would be more realistic to consider the closing time when defining the upper limit of waiting.

The assumptions and settings that are used to simulate the business process in a port are based on theoretical assumptions derived from similar studies. It would be better to collect consistent and trustworthy data for conceptual modeling through conducting a study on a specific case. This will help to improve the validity of the model and acceptance of the solution by stakeholders. Moreover, the schedule generated by agents must be checked by experts from the companies in a port to see if the schedule and selected shortest path is reasonable. This in turn will increase the probability of implementation of the solution. It must be consider that modeling is an iterative process and each iteration aims to improve the validity and feasibility of the solution. It is also necessary to collect data about the average waiting time through current scheduling approach in a port. This can be used as a benchmark to evaluate efficiency of the proposed multi scheduling system.

8.2 Further work

One of the issues that need to be considered is the stowage planning. The order of loading cargoes in a barge must be considered when TDVRP wants to find the path with less waiting time. For example, consider situation, in which if TDVRP decides to stop at terminal X before Y and the cargoes that need to be unloaded at X is at the bottom. This requires extra movement of containers to reach the one at the bottom and so increasing the service time. Therefore, further study must consider the efficient stowage planning and its collaboration with TDVRP.

The other experimental study based on historical data of a specific case must be conducted to find out about effectiveness and acceptance of the solution by stakeholders. This includes clarification about how to cope with players who perform strategic and frustrating behavior and how to prevent such behavior that may collapse the efficiency of the system. As it mention before, in the proposed model all agents are identical and behaves according to defined rules. However, in real situation companies may want to customize their agent. Such customization may damage the efficiency of the system. Therefore, it is necessary to define the level of customization, study about how to cope with strategic and frustrating behavior, what can be regarded as fair and feasible treatment, and what control mechanism can be implemented. This implies study about associated risk with each possible disturbing behavior

The focus of this thesis was more toward introducing an efficient system. However, it is also necessary to put attention on the affectivity of the solution (i.e. acceptability of the solution by companies). Further study should consider change management and requirement that must be considered during implementation of multi-agent system to satisfy interest of each individual actor.

Bibliography

Axelrod, R., 1987. Evolving new strategies – the evolution of strategies in the. In: L. Davis, ed. *Genetic Algorithms and Simulated Annealing*. San Francisco: Morgan Kaufmann Publishers Inc, pp. 32-41.

Axelrod, R., 2003. Advancing the Art of Simulation in the Social Sciences. *Journal of the Japanese,* 12(3), pp. 1-19.

Banks, J., 1998. *handbook of simulation: Principles, Methodology, Advances, Applications, and Practice.* Hoboken, NJ: John Wiley & Sons, Inc.

Chaib-draa, B. & Muller, J. P., 2006. *Multiagent based Supply Chain Management.* Berlin: Springer.

Chung, C. A., 2004. *Simulation modeling handbook.* Florida: CRC Press LLC.

Cresswell, J., 1994. *Research Design: qualitative and quantitative approaches.* Thousand Oaks: Sage.

Davis, p. K., 1992. *Generalizing concepts of verification, validation and accreditation (VV&A) for military simulation.,* Santa Monica: RAND.

Decker, K. & Li, J., 1998. *Coordinated hospital patient scheduling.* Paris, IEEE, pp. 104-111.

Delfmann, W. & Koster, R. d., 2007. *Managing Supply Chains: Challenges and Opportunities.* Denmark: Copenhagen Business school press.

Dinther, C. v., 2008. Agent-based Simulation for Research in Economics. In: B. Peter, J. Blazewicz, G. Schmidt & M. Shaw, eds. *Handbook on information technology in finance.* Berlin: Springer, pp. 421-442.

Ehmke, J. F., 2012. *Integration of Information and optimization models for routing in city logistic.* London: Springer.

Galliers, J. R., 1988. *A Theoretical Framework for Computer Models of Cooperative Dialogue, Acknowledging Multi-Agent Conflict,* UK: PhD thesis, Open University.

Glass, G. V., Peckam, P. D. & Sanders, J. R., 1972. Consequences of Failure to Meet Assumptions Underlying the Fixed Effects Analyses of Variance and Covariance. *SAGE journal: Review of Educational Research,* 42(3), pp. 237-288.

