Valuing and improving shipbuilding pre-processing flows by Lean Manufacturing

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***Abstract*—Market competitiveness compels efficient shipbuilding processes and higher productivity. Lean Manufacturing is widely accepted as effective manufacturing process improvement concept and focuses on the shortening of the production flow by eliminating waste. Effectiveness studies of the application of Lean Manufacturing theory in shipbuilding are performed. However the shipbuilding pre-processing process is still underexposed. The goal of this paper is to theoretically apply the Lean technique of Value Stream mapping (VSM) on the shipbuilding pre-processing process. First the customer requirement is identified as it defines the value in the process. The delineation of major process flows shows that for pre-processing processes the regular VSM approach is too static. Such discrete event simulation is proposed. Valuation metrics are defined for providing focus for data collection and simulation model definition, reviewing process inefficiencies and comparison with future states. Future states are enabled by mitigating the Lean waste types and implementing a balanced and properly timed flow. This is enabled with the definition of product lines, Just-in-time and one-piece flows. All those concepts pose additional constraints on the part generation, by means of the nesting, which are described in this paper. Hence Lean improvements are initiated by flow related nesting improvements. Last a case study is performed and flow improvements are illustrated.**

***Keywords*—Lean Manufacturing, shipbuilding pre-processing, value stream mapping, valuation metrics, nesting constraints**

Introduction

Today's ever-increasingly competitive shipbuilding market makes it essential for a shipbuilding company to have more efficient production processes and higher productivity to obtain its competitiveness (Back et al., 2013; Kieran and Timberlake, 2004). When it comes to improving production the fundamental question is 'what available improvement theories exist and are applicable?' (Netland, 2018; Hayes and Wheelwright, 1984). A shift is occurring in manufacturing around the world as manufacturers in industries from automotive to aircraft moved to a different system of production called Lean Manufacturing (Womack and Jones, 2010; Kieran and Timberlake, 2004; Liker and Lamb, 2001).

According to Liker (2004) Lean Manufacturing requires a way of thinking that focuses on creating a work flow through value-adding processes without interruption that cascades back from customer demand by only replenishing at short intervals what the next operation needs. Lean thinking is well summarised in five principles in the book by Womack et al. (1991). The so called 'value stream mapping' (VSM) approach adopts those principles and provides an implementation approach (Rother and Shook, 2003; Martin and Osterling, 2014). The guiding steps are: 1) establish customer requirements, 2) delineate major processes, 3) draw current state map (CSM), 4) review map for process inefficiencies, 5) determine action plan, 6) draw future state map (FSM), 7) develop project plan.

According to Liker and Lamb (2001), although shipbuilding is very different from both before mentioned industries, the Lean Manufacturing application might be advantageous for improvement of its production process because the theory of shortening lead times by eliminating waste applies to any process, high or low volume, standardised or customised.

The application of Lean Manufacturing theory in shipbuilding has occupied scientific attention for already several years (Storch and Lim, 1999). However most studies mainly consider the shipbuilding assembly processes, like main panel-, section- and block assembly (Liker and Lamb, 2001; Phogat, 2013; Koenig et al., 2002; Storch and Lim, 1999; Lang et al., 2001; Hassan and Kajiwara, 2013). They can be distinguished mainly in 'implementation approaches' and 'case studies' (Kolić et al., 2012b). Within the entire shipbuilding process the pre-processing process receives limited attention (Kolić et al., 2012b; Lang et al., 2001; Hassan and Kajiwara, 2013). This paper responds to that by presenting a Lean Manufacturing implementation approach which specifically considers the shipbuilding pre-processing process.

The pre-processing process (i.e. pre-fabrication process) concerns, by definition, the logistics of the highest number of parts within shipbuilding, due to the material 'explosion' at part generation (Van Ek-

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eren, 2018). Within the entire process several work steps (cutting, bevelling, tapering, forming, grinding and flanging) contribute to the total end product. The 'product' and 'process' characteristics for a pre-processing process tend to make Lean Manufacturing appropriate for initiating flow improvements (Hayes and Wheelwright, 1984; Netland, 2018).
The main contribution of this paper is therefore to study the applicability of the Lean value stream mapping approach, to determine how Lean process improvements can be initiated and proposed, for the specific case of shipbuilding pre-processing. The scope of this study is focused on the pre-processing process of a yard, involved with a diversified portfolio of small (e.g. tugs $\approx$ 30m) and large (e.g. offshore vessels $\approx$ 90m) vessels (Van Ekeren, 2018).
The remainder is structured as follows. First the customer requirements are studied, followed by the delineation of major processes. Thirdly the process data measurement, current state map drawing and review for processing inefficiencies is dealt with. As those are linked they are described jointly. Fourthly the determination of an action plan and future state map construction are jointly considered. Finally case study results are presented.

