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Applying *Lean Quality* with Risk Analysis to Aid Shipyard Block Assembly Decision Making

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The continually ephemeral demands of the shipbuilding market have forced shipyard management to be ready for change in order to maintain competitiveness. The concept of lean quality stresses the importance of quality which is one of the pillars and principles of lean manufacturing. This paper continues and deepens the analyisis of the panel-block assembly line from an earlier work by applying the lean quality concept to enhance and ease the decision making process of management related to changes in production assembly and technology. This includes analyzing and evaluating three methods of block assembly based on quality and feasibility in order to determine which method is best for the present state of shipyard technology and which method should eventually be chosen for the future. Finally, an improved Monte Carlo risk analysis methodology which innovatively illustrates the effects of fixed technology and changing technology enables a clearer picture of the results of the block assembly methods which have minimal risk both in the present and in the future improved state.

Keywords
Lean quality
Monte Carlo risk analysis
Shipbuilding

Ključne riječi
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Primjena koncepta *vitke kvalitete* s analizom rizika pri odlučivanju o načinu sastavljanja bloka u brodogradilištu

Izvornoznanstveni članak

Stalne promjene brodograđevnog tržišta prisiljava uprave brodogradilišta da budu spremne za promjene radi održanja konkurentnosti. Koncept vitke kvalitete naglašava važnost kvalitete koji je jedan stup i načelo vitke proizvodnje. Ovaj rad nastavlja i udubljuje se u analizi linije za proizvodnju panela i kompletirane panele gdje primjena koncepta vitke kvalitete može olakšati proces donošenja odluka upravama brodogradilišta vezano za promjene u proizvodnji. Ovo uključuje analiziranje i ocjenjivanje tri metode sastavaljanja blokova temeljeno na kriteriju kvalitete radi određivanja koja metoda je trenutno najbolja za sadašnje stanje brodograđevne tehnologije i koja se metoda treba izabrati u budućnosti. Konačno korištenje poboljšane metode analiziranja rizika sa prikazom fiksne tehnologije i promijenjenih tehnologija omogućuje jasniju sliku rezultata metoda sastavaljanja blokova s minimalnim rizikom trenutačnog stanja i za buduće poboljšano stanje.

1. Introduction

Shipyards compete in a changing and demanding market which requires frequent updating of decision making with regards to production processes in order to be up to date with world competition. The application of various techniques such as design for production, simulation modeling, and systematic layout planning have shown to produce positive results with regards to shipbuilding production processes [1-3]. However many shipyards continue to lack well defined assembly methods and design standards. As a result, the detailed production decisions are left to the whims of individual production foremen.[1]. This lack of a scientific approach to production means that the level of competitiveness of the shipyard will decline in comparison to other world-class shipyards that apply advanced methods.

This paper analyzes a "core competence" of all shipyards: panel-block assembly which was treated in an earlier work using the design for production concept with risk analysis [1, 4]. The concept of *lean quality* along with an improved Monte Carlo risk analysis methodology is explained and developed in order to aid shipyard management in deciding which block assembly method is best for the present and future states of the shipyard.

2. Lean manufacturing concepts applied to block assembly

Almost twenty years have passed since the famous book *The Machine That Changed the World* by Womack, Jones and Roos launched the idea of lean which originated in Japan to the West. Since then the five lean principles have developed to include 1) specifying product value from a customers point of view, 2) identifying the value stream, 3) making value flow, 4) pull, and 5) the continuous striving for perfection [5-7].

Specifying value from the customer's point of view includes concentrating on processes that produce interim products which make up essential blocks of the final product, a completed ship. The panel-block assembly process can realistically be analyzed and improved in compliance to lean concepts.

The second principle of identifying the value stream is a prerequisite to improving flow. The value stream includes all processes that are involved in the manufacturing process which create added value. The block manufacturing scope starts with panel production and leads towards completed blocks ready for erection on the slipway or berthing dock. There are 9 main value added activities: 1)Plate fitting and tack welding, 2)Plate welding, 3)Panel layout, 4) Longitudinal stiffener fitting and tack welding, 5) Longitudinal stiffener seam welding, 6) Internal structure fitting, 7) Welding and outfitting of built-up unit, 8) Turning and fitting, 9) Welding and outfitting [8-9] (See Figure 1).

