

# Integration of Simulation and Lean Tools in Effective Production Systems – Case Study

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*Production systems that are by their structure designed according to principles of group technology must, despite their perfection, rapidly adapt to changes in surroundings and engage in a battle with their market rivals. First of all, they must get closer to customers and suppliers, representing one of first principles of lean philosophy. It is one of the ways to successfully valorise comparative values with competition, despite its internal restructuring. This paper presents the influence of certain lean tools as well as application of statistical analyses, simulation and graphics tools for achieving greater effectiveness and efficiency of production systems. Application or integration of these tools enables shortening of the production cycle, reduces the degree of complexity of material flows, reduces the supplies and expenditure of energy resources while it creates an increased degree of functionality of the organisation, utilization of workspace etc. Combination of different tools presented in this paper can valorise new technological, organisational and informational achievements in production that will secure an even better position on the market for industrial systems.*

**Keywords:** lean, effective systems, group technology, simulation

## 0 INTRODUCTION

There are many publications on adopting good practices that were introduced during the 90s and have been used since and which refer to directing the focus on consumer demand, material savings and expense elimination (Lean concept) [1] to [4], improvement of quality (Six Sigma, TQM) [5] to [8], product and process development [9],[10] and many others, which are all in accordance with regulations on ecological consciousness, large leading organisations have solidified their positions on a very competitive market [11]. Lean concept, although it originated after World War II in Japan, has undergone a significant worldwide application at the beginning of the fifties after a book “the Machine that Changed the World“ [1] by an MIT professor was published. Authors have presented a model that helped the Japanese car industry (Toyota) achieve incredible rebirth and take leadership position in production compared to the American car industry.

The Japanese model was called Lean, explaining that lean concept provides a way to define factors that affect the creation of new values, control the activities (with tools and methods, for a more detailed description of lean tools and methods see [12] and [13]) that bring values in the best way possible without disrupting the process and enables for the process to be as efficient as possible. Lean means working more with less human effort, equipment, time and space and at the same time provide the product that will satisfy the needs of consumers [2]. Implementation of lean philosophy to production or service systems that do business in more and more

dynamic surroundings of today, require a detailed analysis of time characteristics of the system such as: production takt-time, lead time, delivery time and others. It is known today that one of the more significant problems facing the production industry is timely product or services delivery as a response to an increasing consumer demand, which represents one of the points leading the lean philosophy. In order to better respond to the abovementioned problem Arsovski et al. suggests integration of strategic and tactical decisions and enabling synchronisation and modification of production plans on the production level as soon as possible [14]. In order to introduce synchronisation of the process it is necessary to have a detailed insight into process flows and their overlap. Description and a detailed representation of flows within the production system can be presented by flow maps, i.e. VSM. The book “Learning to See” represents the first publication where Value Stream Mapping is described in detail. Authors have defined VSM with the following sentence: “*Wherever there is a product for a customer, there is a value stream*” [15]. Authors have also described the benefit gained by using VSM true case study [16].

It is well known that there are companies whose production or service systems are still designed according to the traditional approach and where changes are very difficult to introduce, primarily referring to the management and initiating the awareness about the needs to upgrade the system by using new approaches such as lean. In order to ease the access to new ideas it is not enough to draw up flows of the existing system, it also requires additional

tools that, when combined with VSM, could provide the data in earlier decision and planning phases. Therefore, a tool is needed that would enable the generation of necessary production resources and statistical performances in real time, i.e. a simulation [17]. There is no singular definition of simulation [18] and [19] but it can be observed as a virtual environment [20] or model where the current state of the system is possible due to factors defined as significant for improvement of the observed system to virtually display and predict the behaviour of the future state of the system. As output a real time simulation of the system with relevant data is obtained, tables and it presents a significant support for the management in making new decisions. According to Raigipol, simulation models represent a very good tool that can be applied in very complex systems without the need for any detail simplification in order to carry out the simulation [21], on significance and benefits gained by using simulations see [17], [19] and [22] to [25]. The information that the management can gather by applying the simulations enables a comparative analysis of the current and future state of the system, with all performances significant for making decisions concerning whether the system satisfies the initiation of changes; and database as such, represents a significant foundation before lean philosophy is implemented.

