Characteristics which define the success of lock operation policies

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Abstract

Currently most locks are managed by means of a first come, first serve policy. This policy is very well suited for managing locks, however there are some other options. One of the most promising is the shortest processing time first option. This policy focuses on the lock instead of the vessels. This paper tries to identify the most important factors that can influence the choice between these policies. By means of a simulation study, the following characteristics are identified that can influence the choice between those policies: the size of the chambers, the pattern of arrival and the fleet mix. Other characteristics that influence such a decision are the number of chambers and the proximity of obstacles.

Keywords: lock operation policy, lock characteristics, Discrete simulation, lock management

1. Introduction

The entrance of a port might be seen as one of the most important elements considering the capacity of a port. The amount of vessels that can enter the port will be the maximum number of vessels that can be handled by the port. Sooner or later this will limit the growth of a port. The amount of vessels that can enter the port is often limited by some external factor as well. One of the most important factors that might limit the capacity of ports are locks[1]. Locks can limit the capacity in two ways. First of all the flow of vessels will be limited, since vessels cannot continue on the same speed as they would have done on a waterway without obstacles. A second way in which the capacity of a port can be limited by a lock is a limitation of the dimensions of the vessels; if the lock has a maximum length of 200 meters, vessels of more than 200 meters cant pass[2]. The choice to make use of a lock depends on whether the benefits of a lock are higher than the downsides. Looking at the benefits, the following factors should be considered. A lock ensures the fresh water supply for the inland, a constant water level, protection from the water and cost reductions due to lower inland dikes.

Therefore, the impact of the downsides should be reduced as much as possible. The only option to reduce the dimension restrictions is increasing the size of the chambers of the lock. This will not be considered during this paper. The number of vessels that can pass through the locks

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can be influenced. The way this can be achieved is by applying the right lock operation policy. Lock operation policies are the way in which the vessels are scheduled to pass through the chambers of a lock. This includes three main problems which need to be solved in order to achieve a successful policy; the scheduling problem, the assignment problem and the packing problem. The scheduling problem deals with the time vessels should arrive and in which order they should arrive. The assignment problem deals with the assignment of resources such as pilots and tugboats and the assignment of the right chamber, while the packing problem deals with the arrangement of the vessels in a chamber. These the choice for a certain lock operation policy depends on two aspects. First of all the focus of the lock management and secondly the characteristics of the lock. A lot of research is dedicated to the focus of the lock management. In general, the focus can be on two aspects; the lock itself or the vessels. This will be discussed further in the next paragraph. The characteristics of a lock which determine the success of a lock operation policy will be discussed and research during the rest of the paper. This will be done by both literature search as well as by means of a discrete event simulation study. The main question that will be answered during this paper is: 

**What lock characteristics influence the effectiveness of a lock operation policy and what is the link between these characteristics and the focus of the lock management?**

Answering this question will result in a more general view on lock operation policies instead of the focus on case studies which can be found in literature. There are some attempts made to generalize the research towards lock operation policies. The main generalization step that is made is try to solve the complex situation around lock with mathematical models or simulation models which variable inputs[3]. This is however not the generalization step that is intended with this paper. The focus will be on the generalization of the results instead of the generalization of the model.

2. **What is a lock operation policy?**

In order to determine whether a characteristics influence the effectiveness of lock operation policies, it should be made explicit what the influence of the characteristics is on the different focus points of lock management and the corresponding key performance indicators, but before going into the different categories, the lock operation policies will be explained in general. Lock operation policy consist of two major parts. The first part is based on queueing theory and corresponds with the scheduling problem. The second part is based on the two dimensional bin packing problem, it deals with the arrangement of the vessels in the lock and the assignment of the chamber. The queueing theory is often applied for analyzing locks. The reason that it is applied often, is that analyzing a lock with the queueing theory is relatively cheap and the underlying assumption are to a certain extend equal[4]. Especially when a lock with one chamber is observed. This is similar to an M/G/1 system. Meaning that the arrivals follow a Poisson distribution, the service times have a general distribution and that there is one server available. The reason that this is possible is the fact that the system is relatively simple and there are not many choices that need to be made[4]. The results become even more reli-
able if the characteristics of the vessels that arrive at the lock are more similar. The differentiation between the theoretically calculated waiting time and the actual experienced waiting time start to differentiate more and more. This is due to the fact that it becomes possible to make choices between servers which are based on the usage of the servers, the filling rate, instead of the processing time. Therefor it can be said that the queueing theory is a useful tool for analyzing simple locks with just one chamber, but as soon as the system gets more complicated, the theory is less valid for analyzing and improving the system.

