OPTIMIZATION OF THE WELDING IN THE ERECTION SCHEDULING OF A SUEZMAX TANKER SHIP

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SUMMARY

In shipbuilding, blocks are erected to the hull and welded together to form the ship. Welding of blocks after erection involves lots of variation, especially when compared to the production of the blocks, which can be done in a factory environment. Therefore, it is worthwhile to make an erection sequence that optimizes the welding. This paper introduces an optimization model to sequence the erection so that as much welding as possible occurs as early as possible. The model is used to optimize the erection sequence of a Suezmax tanker ship by solving the optimization model using a local search heuristic. Optimized sequence is compared to the sequences got from aft-to-fore, bottom-up and pyramid erection strategies and, further, simulation is used to study how much benefit can be obtained by the optimized sequencing in different capacity conditions.

NOMENCLATURE

N	Total number of blocks
S	Number of slices
$W_{x,y}$	Welding time needed to join block x to block y.
$P_{x,y}$	Precedence constraints. 1 if block x has to be erected before y, 0 otherwise. ´ $P_{x,y} \epsilon \{0,1\}$.
t_x	Position of the block x in the erection sequence. $x \epsilon \{1,2,\ldots,N\}$, $t_x \epsilon \{1,2,\ldots,N\}$.

1. INTRODUCTION

Nowadays, ships are usually built from blocks that are made in a factory and later pre-erected into big blocks before the erection in the dockside area, where they are joined by welding to the other blocks. Welding of blocks after the erection has lots of variance due to the reason that the welders and their utilities have to be moved inside the constructed ship. Therefore, it is important to create an erection sequence which maximizes the usage of the welding capacity. This can be done by optimizing the sequence so that as much welding as possible is done as early as possible, as is done in this paper.

The block erection is one part of the shipbuilding process. However, it is unique to shipbuilding when compared to other production areas. Therefore, in the shipbuilding literature, there are many papers about block erection. However, as in the paper by Lee et al [1], many papers deal with the erection process but they focus on describing the whole planning system, which decreases the level of detail of erection process and therefore its scheduling is typically studied quite roughly. Still, there are papers where discrete-event simulation [2], genetic algorithms [3, 4, 5] or traveling salesman approach [6] are used in the sequencing of the erection. Typical problems include the scheduling of the lifting capacity, optimization of the erection welding capacity, or scheduling the space usage of the finished but not yet erected blocks.

This paper introduces an optimization model to sequence the welding as early as possible. Local search heuristic is used to solve the optimization model. The model is used to optimize the erection sequence of a Suezmax tanker ship. The optimized sequence is compared to the sequences got from the aft-to-fore, bottom-up and pyramid erection strategies. Numerical experiments study how much benefit can be gained from the erection sequencing in different capacity conditions. They show that when the welding capacity is near the average welding need, then the differences between the optimal strategy and the typical strategies are largest. From the non-optimal strategies, aft-to-fore is the best when extra capacity is available and bottom-up strategy when there is a lack of the capacity.

The rest of the paper is organized as follows. Section 2 describes the block erection, welding and different strategies to sequence the erection of blocks. Section 3 introduces a simulation model for a shipbuilding process and presents the numerical calculations on how different strategies work. Section 4 analyzes the results and Section 5 presents the final conclusions.

2. WELDING IN ERECTION SEQUENCE

This chapter studies the block erection strategies in shipbuilding, gives the erection sequence constraints for the Suezmax tanker ship and proposes a mathematical optimization model to optimize the erection sequence so that welding can be done as early as possible. Further, a local search heuristic is introduced to solve the optimization model in reasonable time.

2.1 BLOCK ERECTION IN SHIPBUILDING

In shipbuilding, large steel structures called blocks are erected to the ship and joined together to build a ship. To get the production efficient, the sequence in which the blocks are erected has to be defined. The ship consists of N blocks numbered from 1 to N and t_x is used to denote the position in the sequence for block x. This sequence is typically strictly followed in the production of the blocks. For the determination of block erection sequence, there are several constraints on the blocks placement [2]:

Physical constraints, such that blocks have to be positioned before another in order to assure the stability of the structure. It is not typically possible to build a tower of the blocks due the stability conditions. The blocks are typically built first in the direction of the width of ship.