### 1 METHODOLOGY

Application of the graphical (Sigma Flow VSM), simulation software (Simul8) and the statistical program (Minitab) was done in the industrial system for the production of flexible pipes. The system was, in an earlier period, set on the basis of group technology. Products of this industrial system were sorted into groups based on KS-IIS-08 classification system [26] and are produced in seven work units functioning as production units, depending on which group they belong to. Effective production system structure referring to a total number of work units,

technological systems and other characteristics is given in Table 1.

After a global analysis: of the complexity of the material flows, the section of the load of technological systems and the importance to raise the effectiveness and efficiency in work processes work unit 3 (RJ-3) was chosen for analysis. Visualization of particulars of the current state of the RJ-3 and in the production system related to the process of supply, flows, supplies, unfinished production, the number of employees working in the work process, technological cycles, preparatory-finalizing time and work process rhythm are analysed in the graph of the state done with Sigma Flow VSM (Fig. 1) [27].

With the analysis of the graph, the main storages for raw materials, semi-products and finished products can be seen. Interpretational storages, which are used as queue points for work subjects for the next operation, control and dispatch of parts are also visible.

The timeline at the bottom of the depicted graph has two components:

- a) Duration of the operational cycles (value – added time) is 43 minutes for operations conducted in the work unit, 1.5 minutes for surface protection and 2.5 minutes for the production of finished products;
- b) Non-productive time (non value added time) which is in total 240 hours: 109 for transport and waiting and 131 hours for preparation and finishing.

The state of the work unit RJ-3, production system is based on the traditional MRP planning (material requirements planning), based on the employment of the capacity of machines and people. This includes the state of push production (material purchasing from suppliers), storing at the company, lathe processing, milling machine processing, drilling, surface protection and installation. In front of every work station there is an auxiliary storage for unfinished production (Storage WC1 to storage WC10) and a check point. The graph demonstrates the return and

**Table 1.** Structure of the effective production system

No.	EPS characteristics	Work unit No.							Total
		1	2	3	4	5	6	7	
1	Number of different items	12	6	17	18	30	13	8	104
2	Number of technological systems – machines	13	12	10	14	19	13	14	85
3	Number of identical technological systems in the work unit (RJ)	1	3	3	4	6	6	2	
4	Approach to shaping of the material flows	Group approach							
5	Approach to shaping of the spatial structures	Item approach							

