International Conference on Computer Applications in Shipbuilding, 2011, Trieste, Italy

LEAN MANUFACTURING IN SHIPBUILDING WITH MONTE CARLO SIMULATION

D. Kolich, University of Rijeka, Croatia
R.L. Storch, University of Washington, USA
N. Fafandjel, University of Rijeka, Croatia

SUMMARY

The shipbuilding industry is very competitive, and shipyard management must strive to improve productivity as a way of keeping up with world competition. Analysis of the assembling of interim products through shipyard process lanes is important from a standpoint of modern shipbuilding techniques and methods which includes the *lean manufacturing* and *design for production* concepts. Whereas the *design for production* concept has bean readily applied in many shipyards, a *lean manufacturing* methodology for shipyards is lacking. Therefore, the aim of this paper is to provide a methodology for improving the flow of interim products by applying the *lean manufacturing* concept. Since shipyard management is usually not sure how to approach a transformation of its facilities due to the risks involved, this paper couples lean transformation with Monte Carlo simulation in applying the key parameter for comparing productivity, man-hours. The simulation involves process engineering transformation of an actual shipyard's panel-block assembly facilities. Application of the *lean manufacturing* methodology brings productivity improvements of 60%.

NOMENCLATURE

DFP	Design for production
IPA	Intermediate product assembly
FCB	Flux copper backing
P	Panel
KP	Built up panel
PWBS	Product work breakdown structure
S	Section
T	Three dimensional section

1. INTRODUCTION

Many world class shipyards have adopted design for production (DFP) concpets in order to improve their production and reduce costs. The concept of lean manufacturing has been most readily applied in Japanese shipyards such as IHI [1], [2]. Likewise, lean manufacturing has been successfully applied in many industries such as the automobile and aerospace industries [3]. One key area where shipyard facilities should be considered for lean transformation is the panel-block assembly line. The assembly of repetitive steel block interim products in a shipyard are performed along specialized process lanes known as panel line and built-up panel lines. The downstream flow of interim products includes workstations that are specially outfitted with tools and gears for completing specific activities. The aim of this paper is to display a methodology for a lean transformation of a shipyard. A case study of a shipyard was made using the following steps in developing the methodology:

- analyzing design variations and structural configurations of a shipbuilding production program;
- analyzing the constraints of the panel-block assembly lines;
- analyzing and evaluating the principle methods and sub-options of assembling panels and blocks;
- work content of a typical flat double bottom block (weld-length and man-hours);
- developing a type plan for assembling a typical double-bottom block;
- Lean transformation of the main shipbuilding processes;
- Lean transformation of a typical interim shipbuilding product;
- Monte Carlo analysis useful for estimating man-hours and minimizing risk in decision making for shipyard management.

Once the steps of analyzing a typical double bottom block are made which includes design variations and structural configurations of typical shipbuilding blocks, it is possible to approach a viable lean transformation. Application of a product work breakdown structure (PWBS) takes advantage of group technology, or the grouping of similar products through the assembly process as well as DFP [4], [5]. Lean manufacturing considers one of the key principles which are flow of interim products and built-in-quality [6], [7]. This paper shows how the proper integration of these concepts results in a near optimal lean transformation which translates into a reduction in man-hours, which means savings and cost reductions for the shipyard.

2. SHIPYARD CASE STUDY PANEL-BLOCK ASSEMBLY ILLUSTRATIONS

The present-day panel block assembly activities includes assembling a bed plate from unit plates (Figure 1) and then fitting and welding the longitudinals (Figure 2). Then transverses with cut-outs are fitted over the longitudinals and welded and finally lugs are fitted and welded as well. This is the standard method used in traditional shipyards (Figure 3) [4], [8].