Block assembly constraints, such as the minimum time between the laying of the blocks by the gantry crane. This time is necessary for tacking and welding the block to the ship. Another restrictive constraint is closely linked to the difficulty inserting of a block between two other blocks already erected.

Erection constraints, such as the first blocks to be placed. The blocks which house the machine room are often selected to start the ship erection process because of the required time for assembly and outfitting the engines and other machinery. On the other hand, starting the erection process from the middle of the ship, allows some flexibility to production as ship can be grown in all directions.

In this paper, $P_{x,y}$ defines the precedence constraints. If block x has to be placed before block y, $P_{x,y}$ is one, otherwise zero. Although the above restrictions provide some flexibility to the erection, the planning usually forms a single sequence for the erection. There are different strategies to form this sequence.

From aft/fore to fore/aft strategy where blocks are built one slice of the ship at a time from aft to fore or vice versa. This approach can be effective if the each slice is similar and different block types inside one slice are arranged to be built at different production facilities, because this slice-by-slice approach increases the arrival time between erections of similar blocks.

Bottom-up strategy where the blocks are built from bottom up one level at time. This approach can be effective if the blocks are built at single facility, because the facility can focus on the production of blocks erected to the same position at a time, which are probably similar to each other.

Pyramid strategy where the production starts from the middle of the ship and grows at similar speed to each direction (i.e. to the top, to the sides and to the aft and fore). This strategy can be good if the erection has to proceed fast, because it minimizes the length of the erection schedule if the joining of the blocks after the lifting is the bottleneck [10].

Optimized solution that takes into account the precedence constraints and optimizes the given objective, which can be e.g. the length of the schedule or, as is done in this paper, welding capacity usage.

In this paper, the precedence constraints are taken directly from the structure of the ship, the building of the ship is started from the aft (or fore), and optimized sequence is generated using a local search heuristic. Welding amounts between each pair of blocks, $W_{x,y}$, are used in the optimization of the production.

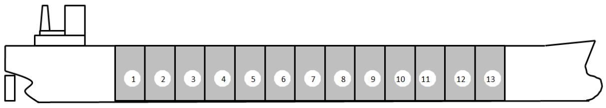
2.2 ERECTION OF A SUEZMAX TANKER SHIP

The present work studies an erection sequence of midship section of the Suezmax tanker ship. The main characteristics of the ship are indicated in Table 1.

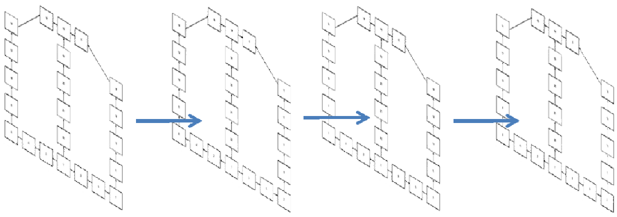
Table 1: Main characteristics of Suezmax Tanker Ship

Length over all	270.0 m
Beam	45.5 m
Depth	24.0 m
Deadweight	145,000 dwt

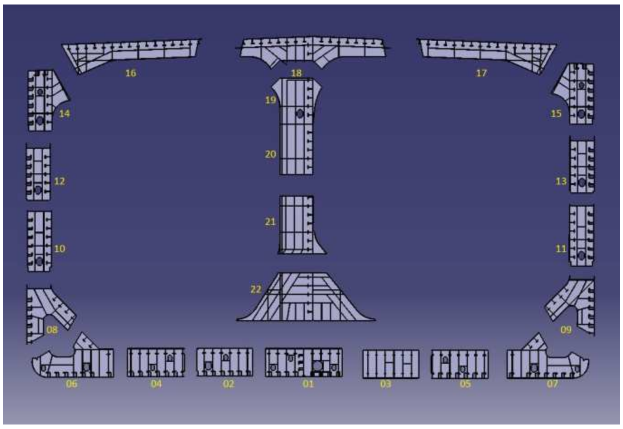
Figure 1 shows the structure of the ship and structural elements of the midship section of the ship. The structural elements are 12 m in length. In addition, the figure presents the precedence constraints inside the midship section. For the purposes of the study in this work, the midship section of the ship was represented by 13 identical slices joined. The effect of the number of slices is also studied, and S denotes the number these slices. The study does not consider the bulkheads between the cargo tanks. The welding times of the blocks, $W_{x,y}$ that are used later in the numerical experiments depend on the sizes of the blocks.