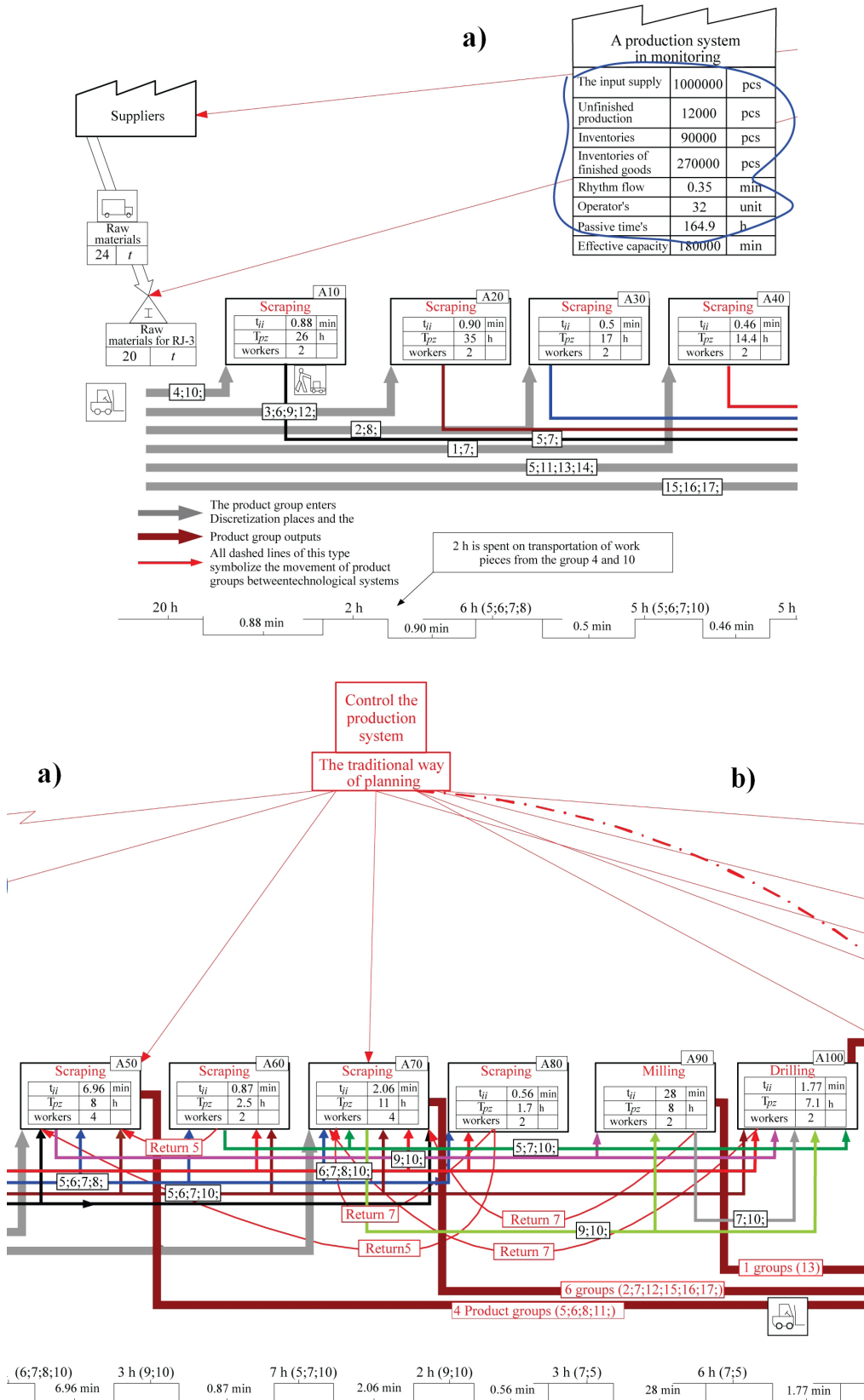


Fig. 1. Graph of the current state of the production system (continues)