1. Customer requirement definition

The implementation of Lean Manufacturing for shipbuilding pre-processing starts with the identification of value. Value is initiated by the customer expectation (Liker, 2004). Within manufacturing processes value-adding activities are generally physical transformations of a product according the customer expectations (Womack and Jones, 2010; Moura and Botter, 2012). For a pre-processing process the customers are the parties which receive the pre-processing products, namely the subsequent assembly work steps, like sub-panel-, main panel-, section-, block-, hull assembly and outfitting. In Figure 1 the 'customer' demands are mapped in time, indicating the sequentiality of customer demand moments. The phase durations are not depicted on a time scale but on time sequence since the section assembly process takes much longer than the sub panel assembly process. The demand cascades in time. Not all process steps have a direct start-finish relationship.
Customer demand analysis shows that the 'customers' want to have two types of product, namely plate and profile parts, which require a specific physical appearance created by specific processing steps. Figure 2 provides an overview of the possible different routines. At the work steps (shown in Figure 2) value-adding activities are performed as there the product is transformed according to customer demand. Since the customer does not want general processed parts, but exactly those it needs, sorting is also considered to be a value-adding activity.

2. Delineation of major processes

Subsequent to the identification of value, the Lean Value Stream Mapping (VSM) approach proposes the delineation of mayor processes (Rother and Shook, 2003). Major processes should follow for 80% the same process steps in order to make an appropriate VSM as mapping all flows is too extensive (UPD, 2018). These processes can involve shared and dedicated resources. Where dedicated resources concern one specific process, shared resources are used by different processes. Consequently, shared resources should be carefully considered (Martin and Osterling, 2014; UPD, 2018). By means of incorporating margins on the shared resources the uncovered 20% can be assessed.
Based on the product data of both small and large ships the contribution of each routine is determined. The results are presented in Table I and show approximately the same result for both ships. The codes correspond to the first letter(s) of the work steps as defined in Figure 2. For each routine the number of parts and cumulative weight, to determine the size of the parts, is listed (Kolić et al., 2012a). A closer look is taken at small ($\leq$20kg) and large ($>$20kg) parts because part size can differ significantly in shipbuilding and this boundary decides whether parts can be moved manually or not. This difference determines waiting-, transport- and processing times and is therefore important within Lean Manufacturing.
For the application of the VSM approach clearly no standard flow, which at least 80% of the parts follow, is observed, for both ships and both measured units. The C-G route is numerically reasonably large, but is build up from small parts mainly. Considering this to be the standard flow results in a flawed approach as small parts are much easier to handle than large parts. Moreover grinding requires much less resources than (e.g.) forming. The cutting, forming and flanging work step require the deployment of cutting machines and presses, with which significant investments are involved. Contrary the bevelling, tapering and grinding work step do not require the deployment of expensive, significant resources. Such the flawed approach is further underlined by the investment side of value stream mapping and redesign.
Consequently, there are several severe limitations to using VSM for shipbuilding pre-processing processes. The main limitations relate to complex routines (shared resources), absence of a clean standard flow and part variability.

These limitations are acknowledged by Schmidtke et al. (2014) and McDonald et al. (2002) as well, for general manufacturing processes. Both studies propose the utilisation of discrete event simulation for obtaining the VSM. Discrete event simulation is suitable as it includes dynamic relations between different processes, which could not be addressed using