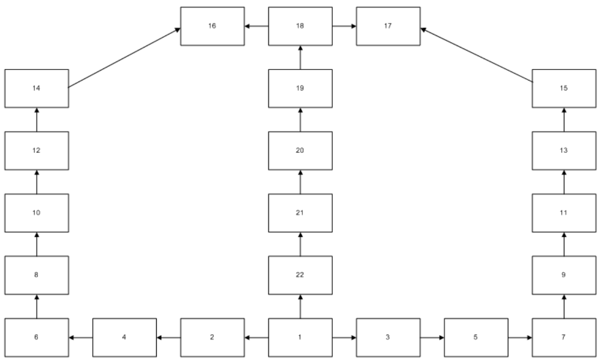
a) Body of the ship (Only the numbered slices are considered in this paper)



b) Precedence constraints between the corresponding blocks of adjacent slices



c) Structure of a slice



d) Precedence constraints inside a slice

Figure 1: Structure and precedence constraints of the midship section of Suezmax tanker ship

2.3 MODEL FOR WELDING SEQUENCE

In order to optimize the erection sequence, optimization of the welding capacity is crucial. Therefore, here the sequence is optimized so that welding is done as early as possible. A mathematical model of the problem is constructed and local search heuristics are used to find a good solution for it. The optimization model is the following.

$$minimize \sum_{x=1}^{N}\sum_{y=1}^{N}\max(t_x,t_y)W_{xy} \quad (1)$$

subject to

$$\forall x,y \in [1,\ldots,N]: t_x \geq t_y+1 \,\|\, t_y \geq t_x+1 \quad (2)$$

$$\forall x,y \in [1,\ldots,N]: t_y \geq P_{x,y}(t_x+1) \quad (3)$$

$$\forall x \in [1,\ldots,N]: t_x \geq 1 \quad (4)$$

The equations 1-4 define the objective function, order constraints, precedence constraints and starting time, respectively. Objective function in equation 1 tries to move the welding as early as possible by weighting the welding amount by the position where that welding takes place. These weighted amounts are minimized in the model. The order constraint in equation 2 makes sure that there is only one block in each position of the sequence. The precedence constraint in equation 3 forces the predecessors of a block to be in the place when it is placed. The equation 4 makes sure that the block's position cannot be negative and defines the first block in the sequence to be at the position one.

Solving the above model optimally takes a long time. For example, solving the sequence for one slice of ship consisting of 22 blocks took 4 hours (using IBM ILOG CPLEX Optimization Studio version 12.2 on Intel Core 2 Duo 2.00Ghz). Therefore a local search heuristic is constructed to solve the problem. This local search heuristic first makes random changes to improve the solution. A simplified description of the heuristic is the following.

1. Generate the initial sequence using the blocks in the default (given) order. Check if the precedence constraints are feasible according to equation 3 and fix them if necessary, i.e. if block y should follow block x, but it is not following, move block y immediately after x in the sequence.

2. Interchange the position of two random blocks in current solution, check and fix the precedence constraints as done above and calculate the objective function using equation 1. If the new solution is better than current solution, make it the new current solution or otherwise discard it.

3.Repeat step 2 until the given number of repeats is reached.

The above local search model was further updated to sometimes accept changes to worse solution in step 2 to avoid getting stuck into local optimums. Search also makes sometimes a move of single block in the sequence to make the solution converge faster. After implementing the search, it took less than a second to find the optimal schedule for the 1-slice problem consisting of 22 blocks (using a VBA program written for Microsoft Excel 2007 on Intel Core 2 Duo 2.00

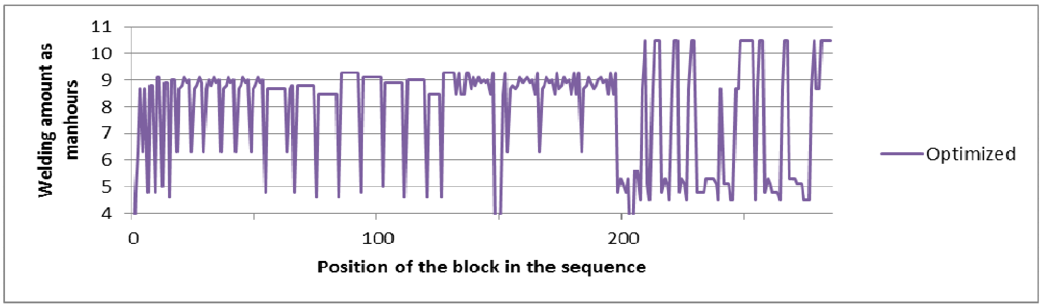
GHz). Although the optimum solution was easily found for this small case, it does not guarantee the optimal results for larger cases. However, it can be used easily and especially quickly to generate good solutions, and therefore it is used to generate the results in the numerical experiments.