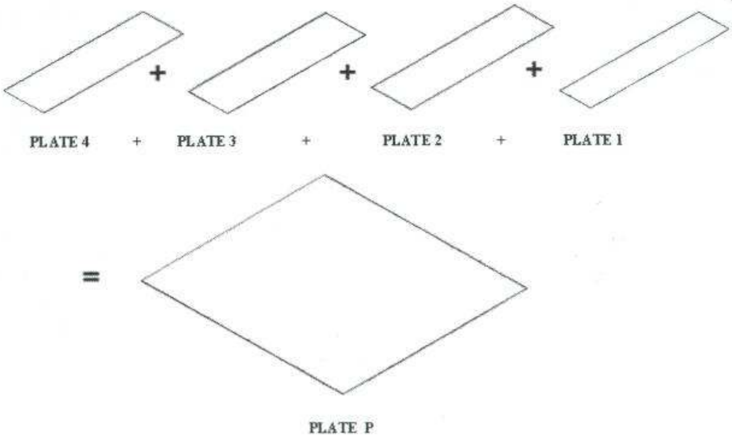


Figure 1: Bed plate assembly sequence on the present panel line

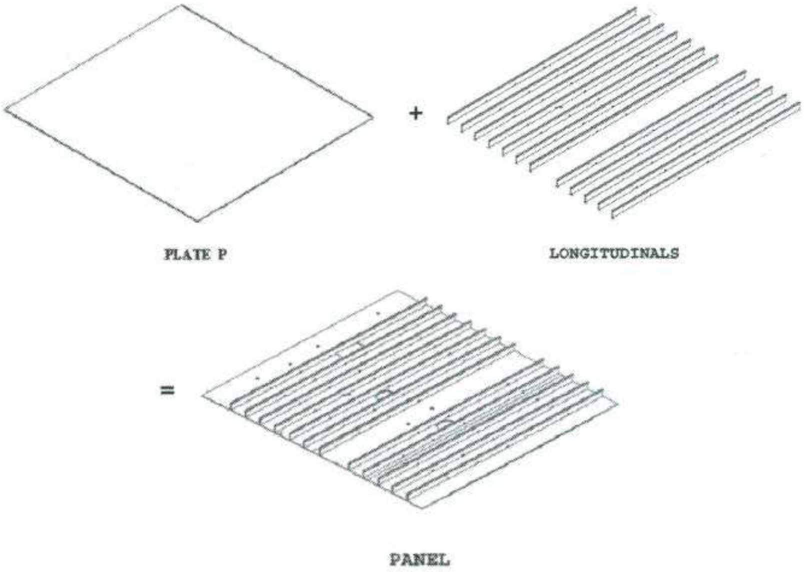
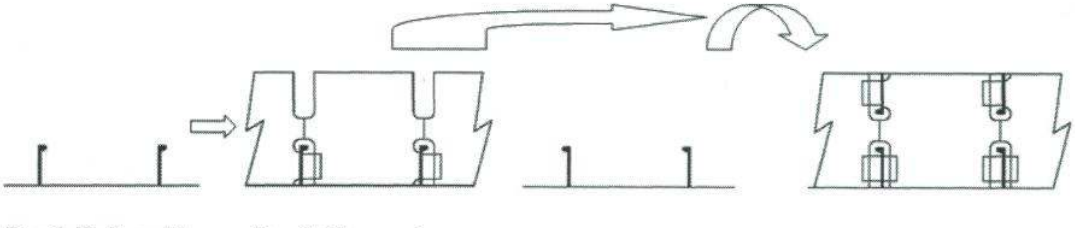


Figure 2: Panel assembly on the present panel line



Step 1: Fully weld longitudinals to first plate blanket.

Step 2: Place webs over longitudinals and fit and weld one side lugs.

Step 3: Fully weld longitudinals to second plate blanket.

Step 4: Turn first built-up panel onto second panel. Fit two sided lugs and fully weld.

Figure 3: Shipyard block assembly method [4], [9]

3. LEAN TRANSFORMATION OF SHIP BLOCK ASSEMBLY

The importance of flow, especially the application of one-piece flow is key for lean transformation. Unit plates are fitted with longitudinals (see Figure 4) as opposed to first assembling a bed plate from unit plates and then fitting longitudinals as in Figure 2 above. The fitting of longitudinals on the unit plate is performed by one operator as opposed to multiple workers in the traditional process due to the greater size of the bed plate. The fitted longitudinals are then simultaneously welded with only one operator at the control panel. See Figure 4. Afterwards, the use of one-sided Flux Copper Backing (FCB) machines to weld the unit panels [1] eliminates the need for turning of the panel which is presently done in the subject shipyard (Figure 5). This transformation of assembly processes (Figure 6) results in a man-hour decrease and allows takt time to be followed which is necessary for balanced flow.