Goddard, W. & Melville, S., 2007. *Research Methodology: An Introduction.* 2nd ed. Lansdowne: Juta & Co.Ltd.

Golden, B., Wasil, E. & VoB, S., 2008. *The Vehicle Routing Problem: Latest Advances and New Challenges.* New York: Springer Science & Business Media.

Gregory, I., 2003. *Ethics in Research.* London: continuum.

Guan, Y. & Cheung, R. K., 2004. The berth allocation problem: models and solution methods. *OR Spectrum,* 26(1), pp. 75-92.

Håkansson, A., 2013. *Portal of Research Methods and Methodologies for Research Projects and Degree Projects.* Las Vegas, WORLDCOMP'13.

Halvorsen-Weare, ,. E. E. & Fagerholt, K., 2010. Routing and scheduling in a liquefied natural gas shipping problem with inventory and berth constraints. *Annals of Operations Research,* 203(1), pp. 167-186.

Helbing, D., 2012. *Social Self-Organization: Agent based simulations and experiments to study emergent social behavior.* London: Springer.

Hillegersberg, J. V., Miller, I., De Rakt, B. V. & Moonen, H., 2005. *Agent technology supports inter-organizational planning in the port,* New York: SSRN.

Jennings, N. R., Sycara, K. & Wooldridge, M., 1998. A Roadmap of Agent Research and Development. *Autonomous Agents and Multi-Agent Systems,* 1(1), pp. 7-38.

Kanda, A. & Deshmukh, S., 2008. Supply chain coordination: Perspectives, empirical studies and research directions. *International Journal of Production Economics,* 115(2), pp. 316-335.

Kentrop, M., Schut, M. & Melis, M., 2003. distributed rotation planning for container barges. In: T. Verduijn & B. van de Loo, eds. *Intelligent Logistics Concepts: Improving Your Supply Chain with Collaboration and ICT.* Delft: Eburon Publishers, pp. 101-116.

Konings, R., 2007. Opportunities to improve container barge handling in the port. *Journal of Transport Geography,* Volume 15, pp. 443-454.

Kothari, C. R., 2004. *Research Methodology: Methods and Techniques.* 2nd ed. Delhi: New Age International Ltd.

Lix, L. M., Keselman, J. C. & Keselman, H. J., 1996. Consequences of Assumption Violations Revisited: A Quantitative Review of Alternatives to the One-Way Analysis of Variance F Test. *SAGE journal: Review of Educational Research,* 66(4), pp. 579-619.

MacDougall, M. H., 1987. *Simulating Computer Systems: Techniques and Tools.* Cambridge: MIT Press.

Maxwell, S. E. & Delaney, H. D., 2004. *Designing Experiments and Analyzing Data: A Model Comparison perspective.* 2nd ed. New York: Tylor & Francis Group.

McCain, R. A., 2009. *Game Theory and Public Policy.* Cheltenham: Edward Elgar.

McDonald, J. H., 2015. *Hand book of Biological Statistics.* [Online] Available at: http://www.biostathandbook.com/onewayanova.html [Accessed 20 March 2015].

Miller, I. et al., 2004. *APPROACH: Decentralised Rotation Planning for Container Barges.* Valencia, ECAI, pp. 755-759.

Port-of-victoria, 2015. *Barge Advantage.* [Online] Available at: http://www.portofvictoria.com/default/environment/bargeadvantage.aspx [Accessed 12 3 2015].

Robinson, S., 2004. *Simulation: the practice of model development and use.* West Sussex: John Wiley & Sons, Ltd.

Robson, C., 2002. *Real World Research.* 2nd ed. Oxford: Blackwell.

Rosenschein, J. S. & Genesereth, M. R., 1985. *Deals among rational agents.* Los Angeles, CA, In Proceedings of the Ninth International Joint Conference on Artificial Intelligence (IJCAI-85), pp. 91-99.

Rutherford, A., 2011. *ANOVA and ANCOVA: A GLM Approach.* New Jersey: John Wiley & Sons Inc.

Sadeh, N. M., Swaminathan, J. M. & Smith, S. F., 1998. Modeling Supply Chain Dynamics: A Multiagent Approach. *A journal of the decision sciences institute,* 29(3), pp. 607-632.

Saunders, M., Lewis, P. & Thornhill, A., 2012. *Research methods for business students.* 6th ed. Harlow: Pearson Education Limited.