3. NUMERICAL EXPERIMENTS

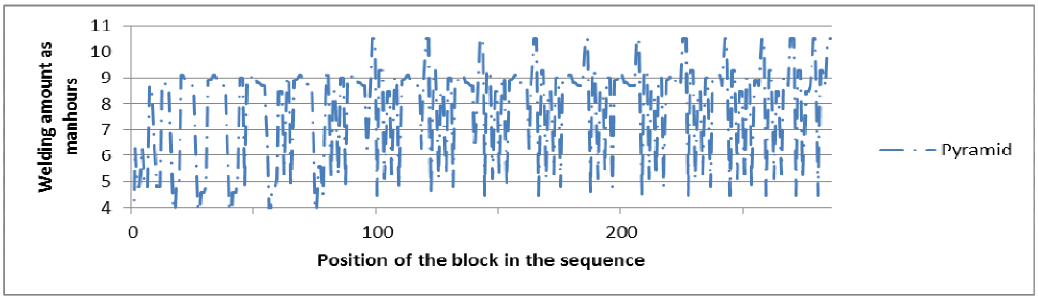
In the experiments, the goal is to compare the sequences of different erection strategies to the optimized one that enables the welding to be done as early as possible. Later the shipbuilding simulation model is used to study the effects of sequences with different welding capacities.

3.1 WELDING SEQUENCE

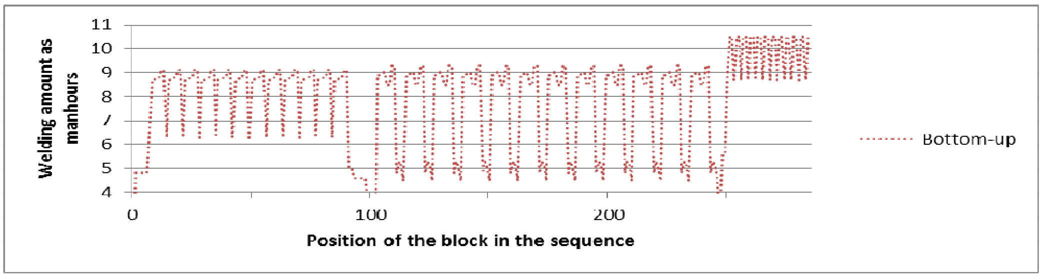
First, different strategies are used to generate the sequences for 13 slices of the ship. The precedence constraints inside one slice are taken from figure 1. Figure 2 shows the welding amounts in each sequence for these strategies in the 13-slice cases. Figure 3 compares the sequences by showing them accumulate.