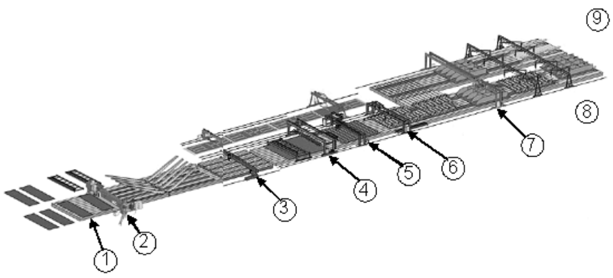

Figure 1. Panel block assembly line [10]

Slika 1. Linija za proizvodnju panela i blokova [10]

Enabling or improving flow, the third lean principle requires improving and maintaining added-value activities while eliminating or reducing non added-value activities during the manufacturing process. Added-value activities in the panel block process include the nine main activities such as welding and outfitting, while non added-value activities includes preparations, setting up, waiting, storage, and excessive unnecessary fitting. Combining the panel line with block assembly eliminates the transportation and waiting buffer between the two processes which additionally improves flow.

Principle four deals with pull which in the panel-block process means that the workstations create intermediate products as required by demand so that large groups of blocks do not collect in the shipyard. This is in compliance to group technology and the product work breakdown structure (PWBS) which require that interim products are built in small batches as required by demand as opposed to large batches that results in unnecessary storage and is contrary to lean principles [5, 9].

Finally principle five concentrates on perfection or quality which is complementary to flow and creating added-value, because if an interim product (block) has defects, then flow is interrupted due to required repairs. Likewise the added-value of the impaired block is decreased as well. Therefore maintaining and improving upon quality aids continuous flow and the creation of interim products with real added-value.

This paper concentrates on the third and fifth principles which include improving flow of interim products along with maintaining and or improving quality at the same time, because the two principles are complementary to one another. The shipbuilding industry with many types of manufacturing processes and interim products lacks a specific methodology which will allow management and production engineers to develop a program that improves flow of interim products while maintaining and/or improving quality at the same time. Improving flow without maintaining quality would create bigger problems than it solves, because the interim manufactured products would have to be repaired or reworked, which means that flow would actually be disrupted and not improved and waste would result. In summary, the five lean principles are interrelated and it is unrealistic to intentionally ignore any one of them while approaching manufacturing problems.

2.1. Just in time and built in quality

Just in Time (JIT) is the lean principle which means that the "right part must arrive at the right time in the right amount" [5]. Buffers are removed as much as possible and takt time is balanced between different workstations [11]. For example, in the panel-block line assembly process, the movement of the interim products between the different workstations should be relatively balanced so that level flow is achieved. The prerequisite for JIT is Built in Quality, because the entire system would fail without quality due to the removal of buffers. Therefore due to the reduced interim inventory of JIT, the quality must be up to par in order for flow to be continuous. Otherwise there would be many interruptions and interim products would not be built on time.

2.2. The seven wastes in manufacturing

Likewise constant attention to elimination of the seven wastes will help in implementing and maintaining a lean production system [5], [11]:

- *Overproduction* is making too much too early and is not in compliance with the JIT principle. For instance if too many panels are created and the block assembly process can not keep up, then panels will start to take up valuable space, and there is more chance that defects will be uncovered late as well. Flow is negatively affected.

- *Waiting* is in contradiction to smooth flow and JIT. Whenever workers wait for tools, a machine or for other workers, steps should be taken to reduce this non added-value activity.
- *Unnecessary motions* are related to workers and facilities layout structure. For instance, shipyards must always strive to reduce overhead welding and maximize downhand welding. Overhead welding is more difficult for workers, requires more time and is less efficient than downhand welding. Reducing unnecessary motions will yield a reduction in man-hours and therefore create added-value.
- *Transport* is a waste that can never be completely eliminated, but it can be reduced. Shipyard panel-block assembly lines are created in order to reduce the transportation that would otherwise be necessary without them. At the same time these same line facilities can and should be improved upon in order to reduce transport and internal movement even further.
- *Overprocessing* involves using the inappropriate tools and methods for performing a task. For instance during the assembly of a block, overprocessing leads to greater man hours than necessary and should be avoided.
- *Unnecessary inventory* where inventory is considered the "enemy of quality and productivity" because it takes up valuable space and hinders communication as well as slowing down the identification of problems with quality [1].
- *Defects* cause waste because they require time and space for performing repair and rework, which is a non added-value activity that needs to be avoided.

2.3. Kaizen (continuous improvement)

Kaizen is the Japanese word for continuous improvement, since "no process can ever be declared perfect, there is always room for improvement" [5]. In the case of the shipbuilding panel-block assembly line, even after production engineers determine which method is best for the present technology level of the shipyard, it is necessary to continue to analyze new methods and technologies that will improve the process even further. This is the only way that shipyards could expect to be competitive in the global market.

