Discrete Event Production Simulation and Optimisation of Ship Block Erection Process

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Abstract

Nowadays, shipyards are making every effort to efficiently manage equipments and resources such as labourers, gantry cranes, transporters, steel and block stock yards, etc. The block erection scheduling of a gantry crane has thus far been manually performed by a manager of a shipyard. Such a scenario leads to undesirably long times for producing scheduling results. In addition, the quality of the scheduling results may not be optimal. To improve the overall process, block erection discrete event simulations have been developed in this study by using techniques of optimization. The first results presented in this paper are promising even if some future work must be realized.

1. Introduction

Production simulation is a very useful tool concerning the possibilities of gains in the process of production and as result, cost reduction. In order to achieve an optimum integration design vs. production, it is necessary to model not only the ship but also the shipyard facilities and integrate them into a single simulation model. Best results are achieved when this model is linked to other optimization systems. The simulation allows finding the best workshop layout and assembly sequence according to the building strategy of the ship.

2.1 Production simulation in shipbuilding industry

The simulation of shipbuilding process can be useful to assess, decide and communicate manufacturing planning's, allowing a dynamic and transparent review of the production. The technique can help the project definition of the vessels, or the assessment of production, according of different types of vessels, *Kasemaker et al. (2006)*. During the last decade, shipyards, research centres and universities started to use this powerful tool to analyze shipbuilding operations. The group SimCoMar (Simulation Cooperation in Maritime Industries) is an example of an initiative to accelerate the development of simulation in the industry, helping North American and European shipyards. The Flensburger Nordseewerke Emden shipyard, the universities TUHH (TU Hamburg-Hamburg), DUT (Delft University of Technology) and Anast (University of Liege), and the Center of Maritime Technology (CMT) in Germany are participating in this initiative. Besides SimCoMar, other partnerships have been established between shipyards and universities such as the University of Seoul South Korea, Japan's Kinki, Michigan University, and Federal University of Brazil (LABSEN laboratory).

In recent years, the Dutch and German shipbuilding industry is seeking to reduce delivery times, production costs and increase product quality, using the process simulation. Some German yards are well advanced in the use of simulation and integration solutions to environmental planning processes, such as Meyer Werft and Flensburger.

2.2 Discrete Event Simulation Software's

Currently many simulators are available commercially. Some of them were compared with information obtained from manufacturers, users (Internet discussion groups), for articles published in congresses and simulation for manuals and textbooks. Table I lists some features of each program as the application price, model visualization, popularity, etc.

Table 1: List of DES software

	ARENA	PROMODEL	PLANT SIMULATION	FLEXSIM	QUEST
Application Price	Good	Good	Very poor	Poor	Very poor
Easy to Learn	Poor	Very poor	Poor	Average	Average
Custom Extensions	Average	Average	Good	Poor	Very Good
Technical Capacity	Average	Very poor	Very Good	Average	Very Good
Model Visualization	Poor	Very poor	Good	Good	Very Good
Graphical User Interface	Poor	Poor	Average	Average	Poor
Modularity	Good	Good	Good	Average	Good
CAD connection	Average	Average	Good	Good	Good
Thechnical Support	Poor	Very poor	Average	Very poor	Average
Popularity (forums)	Good	Good	Poor	Good	Poor
Compatibility with others softwares	Very Good	Very Good	Very Good	Very Good	Very Good
Reuse of models and objects	Good	Good	Very Good	Poor	Very Good
Statistical Analysis	Good	Average	Very Good	Good	Good
Pre and Post Processing of Data	Very Good	Very Good	Very Good	Very poor	Very poor
Special Features	Input Analyzer, Output Analyzer	Stat-fit, Output Result	DataFit package, Bottleneck analysis, Sankey Diagram (material flow analyses)	Button with direct connection to the Excel program to import data , Gantt Chart, Financial reports	Kinematic geometry to associate with machinery and transport systems

Considering the criterion of animation, the software Arena has two-dimensional representation and users must acquire a specific module to have the three-dimensional visualization. In the simulator Promodel the most common representation is also a two-dimensional, but according to forums the three-dimensional visualization can be configured and it is considerably more complex than the two-dimensional. The programs Flexsim, Plant Simulation and Quest have three-dimensional visualization. All programs have modules for optimization. In some software's such Arena, Plant Simulation and Promodel, the modules are coupled to data processing. Modules checking and tracking errors are common in all simulators discussed.