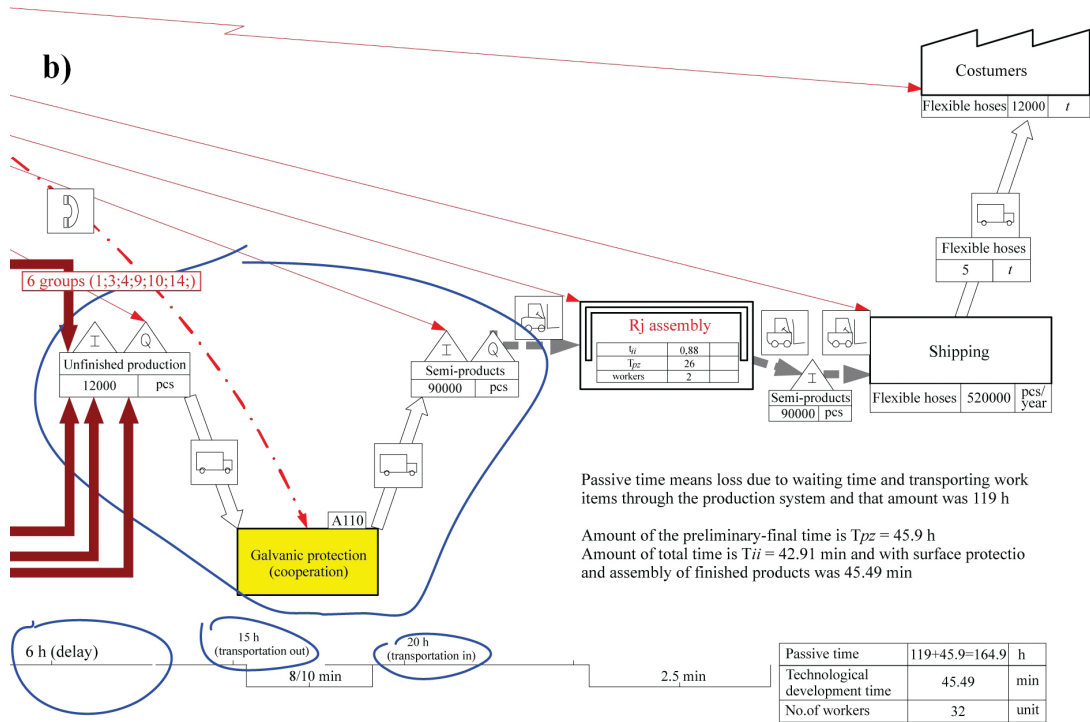


Fig. 1. Graph of the current state of production system (extension)

canceled material flows, large waiting lines in front of work centers, forbidden unfinished production and a longer waiting period for the delivery of products to the buyer.

17 different parts of products (P1, P2, ..., P17), being produced on 10 different machines (WC1, WC2, ..., WC10) are produced in RJ-3. The graphic depiction of the flow of material in RJ-3 is demonstrated in (Fig. 2). Based on these depictions

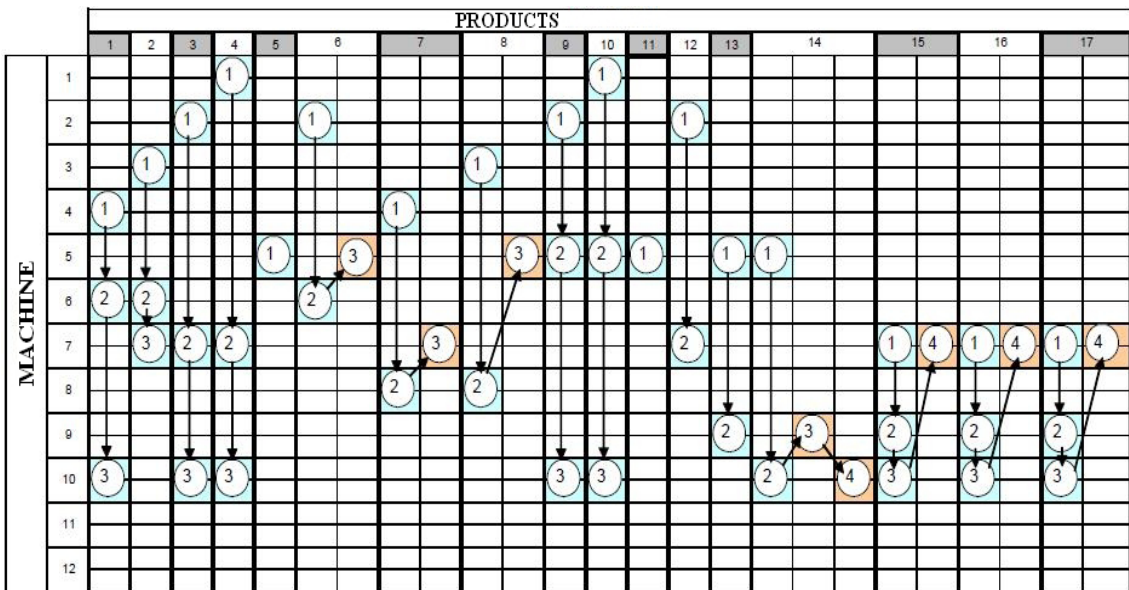


Fig. 2. Graphic depiction of flows in work unit 3 (RJ-3)

it can be concluded that the flow path for 6 to 8 and 14 to 17 does not comprise of progressive movement between neighboring machine pairs and that there are reverse and cross flows.