3. Analysis of block assembly methods

3.1. Block assembly methods

First Marine International consultants conducted a case study at NASSCO shipyard in San Diego that analyzed various block assembly methods to determine which one is most suitable for the shipyard technology level [8]. The authors of this paper had conducted an analysis which involved the two principle assembly methods [1]. The first principle assembly method is the standard that is used by most shipyards in Europe and the United States where the web transverses have longitudinal cut-lugs and lugs are welded to one side of the longitudinal stiffeners in order to satisfy classification society strength requirements. The second principle block assembly method uses web transverses with fitted slots instead of cut-outs and therefore eliminates the need for loose lugs. The advantage of this method is that the elimination of lugs results in a total decrease of weld length in comparison to principle block assembly method 1. However a work content analysis showed that even though the weld length is reduced, the total time for assembling a typical double bottom block requires 25 percent more man hours in comparison to assembly method 1 due to the difficulties related to "part cutting, accuracy control and stabilized assembly sequences and processes" when the technology level is not updated to suit the new method [1, 8].

The authors of this paper decided to include an analysis of a third principle method which is becoming more prevalent in Japanese shipyards and is known as the "egg crate system" [7]. Egg-box construction is made on the first plate panel. Similar to method 2, stiffeners with fitted slots instead of cut-outs in webs are used. The first transverse web is placed in a jig in order to hold it securely. The longitudinal stiffeners are then pulled through the slots of the first transverse web. The remaining webs are then pulled over the stiffeners. Finally the total construction is tacked and welded (Figure 2) [8].

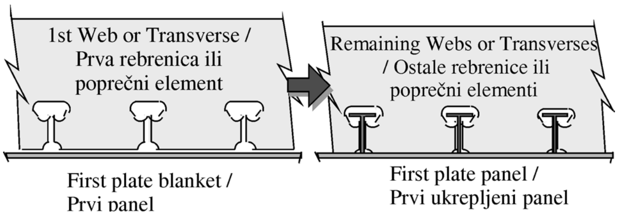

Figure 2. "Egg crate system" assembly method [8]

Slika 2. Jajasta kutija-metoda sastavljanja bloka [8]

3.2. Determining the optimal assembly method using production engineering criteria

"Production engineering criteria" are used to measure each assembly methods technological compliance level to the shipyard facilities by grading wasteful manufacturing techniques (unnecessary motions, overprocessing and inappropriate processing) with a "0" and efficient techniques with a "1" [8]. These include: 1) maximizing downhand and automatic welding, 2) enabling easy access to joints during assembly, 3) self-supporting interim products, 4) minimizing turning during assembly, 5) simplifying connections and minimizing variety, 6) maximizing downhand fitting, 7) minimizing joint length and reducing the number of parts, 8) reducing the need for high accuracy levels, 9) maximizing the use of automated assembly lines, 10) maximizing current facilities, 11) classification society approval [8]. Likewise for each of the 11 criteria there is a column for standardization and a column for simplification since flow is improved with simplified and standardized processes. Finally, the values for each method for both columns were summed up and compared, Table 4. Principle block assembly method 1 has the highest value of 21 which means that it is most compliant with the present technology of the shipyard facilities.

3.3. Work content analysis

The three block assembly methods were compared using work content analysis which was treated in the prior work [1, 8]. However, the innovative assembly method 3 has been added for comparison and for treatment later in this work. See Table 1 below.

Table 1. Summary of work content analysis [8]

Tablica 1. Sažetak analize radnog sadržaja [8]

Assembly method / Metoda sastavljanja	Weld length / Duljina zavarivanja, m	Line technology (man-hours) / Linijska tehnologija (efektivni sati)	Static tehnology (man-hours) / Statična tehnologija (efektivni sati)	Line welding rate (m/h) / Linijski odnos zavarivanja (m/h)	Static welding rate (m/h) / Statički odnos zavarivanja (m/h)
1	1732	843	1324	2,04	1,31
2	1468	1046	1299	1,40	1,13
3	1468	1095	1344	1,34	1,10

Table 2. Evaluation of block assembly method 1 [8]

Tablica 2. Ocjenjivanje metode sastavljanja bloka 1 [8]