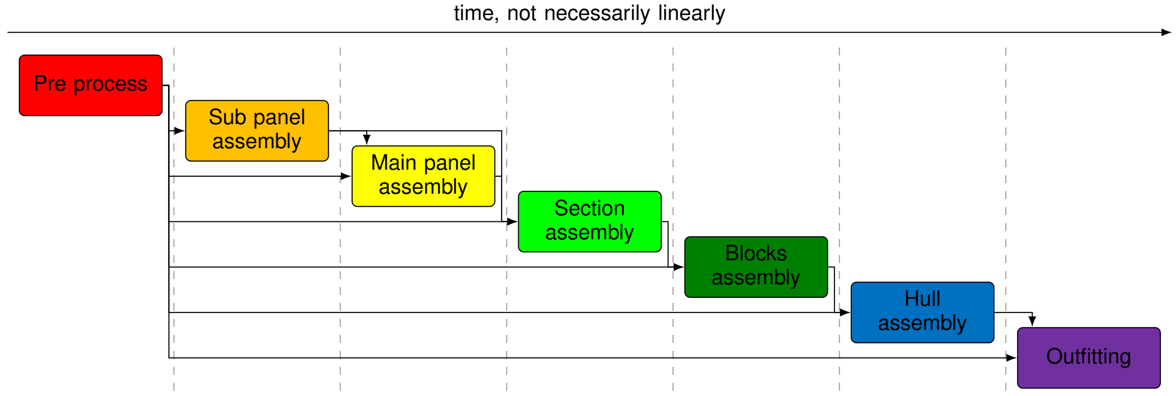

Figure 1. Pre-processing customers' demand mapped in time

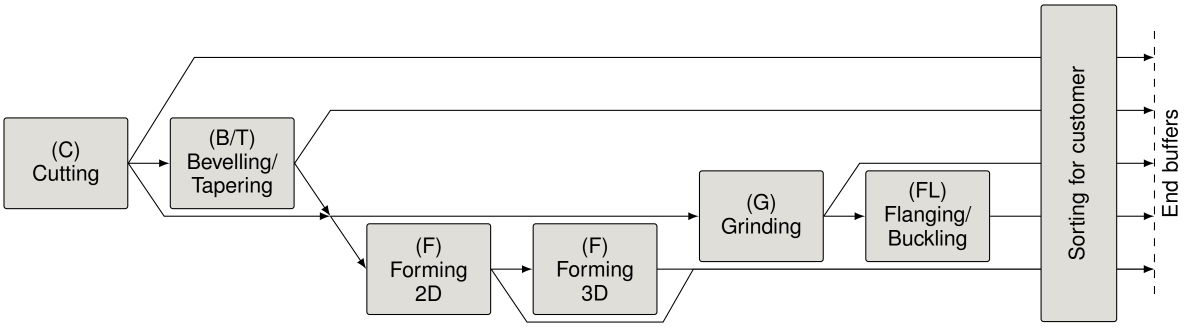

Figure 2. Part routing in pre-processing

Table I. Normalised part routing appearance

	Small ship						Large ship					
	All parts		Parts ≤ 20kg		Parts >20kg		All parts		Parts ≤ 20kg		Parts >20kg	
Routing	No.* [-]	W.** [-]	No. [-]	W. [-]	No. [-]	W. [-]	No. [-]	W. [-]	No. [-]	W. [-]	No. [-]	W. [-]
C	0.23	0.34	0.14	0.02	0.09	0.33	0.24	0.55	0.17	0.02	0.07	0.53
C-B/T	0	0.03	0	0	0	0.03	0	0	0	0	0	0
C-B/T-F	0	0.02	0	0	0	0.02	0	0	0	0	0	0
C-B/T-G	0	0.02	0	0	0	0.02	0	0	0	0	0	0
C-F	0.03	0.24	0	0	0.03	0.24	0.01	0.09	0	0	0.01	0.09
C-F-G	0.04	0.03	0.02	0	0.02	0.03	0.02	0.01	0	0	0.01	0.01
C-G	0.66	0.28	0.54	0.06	0.12	0.23	0.71	0.34	0.52	0.04	0.19	0.29
C-G-Fl	0.01	0.01	0.01	0	0	0.01	0.02	0.02	0.02	0	0.01	0.01
C-Fl	0.03	0.04	0.02	0	0.01	0.03	0	0	0	0	0	0
Total	1	1	0.73	0.08	0.27	0.92	1	1	0.71	0.07	0.29	0.93

* Normalised number of parts per specific routine, ** normalised cumulative weight of all parts

the static view provided by VSM (McDonald et al., 2002; Hassan and Kajiwara, 2013). The dynamic relations within the simulation cover buffer- and waiting times (Steinhauer, 2011). Subsequently the process-, cycle- and up time can be determined. Moreover, simulation incorporates feasibility and trade-off analysis, which enables the shared resource principle to be addressed more easily (Schmidtke et al., 2014).