A two dimensional bin packing problem can be described as packing as many rectangle units in the minimum amount of large rectangle bins[5]. This theory can be applied in many field, like placing advertisements in a newspaper. This theory has some shared underlying assumptions with placing vessels in a chamber[5]. First of all, the rectangles cannot be rotated in order to fit in the rectangle bin. It should be noted that vessels are considered to be rectangular. Secondly, the dimensions of the bin (chamber) are fixed and the number of bins is unlimited. The benefit of applying this theory is that the locks can be used in an efficient way. It will minimize the number of lockages and therefor the energy consumption and the salt water exchange. Although this theory corresponds with the arrangement of vessels in a chamber, there are some crucial assumptions which do not correspond with fitting vessels in a chamber. The main assumptions that is not valid is that the ordering of the vessels is related to time. The two dimensional bin packing problem assumes that rectangles can be places in any order, while vessels who arrive at a chamber will enter the chamber in the other they arrive. This method of entering the locks saves waiting time, since vessels dont have to moor outside of the chamber or pass each other. A second assumption which is not in line with the lock process, is the placement of the vessels itself. The theory assumes that every empty space can be filled with a rectangle, while in the lock process vessels block some empty spots due to their location in the chamber.

As been said earlier, two categories of policies can be identified. Policies that focus on the locks or the vessels. Policies that focus on the locks itself can be identified by the focus on the following key performance indicators. The filling rate, this is a measure for the use of the lock[6], the number of lockages, which represents the CO² pollution, energy consumption and noise[7][8][9] and the utilization rate of the infrastructure[10][11][8]. It should be noted that the key performance indicators which are characteristic for the other policy are taken into account as well is a policy which focus on the locks is applied. There are a couple theoretical variation within this focus. The first is the Shortest Processing Time first (SPT) theory. This theory focuses on the utilization of the lock by handling the vessels with the shortest processing time first[12]. This can be done in two ways, either considering the shortest processing time per vessel or the shortest processing time per unit of cargo[12][13]. by selection the vessels based on processing time, the number of vessels or the units of cargo that go through the locks at once will be maximized for each locking process. It is possible to set maximum waiting times in order to exclude on wanted waiting times for the vessels. This method minimizes the number of lockages and maximizes the batch size and the filling rate.
Policies that focus on the vessels have on average a high score on the following KPI: the waiting time, both for resources as well as for the lock itself[14][15][16][17]. The waiting time should be taken into account in two ways. The average waiting time and the variance in waiting time. The combination of those factors is important for both the time it takes to pass through the system as well as the reliability of the given waiting time. The utilization rate and queue length are an important KPIs as well[14][16]. These represent the utilization of the lock and whether this is high or not. If there are a lot of vessels waiting, the utilization is high or too high. The mostly used lock operation policy is a policy that focuses on the vessels. This is the first come, first serve policy[18][12][13]. It minimizes the waiting time for each individual vessel that arrives. For each vessel that arrives, it is determined what the fastest way is to pass through the lock. Since the order of vessels cannot be changed, the minimisation of the first vessel might result in extra waiting time for the other vessels.

3. Characteristics of a lock

This paragraph is dedicated to the characteristics that define a locking system and might influence the effectiveness of the lock operation policies. The characteristics of the locking system consist of the number of chamber, the size of the chamber, the proximity of other obstacles, the number of arrivals, the pattern of arrivals, and the mix of arrivals[19][20]. The number of chambers is important since multiple chambers allow for more sophisticated management approaches and more variety in the planning. For example it is possible to plan in such a way that there is always a chamber available at each side of the locks. This will reduce the waiting time outside the chambers. The second factor, the size of the chamber, relates to size difference. If chambers have different dimensions, it is possible to assign certain types of vessels to a certain chamber or make preferred combinations of vessel types and chambers. For example, is it better to send small vessels through the smallest chamber or is it more beneficial to combine them in one bigger chamber. The third factor is the proximity of other obstacles. If locks are located in a river and other locks are located up or downstream, the flow of vessels will be influenced by those locks. As a result, the vessels will arrive in batches which limit the possibilities for own lock operation policies. The next three characteristics are dedicated to the vessels and not to the lock or the location of the lock. These characteristics will be tested later on. Since most, if not all, case study take a certain lock into account, the arrivals are a fixed input. This results in a neglecting the effects of a change in these characteristics. The number of arrivals is mainly important for the lower bound of effectiveness of a certain lock operation policy. A lock operation policy is not likely to have any effect if the number of arrivals is too low. Every policy would be sufficient and produce more or less the same results. The pattern of arrivals influence the peaks on the system. If the arrival pattern is flat, it is easier to adapt the policy to the arrivals, while peak arrivals cause delays which might be lower with another lock operation policy. The last characteristic, the mix of arrivals, influence the flexibility of the lock. If all vessels that arrive at the locks are vessels that can only pass through the largest chamber, the system will col-
lapse sooner than a more balanced mix. All kind of variation in the mix are possible.