No./ Broj	Engineering criteria / Inžnjerski kriterij	Block assembly method 1 / Metoda sastavljanja bloka 1	
1	Maximize downhand and automatic welding / Maksimizirati zavarivanja prema dolje i automatsko zavarivanje	No overhead welding / Nema zavarivanja iznad glave	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
2	Easy access to joints during assembly / Pristup zglobovima tijekom sastavljanja	Simplified access to assembly joints / Pojednostavljen pristup zglobovima	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
3	Self supporting interim products / Samostejeći međuproizvodi	Yes / Da	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
4	Minimize turning during assembly / Minimizacija okretanja tijekom sastavljanja	One assembly turn of built up 1st panel onto second plate panel. / Jedno okretanje prve kompletirane panele na drugu panelu.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
5	Simplify connections. Minimize variety. / Pojednostavljenje spojeva. Minimizacija varijanti	Cut outs with lugs top and bottom. / Izrezi s pločicama gore i dolje.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1

6	Maximize downhand fitting. / Maksimizirati postavljanje elemenata prema dolje.	All downhand fitting. / Svi elementi se postavljaju prema dolje.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
7	Minimize joint length. Reduce number of parts. / Minimizirati duljine zglobova. Smanjiti broj elemenata.	For a typical 22” T beam longitudinal. Simple lug: 13 feet of weld. Double lug: 20 feet of weld. / Za tipićnog 22” T nosača. Pločica: 13 stopa zavara. Dupla pločica: 20 stopa duljine zavara.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 1
8	Self aligning interim products. Reduce need for high accuracy levels. / Samo poravnanje međuproizvoda. Smanjiti potrebu za visoku preciznost.	Web alignment at single lug cut out. Minimum accuracy need for fitting webs to first panel and longls to 2nd panel. / Usklađivanje rebara kod pojedinačnog izreza za pločicu. Minimalna potreba za visoko preciznih razina.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
9	Maximize the use of automated assemble lines. / Maksimizirati upotrebu automatiziranih proizvodnih linija.	Uses automatic twin fillet welding of longitudinals on 1st and 2nd panels. / Koristi automatsko dvostrano kutno zavarivanje uzdužnjaka na prvim i drugim panelima.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
10	Maximize current facilities. Applicable to current technology level. / Maksimizira korištenja trenutnih postrojenja. Primjenjivo na sadašnju tehnološku razinu.	Requires no technology development. Maximizes automatic twin fillet welding. / Ne zahtijeva tehnološku obnovu. Maksimizira korištenja obostrano kutno zavarivanje uzdužnjaka.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
11	Classification approval. / Odobrenje klasifikacijskog društva	Within current technology level, all details approved. / Unutar tehnološke razine brodogradilišta, svi detalji obreni.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
Total / Zbroj		**10**	**11**

Table 3. Evaluation of block assembly method 2 [8]

Tablica 3. Ocjenjivanje metode sastavljanja bloka 2 [8]

No./ Broj	Engineering criteria / Inžnjerski kriteriji	Assembly method 1 / Metoda sastavljanja 1	
1	Maximize downhand and automatic welding / Maksimizirati zavarivanja prema dolje i automatsko zavarivanja	No overhead welding / Nema zavarivanja iznad glave	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
2	Easy access to joints during assembly / Pristup zglobovima tijekom sastavljanja	Simplified access to assembly joints / Pojednostavljen pristup zglobovima	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
3	Self supporting interim products / Samostojeći međuproizvodi	Yes / Da	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
4	Minimize turning during assembly / Minimizacija okretanja tijekom sastavljanja	One assembly turn of built up 1st panel onto second plate panel. / Jedno okretanje prve kompletirane panele na drugu panelu.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1

5	Simplify connections. Minimize variety. / Pojednostavljenje spojeva. Minimizacija varijanti	Fitted slots for longitudinals on first panel. Cut outs with lugs both sides on second panel / Utori za uzdužnjake na prvi panel. Izrezi za pločice na obje strane na drugom panelu.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
6	Maximize downhand fitting. / Maksimizirati postavljanje elemenata prema dolje.	All downhand fitting. / Svi elementi se postavljaju prema dolje.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
7	Minimize joint length. Reduce number of parts. / Minimizirati duljine zglobova. Smanjiti broj elemenata.	For a typical 22 inch T beam longitudinal. Double lug: 20 feet of weld. Slots: 6 feet of weld. / Za tipičnog 22" T nosača. Dvije pločice: 20 stopa zavara. Utori : 6 stopa duljine zavara.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
8	Self aligning interim products. Reduce need for high accuracy levels. / Samo poravnanje međuproizvoda. Smanjiti potrebu za visoku preciznost.	Very high level of accuracy required to fully weld longitudinals and slide webs. No self alignment with open cut outs on 2nd panel. / Visoka razina preciznosti potrebna radi kompletnog zavarivanja uzdužnjaka i navlačenja rebra. Nedostaju samo poravnanja na izrezima na drugoj paneli.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
9	Maximize the use of automated assemble lines. / Maksimizirati upotrebu automatiziranih proizvodnih linija.	Uses automatic twin fillet welding of longitudinals on 1st and 2nd panels. / Koristi automatsko dvostrano kutno zavarivanje uzdužnjaka na prvim i drugim panelima.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
10	Maximize current facilities. Applicable to current technology level. / Maksimizira korištenja trenutnih postrojenja. Primjenjivo na sadašnju tehnološku razinu.	Requires significant accuracy control development. Requires special web pulling equipment. / Zahtijeva značajni razvoj kontrole preciznosti. Zahtijeva specijalne uređaje za navlačenja rebara.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
11	Classification approval. / Odobrenje klasifikacijskog društva	Requires design and approval of longitudinal slots. / Zahtjeva projekt i odobrenje klasifikacijskog društva.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
Total / Zbroj		**6**	**6**