Devices for identifying bottlenecks and streams are offered by Plant Simulation. The software Quest has a module that provides kinematic motion of machinery and equipment making the visualization more realistic. Most simulators studied shows good compatibility with programs from Microsoft's Windows platform. The Active X technology, present in some simulators, allows the integration of models with data from spreadsheets, text files, and others format of files.

2.3 Difficulties to apply production simulation in shipyards

Despite some success stories for the application of production simulation in shipyards such as Flensburg and Meyerwerft, it seams that most of shipyards in the world are not using a day to day production simulation.

The quality of production simulation which requires accurate, reliable, repeatable and understandable results depends mainly on the quality of the input data. Moreover, the implementation of simulation models necessarily involves the manipulation of large amounts of data from both the ship and the manufacturing environment. It follows several types of problems, often very cumbersome, tedious and time consuming to solve. Here are presented the major problems that we may encounter:

- **Lack of available data** – Production time estimates usually make use of previously designed and constructed ships of similar type and size. Unfortunately, access to relevant data may be hindered by proprietary restrictions, interdepartmental communication gaps, etc. In certain cases, when the shipyard is entering a new market, no relevant data is available.
- **Insufficient data definition** – Fields of Data Bases (DB) are rarely defined precisely enough to permit direct comparison of data from different studies or reformulations to suit overlapping or otherwise differing definitional boundaries, *Koenig (2002)*.
- **Inconvenient data format** – The data may be in a hard copy and not in an electronic DB, necessitating time-consuming keypunching. The data hierarchy may be unfamiliar, and require resorting a hierarchy appropriate to the present project. The constant evolution of the production tool implies a constant evolution of the data structure so that it is very difficult to compare past data with actual projects.
- **Unknown validity of data** – The data may itself be an estimate and not a record of the actual value. The value may have changed because a supplier has gone out of business or has moved out of country. The year in which the data was generated may not be known, so that the impact of inflation is in question. The data may be provided by a consultant, and its validity unknown.
- **Inaccessibility of data** – Object oriented databases are often used inside CAD/CAM tools such as TRIBON, CATIA, etc. in order to store the ship models. For design purposes it is the most appropriate solution because of the hierarchical structure of the product (eg. Scheme→Plates→Holes). Nevertheless, for general-purpose queries on the same information, pointer-based techniques will tend to be slower and more difficult to formulate than relational databases. In fact there is an intrinsic tension between the object encapsulation, which hides data and makes it available only through the interface methods of the CAD/CAM tool. So that, the extraction of the data from the CAD/CAM tools to a traditional relational database is required for production simulation purposes. It is a time consuming task mainly because the extraction of the data induces the implementation of macro using the specific export modules of the design tools.
- **Quality of the data** – It is clear that the effectiveness of any simulation ultimately comes down to the quality of the data used in the simulation. While more advanced simulation models are being developed, in our experience, the collection of data to drive these models often seems poor. Furthermore, the more advanced models require richer data sets.
- **High quantity of data** – The design and production description of a ship contains an amazing quantity of information. For example, it is a question of several million of rows with several hundred attributes for the steel structure description of a passenger vessel of 300 meters in length (eg. about 200000 steel items). It is much more when you are considering the outfitting.
- **Data integrity** – During the management of data it is very important to have the assurance that data are consistent, correct and complete. It may happen that this is not the case so it is necessary to report these data as outliers.
- **Data temporal heterogeneity** – The continual changes in technological processes and business practices invalidate the data of previous ships.

Beside the problems involving the data management, the following other issues can also explain why the majority of the shipyards don't yet use production simulation to manage their planning's:

- The cost of some production simulation software is really a drag for some shipyards and especially for small and medium shipyards.
- Despite the last development of simulation toolkits for shipyards, modelling time remain a cumbersome task when the shipyard is implementing production simulation for the first time. It is realistic to tell that it can reach 6months to 1.5 years for a complex full shipyards model.
- High skilled people are required to develop and maintain the simulation models up-to-dates with the technical evolution of the shipyard. It required a big investment from the shipyard.
- It is still difficult to integrate the simulation models with the CAD/CAM systems (DB management). There is not yet efficient commercial interfaces to share the data between the CAD/CAM software's and the production simulation software's.