3.1. Literature about the relation between characteristics and Lock operation policies

The previous paragraphs focused on the lock operation policies and the characteristics of a lock separately. The goal of this paragraph is to merge those two aspects and find a relation between the characteristics of a lock system and the effectiveness of lock operation policies based on case studies which can be found in literature. Since these case studies do not link the effectiveness of the lock operation policies to the characteristics of the lock, it should be distracted from context what the exact characteristics were and whether they influence the effectiveness of the lock operation policies. The first step is to distinguish these characteristics from the case studies. This will give an overview of the characteristics and the influence on the lock operation policies.

It should be noted that most case studies which compare different lock operation policies focus on the difference between the policies that focus on vessels (first come, first serve) and policies that focus on the lock (shortest processing time first). The first characteristic that will be discussed is the number of chambers. Ting and Schonfeld conducted a research which include the difference between one or two chambers[21]. They concluded that both the FCFS and the SPT can be applied in both cases, where the SPT alternative gives better results concerning the waiting time for the vessels. The size of the chamber is more difficult to vary, since it is dependent on the arrivals. If the chambers are bigger, it is likely that the number of arrivals or the dimensions of the vessels are larger. Some studies do take larger chambers into account[13], but this is mainly as a new situation instead of a variation on the current situation. Therefore the results are not useful for this study. In order to investigate the influence of the chamber size on the effectiveness of lock operation policies, this factor is taken into account during the simulation study. The proximity of other obstacles are described by Nauss and Smith et al.[12][13]. They describe the effect of the lock operation policies on series of locks. These locks can be seen as the obstacles. Again this research compared the FCFS and the SPT views. Although there is a difference between the results of FCFS and SPT, the difference is by far not as large as without obstacles (5% vs. 78%), the SPT performs better in all cases. The same can be said about the number of arrivals. If the number of arrivals increases, the SPT alternative performs better than the FCFS alternative. This difference tend to be larger if the number of arrivals increases, therefore the SPT can be considered as a better alternative if the number of arrivals increases[13][21][20]. The last two factors, the pattern of arrivals and the mix of arrivals are not factors that are used in other case studies for determining the effectiveness of the lock operation policies. Therefore these factors will be taken into account during the simulation study as well. The reason these factors are not included in a case study as a variable is that these factors are case specific, so there is no need to change these variables during a case study.

3.2. Simulation of the characteristics

This paragraph will be used to test certain characteristics on their correlation with the effectiveness of lock operation policies.
The first step in conducting this research is defining the case itself. Secondly, the results of variations in the size of the chamber, the pattern of arrivals and the arrival mix are shown. The external conditions, such as weather, current, tide and human behavior are not taken into account in this simulation study.

3.2.1. Model description and validation

The lock that is used as an initial situation has three different sized chambers, no nearby obstacles, a fixed number of arrivals, a flat arrival pattern and a certain mix of arrivals. The vessels arrive from two directions; sea going vessels and inland going vessels. The run time of the simulation will be one year in order to include possible seasonal influences. In order to reduce the influence of outliers on the result, each scenario is replicated 10 times and the averages are used in further analyses.

The next step is to validate the model that will be used. Validation can be seen as determining the rightness of a model [22]. This will be done in a couple of ways: extreme conditions tests, face validity and historical data validation.

During the extreme condition test, some variables will be set to zero or to a high number. If the underlying logic is right, some parts of the system should be disabled. If the model passes this test, the underlying logic can be seen as a valid representation of the real system. This test is performed on the processing times of the chambers and the waiting time for other ships. If the processing time of a certain chamber is set to a high value, this chamber is not chosen during the planning. If the waiting time for other ships is set to zero, the average batch size drops to one, which is consistent with the general idea. Therefore, this test can be considered as passed.