Table 4. Evaluation of block assembly method 3 [8]

Tablica 4. Ocjenjivanje metode sastavljanja bloka 3 [8]

No./ Broj	Engineering criteria / Inžnjerski kriteriji	Block assembly method 1 / Metoda sastavljanja bloka 1	
1	Maximize downhand and automatic welding / Maksimizirati zavarivanja prema dolje i automatska zavarivanja	No overhead welding / Nema zavarivanja iznad glave	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
2	Easy access to joints during assembly / Pristup zglobovima tijekom sastavljanja	Simplified access to assembly joints / Pojednostavljen pristup zglobovima	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
3	Self supporting interim products / Samostejeći međuproizvodi	Yes / Da	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1

4	Minimize turning during assembly / Minimizacija okretanja tijekom sastavljanja	One assembly turn of built up 1st panel onto second plate panel. / Jedno okretanje prve kompletirane panele na drugu panelu.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
5	Simplify connections. Minimize variety. / Pojednostavljenje spojeva. Minimizacija varijanti	Fitted slots for longitudinals on first panel. Cut outs with lugs both sides on second panel / Utori za uzdužnjake na prvi panel. Izrezi za pločice na obje strane na drugom panelu.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
6	Maximize downhand fitting. / Maksimizirati postavljanje elemenata prema dolje.	All downhand fitting. / Svi elementi se postavljaju prema dolje.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 1	Standardization / Standardizacija 1
7	Minimize joint length. Reduce number of parts. / Minimizirati duljine zglobova. Smanjiti broj elemenata.	For a typical 22" T beam longitudinal. Double lug: 20 feet of weld. Slots: 6 feet of weld. / Za tipićnog 22" T nosača. Dvije pločice: 20 stopa zavara. Utori : 6 stopa duljine zavara.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
8	Self aligning interim products. Reduce need for high accuracy levels. / Samo poravnanja međuproizvoda. Smanjiti potrebu za visoku preciznost.	Very high level of accuracy required to fully weld longitudinals and slide webs. No self alignment with open cut outs on 2nd panel. / Visoka razina preciznosti potrebna radi kompletnog zavarivanja uzdužnjaka i navlačenja rebra. Nedostaju samo poravnanja na izrezima na drugoj paneli.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
9	Maximize the use of automated assemble lines. / Maksimizirati upotrebu automatiziranih proizvodnih linija.	Uses automatic twin fillet welding of longitudinals on 1st and 2nd panels. / Koristi automatsko dvostrano kutno zavarivanje uzdužnjaka na prvim i drugim panelima.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
10	Maximize current facilities. Applicable to current technology level. / Maksimizira korištenja trenutnih postrojenja. Primjenjivo na sadašnju tehnološku razinu.	Requires significant accuracy control development. Requires special web pulling equipment. / Zahtjeva značajni razvoj kontrole preciznosti. Zahtjeva specijalne uređaje za navlačenja rebara.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
11	Classification approval. / Odobrenje klasifikacijskog društva	Requires design and approval of longitudinal slots. / Zahtjeva projekt i odobrenje klasifikacijskog društva.	
	Criteria assessment / Kriterijsko vrednovanje	Simplification / Pojednostavljenje 0	Standardization / Standardizacija 0
Total / Zbroj		**5**	**5**

Table 5. Summary of block assembly method evaluations [8]

Tablica 5. Sažetak ocjena za metode sastavljanja bloka [8]

	Assembly method 1 / Metoda sastavljanja 1	Assembly method 2 / Metoda sastavljanja 2	Assembly method 3 / Metoda sastavljanja 3
Rating/ Ocjena	21	12	10