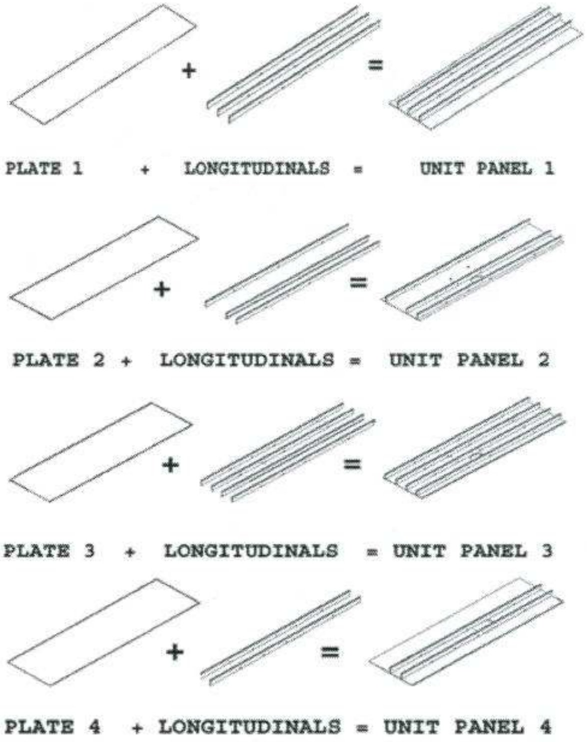


Figure 4: Assembly sequence on the Lean unit panel assembly line workstations 1-3

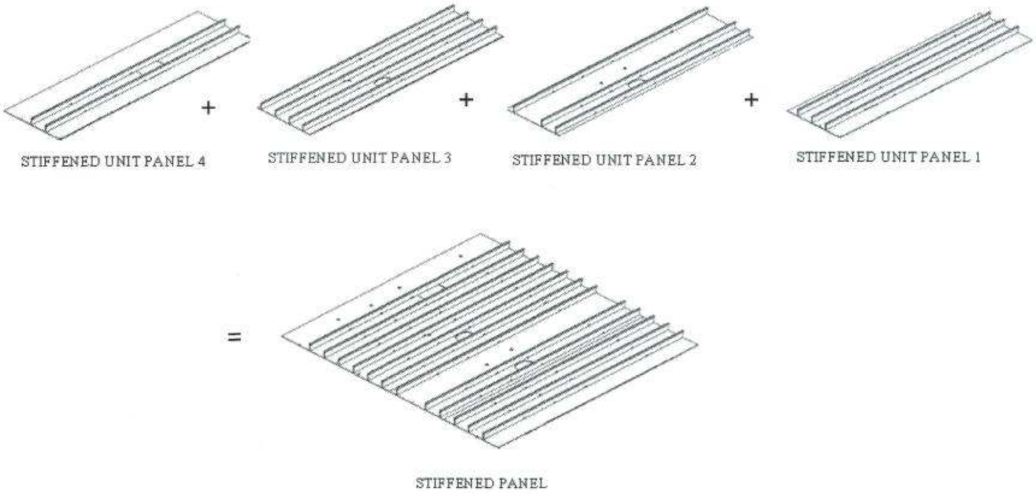
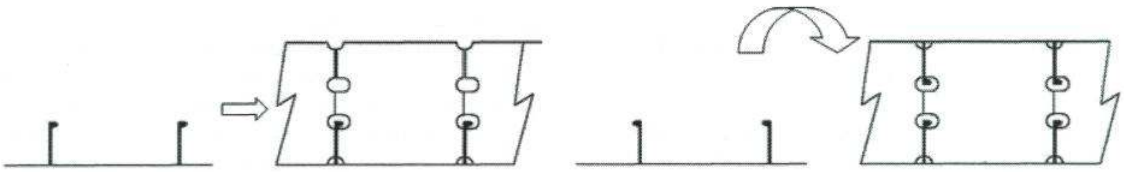


Figure 5: Assembly sequence on the Lean unit panel assembly line workstation 4



Step 1: Fully weld longitudinals to first plate blanket.

Step 2: Slide webs over longitudinals and fully weld.

Step 3: Fully weld longitudinals to second plate blanket.

Step 4: Turn second bed plate over and slide through the upper slots of the first built-up panel. Then fully weld.