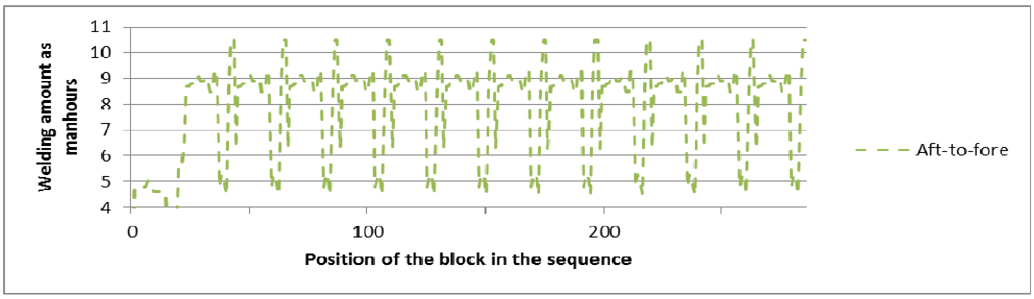
a) Optimized



b) Pyramid

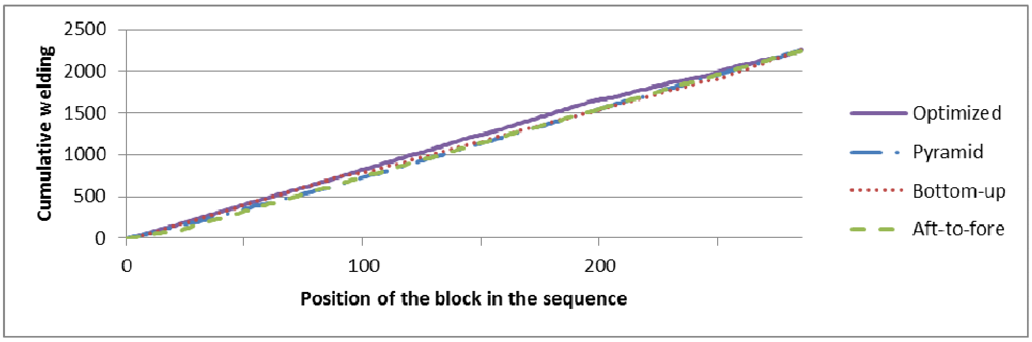


c) Bottom-up

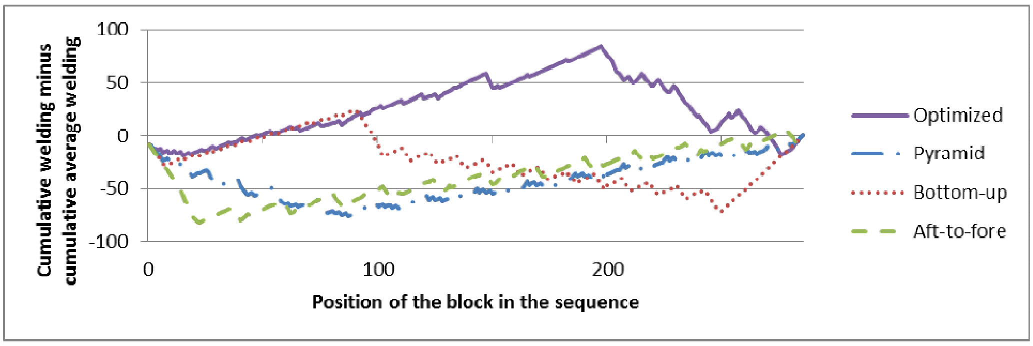


d) Aft-to-fore

Figure 2: The welding amounts during the sequence when different erection strategies were used (S=13)



a) Cumulative welding amounts



b) Cumulative welding amounts minus linearly accumulating average welding amount. Average welding is got by calculating the total welding work and dividing it by the number of blocks.

Figure 3: The cumulative welding work during the sequence when different erection strategies were used (S=13)

3.2 SHIPBUILDING SIMULATIONS

To illustrate the effects of the optimized sequence in the practice, a simulation model of a shipyard was built using the QUEST® software developed by the Dassault Systemes [11]. The model has been used to simulate the erection of the parallel middle body of a Suexmax tanker, as described in Chapter 2. The information concerning the block and the welding lead times are stored in a data file that is read by the simulation software. Figure 4 shows a screenshot from the simulation model. In addition to the numerical results, simulation software enabled 3D visualization of the process including the geometry of the product.

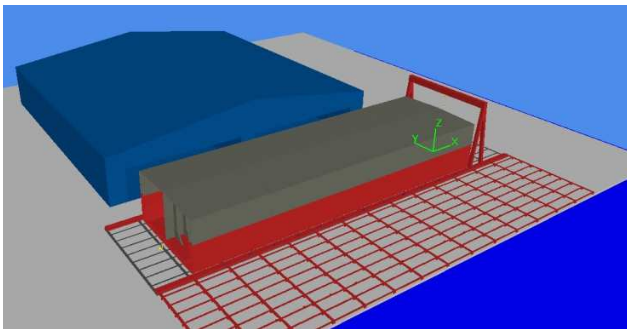


Figure 4: Parallel Body of Suezmax Tanker Ship in a 3D simulation

The simulation is used to study the effects of the different strategies and available welding capacity. Arrival rate of the blocks is assumed to be constant and deterministic. The available welding capacity is varied from 7 to 9 in steps of 0.25. For each erection strategy an erection sequence is generated and the discrete event simulation is launched in order to evaluate the lead time of the erection process. Utilization of the welders is calculated during the construction of the ship using the following formula.

$$\text{Utilization} = \text{Welding capacity used} / \text{Lead time} \qquad (5)$$

The results from the simulation study are shown in Figure 5. Because the total welding capacity used is the same for all strategies, the lead time is inversely proportional to the utilization.