Other methods for mapping complex processes exist (Braglia et al., 2006; Toivonen and Siitonen, 2016). Some of them specifically focus on IT environments and are not straightforward for manufacturing processes (Toivonen and Siitonen, 2016). Braglia et al. (2006) proposes another method to acknowledge the complex routines problem. The basic idea is to execute a preliminary analysis to identify the 'critical production path'. Then, improvements are made considering all possible sharing with other secondary paths as possible constraints. Once the critical path has been optimised, a new path may become critical. The inability to capture the resource specifics is a deficit for mapping the shipbuilding pre-processing application (Schmidtke et al., 2014). Furthermore the shared resource issue is not entirely addressed.

Therefore within this article the application of discrete event simulation for obtaining the VSM of shipbuilding pre-processing processes is acknowledged, for better incorporation of the shared resource principle and expensive, set resources. Furthermore it provides visual insight in the process systems (Steinhauer and Soyka, 2012)

Despite the limitations of the VSM technique the construction of the VSM 'current state map' (CSM) is useful as its elements can still be constructed (Schmidtke et al., 2014; Seth et al., 2017). The layout and static flow analysis, as part of the CSM, support the construction of a simulation model (McDonald et al., 2002).
According to Bringezu and Moriguchi (2002), from static perspective Material Flow Analysis (MFA) can be used to analyse the significance of each flow, in accordance with the VSM approach. MFA refers to the analysis of throughput of process chains comprising manufacturing, consumption, recycling and disposal of materials (Brunner, 2004). It is based on accounts in physical units (usually in terms of tons), quantifying the inputs and outputs of those processes.

3. Current state map construction and review

Prior do drawing the current state map, conform the approach above, process data needs to be measured (Martin and Osterling, 2014). Subsequent the VSM approach proposes the review for process inefficiencies, which entails a Lean Manufacturing waste analysis (Rother and Shook, 2003). Furthermore this review entails the determination of the ratio between value-added and non-value-added processes. For this reason and for enabling comparison between current state models and future state models (FSM), valuation metrics are to be defined (Nightingale, 2005).
Since the review for process inefficiencies is the objective of the current state mapping, the definition of valuation metrics is recommended, prior to drawing the current state map. It provides focus for data collection and simulation model definition (Rother and Shook, 2003; Steinhauer, 2011). Since as such they support the current state map construction specific attention is paid to their definition.
Different key performance indicators (KPI's) can be defined conform the improvement objective, like on enterprise, stakeholder, employee or process level (Blackburn and Valerdi, 2009). Conform the article's contribution particular attention is paid to the process redesign, which affects the process level. Hence also the process related Lean Manufacturing principles are of interest (Liker, 2004).
The static analysis enables the definition of space and static flow related KPI's. Those KPI's cannot, by definition, depend on the variable time. Those are defined first. For studying the time effects throughput related KPI's are defined, since those incorporate the time effects and the variability due to process trade-off analysis. Those are defined second. Last the use of the Lean Manufacturing framework to interpret the KPI results is discussed.

Static key performance indicators

Important for the pre-processing process redesign is the extend to which space is utilised, since this property drives the requirement for facility buildings and areal reclamation (Van Ekeren, 2018). Therefore it is a clear design related measure. For this the total area metric is appropriate since exact space utilisation cannot straightforwardly be checked mathematically (Steinhauer, 2017). The total area can be divided by process area, infeed and outfeed, indicating what area is used for value adding processes and buffers (Hines and Rich, 1997). Strictly speaking buffers enable certainty about part arrival, which is valuable. Nevertheless it does not enable physical product transformation. Furthermore sorting spaces are not including process space, because no clear rules exist to define what valuable sorting space is.

$$KPI_1 = Area_{total}$$

$$KPI_2 = \frac{\text{Process space}}{\text{In/outfeed space}}$$

From a manufacturing theory perspective the total available area for executing the processes should be kept minimum, given a certain set of operations. Lean Manufacturing clearly distinguishes whether the process is value-adding or non-value-adding. KPI_2 clearly responses to that. Hence for an ideal lean flow this KPI should score high.