Figure 6: Lean manufacturing panel-block assembly method [4], [9]

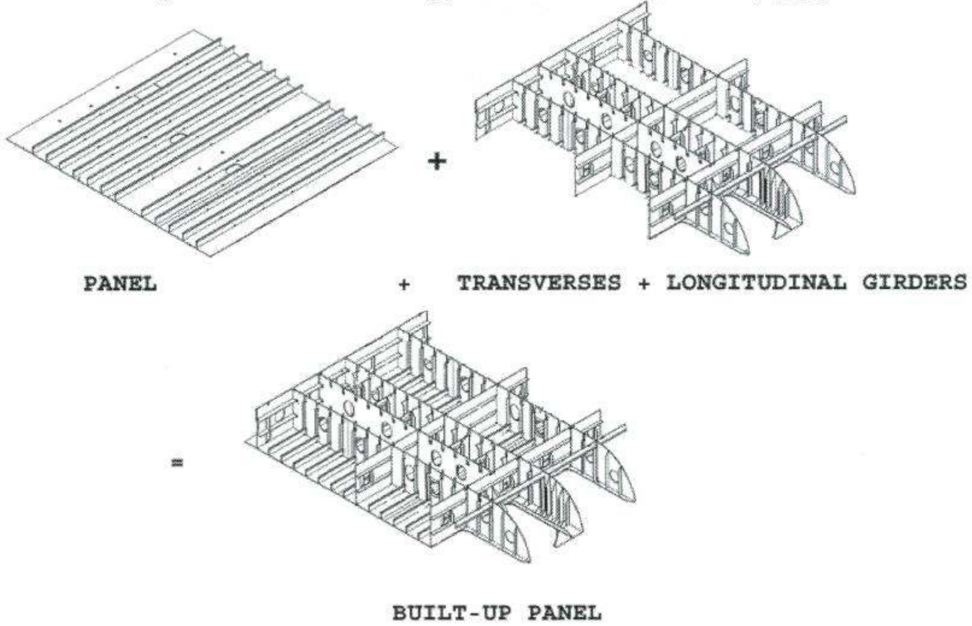


Figure 7: Assembly sequence on the Lean built-up panel assembly line

The transverses and longitudinals are assembled in a matrix jig off the line as recommended in the DFP manual. Then they are slid through the longitudinals, fitted and welded on the built-up panel line. The advantage of using a matrix jig [4] along with the application of the Just-in-Time (JIT) concept [7] means that the man-hours on the assembly line are drastically reduced. In traditional panel lines, transverses with cut-outs instead of slots are placed over the longitudinals. Then fitters adjust the transverses until they are finally in the correct position. Afterwards, the transverses are welded to the bed plate usually manually. Finally, lugs are fitted and welded in order to meet strength requirements of the classification society. The unit panel and slot construction involves the sliding of transverses through the longitudinals. This sliding inherently takes advantage of built-in quality because the slot has a clearance of 1.5 mm (Figure 8) [1]. Therefore quality control is performed during working time. This elimination of the non-value added work [7] of additional accuracy control is compliant with lean manufacturing principles.

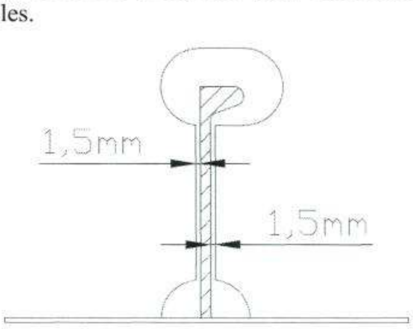


Figure 8: Detail of slot for a bulb plate longitudinal [1], [9]

4. CASE STUDY INTERIM PRODUCT MAN-HOUR ESTIMATION

In order to justify an eventual lean manufacturing panel-block assembly transformation of the shipyard, it was necessary to use a key parameter, man-hours for comparison of the present-state versus a future lean state. The following equations describe the calculation of the interim products that make up a typcial double bottom block in the shipyard for the present state, equation 1 and the future lean state, equation 2.

$$\text{IPA time} = \sum_{i=1}^{i=m} \text{P} + \sum_{i=1}^{i=n} \text{KP} + \sum_{i=1}^{i=p} \text{S} + \sum_{i=1}^{i=q} \text{T} + \sum_{i=1}^{i=r} \text{Misc} \qquad (1)$$

$$\text{Lean IPA time} = \text{C}_\text{P} * \sum_{i=1}^{i=m} \text{P} + \text{C}_\text{KP} * \sum_{i=1}^{i=n} \text{KP} + \text{C}_\text{S} * \sum_{i=1}^{i=p} \text{S} + \text{C}_\text{T} * \sum_{i=1}^{i=q} \text{T} + \text{C}_\text{Misc} \sum_{i=1}^{i=r} \text{Misc} \qquad (2)$$

IPA time: All interim product assembly times in hours; P: panel, m is the number of panels in the VT section; KP: built up panels, n is the number of built up panels; S: sections, p is the number of sections; T: three dimensional sections, q is the number of three dimensional sections; Misc.: miscellaneous parts, r is the number of miscellaneous parts; C: lean transformation coefficient

The Figure below illustrates the double-bottom block treated in the case study (Figure 9).