4. ANALYSIS

In this chapter, the numerical results showed in the above chapter are analyzed. This is done by studying how the optimized solution works, pointing out the differences between the strategies and, finally, discussing the drawbacks of our solution.

From the results of the timing of the welding amounts in the sequence shown in figures 2 and 3, we can see that the optimized solution moves the welding work earlier. In the optimal schedules, the construction of the middle part of the slices with low work content is postponed to the end of the schedule. In addition, first slice itself has

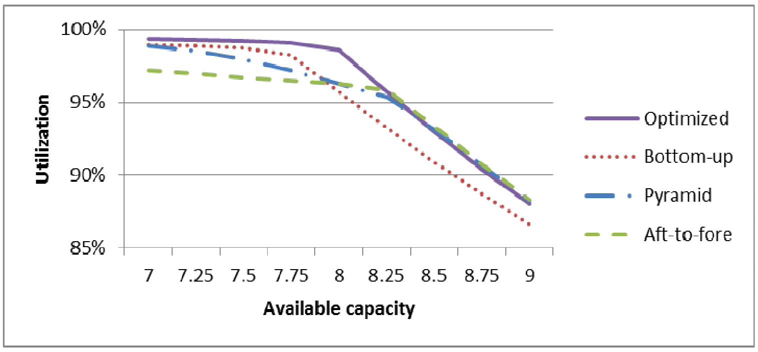


Figure 5: Welding capacity and welding usage (S=13)

low work content because there is no welding between two slices, and so at least the two first slices should be started parallel to ensure high work content as early as possible by facilitating the joining welding of the two slices. In addition, because of the tight precedence constraints, there are problems in the optimized sequence as well. In the end of the optimized sequences there are some large welding jobs in the optimized sequences; they cannot be advanced without penalties to the average earliness of welding. In practice some kind of extra workforce could be used here to ensure that blocks can be done in time.

The results from the simulation study in the figure 5 show that the optimized solution gives better usage of the fixed welding capacity. If the welding capacity is near the average welding need, the difference to other strategies is the largest. In that case, the relative difference between strategies is 3 percent. There are significant differences between non-optimal strategies as well. Aft-to-fore is the best when extra welding capacity is available, when the capacity is over the average welding need of 7.8. If this is the case, then the welding done in the end part of the erection sequence has the largest effect, because work in the beginning of the sequence can be completed in time and there is no queuing of the blocks. In a similar way, when capacity is less than the average welding need, the beginning of the sequence is more important. In this case, bottom-up strategy follows the optimized solution during the first 100 blocks and has significantly more welding work in the beginning of the sequence, which yields better performance in the case of low welding capacity. Pyramid approach can be thought of as a balanced version of aft-to-fore and bottom-up strategies.

It should be noted that there are some drawbacks in our approach as well. For example, a paper by Chung et al[7] states that the major problem in the block erection is that blocks arrive too early to the place where erection occurs. If the spatial capacity is major problem, our solution can make it worse. In addition, if the capacity of the welding crew is flexible, the optimization of the welding as early as possible does not give any benefit. However, if the welding capacity is fixed and near the average welding load, then the optimized sequence can give significant savings.

5. CONCLUSION

This paper studied the erection scheduling in the case of a Suezmax tanker ship. It introduced an optimization model to sequence the welding as early as possible. A local search heuristic, which is derived from the scheduling literature, is used to optimize the sequence quickly. This sequence was compared with aft-to-fore, bottom-up and pyramid erection strategies. The numerical results show that there is a certain capacity area where the optimized sequence affects the usage of the welding capacity, giving at best a 3 percent benefit.

In future research, several topics discussed in this paper can be studied in more detail. The erection strategies could be considered in a ship with more complex block structure. The other things such as variance in the welding and learning of the welding capacity could also be taken into account. In the simulations of this paper, the interarrival times of the blocks were assumed to be fixed, however stochastic and block related interarrival rates could be more realistic.

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