4. Monte Carlo risk analysis simulation

The authors of this paper upon analysis of previous work with relation to simulating duration times and man-hours and costs with triangular and normal distributions [12-14] decided to make use of the Palisades Corporation Monte Carlo risk analysis in conjunction with a Program evaluation review technique (PERT) distribution to produce accurate simulations of man-hours [15-19]. Utilizing the results from table 5 with the Monte Carlos risk analysis results in a new simulation method that will help shipyard management make production decisions for the present, the immediate future and in the long-term

Table 6. Monte Carlo input table

Tablica 6. Monte Carlo tablica

Activity / Aktivnost	Index/ Indeks	Lower bound (man-hours)/ Donja granica (efektivni sati)	Most likely (man-hours)/ Najvjerojatnije (efektivni sati)	Upper bound (man-hours)/ Gornja granica (efektivni sati)
FST	0	1299	1324	1344
FLT Method 1/ FLT Metoda 1	1	800	843	880
FLT Method 2/ FLT Metoda 2	2	994	1046	1098
FLT Method 3/ FLT Metoda 3	3	1040	1095	1150
F/CLT	4	590	843	1095

Symbols of Table 6 / Oznake tablice 6:

- FST: Fixed static technology / Fiksna statična tehnologija,
- FLT: Fixed line technology / Fiksna linijska tehnologija,
- F/CLT: Fixed - changing line technology / Fiksna - promjenljiva linijska tehnologija

4.1. Monte Carlo application and results

Using the summary of the work content analysis, Table 6 is created in Excel.

The activity column lists the following as described:

- FST: is the fixed static technology simulation using all three methods. The lower bound value of 1299 is from method 2 (Table 1), the upper bound value is the value from method 3 (Table 1), and the most likely is the value from method 1 (Table 1), which is also very close to the mean value.
- FLT Method 1 is the fixed line technology of Method 1 simulation. The lower and upper bound values are approximately ±5 % of the method 1 value of 843 man-hours for line technology (Table 1).
- FLT Method 2 is the fixed line technology of Method 2 simulation. The lower and upper bound values are approximately ±5 % of the method 2 value of 1046 man-hours for line technology (Table 1).
- FLT Method 3 is the fixed line technology of Method 3 simulation. The lower and upper bound values are approximately ±5 % of the method 3 value of 1095 man-hours for line technology (Table 1).
- F/CLT is the fixed / changing line technology simulation which represents all three methods. The upper bound value of 1095 represents the highest duration time recorded by assembly method 3, while the lower bound value of 590 man-hours derives from a maximum possible 30 % expected decrease from the method 1 value of 843 man-hours (Table 1).

This curve represents the results of using non-automated or static technology. These would be the hours that could be expected from subcontractors creating a double skin block without the panel-block assembly line. The expected man hours is 1322.9 hours.

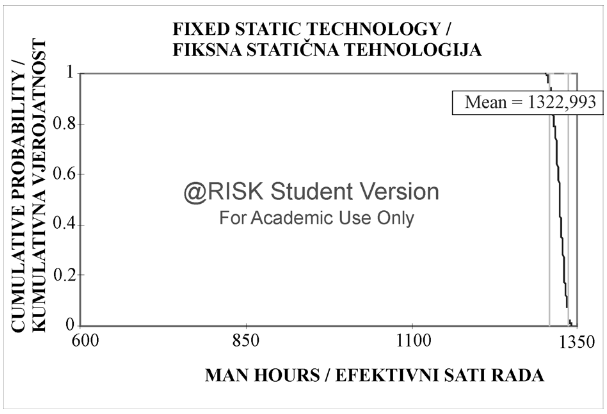

Figure 3. Fixed static technology simulation

Slika 3. Simulacija fiksne statične tehnologije

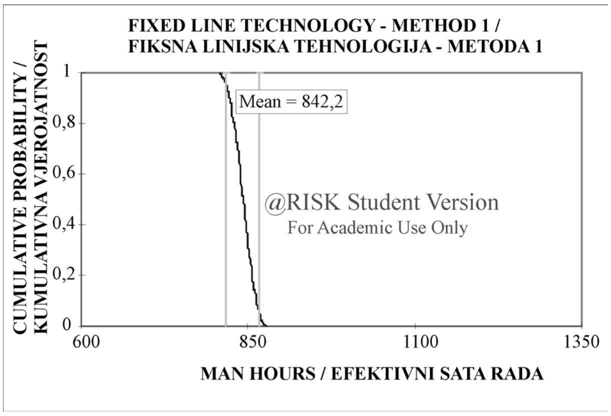

Figure 4. Fixed line technology – Method 1

Slika 4. Fiksna linijska tehnologija – Metoda 1

Fixed line technology means making use of the automated line technology using the first method mentioned earlier and not changing the technology. The expected man hours is 842,2 hours.