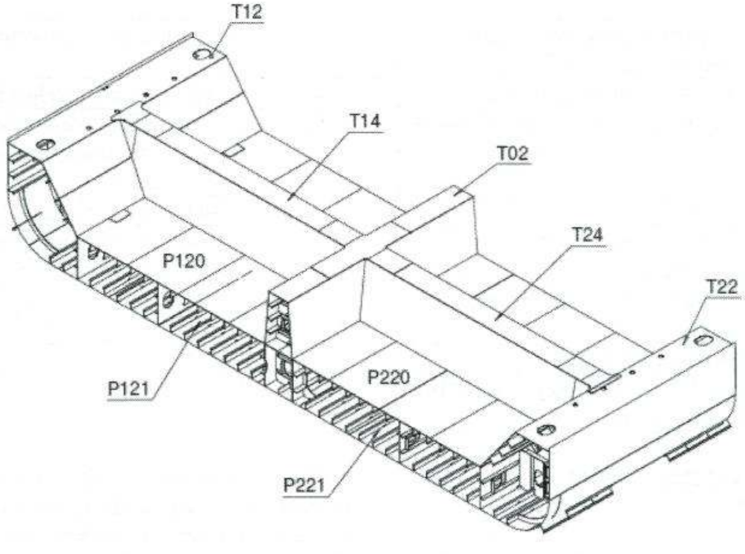


Figure 9: The final double bottom block (Very large three dimensional section) [9]

A practical method of summing up the assembly times is shown in Table 1. Likewise, Table 2 below describes the assembly steps of the case study for the present state versus a transformed lean state.

Table 1: Interim product assembly times in hours for present state and lean transfomation state

Interim product designation	Present-state assembly time (man-hrs)	Transformed Lean-state assembly time (man-hrs)
P121	114	45,6
P221	104,5	41,8
P120	98	39,2
KP12	552	220,8
P220	104,5	41,8
KP22	592	236,8
S02	138	55,2
T02	213	85,2
S14	97	38,8
T12	98	39,2
S15	117,5	47
T14	189	75,6

S24	91	36,4
T22	98	39,2
S25	117,5	47
T24	189	75,6
M002VOD*2	17	17
Sum	**2930**	**1182**

P: panel, KP: built-up panel, S: Section, T: Three dimensional section, M002VOD: curved steel plate

Table 2: Present day vs. Lean transformation of panel block assembly workstations

Present day panel-block assembly workstations		**Lean transformation of panel block assembly workstations**	
Workstation	Description	Workstation	Description
1	Joining and welding of steel plates to form plate blanket	1	Edge trimming of skin plate
2	Plate blanket turned over and butt welded on the second side	2	Fitting of longitudinals on unit panel
3	Marking the plate blanket for longitudinal stiffeners, ultrasound control.	3	Welding of longitudinals
4	Fitting and welding of longitudinals	4	One sided butt welding (FCB)
5	Transporting to the next built-up panel line	5	Inserting of internal structure (egg-crate) with slots assembled on a matrix off the workstation
6	Turning and levelling with heat	6	Welding of egg-crate by robots
7	Labelling, laying down, cutting and tack welding of transverses	7	Final three dimensional block assembly prior to erection on the slipway
8	Welding of transverses and cleaning the weld		
9	Fitting of ships equipment		
10	Final three dimensional block assembly prior to erection on the slipway		

5. MONTE CARLO RISK ANALYSIS SIMULATION

The Monte Carlo method has shown its effectiveness in simulating duration times and man-hours in shipbuilding processes [11], [12], [13]. Likewise, stochastic modelling has shown its practicality for displaying and predicting changing behaviour of otherwise unpredictable events in large engineering production facilities [14]. The PERT (Program evaluation review technique) distribution is practical for modelling industrial man-hours [13]. Equation 3 illustrates the command used in Microsoft Excel with a risk add-on from Palisades Corporation [15], [16], [17].

$$= \text{RISKPERT(Lower bound value, Most likely value, Upper bound value)} \qquad (3)$$