Nowadays the Brazilian shipbuilding industry has Greenfield shipyards. The use of simulation models, in this case, can provide vital information to optimize investments in facilities, resources and equipments. The study of processes and systems by Discrete Event Simulation tool can promote practices more efficient to achieve the long-term strategies of the new shipyards and to ensure their competitiveness and responsiveness. Following the author opinion, Brazil is thus the ideal country to convince the shipyard to use DES system everyday.

2.4 Potential use of simulation in the Brazilian shipbuilding

According to Lloyd's Register, in 1980 Brazil was the world's 2nd largest shipbuilding nation behind Japan. However, the industry collapsed in the following decades due to local economic factors such as hyperinflation, high interest rates and the ending of state subsidies. By 1999, no ships over 100 tons were being built and the industry had shrunk to only 2000 workers nationwide, *Paschoa (2010).*

- **Alusa Galvão Shipyard (PE)**
  - fabrication of offshore drilling units (ships and platforms semisubmersíveis - drilling units), offshore support vessels (Supply Boats) and modules for oil platforms (topside modules).
- **EISA Alagoas Shipyard (AL)**
  - Besides ships, the shipyard will produce naval platforms and will do repair services.
- **Enseada de Paraguaçu Shipyard (BA)**
  - The construction of the drillship for Petrobras and topsides assembly units manning the decks, are among the main interests of investors
- **Jurong Shipyard (ES)**
  - Converting the hull of a tanker to the platform P-62, which will operate in the Roncador field, Campos Basin, with capacity to produce 180 thousand barrels per day from 2013
- **Inhaúma Shipyard (RJ)**
  - Conversion of ships into FPSO (Floating Production and Storage), now held abroad. Still, will serve as a support base for ferries owned by Petrobras, and use the area to support various operations.
- **OSX Shipyard (RJ)**
  - FPSO, TLWP, Fixed Plataforms and Drillships
- **Promar Shipyard (PE)**
  - LNG
- **Antlantico Sul Shipyard (PE)**
  - Cargo ships - tankers, bulk carriers, ore and general cargo - as well as offshore platforms, drilling rigs and vessels for the oil and gas industry.
- **Engevix Shipyard (RG)**
  - N/A

Fig. 1: Greenfields shipyards in Brazil

However, an amazing revival has occurred in the last decade in response to large deepwater offshore oil and gas discoveries. For political reasons, the Brazilian Government through its state-sponsored oil company Petrobras and its shipping subsidiary Transpetro have used these oil discoveries as a vehicle for job creation. Wherever possible the Brazilian government has required as many of the requisite vessels and oil rigs to be built within the country. This has resulted in a shipbuilding boom. Today, the industry has a national workforce of over 45 000 with approximately 80 booked orders for a variety of ships and rigs, *França (2009)* and *Paschoa (2010).*

Fig. 1 shows the different Greenfields shipyards of Brazil. There are recently constructed or in plan to be constructed soon. The Brazilian shipyards can be divided into:

- Shipyards under planning (Greenfield) or construction and shipyards that are making retrofitting or extension of existing workshops – Layout planning
- Shipyards in operation – Production planning

2.4.1 Layout planning

The simulation for layout planning facilities can improve the evaluating of investments and of long-term strategies. Fig. 2 shows the layout of one Brazilian shipyard under planning.

One of the most important advantages of simulation of steel processing shops is the possibility to test different equipment, different suppliers and accounting costs (acquisition, installation, etc.). Different processes (automatic, semi-automatic or manual) can be studied and lines can be integrated (cutting and fabrication of flat panels, for example), reducing costs and integration time.

Fig. 2 : Example of shipyard under planning (Atlantico Sul Shipyard – PE/Brazil)

Testing different positions of machinery and material flow allows the definition of a configuration that minimizes the distances and movements before the machines are installed. After the installation of certain equipment, the repositioning could be infeasible. The simulation permits analyze inventory levels, avoiding stops of production. The assembly blocks can be studied according of different strategies for building. Different methods can be investigated considering the inclusion of advanced outfitting.

Sharing resources such gantries, cranes and trucks can also be checked. Productivity and time, considering different demands can be estimated more accurately by providing greater support to managers. In pre-erection, large blocks of different sizes can be modelled. The physical space and resources can be defined depending of the size of blocks.

The workload in accordance with different types of vessels can be evaluated as the operational implications, such as proper inventory levels of intermediate products, and equipment parameters (speeds, etc.). The simulation of the erection could provide important information to determine the best strategy and choose the most appropriate resources. The simultaneous construction is another issue that could be addressed.