The next step during the validation is a face validity test. This is done at three ports; the port of Amsterdam, the port of Ghent and the port of Antwerp. The port of Amsterdam and the port of Ghent considered this model as a valid representation of their system and considered it useful in the future. The port of Antwerp did not consider this tool useful, since the premises of the model were not consistent with their characteristics. So, it can be concluded that the model is valid according to this test if the premises of the model correspond with the characteristics of the port.

The last validation test is the historical data test. During this test, the results of the model are compared with historical data of the system of interest. This test is performed with the processing time of the chambers and the division of vessel types over the chambers. The processing time of the chambers can be considered as equal to the historical data. The division of ships over the chambers is somewhat different from the historical data, but not that different that the model should be seen as invalid. The difference is caused by the external conditions that are not taken into account. Overall, it can be concluded that the model can be seen as a valid representation of the system.

3.2.2. Experimentation

Since the influence of the number of chamber, the proximity of other obstacles and the number of arrivals is already known, those characteristics will not be taken into account during this simulation study. The characteristics that will be tested are the size of the chambers, the pattern of arrivals and the mix of arrivals. This will be done by varying these characteristics for the case
study. These variations are shown in Table 1. These variations will be tested for each of the two earlier mentioned focus points of lock management.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of the chambers</td>
<td>Equally sized chamber, 10% larger, 10% smaller</td>
</tr>
<tr>
<td>Pattern of arrivals</td>
<td>Flat pattern, peak arrivals</td>
</tr>
<tr>
<td>Mix of arrivals</td>
<td>Full factorial design with steps of 25% with one category of each chamber</td>
</tr>
</tbody>
</table>

**Table 1: Variations in characteristics**

Results of size of the chamber
As explained before the variation in chamber size are performed for each of the two focus points of lock management. The next step is to compare the results of these two analyses. This will be done by comparing the difference with the base case and the alternatives for the two focus points. It should be noted that the values are standardized with the base case (FCFS) as reference point.

Table 2 shows the effect of differentiations in the size of the chamber on the performance of the locks. The filling rate shows the behavior that was expected. Since the number and characteristics of the arriving vessels are equal, a larger chamber should give a lower average filling rate and the other way around. The relation between the size of the chambers on the one hand and the number of lockages and batch size on the other hand is less certain. It is very plausible that the number of lockages will decrease if the size of the chambers is larger, since more vessels can fit in the chambers. It is not sure that this will happen since it is dependent on the distribution over the chambers as well. The relation between the number of lockages and the batch size can be explain with certainty as long as the number of vessels that is handled is equal. If the number of lockages is lower, the batch size will be higher and the other way around.

It can be concluded that the size of the lock does influence the choice between lock operation policies. If the size of the locks are relatively large compared to the supply of vessels, the focus on the locks with the shortest processing time first principle can be beneficial. The downside is that if the balance between the size of the locks and the vessels shifts to relatively small chambers, the variance in waiting time increases and the average waiting times increases as well. Looking at smaller chambers, it is more beneficial to focus on the vessels than on the locks. It should be noted that the focus on the locks cause on average lower waiting times, but more lockages.
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average waiting time</th>
<th>Maximum waiting time</th>
<th>Variance waiting time</th>
<th>Number of lockages</th>
<th>Batch size</th>
<th>Filling rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>vessel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial situation</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Size +10%</td>
<td>0.95</td>
<td>1.17</td>
<td>0.9</td>
<td>1</td>
<td>1.02</td>
<td>0.84</td>
</tr>
<tr>
<td>Size -10%</td>
<td>1.08</td>
<td>1.16</td>
<td>1.12</td>
<td>1.01</td>
<td>0.96</td>
<td>1.19</td>
</tr>
<tr>
<td>Equally sized chambers</td>
<td>0.94</td>
<td>1.31</td>
<td>0.99</td>
<td>0.99</td>
<td>1.04</td>
<td>0.53</td>
</tr>
<tr>
<td>Lock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial situation</td>
<td>0.97</td>
<td>0.99</td>
<td>0.92</td>
<td>1.09</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>Size +10%</td>
<td>0.96</td>
<td>0.89</td>
<td>0.88</td>
<td>1.07</td>
<td>1.01</td>
<td>0.84</td>
</tr>
<tr>
<td>Size -10%</td>
<td>1.13</td>
<td>1.05</td>
<td>1.34</td>
<td>1.09</td>
<td>0.95</td>
<td>1.19</td>
</tr>
<tr>
<td>Equally sized chambers</td>
<td>1.01</td>
<td>1.05</td>
<td>1.23</td>
<td>1.08</td>
<td>1.02</td>
<td>0.49</td>
</tr>
</tbody>
</table>

**Results pattern of arrival**

The difference in arrival patterns will be investigated in the same way. The difference between the initial situation with the FCFS (focus on vessels) and SPT (focus on locks) will be compared with their corresponding alternative arrival patterns.