1		Machine									
		2	3	4	5	6	7	8	9	10	
Product groups	1				1		1				1
	2			1			1	1			
	3		1						1		1
	4	1							1		1
	5					1					
	6		1			1	1				
	7				1			1	1		
	8			1		1			1		
	9		1			1					1
	10	1				1					1
	11					1					
	12		1					1			
	13					1				1	
	14					1				1	1
	15							1		1	1
	16							1		1	1
	17							1		1	1

Fig. 3. Preview of the initial matrix for RJ-3

By creating material flows we have accessed the transferal of paths to the initial matrix “machine-part” that demonstrates the presence “1” or absence “0” of parts on the specific machine (Fig. 3).

By using the data 0-1 two matrixes of Jaccard’s similarity coefficient SC are generated – one for parts and one for machines (Fig. 4).

$$S_D = \frac{a_{ij}}{a_i + a_j - a_{ij}}$$

where number of parts present at *i* and *j* machine, number of parts present at *i* machine, and number of parts present at *j* machine.

	1	2	3	4	5	6	7	8	9	10
1	1	0	0	0	0.111	0	0.111	0	0	0.200
2	0	1	0	0	0.200	1.166	0.200	0	0	0.182
3	0	0	1	0	0.111	0.250	0.111	0.333	0	0
4	0	0	0	1	0	0.250	0.111	0.333	0	0.100
5	0.111	0.200	0.111	0	1	0.100	0	0.111	0.192	0.214
6	0	0.165	0.250	0.250	0.100	1	0.100	0	0	0.091
7	0.111	0.200	0.111	0.111	0	0.100	1	0.111	0.300	0.417
8	0	0	0.333	0.333	0.111	0	0.111	1	0	0
9	0	0	0	0	0.182	0	0.300	0	1	0.400
10	0.200	0.182	0	0.100	0.214	0.091	0.417	0	0.400	1

Fig. 4. Jaccard’s matrix of the machine similarity coefficient

By using the similarity matrixes in the statistical program MiniTab an analysis has been performed of the hierarchical grouping of the machines and products. Based on the results 5 departments have been formed in the raw material storage (queue P1, P10 WC1, etc.), (Figs. 5a and b), four groups of machines with auxiliary product storages, establishing product kanban cards. The final group of machines at the installation work unit supplies the time for the tact, meaning the necessary rhythm for the product delivery to a specific buyer. On the researched basis it is possible to perform a reconfiguration of the space structure of a work unit (layout).

With the performed grouping the final appearance of the reconfigured layout of technological systems and flows in RJ-3 is achieved which is shown in Fig. 6 and it represents all parts as a single operating group and two groups of machines between which there are only four inter-group progressive flows.

Based on the given graph and observed deficiencies we have approached the production of the graph of the future state (VSM) of the production system with progressive material flows, eliminated reverse and interrupted flows, kanban system, on buyer demand production- pull system, known as “lean production system”, (Fig. 7) [27].

## 2 SIMULATION AND STATISTICAL ANALYSIS

After applying the graphic software we move on to the simulation of the production system by using simulation software (Simul8). The simulation is used for predicting the future state of the system based on Figs. 1 and 7 where the graphic depictions of current and future state of the system are shown. The main elements of the model, measurement parameters in the simulation and the simulation of the given system case can be seen in paper [28]. After the simulation with the Simul8 software package, a factor 2<sup>3</sup> analysis was performed of the lean principle and tools (production system, TPM and SMED). The influence of the aforementioned factors was observed in relation to:

1. duration of the production cycles *T<sub>cp</sub>* and
2. size of stock in the processes.