To study the available space arrangement and transport waste, the transport distances require investigation (Liker and Lamb, 2001). It enables studying the layout logicality, by the positioning of different work stations. Using MFA analysis and the related transport distances it can be determined what percentage of the entire flow 'travels' which distance. The KPI is defined as the mean transport distance per part, in the units of 'number of parts' and 'cumulative weight' to incorporate the relevant difference between small and large parts. This KPI incorporates both the non-value-adding- and necessary-non-value adding activities. Since transport distances depends on the layout arrangement the definition of minimal transport distances is not straightforward. However it enables clear comparison of the current with future states (Hines and Rich, 1997). For reduction of the transport waste, as defined by Lean Manufacturing, KPI_3 should be reduced (Liker, 2004; Storch and Lim, 1999)).

$$KPI_3 = \text{Mean transport distance} = \bar{s} \text{ for } \begin{cases} \text{Number} \\ \text{Weight} \end{cases}$$

The implication of a specific distance travelled is enhanced by the time it takes (Sly, 1996). For the longer distances generally more ‘transfer points’ are occurring, which are more susceptible for waiting times, due to resource availability. Hence the number of transports is incorporated in the next KPI, indicating the number of crane, carriage, conveyor or manual actions used:

$$KPI_4 = \text{Mean number of transport moves} = \bar{n} \text{ for } \begin{cases} \text{Number} \\ \text{Weight} \end{cases}$$

It is routine specific to what KPI_4 should be reduced. Ideally the number of transports equals the number of routines plus one.

Dynamic key performance indicators

For studying the time effects, throughput related KPIs are defined. From Lean Manufacturing perspective the ‘time to market’ metric is of reasonable importance since it captures the extend to which the flow is continuous and value adding (Liker, 2004; Nightingale, 2005; Womack and Jones, 2010). When applying this to a shipbuilding pre-processing process it concerns the fast, in-time delivery of customer demand batches. Hence the part throughput analysis is assessed next, which mainly concerns the definition of the duration of each work step per part (Nightingale, 2005). Using the simulation model the time of specific state changes can be captured coherently. Because of part variability and several routines, a distribution of parts throughput durations result. The average of this distribution is included in KPI_5.

$$KPI_5 = \text{time average of ‘process time’ per individual part distribution} = \bar{x}_{time}$$

This KPI can be defined for each rouine or customer. Moreover this KPI can be defined for the strictly value adding activities to enable comparison. The ratio between the process KPI and value-adding KPI should approach one for a proper Lean flow.

Besides the yard throughput is dealt with, which deals with the station/yard occupancy. For the development of KPI's three measures are of interest. The first one (KPI_6) has to capture the ability of the system to meet annual capacities, for which the cumulative annual throughput is appropriate (Blackburn and Valerdi, 2009). Like in every manufacturing system this property is of importance for pre-processing processes.

$$KPI_6 = \text{annual throughput (weight)}$$

Moreover KPI's have to capture whether the pre-processing work stations have a levelled throughput (Nightingale, 2005). This property is of importance as it is strongly related to the establishment of a smooth, uniform flow (Liker, 2004; Womack and Jones, 2010). This is captured by the ‘station occupancy rate’ (KPI_7), distinguishing the difference between idle and occupied time of each work station. The unit weight is used in order to incorporate the difference between parts. Since the entire station is considered, insight in the in/outfeed buffer loading is obtained as well. Such it links to daily ‘work in progress’ measures per station (Stevenson et al., 2007). For a Lean, levelled flow KPI_7 need to be close to 1, since this means that the station load is spread per time unit.

$$KPI_7 = \text{station occupancy rate} = \frac{x_{all} - x_{idle}}{x_{all}} \text{ per pre-processing work station}$$

It is of interest to what extend the work station is active when being occupied, which is assessed by KPI_8, distinguishing the degree of occupancy when being occupied (Liker and Lamb, 2001). Conform the Lean Manufacturing framework objective this KPI needs to be close to zero, since this means that the station load is always equal. Since the entire station is considered, measures for the instantaneous inventory waste types are observed.

$$KPI_8 = \text{active station occupancy variability} = \frac{\sigma_{occupancy}}{\mu_{occupancy}} \text{ per pre-processing work station}$$

The mean value is deliberately not considered as it does not provide global comparable measures as the station occupancy is very much determined by the routine operations.

Closely related are the resource utilisation measures, which are machine related contrary to the station related KPI_7 and KPI_8. It distinguishes the ratio between utilised time and total time. It provides measures of the waiting waste (Steinhauer, 2011). Whether the utilised time is also value adding is resource specific.

$$KPI_9 = \text{resource utilisation} = \frac{\text{utilised time}}{\text{total time}} \text{ per pre-processing resource}$$

Using both the static and dynamic KPI results, relative KPI's can be defined as well, depending on the measure of interest.