The results of the scenarios which focus on locks are slightly different than the results of the scenarios that focus on vessels. This was expected since the planning method is different. The most important part for this analysis is the difference between the initial situation and the alternative arrival pattern for both lock operation policies. The difference is expressed in percentages which can be found in table 3. The largest difference percentage point wise is 2. It can however be concluded that the focus on the locks result in lower waiting times. This is due to the fact that it aims at high filling rates. This affects not only the average waiting times, but also the maximum and the variation in waiting times. On the other hand the batch size and filling rate looking at the effects of the alternative arrival patterns on the effectiveness of the policies, it can be concluded that the effects on both policies are more or less the same. Therefore, it can be concluded that the arrival pattern is not a good factor to base the choice of the lock operation policy on.
<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average waiting time</th>
<th>Maximum waiting time</th>
<th>Variation in waiting time</th>
<th>Number of lockages</th>
<th>Batch size</th>
<th>Filling rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on vessels</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Focus on vessels alternative</td>
<td>1.64</td>
<td>1.35</td>
<td>2.26</td>
<td>0.88</td>
<td>1.08</td>
<td>1.05</td>
</tr>
<tr>
<td>arrival pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focus on locks</td>
<td>0.97</td>
<td>0.99</td>
<td>0.92</td>
<td>1.09</td>
<td>0.98</td>
<td>1.00</td>
</tr>
<tr>
<td>Focus on locks alternative</td>
<td>1.59</td>
<td>1.33</td>
<td>2.07</td>
<td>0.95</td>
<td>1.08</td>
<td>1.05</td>
</tr>
<tr>
<td>arrival pattern</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Results for mix of arrivals

In order to analyze the mix of arrivals, the scenarios are set up in such a way that a full factorial design is created with steps of 25% for each of the three chosen vessel types; one type for each chamber. After setting up the experiment, the results of the scenarios will be compared based on the average waiting time for the vessels and the batch size. These performance indicators are chosen, since the other performance indicators will not give valid results to compare. The filling rate is mainly dependent on the size of the vessels and the choice of the chamber. Since the size of the vessels is altered during this analysis, it will not give representative values.
The figures above represent the average waiting times for different sizes of vessels. They are sorted based on the percentage of the mix of arrivals that represent the vessel type. It can be noted that the average waiting time for small vessels is in general smaller if the focus is on the lock. The most likely reason is that these vessels are more often used to fill a chamber. The pattern that can be identified for the medium vessels can be seen as identical, so the choice between the two lock operation policies does not affect the waiting times of the medium sized vessels. The pattern of the waiting time for large vessels differs, it can however not be said which policy is better for the large vessels. This is dependent on the fleet mix of the specific lock. It should be noted that in general the waiting time for large vessels is lower when focusing on the vessels. Another conclusion that can be drawn about the waiting times for the vessel types, is that the percentage of small vessels does not influence the performance of those small vessels, while the other two categories should have a restriction on their maximum share. The share of medium sized vessels should be more than 25%. The peak around a share of 50% is cause by a 50% share of large vessels. The maximum amount of large vessels should therefore be 25% in order to keep the waiting times within a reasonable time.

Looking at the batch size of the different scenarios (Figure 4), it can be concluded that the average batch size is larger when focusing on the vessels. An explanation is that the algorithm optimizes each locking process individually, instead of the total of lockages. Therefore, the number of lockages is higher as well.