From the shipyard case study, the assembly of interim products takes 2930 man-hours when the present state shipyard technology level remains the same, which is represented as the most likely value in the first row of Table 3. The lower bound value of 2051 man-hours and upper bound value of 3809 man-hours represent the range of the fixed/changing line technology application of the block assembly process using different DFP assembling methods which includes those described and explained in Figures 3 and 6. Whereas some block assembly methods from the DFP manual reduce weld length, such as use of the slot as opposed to cut-outs (see Figure 8), the man-hours actually increase when the complementary technology is not updated correspondingly. The upper bound value of 3809 man-hours represents the increase in man-hours due to the replacement of the cut-outs with slots, and not implementing the proper technology to go along with it, such as equipment necessary for the pushing of the webs or internal structure through the slots. When the improved slot methodology is complemented with the proper technology, the result is the lower bound value of 2051 man-hours which is a 30% production improvement. Application of a lean manufacturing transformation of the facilities yields an even greater productivity improvement of 1182 or 60%, which is represented in the second row of Table 3. The lower bound and upper bound values of 1123 and 1241 man-hours represent realistic fluctuations of ±5 percent from the most likely value.

Table 3: Input table for Monte Carlo simulation

Block Assembly Method Category	Lower bound	Most likely	Upper bound
	Man-hours	Man-hours	Man-hours
F/CLT	2051	2930	3809
Lean Transformation	1123	1182	1241

F/CLT: Fixed/Changing Line Technology

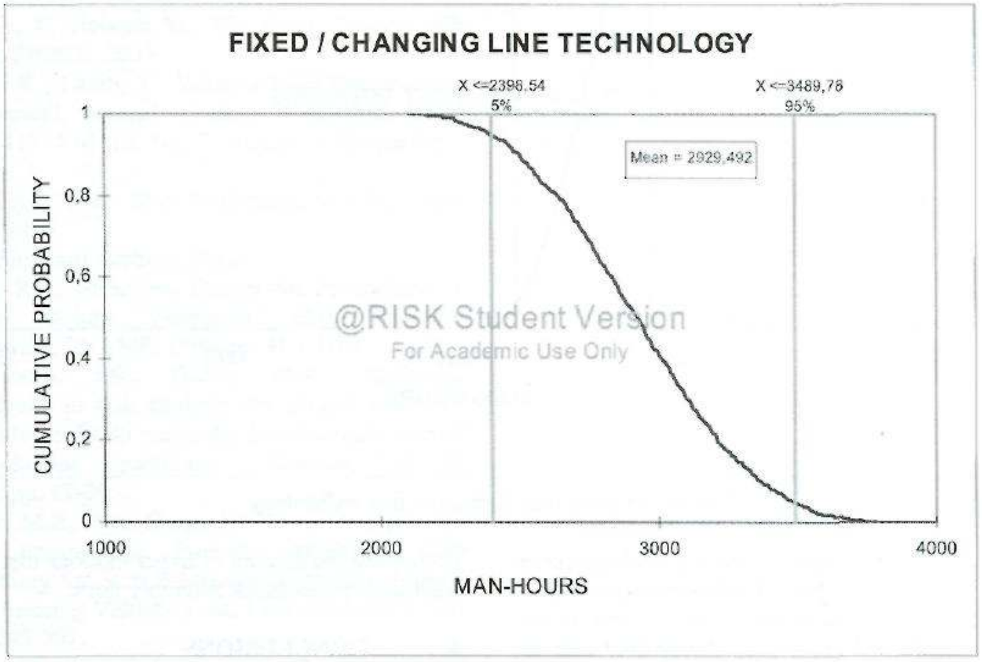


Figure 10: DFP Fixed / changing line technology

The Fixed/Changing Line Technology curve (Figure 10) is a result of applying Monte Carlo simulation of the PERT distribution of values from table 3. The PERT distribution is represented by the inputted three values, minimal, maximum and most likely. The purpose of the simulation is to determine the mean value as well as illustrate the sigma or the range of most likely values between the percentiles of 5% and 95% which represent the range of realistic values that result from applying various DFP categories of block assembly methods to the traditional shipyard block assembly process (see Figure 3). The various categories include the assembly of transverses with cut-outs, with a combination of cut-outs and slots, as well as only slots.

The mean value of 2929,49 hours represents the most likely value when the technology and methodology of block assembly remain the same. The part of the curve which is to the left of the mean of **2929,49** hours decreases towards **2398,54** hours at the 5 percentile. This ck

assembly.