Schuur, P., Schutten, M. & Douma, A., 2009. Waiting profiles: An efficient protocol for enabling distributed planning of container barge rotations along terminals in the port of Rotterdam. *Transportation Research Part C-emerging Technologies,* 17(2), pp. 133-148.

Shoham, Y., 1993. Agent-oriented programming. *Artificial Intelligence,* 60(1), pp. 51-92.

Siswanto, N., Essam, D. & Sarker, R., 2011. Solving the ship inventory routing and scheduling problem with undedicated compartments. *Computers & Industrial Engineering,* 61(2), pp. 289-299.

Stahlbock, R. & Voß, S., 2008. Operations research at container terminals: a literature update. *OR spectrum,* 30(1), pp. 1-52.

Vollmann, T. & Davis, M., 1990. A framework for relating waiting time and customer satisfaction in a service operation. *Journal of Services Marketing,* 4(1), pp. 61-69.

Wang, F. & Lim, A., 2007. A stochastic beam search for the berth allocation problem. *Decision Support Systems in Emerging Economies,* 42(4), p. 2186–2196.

Weiss, G., 2013. *Multiagent Systems.* 2nd ed. Cambridge: MIT press.

White, J. E., 1994. *elescript technology: The foundation for the electronic marketplace,* 2465 Latham Street, Mountain View, CA 94040: White paper, General Magic, Inc.

White, K., Spratt, S. & Cobb, M., 2000. *A comparison of five steady-state truncation heuristics for simulation.* Piscataway, NJ, IEEE, pp. 755-760.

Wooldridge, M., 2009. *An introduction to multiagent systems.* 2nd ed. West Sussex: John wiley &Sons Ltd.

Wooldridge, M. & Jennings, N., 1995. Intelligent agents: Theory and practice. *The Knowledge Engineering Review,* 10(2), pp. 115-152.

WorldBank, n.d. *Container port traffic.* [Online] Available at: http://data.worldbank.org/indicator/IS.SHP.GOOD.TU/ [Accessed 1 11 2014].

Yin, R. K., 2003. *CAse study research: Design and method.* 3rd ed. London: Sage.

Zambonelli, F., Jennings, N. R. & Wooldridge, M., 2002. Organisational Abstractions for the Analysis and Design of Multi-agent Systems. *Agent-Oriented Software Engineering,* 1957(2001), pp. 235-251.

Appendixes

Appendix A

Two-way ANOVA test to compare non-cooperative and cooperative strategy with different level of time gap under deterministic model and High arrival rate

Univariate Analysis of Variance

Descriptive Statistics
Dependent Variable: waiting time

gap	policy	Mean	Std. Deviation	N
0	cooperative	11.0549	5.39998	4806
	non-cooperative	12.0084	4.56602	4803
	Total	11.5315	5.02296	9609
30	cooperative	12.1814	4.70067	4804
	non-cooperative	12.6836	4.91128	4804
	Total	12.4325	4.81343	9608
60	cooperative	14.0939	5.38377	4799
	non-cooperative	13.4366	4.74195	4804
	Total	13.7651	5.08323	9603
Total	cooperative	12.4426	5.32130	14409
	non-cooperative	12.7096	4.77728	14411
	Total	12.5761	5.05827	28820

Levene's Test of Equality of Error Variances[a]
Dependent Variable: waiting time

F	df1	df2	Sig.
52.009	5	28814	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.
a. Design: Intercept + gap + policy + gap * policy

Tests of Between-Subjects Effects
Dependent Variable: waiting time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	28086.216[a]	5	5617.243	228.197	.000	.038
Intercept	4558377.741	1	4558377.741	185181.343	.000	.865
gap	24260.077	2	12130.039	492.775	.000	.033
policy	510.257	1	510.257	20.729	.000	.001
gap * policy	3316.090	2	1658.045	67.357	.000	.005
Error	709278.235	28814	24.616			
Total	5295490.000	28820				
Corrected Total	737364.451	28819				

a. R Squared = .038 (Adjusted R Squared = .038)

Estimated Marginal Means

1. gap

Estimates

Dependent Variable: waiting time

gap	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
0	11.532	.051	11.432	11.631
30	12.433	.051	12.333	12.532
60	13.765	.051	13.666	13.864