4. Conclusion

As been said the effects of variations in chambers size and the variations in lock operation policy on the performance of a lock cannot be found. Therefore, the conclusions about this aspect of a lock are solely based on the simulation study performed in this paper. It can be concluded that the size of the chambers does influence the choice between lock operation policies. Relatively large chambers are more suitable for a focus on the locks, while equally sized chambers and relatively small chambers are more suitable for a focus on the vessels. However, the problem is that it is hard to determine whether the chambers of a lock are large or small, since it is dependent on the number and size of the arrivals. Literature shows that an increase of arrivals will be in favor of the choice for the focus on the locks. This is supported by this study concerning the pattern of arrival. If the pattern of arrivals is changed and peak arrivals are present, the shortest processing time first principle scores better on the waiting times. So in general it can be said that if a lock is crowded or if there are large peaks in the arrivals, the focus on the locks is preferred over the focus on the vessels. It can be said that the focus on the locks
is most beneficial for the small vessels considering the mix of arrivals. The waiting times for medium sized vessels are more or less equal for the two points of focus, while the large vessels suffer from the focus on the lock. Therefore, some boundaries can be introduced in order to reduce the increase in waiting time for a certain vessel type. The share of small vessels does not affect the waiting time of the vessels, therefore the results are valid for the whole range. This makes sense since these vessels can pass through all the chambers. For the same reason the share of medium sized vessels should be 25% or larger. The main limitation is on the large vessels, the share of this category should not exceed 25% in order to keep the waiting times for each vessel category acceptable.

In generally it can be said that the following factors do influence the choice between lock operation policies. First of all the number of chambers. If the number of chambers is larger, there is more room for improvement in the lock operation policies. This is especially beneficial for the focus on the locks, but it has to be said that the focus on the vessels becomes more efficient as the number of chambers increases. The second and third factor are closely related. These are the number of arrivals and peak arrivals. If the number of arrivals increases, the focus on the locks performs better, since there is more room for alterations in the order of the vessels. This principle is also applicable if peak arrivals occur.

The following factors have a limited influence on the choice between the focus on vessels and the focus on locks. If there are any obstacles present near the locks, for example other locks, the effects of both focus point diminishes. So, the choice between those policies is not important any more. It should be noted that the focus on the locks does perform slightly better than the focus on vessels. A second factor that does not influence the choice is the size of the chambers. Although the relative size of the chambers does influence the choice for a certain focus, it is nearly impossible to determine whether the size of the chambers is large or small. The only thing that might influence the choice is if the chambers are equally sized. If this is the case the variety in choices is less since all chambers have the same characteristics. So, the focus on the vessels would in this case be sufficient and gives slightly better results than the focus on the locks.

5. Reflection

This section will be used to compare the articles used for this paper with the results. Most other studies focus on case specific situations, while this study tries to generalize these results and find common ground between the case studies. Next to the literature review, a simulation study is performed in order to investigate the characteristics which are missing in literature.

There are some other studies which try to generalize the analysis of lock management. However, most attempts do not grasp the full complexity. Looking at the studies done by Backalic and Bukurov[19] and Coene and Spieksma[23]. Both studies set up a research framework that aims at a general approach, but in the end they are not. They fix numerous of factors that might influence the results if the policies were used somewhere else. For example they fix the mix of arriving vessels, the characteristics of the lock or even the processing time of the vessels. Although they are not specifically mentioning a certain case, it becomes
a case study since the characteristics of the system are fixed. The study perform in this research does not fix such factors and therefore the results are more suitable to be generalized. Moreover, the study performed by Backalic and Bukurov does not show any results although it would be a good comparison for the results of this study. Coene and Spieksma focus on certain lemmas which are tested by means of a model. These lemmas are theoretical dilemmas which are not comparable with the results of this study, since this study focus on the performance of a lock while the study of Coene and Spieksma focus on the limits of lock operation policies. Their study stops at the moment the model is constructed.

The studies that are performed towards the theoretical approaches of the lock operations focus mainly on one aspect of the policies. For example, the focus on the queueing theories [4] or the focus on bin packing problem [5]. Since all three aspects of the policies, the scheduling, assignment and packing problem, are equally important aspects of the lock operation policies. Therefore, the results will not be compared with these studies.

6. Discussion

Initially, a third focus group was used during this analysis. This concerned the focus on the resources. After conducting the research for this focus point, it became clear that the focus on the resources is only effective if the number of arrivals is large and the available resources are the limiting factor. If this is the case, the problem is not the lock operation policy itself, but the boundary conditions which make the policies possible. Therefore, this view on the lock operation policies is not taken into account. There are some factors which do influence the performance of a lock, but that are not taken into account. These mainly concern meteorological and hydrological conditions and failure of some parts of the system. Failure can be seen as either the failure of a certain chamber, the system as a whole or the failure of humans.

References