Lean Manufacturing waste analysis

According to Lean Manufacturing the 'non-value-adding' activities can be separated in several categories: Transport, Inventory, Motion, Waiting, Over-production, Over-processing and Defects (Womack et al., 1991). Liker (2004) introduces another type of waste being skill. Nowadays these waste types are being referred to as TIMWOOD'S based on the first letters of the waste types (LBSPartners, 2014).
The transport, inventory, motion and waiting waste are especially captured by means of the above defined valuation metrics. Within Lean Manufacturing there is also specific focus on quality and people development (Liker, 2004; Nightingale, 2005). For those also KPI's can be developed. However that is not considered within the scope of this paper.
By adopting the waste types the KPI results can be interpreted and root causes can be found (Liker, 2004; LBSPartners, 2014). Understanding about those root causes provides input to the future state map (FSM) definition. This approach can be adopted for analysing pre-processing processes. Apart from extensiveness, the waste analysis does not suffer from the complex process routines and shared resource issue.

4. Future state map design and construction

Subsequent to drawing and reviewing the current state map the Lean value stream mapping approach proposes the determination of an action plan and construction of the future state map (Rother and Shook, 2003; Martin and Osterling, 2014). Therefore a shipbuilding pre-processing process related action plan is derived. In order to devise Lean process flows in shipbuilding pre-processing, the two key concepts of balancing and timing flow are applied (Storch and Lim, 1999; Kolić et al., 2012b). The application of balancing and timing efforts poses additional constraints on how the parts should be nested.

Balancing pre-processing flows

Liker and Lamb (2001) observed that the shipbuilding process is traditionally organised by functions. This also concerns the pre-processing processes. They propose a process redesign to an organisation by product lines. This concept is also acknowledged by Storch and Lim (1999) (and Kolić et al. (2011)), describing that 'the basis for the establishment of Lean thinking in shipbuilding is the appropriate application of group technology through the use of a product-oriented work breakdown structure'. Group Technology (GT) is a technique for identifying and bringing together related or similar parts in order to take advantage of their similarities by making use of, e.g. the inherent economies of flow production (Gallagher and Knight, 1973; Storch and Lim, 1999). GT application results in the definition of process lanes using standard work processes for the different part groups, which can be interpreted as the routines presented in Figure 2. Besides product lines can be determined based on part attributes like geometry, weight and processing length. Last but not least the customer demand can be incorporated into the product lines.

Essential to achieving the product lines based on routines and linking them to a layout, is the use and availability of resources. The deployment of resources limits the number of applicable product lines. This mainly implies the cutting, forming and flanging work steps as significant resources are deployed.
The definition of product lines based on customer demand focuses on the successor process input requirements. For each customer defined in Figure 1 those inputs can be derived. A Just-in-Time Lean Manufacturing review influences the number of product lines.
Concerning product lines based on part attributes the following attributes exist; weight, dimension, part type, processing type (bevelling, tapering, forming 2D/3D curvature, grinding and flanging).
The application of all product lines is not entire feasible or advisable. This is mainly because of minor flow contributions, expensive required resources and inefficient part nestings. Linking the resources to product lines affects the space arrangement related KPI's, namely KPI_3 and KPI_4. Strict implementation of product lines result in levelled flows, which results in ideal KPI_7 and KPI_8 results. Any deviation thereof is captured by these metrics. The assignment of resources to product lines affects the utilisation thereof, which is captured by KPI_9.

Timing pre-processing flows

Koenig et al. (2002) (and Storch and Lim (1999)) formulate that perfect timing means maintaining the status of having exactly needed work (completed interim products) at exactly needed times within the manufacturing levels. This corresponds to the Just-in-Time (JIT) concept. Basically, perfect timing will prevent unnecessary interruptions or waiting, and guarantee continuous flow. Liker (2004) states that continuous flow is enhanced by the Lean Manufacturing principle 'one-piece' flow.
Related to the JIT principle are the batches in which the parts are demanded (Womack and Jones, 2010). For shipbuilding pre-processing the demand and generation batches are different. The plate capacity and thickness play the main role in the generation batches. The JIT principle is significantly enhanced by reducing the cutting and processing process batches.