Pairwise Comparisons

Dependent Variable: waiting time

(I) gap	(J) gap	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
0	30	-.901*	.072	.000	-1.041	-.761
	60	-2.234*	.072	.000	-2.374	-2.093
30	0	.901*	.072	.000	.761	1.041
	60	-1.333*	.072	.000	-1.473	-1.192
60	0	2.234*	.072	.000	2.093	2.374
	30	1.333*	.072	.000	1.192	1.473

Based on estimated marginal means
*. The mean difference is significant at the .05 level.
b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: waiting time

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	24260.077	2	12130.039	492.775	.000	.033
Error	709278.235	28814	24.616			

The F tests the effect of gap. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

2. policy

Estimates

Dependent Variable: waiting time

policy	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
cooperative	12.443	.041	12.362	12.524
non-cooperative	12.710	.041	12.629	12.791

Pairwise Comparisons

Dependent Variable: waiting time

(I) policy	(J) policy	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
cooperative	non-cooperative	-.266*	.058	.000	-.381	-.152
non-cooperative	cooperative	.266*	.058	.000	.152	.381

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Univariate Tests

Dependent Variable: waiting time

	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Contrast	510.257	1	510.257	20.729	.000	.001
Error	709278.235	28814	24.616			

The F tests the effect of policy. This test is based on the linearly independent Pairwise comparisons among the estimated marginal means.

3. gap * policy

Estimates

Dependent Variable: waiting time

gap	policy	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
0	cooperative	11.055	.072	10.915	11.195
	non-cooperative	12.008	.072	11.868	12.149
30	cooperative	12.181	.072	12.041	12.322
	non-cooperative	12.684	.072	12.543	12.824
60	cooperative	14.094	.072	13.954	14.234
	non-cooperative	13.437	.072	13.296	13.577

Pairwise Comparisons

Dependent Variable: waiting time

gap	(I) policy	(J) policy	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
0	cooperative	non-cooperative	-.953*	.101	.000000	-1.152	-.755
	non-cooperative	cooperative	.953*	.101	.000000	.755	1.152
30	cooperative	non-cooperative	-.502*	.101	.000001	-.701	-.304
	non-cooperative	cooperative	.502*	.101	.000001	.304	.701
60	cooperative	non-cooperative	.657*	.101	.000000	.459	.856
	non-cooperative	cooperative	-.657*	.101	.000000	-.856	-.459

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

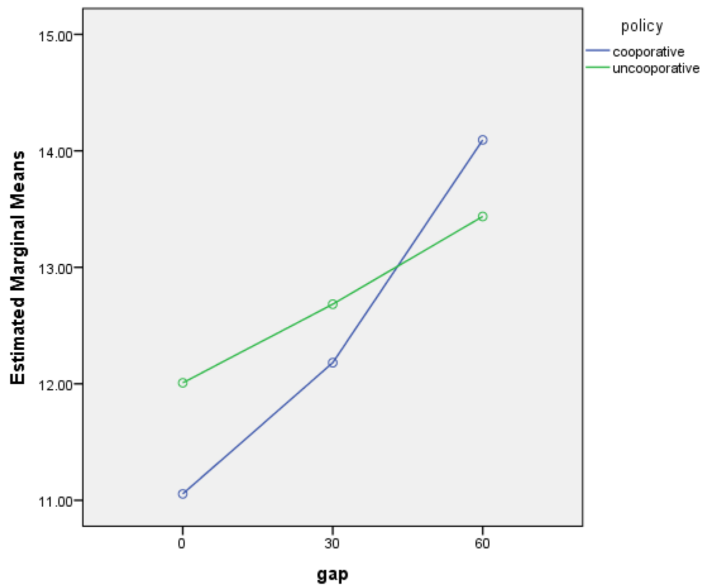
Univariate Tests

Dependent Variable: waiting time

gap		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
0	Contrast	2183.896	1	2183.896	88.719	.000	.003
	Error	709278.235	28814	24.616			
30	Contrast	605.840	1	605.840	24.612	.000	.001
	Error	709278.235	28814	24.616			
60	Contrast	1037.317	1	1037.317	42.140	.000	.001
	Error	709278.235	28814	24.616			

Each F tests the simple effects of policy within each level combination of the other effects shown. These tests are based on the linearly independent pairwise comparisons among the estimated marginal means.

Profile Plots



Appendix B

Milestone