2.4.2 Production planning

Fig. 3 : Example of shipyard in operation (Eisa S.A – RJ/Brazil)

Unlike most applications in industries with series production the main added value of the use of production simulation in shipbuilding is obtain in the support of the production planning and control and not on the layout planning. Fig. 3 shows a layout of a Brazilian shipyard.

The existing shipyards need to constantly refine their processes and techniques to establish competitive conditions. These shipyards must adapt their operating strategies in order to achieve lower costs and production times. Transport systems for workshops can be tested under different parameters. For the steel processing process, different sequences and cutting planes can be evaluated, reducing the setup times of equipment and allowing a better use of resources.

The production of curved panels and sub-assemblies can be balanced, and different assembly methods can be studied. The sequences of production (daily or weekly) can be planned in order to optimize the production. Any gaps between the planned schedule and the simulated schedule can be analysed and solved before that the real production take place. In the pre-erection and erection process, the constraints and conflicts between the transport systems can be predicted and the time of constructions can be estimated considering risks and uncertainties.

2.5 Coupling production simulation and optimization

Nowadays, more and more applications of simulations and optimisations are used in production planning to increase production performance and competitiveness of shipyards, *Steinhauer et al. (2006), Kim et al. (2007), Souza et al (2008)* and *Bentin et al. (2008).*

In the context of production planning, the performances achieved with an overall production strategy can be assessed according to different criteria, such as lead time and manufacturing costs. The typical issues arise during the production are the balancing of working load and working force, the detection of bottlenecks and the maximization of resources utilization.

The production scheduling consists in establishing the best fabrication strategy (that can be represented by a production parameters system) in order to minimize both lead time and manufacturing costs. Those parameters can be quantitative, such as human resources or production facilities features, or qualitative, such as manufacturing sequence, workload dispatching on different working areas or priority strategies.

If the consequences of the variation of only one quantitative parameter on the production performances are relatively easy to foresee without the help of simulation, it becomes quickly much more complicated if several parameters are simultaneously modified. Optimisation based on production simulation models can be used to find one of the best set of values to minimize both lead time and manufacturing costs.

Production simulation coupled with optimisation tools used during the design stages can enhance the productivity of shipbuilding industry. Advantages are among others:

- New policies, production procedures, decision rules, production flows, organizational procedures, transportation systems, and so on, can be assessed without committing resources for their acquisition
- Hypotheses about how or why certain phenomena occur can be tested for feasibility before the production
- Insight of the interactions between production variables can be obtained
- Insight of the variables importance on the production performance can be obtained
- A production simulation study can help in understanding how the system operates rather than how individuals think the system operates
- The “What’s happen if” questions can be answered. This is particularly useful in the design of new production systems.
- We can do the evaluation of very complex systems where analytic solutions are not known and for which production simulation is the only possible approach
- Production simulation models often have a visual interface, sometimes with graphic animations and this fact makes them more reliable to the eyes of managers

3 Case study - Erection sequence optimization

3.1 Erection sequence issue

After the block splitting, the next scheduling stage to be performed is the definition of the optimal erection sequence. The erection process is a very complicated and highly networked operation involving decision-making interlinked with a lot of structural items. Manual solutions are often

inadequate for optimising the process, *Souza et al (2006)*.
The main issue of erection sequence is that this process follows a huge number of implicit physical and production rules. During the definition of block sequence, consideration must be given to:

- Physical constraints, such as some blocks are supposed to support other ones and have therefore to be positioned before.
- Planning and production control constraints, such as the desire for constancy of work inside the workshop.
- Block assembly constraints, such as the minimum time between the laying of blocks. This time is required in order to tack and weld the block on the ship. Another very restrictive constraint is that it is usually impossible to insert a block between two blocks already erected. Indeed, it would increase the complexity of block assembly stage. Moreover, the required gap necessary to insert the block is not compatible with the minimum welding gap.
- Erection constraints, such as the first's blocks to be placed. The blocks contain the engines are often the first blocks to be placed because they require time for assembly and outfitting much higher than others.
- Erection strategies, such as the laying of ship blocks starting from the middle, fore or aft part of the ship; by layers or by slice or finally with a pyramidal strategy.