On the other hand, moving to the right of the mean of **2929,492** hours is the situation when technology is not adjusted but remains fixed while applying improved decrease in man-hours occurs when the complementary technology changes are made in parallel with the methodology changes for the method that requires the pushing of transverses with only slots. A key complementary technology change for the slots requires special precise pushing equipment for inserting the transverses with slots through the longitudinals.

The minimal value of man-hours is theoretically 2051 hours (see Table 3), which is a maximum decrease of **30%**, whereas the value at 5% is 2398 hours, which means that even if the technology with pushing equipment for the insertion of transverses with slots can theoretically be 2051 man-hours, it is more likely that the value will not be lower than the 5 percentile value of 2398.54 hours (Figure 10). Therefore the Monte Carlo simulation makes us realize that it is unlikely that the theoretical minimal value for man-hours will be approached in actual blo

methods. For instance, using the slot method but not investing in pushing type equipment for precise insertion of transverses results in a value of **3489,76** man-hours.

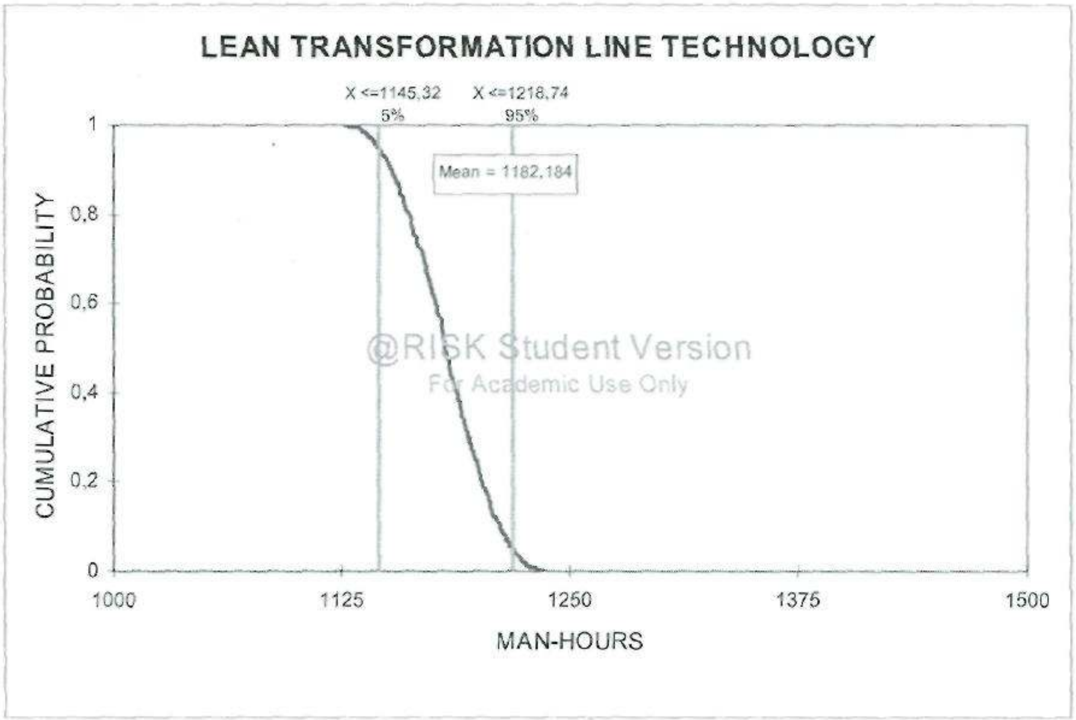


Figure 11: Lean transformation line technology

Finally, the Lean Transformation Line Technology curve (Figure 11) illustrates the Monte Carlo simulation with a mean value of 1182,18 man-hours which is close to the calculated value of 1182 man-hours. Please note that the x-axis (man-hours) of Figure 11 (between 1000 and 1500 hours) is a smaller range than that of Figure 10 (between 1000 and 4000 man-hours) in order to permit easier reading of the 5% and 95% values.

The lean transformation which requires changes in both technology and block assembly methodology will result in realistic values that will most likely not alter from the range between (1145,32 and 1218,74 man-hours) The standard deviation of 22,14 man-hours for Figure 11 is much lower than the standard deviation of 333,10 man-hours for Figure 11. This is evident in the narrower sigma range of Figure 11 between the 5% and 95% values (1145,32 and 1218,74 man-hours respectively) especially in comparison with Figure 10 which has a wider range between the 5% and 95% values (2398,54 and 3489,76 man-hours) along its x-axis. When the subject shipyard has its panel-block assembly transformed using both lean technology and methodology for block assembly, the greatest improvement of a 60% decrease from the original 2930 man-hours results, 1182.18 man-hours. Therefore, a lean transformation of the shipyard panel-block assembly line will result in greater savings in man-hours with minimal risk in man-hour discrepancies because of the well defined structure that includes one-piece flow as well as decreasing the amount of hyper motions that occur in the traditional panel-block assembly lines.