Hence reducing the cutting group batch size is a promising concept to reduce the inventory waste. Theoretically the lowest level of reducing the cutting group batch size is the size of one plate. However this has an implication on transportation requirements. Hence a balance needs to be obtained or the flow has to be improved.
Contrary to plate cutting, profile cutting stations generate parts in smaller batches. Hence it is better able to enable the JIT principle. By cutting flat bar profiles in a profile cutting station (contrary to cutting them from plate in a plate cutting station) the flexibility of the profile cutting station can be used and the implication of different thicknesses is reduced significantly.
KPI_5 captures the extend of approaching a continuous flow. The ability of the system to enable the pre-processing aspect of JIT arrival (until collection of customer demand batch) is derived by the end buffer process part throughput (KPI_5).

Nesting implications

Conclusively the implementation of Lean Manufacturing in shipbuilding pre-processing starts with the part generation. The creation of product lines and establishment of the timing principles drive additional constraints on the way parts are generated from a raw plate, which are captured in the nestings. The following nesting constraints are found and discussed:

1) Conform the one-piece flow principle, the number of different sections per end buffer nested in one plate should be reduced. It will result in reduced sorting time, less sorting/buffer space requirement, inventory waste reduction and shorter finalisation of one customer demand batch (more continuous). Left over plates are mitigated and nesting freedom is introduced by nesting the parts as an infinite sequence instead as cutting groups. Hence KPI_1, KPI_2 and KPI_5 are directly affected by proper implementation of this constraint.
2) In order to enhance flow and reduce buffer space all parts for a customer demand batch need to be cut 'instantly' (in a small period of time). This is most stringent for the sub panel customer demands as those batches are small and therefore require more space, since they can be stacked less. This very much links to the 'work-in-progress', which's variability is captured by KPI_7 and KPI_8. More importantly it related to the part throughput captured in KPI_5.
3) The parts should be nested conform the pace of the subsequent processes (forming, grinding, flanging, sub panel assembly etc.), in order to reduce buffer space requirement and enable proper occupancy. This notion is supported by the JIT principle which tends to link the generation batches to the demand batches. Applied to the part generation (cutting work step) this means that all parts for one customer demand point are to be cut out of one (or two subsequent) plate. Due to the number of customer demands in time this is most stringent for sub panel assembly, followed by main panel assembly.
4) Only specific customer demand product lines need to be assigned to a cutting station by limiting the number of product lines originating from one plate. Hence the cutting station can then be positioned more favourable on a layout diagram. Layout design freedom has particular influence on KPI_1 to KPI_4. Scrap efficiency is enabled by combining product lines on the basis of part size (small and large parts balance).
5) For levelling the cutting program duration an approximately equal number of parts or cutting length has to be cut from each plate. This also affects the arrival of parts at the other stations. Hence it influences the occupancy related KPI's. Due to the high part variability in shipbuilding pre-processing this constraint is not likely. However excessive cases can be avoided.
6) Whenever possible, parts are to be cut on the profile cutting line. Since the profile cutting batch size is smaller, it is much better able to enable the JIT principle and therefore reduce the inventory waste and create a continuous flow.

5. Case study

There is much theoretical treatment on the Lean Manufacturing principles and value stream mapping. A practical way of understanding how to implement the method in a real manufacturing setting is necessary for shipyard Lean transformation (Kolić et al., 2012b; Lang et al., 2001). Therefore a case study on Lean implementation in a shipbuilding pre-processing process is executed.

A real world yard is considered, involved with the construction of both small and large vessels (Van Ekeren, 2018). The value stream mapping approach proposed in this paper is followed to identify the value- and non-value-adding activities. The definition of the KPI's and the corresponding waste analysis proved to be advantageous and clearly surfaced the inventory, transport and waiting waste. Furthermore the qualitative description of the layout and static flows provided insight concerning the other waste types. Both the MFA analysis and the simulation model construction proved to be a proper means of communication in order to validate and generate feedback on the flow descriptions.