Each of these sets of constraints comes from a different constituency within shipyard, and the definition of block sequence has traditionally involved a process of iterative definition, review, and negotiation. Depending on the shipyard, this process may be well defined or somewhat inaccurate. Even when the process is well defined, it involves multiple channels and cycles of communication, and as a result it can be not only lengthy but also subject to errors and omissions that results in less than optimal block sequence.

The intent of this study is to examine how various computer-based analysis and simulation techniques might be used to improve the efficiency of the block sequence definition process.

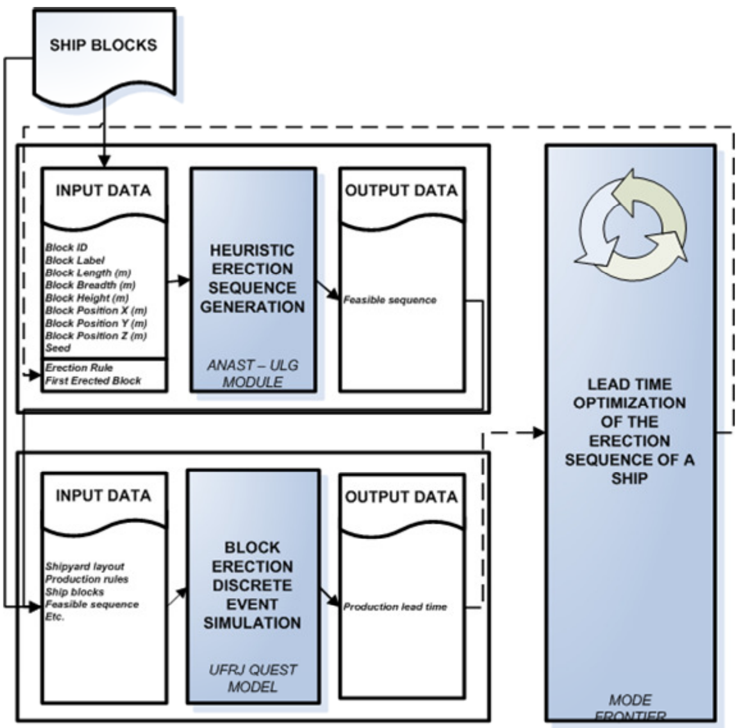


Fig. 4 : Workflow of the optimization process

3.2 Presentation of the overall optimization workflow

Fig. 4 shows the overall workflow of the optimization process. Three different codes are involved in the optimization loop. Firstly an in-house development to generate feasible sequences, secondly a DES software (Quest - Delmia - Dassault) to evaluate the lead time of the production process, and finally an optimization platform (ModeFRONTIER).

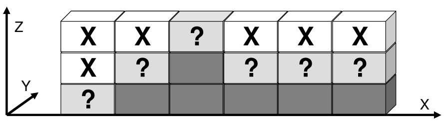
3.2.1 The feasible sequence generator

The purpose of this module is to generate one/several feasible sequence according to the assembly technical requirements (production rules). The sequence is filled up with the blocks one by one. It is based on successive decision stages. The algorithm is launch recursively to choose the next bloc in the sequence.

The algorithm determines at each bloc selection step the neighbour blocs of the partial solution. Among them, the algorithm chooses only the blocks fulfilling the technical constraints. Finally, he can select heuristically one of the block providing a technical feasible sequence.

If we wanted to generate all possible sequence, there would factorial *n*, where *n* is the number of blocks. One of the advantages of the technical constraints is the fact that they are extremely selective, and the number of feasible sequences decreases hugely.

The principle is the following. Blocks are selected one by one to be erected on the dry dock. As *n* blocks have to be erected, *n* decision steps have to be executed. At each step of the selection process, another block must be chosen among the blocks not already welded. For that purpose, a list of potential neighbours, which could be chosen as the next block in the sequence, because satisfying the technical conditions, is filled up, Fig. 5. Finally, a block is selected heuristically in the list of potential neighbours satisfying the technical conditions to be the next in the sequence.



– Block already positioned inside the ship
X – Block not positioned inside the ship yet, and not neighbour
? –Block not positioned inside the ship yet and potential neighbour

Fig. 5 : Blocks selection step for the sequence generation

This erection sequence generator has several advantages like the:

- Automation of the block erection sequences
- Very fast process (< 1s)
- Consider 3 different erection rules (by layer, by slice or by pyramid propagation)
- Generation of multiple feasible sequences with the same starting point (first block)
- Possibility to start with different initial blocks (or sequences)
- Possibility to add other production rules
- Input and Output text files
- Independent Java modules (Multi Platform)

Nevertheless some limitations are remaining. It seems very complex to take into account all production rules simultaneously during the construction of the erection sequence. It follows that some situations are not yet solved by the algorithm.