6. CONCLUSIONS

The transformed *lean manufacturing* work stations and technology along with one-piece flow in block assembly creates a more factory like assembly process, which results in a reduction of man-hours, as well as saved space in the shipyard. The *lean transformation* is justifiable due to the significant savings that could be reaped. Additionally, for future lean case studies, it would be useful to extend the analysis to outfitting activities such as pipe fitting, ladders, supports, man-hole covers, trays and other related tasks done prior to erection. The methodology would continue to analyze the present-state and perform a DFP improvement analysis and finally a lean transformation and Monte Carlo simulation. This would aid in further reducing shipyard man-hours in the outfitting trades which are also very significant.

7. REFERENCES

[1] Okomuto, Y., Advanced Welding Robot System to Ship Hull Assembly, Journal of Ship Production, Vol. 13, No.2, 1997, pp. 101-110

[2] Koenig, P.C., Lean Production in the Japanese Shipbuilding Industry?, Journal of Ship Production, Vol. 18, No.3, 2002, pp. 167-174

[3] Storch, R.L., Lim, Sanggyu., Improving flow to achieve lean manufacturing in shipbuilding, Production Planning and Control, Vol. 10, No.2, 1999, pp.127-137.
[4] Design for Production Manual, 2nd edition, National Shipbuilding Research Program, U.S. Department of the Navy Carderock Division, Vol. 1-3, 1999
[5] Storch, R.L., Sukapanpotharam, S.,: Development of Repeatable Interim Products Utilizing the Common Generic Block Concept, Journal of Ship Production, Vol. 18, No.4, 2002, pp. 195-202.
[6] Bicheno, J., Holweg M., *The Lean Toolbox*, 4th edition, PICSIE, 2009
[7] Liker, J.K.; Lamb, T.: What is Lean Construction and Repair?, Journal of Ship Production, ISSN 8756-1417, Vol. 18, No. 3, August 2002, pp. 121-142
[8] Storch, R.L. et al.: Ship Production, SNAME, New Jersey, 1995
[9] 3.Maj Shipyard Archive, 2010
[10] Storch, R.L., Structural Design for Production: A Human Factors Viewpoint, Ship Structure Symposium, SNAME, 1996, pp. H-1-H19.
[11] Van Dorp, J.R., Duffey M.R.: Statistical dependence in risk analysis for project networks using Monte Carlo methods, International Journal of Production Economics – Elsevier, Vol. 58 (1999), pp. 17-29.
[12] Duffey, M.R., Van Dorp, J.R.: Risk Analysis for Large Engineering Projects: Modeling Cost Uncertainty for Ship Production Activities, Journal of Engineering Valuation and Cost Analysis (1999) 2, pp. 285-301.
[13] Kolich, D., Fafandjel, N., Čalić, B.: Determining how to apply the design for production concept in shipyards through risk analysis, Engineering Review 1 (2010) 30, pp. 63-72
[14] Berends, K.: Engineering and construction projects for oil and gas processing facilities: Contracting, uncertainty and the economics of information, Energy Policy – Elesevier, Vol. 35 (2007), pp. 4260-4270.
[15] Winston, W.L., Introduction to Probability Models Operations Research, Vol 2, 4th edition, Thomas Learning, Canada 2004.
[16] @RISK, Advanced Risk Analysis for Spreadsheets, Palisades Corporation, 2001.
[17] Winston, W.L., Operations Research: Applications and Algorithms, Vol 2, 3rd edition, Thomas Learning, Canada 1994.

8. AUTHORS' BIOGRAPHIES

Damir Kolich is a Senior Assistant (PhD) in the Technology and Organisation (Naval Architecture and Ocean Engineering Department) at the University of Rijeka, Croatia.

Richard Lee Storch is a Professor (PhD) and Chair of the Industrial and Systems Engineering Department at the University of Washington, Seattle, WA, USA.

Niksa Fafandjel is a Professor (PhD) and Chair of the Technology and Organisation (Naval Architecture and Ocean Engineering Department) at the University of Rijeka, Croatia.