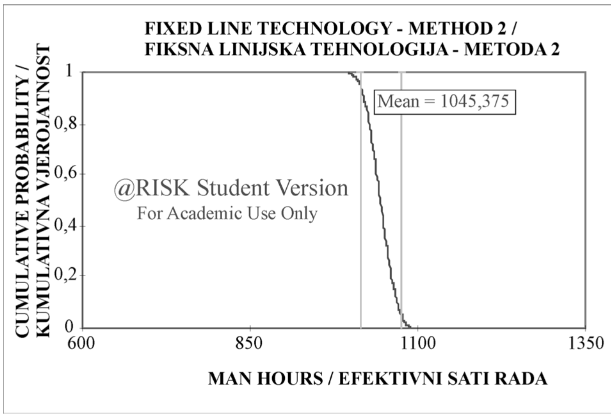

Figure 5. Fixed line technology – Method 2

Slika 5. Fiksna linijska tehnologija – Metoda 2

Fixed line technology that makes use of automated line technology using the second assembly method is described next. The expected man hours are 1045,4 hours. Even though method 2 is superior to method 1, the man-hours for assembling the double bottom block have increased. This is because the production design of fitted slots instead of open cut-outs with lugs requires major changes in production technology such as "part cutting, accuracy control and stabilized assembly sequences and processes" [1]. Using the new design technology with the present technology level yields increased man-hours.

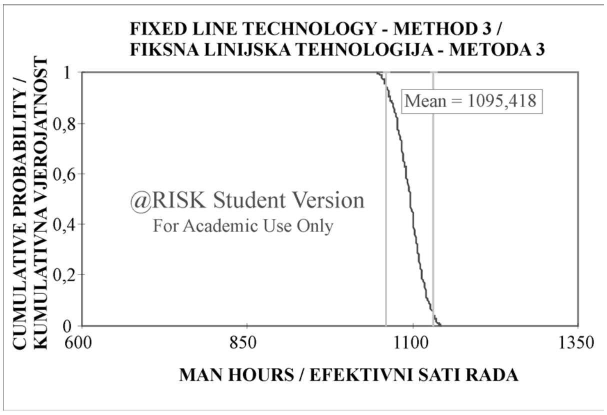

Figure 6. Fixed line technology – Method 3

Slika 6. Fiksna linijska tehnologija – Metoda 3

Fixed line technology using method 3 yields an even greater value of man hours: 1095,4 hours.

The results show that by keeping the same technology level (fixed) of the automated line technology, and only altering superior methods, the man-hours again increase instead of decreasing. Since the production technology of method 3 is even more complex than that of method 2, the increase in man-hours are somewhat higher as well.

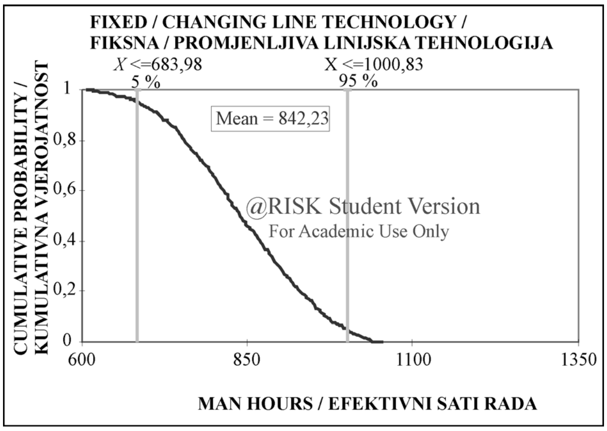

Figure 7. Fixed / changing line technology

Slika 7. Fiksna / promjenljiva linijska tehnologija

The Fixed/Changing Line Technology curve illustrates all three methods. The part of the curve which is left of the mean of 842,2 hours decreases towards 683,98 hours. It is important to understand that man-hours will decrease only when the technology of the panel-block line is adjusted to be in compliance with the improved methodology by making technology changes to the tools used for cutting fitted slots which require more accuracy than cut-outs, as well as planning the most efficient sequence of steps where the web transverses are accurately slid through the longitudinal stiffener slots that have minimal clearance. Method 1 on the other hand does not require the same level of accuracy control since the web transverses are simply placed over the longitudinal stiffeners due to having cut-outs instead of slots.

On the other hand, moving to the right of the mean is the situation when technology is not adjusted but remains fixed while applying improved methods. In this simulation it is shown as 1000.8 hours which is an increase in man-hours.