For each value of the input data (erection rule, first block to be placed), this in-house development can generate heuristically several feasible block erection sequence. Then the sequences are passed to the DES in order to evaluate the lead time of the production process.

3.2.2 The DES software

The Quest software has been selected by the authors to perform this study. The QUEST software (Queuing Event Simulation Tool) has been developed by Dassault Systems group. One of advantage of this simulation package is the possibility to reuse procedures, geometries of products and resources which are stored in a user library. Another point to be highlighted is that message boxes are showed, during the simulation run, containing indications of the element with problems and the type of error, helping the users to verify the model. The user can also modify or rewrite a selected behavioural rule and can even add new rules. This open architecture allows the user to control model behaviour at a very detailed level. In most cases, the behavioural rules defined by SCL (Quest Simulation Control Language) are sufficient. However, modifications can be made where ever necessary.

After the generation of one erection sequence the DES is launched in order to evaluate the lead time of the erection process. The study focuses the erection of a Suez Max Tanker as shown in Fig. 6.

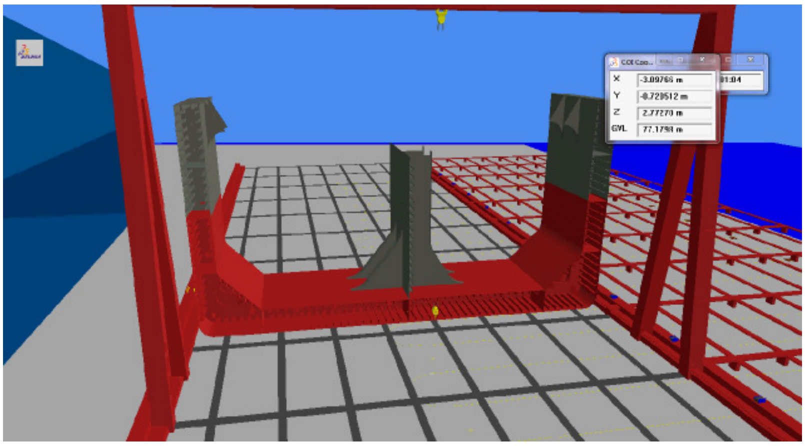


Fig. 6: Production simulation of the block erection

3.2.3 The optimization software

The ModeFRONTIER software has been selected for this study. ModeFRONTIER is a multi-objective optimization and design environment designed to couple CAE/CAD/CAM, CFD, simulation software to various optimization algorithm. It is developed by ESTECO Srl and provides an environment for product engineers and designers. This optimisation toolbox is a GUI driven software that wraps around the CAE tool, performing the optimization by modifying the value assigned to the input variables, and analyzing the outputs as they can be defined as objectives and/or constraints of the design problem.

The logic of the optimization loop has been set up in a graphical way, Fig. 7, building up the workflow structure presented in section 3.2 by means of interconnected nodes.

Lead time of the block erection process has been defined as objective function. Two design variables have been defined respectively the first erected block and the erection rule (by layer, by slice or by pyramidal propagation). No constraints have been added in the optimization workflow because the constraints are already included in the sequence generator algorithm. Simplex algorithm and a genetic algorithm have been tested during the optimization process.