Different product lines are defined and adopted. By redesigning the process layout the batch size is reduced to the number of parts cut from one plate. Within this case study difficulty is found when attempting to implement the additional nesting constraints. The need for future research on this topic is underlined to study the effect of the constraints on the scrap rate. Scrap is a from of material waste and is therefore from significant importance (Storch and Lim, 1999; Koskela et al., 2004).
Nevertheless the effect of flow improvements, by implementing additional constraints to part generation, is quantified. Constraint 1 and 4 show a feasible, global effective implementation for batch size reduction and logistic flow improvements, contrary to the other constraints. Different scenarios are defined to check the effect of these constraints. Scenario 1 concerns the implementation of constraint 1. Due to this implementation the buffer spaces can be reduced significantly. As all flows can originate from one plate, a central cutting station is required. In scenario 2 constraint 4 is additionally implemented. Due to product line separation more design freedom is available. It is used to define two separate cutting stations.
For both the current and future states the KPI's are obtained. Furthermore the improvement ratios relative to the current state are derived. They are defined positive, meaning that an increased ratio implies an improvement. The improvement ratios of KPI_1 to KPI_6 are presented in Figure 3. KPI_7 to KPI_9 are not presented since they are linked to the specific layout redesign. Generally those are improved as well.

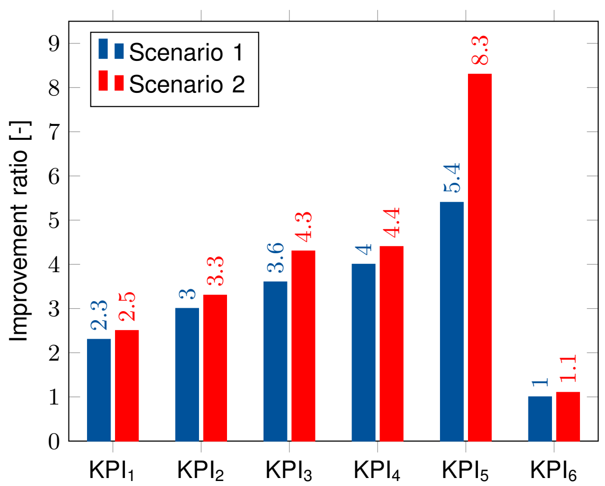

Figure 3. Case study comparison result

Although the total available area for executing the pre-processing activities (KPI_1) is reduced significantly the total annual throughput (KPI_6) is not affected negatively. This is mainly caused by the reduction in buffer space (KPI_2). Especially KPI_5 improved significantly, meaning that the flows became much more continuous since the part move much faster through the process. Scenario 2 shows a further improvement compared to scenario 1. Resuming the batch size reduction and implementation of additional nesting constraints show a significant improved pre-processing performance.

Conclusion

This article discussed the application of the Lean value stream mapping (VSM) approach to shipbuilding pre-processing processes. The VSM approach is applicable but some limits are found.
First the customer requirement (the value) identified, being a physical transformation of a product (plates/profiles) according to customer expectation. Secondly major processes delineation attempts are executed. Since there is no clear main flow and the process is rather complex, due to the existence of several routines and shared resources, limits concerning straightforwardness are found concerning the implementation of the value stream mapping approach. Discrete event simulation is proposed to incorporate the dynamic behaviour of the process.
Subsequent the current state map is constructed and inefficiencies are reviewed. This article introduced valuation metrics to value and compare the performance of the current state and future states. Moreover they provide focus on data collection and simulation model definition. The static analysis enables the definition of space and static flow related KPI's, by means of layout description and static flow analysis. The latter focus on transport distances and moves. The throughput related KPI's are defined by means of simulation and focus on part throughput, station levelness and resource utilisation.
Subsequent to drawing and reviewing the current state map the Lean value stream mapping approach proposes the determination of an action plan and construction of the future state map. Flow improvements are defined by means of balancing and timing the flows. Product lines need to be defined to benefit from repeated manufacturing and facilitate continuous, uniform flows. Product lines based on routines, customer demands, and part attributes exist. The implementation of the Lean Manufacturing flow and timing principles is directly related to the parts generation, which make that key for improvements. Additional constraints on the nestings result. Those nesting constraints enable one-piece, Just-in-Time, flexible and levelled flows. The quantitative effect of

the nesting constraints implementation requires additional investigation. The constraints underline the usefulness of the defined valuation metrics.
Last this article provides a case study to two global and qualitatively feasible nesting constraints. The implementation of the first shows already a significant improvement, which is further improved by the implementation of a second constraint. Given approximately the same annual throughput the required space is reduced. Moreover a much more continuous, smooth, one-piece flow is enabled.

Further research

Since Lean production process improvements start with part generation specific attention is required to the definition of the nestings. Since uncertainty exist about the effect of additional nesting constraints on the scrap rate, additional research into this topic is required.

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