5. Conclusions

The Monte Carlo risk analysis methodology developed in this paper follows the *lean quality* concept and allows a summary picture of all three block assembly methods and what happens as the technology changes and what occurs when the technology level of the process remains fixed. For instance, without this analysis most managers and even many designers and engineers would logically conclude that assembly method 2 or assembly method 3 which reduces the amount of weld length required to produce a block should be immediately applied by the shipyard production. However, the results show that assembly method 1 is the best method for the shipyard with the present technology level.

Even though applying superior methods of assembling a double bottom block with an automated panel-block assembly line process should reduce the man-hours because the quantity of welds has decreased, it actually increases. While the building methodology was improved, the technology has remained fixed and therefore is not compliant to the high level of quality required for the improved methodologies.

Likewise, improving shipyard panel-block line technology without changing and improving the methodology will also most likely create problems for the shipyard production. Therefore, the key is to always keep methodology in par with technology because changing and/or improving one without the other is risky and will most likely have an opposite effect than logically desired and lead to an increase in man-hours and an overall decline in results.

For future plans in compliance to kaizen or continuous improvement, the shipyard will eventually have to adjust to the superior assembly method 2 and/or assembly method 3 illustrated by the Fixed / Changing Line Technology curve. This will require adjusting the technology to a level which will be quality compliant to the new methods. Only by constantly analyzing and thinking about what is best for the shipyard today and what will be best in the future can they hope to be competitive in the global market.

REFERENCES

[1] KOLIĆ, D.; FAFANDJEL, N.; ČALIĆ, B.: *Determining how to apply the design for production concept in shipyards through risk analysis,* Engineering Review 1 (2010) 30, 63 – 72.

[2] HADJINA, M.: *Simulation Modeling Based Methodology for Shipbuilding Production Process Design,* Strojarstvo 6 (2009) 51, 547 – 553.

[3] FAFANDJEL, N.; RUBEŠA, R.; MATULJA, T.: *Improvement of Industrial Production Process Design Using Systematic Layout Planning,* Strojarstvo 3 (2009) 51, 177 – 186. [1] BICHENO, J., HOLWEG, M.: *The Lean Toolbox, PICSIE,* Buckingham, 2009.

[4] ČAGALJ, A.; VEŽA, I.; MARKOVINA, R.: *Interactive Networked Company in Shipbuilding Industry,* Strojarstvo 1 (2009) 51, 15 – 26.

[5] BICHENO, J.; HOLWEG, M.: *The Lean Toolbox, 4th edition, PICSIE Books,* Buckingham, 2009.

[6] STORCH, R.L.; LIM, S.: *Improving flow to achieve lean manufacturing in shipbuilding,* Production Planning and Control 2 (1999) 10, 127 – 137.

[7] KOENIG, P.C.; NARITA, H.; BABA, K.: *Lean Production in the Japanese Shipbuilding Industry?,* Journal of Ship Production 3 (2002) 18, 167 – 174.

[8] *Design for Production Manual, 2nd edition, National Shipbuilding Research Program, U.S. Department of the Navy Carderock Division,* Annapolis, 1999.

[9] STORCH, R.L., et al.: *Ship Production, Society of Naval Architects and Marine Engineers,* Jersey City, 1995.

[10] ...: *Pema Shipbuilding and Offshore*, brochure, Pemamek OY Ltd., Loimaa, 2009.

[11] LIKER, J.K.; LAMB, T.: *What is Lean Ship Construction and Repair?,* Journal of Ship Production 3 (2002) 18, 121 – 142.

[12] 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 (1999) 58, 17 – 29.

[13] BERENDS, K.: *Engineering and Construction Projects tatistical dependence in Risk Analysis for Project Networks using Monte Carlo Methods,* International Journal of Production Economics - Elsevier (1999) 58, 17 – 29.

[14] 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, 285 – 301.

[15] WINSTON, W.L.: *Introduction to Probability Models Operations Research, Vol 2, 4th edition, Thomas Learning,* Canada, 2004.

[16] BETA PERT Distribution http://www.riskamp.com/library/pertdistribution.php 2005.

[17] @RISK, Advanced Risk Analysis for Spreadsheets, Palisades Corporation, 2001.

[18] WINSTON, W.L.: *Operations Research: Applications and Algorithms, 3rd edition, Duxbury Press,* Belmont, 1994.

[19] DAVIS, R.: *Teaching Project Simulation in Excel Using PERT-Beta Distributions,* Informs Transactions on Education 3 (2008) 8, 285 – 301.