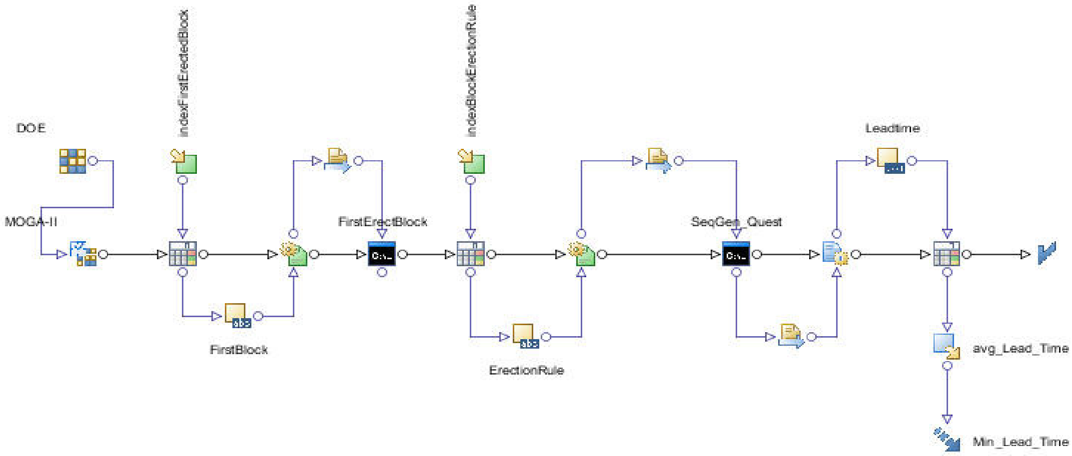


Fig. 7 : Optimization workflow in ModeFrontier

3.3 First results

The first intermediate results of the case study are presented in this section. Fig. 8 shows the objective function after 350 iterations. It takes about 2 min for each simulation run i.e. about 12 h for 350 iterations. The reader would be easily noted that unfortunately no convergences are reached.

The authors are currently investigating the causes that of this results. The most probable source of this behaviour is that the feasible sequence generator module has a heuristic comportment that is too random for the optimization algorithm. The main advantage of the actual version of the model is that we are generating only the feasible sequence avoiding a lot of non feasible design during the optimization. The drawback is that the constraints are not implemented in the optimization software but in the feasible sequence generator module.

Despite the no convergence, an interesting outlook of this first analyse can be highlighted here. The block erection rule by layer takes about 6% more time than the other two erection strategies whatever the first erected block selected.

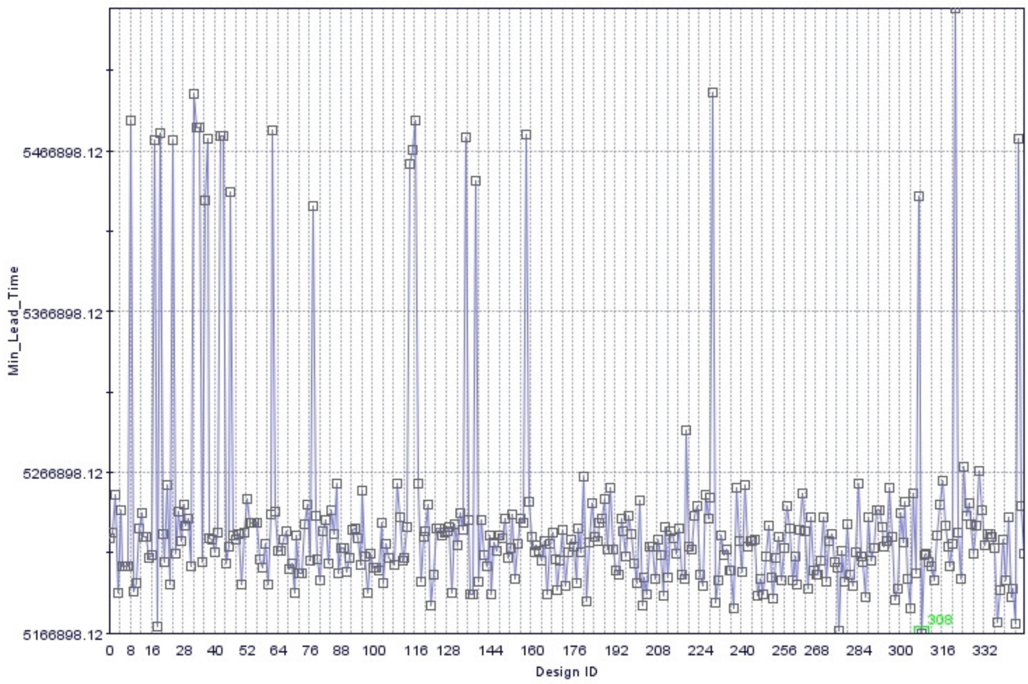


Fig. 8 : Objective function convergence

4. Conclusion and future work

The aim of this study is to improve the efficiency of the block sequence definition process and the optimality of the resulting block sequence regarding the lead time of the erection process. The selection of a right erection sequence seems to be a great potential to improve the manufacturing lead time. Nevertheless, the first intermediate results presented in this study are not yet valuable. A new approach is required to modify the modelling of the problem and/or the comportment of the optimization algorithm. Authors are in contact with the optimization software company in order to find an appropriate solution to solve this issue.

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