Data on duration of the production cycle on every level is provided in Table 2. The data from the first measurement in both EPS (current and future) was compared to the measured sizes in the realistic production conditions. The data matched in the span of up to 10%. The remaining measurements were simulated in the given span for the purpose of statistical processing. Statistical processing allowed

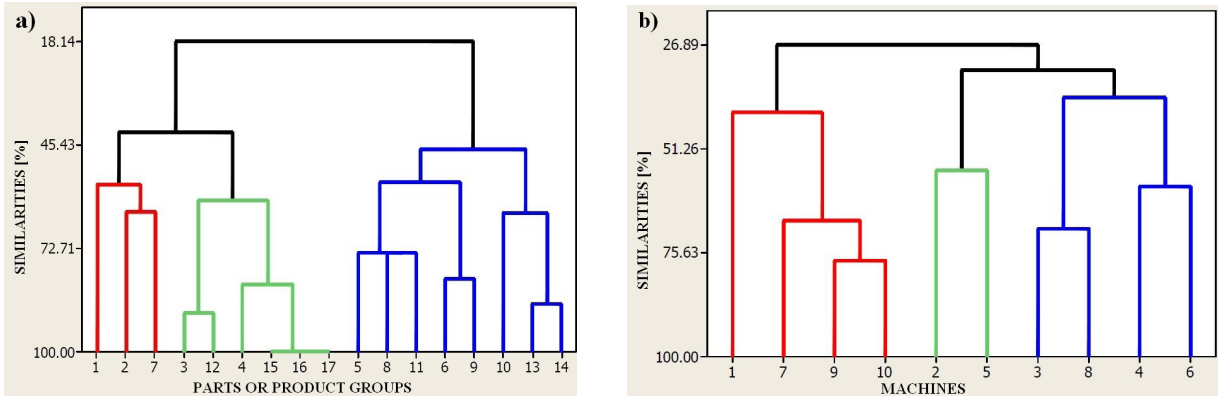


Fig. 5. Group analysis for; a) parts, and b) machines

Machine	PRODUCTS																
	3	6	9	12	5	8	11	1	2	7	13	14	4	10	15	16	17
GROUP 1	2	1	1	1	1												
	3					1			1								
	4							1		11							
	6		2				2	2	2								
	5	2	3	2	2	1	3	1				1	1				
	8									2							
	10	3		3					3				2				
GROUP 2	1												1	1			
	7								3	3			2	2	1	1	1
	9										2	3			2	2	2
	10											4	3	3	3	3	3
	7														4	4	4

Fig. 6. Reconfigured layout of the technological systems and flows RJ-3

the demonstration of dependence between observed factors.

The spatial layout of the plan of the experiment is presented in Fig. 8a. The numbers next to the tops of the squares represent the mean duration of the production cycle for the given factor level. While the graphic depiction of the influence of the observed factors on the production cycle (Pareto diagram) is given in Fig. 8b.

From Fig. 8b it is visible that factor “a” (production system) has the biggest influence. It is followed by factors “c” (SMED), “b” (TPM) and a combination of factors “ac”, “bc”, “ab” and “abc”. It can be determined that a triple interaction is not significant. ANOVA output from Minitab sums up the main effects for three factors into one measure, which can be visible in Table 3. The value of “P” in the table

is from 0 to 0.919. The factors that have a value closer to zero have higher influence significance on the production cycle. It is visible that the biggest effect is produced by factor “A”, i.e. production system, its layout and pull principle. The interaction between factors “production system × SMED” is the strongest and amounts to -1.62 i.e. it produces the effect of 3.25. Model results of *T* estimate the value of each factor and an interaction between them. *T*-test in the table reveals and ranks the importance of certain factors: production system, SMED and finally TPM. However, the future state will change the order of SMED and TPM because the tuning of tools has been perfected, so the duration cannot be shortened. All that remains is the perfecting of tools so that TPM system fails less (the equipment ages), and it will result in higher use of the equipment, bigger production and shorter

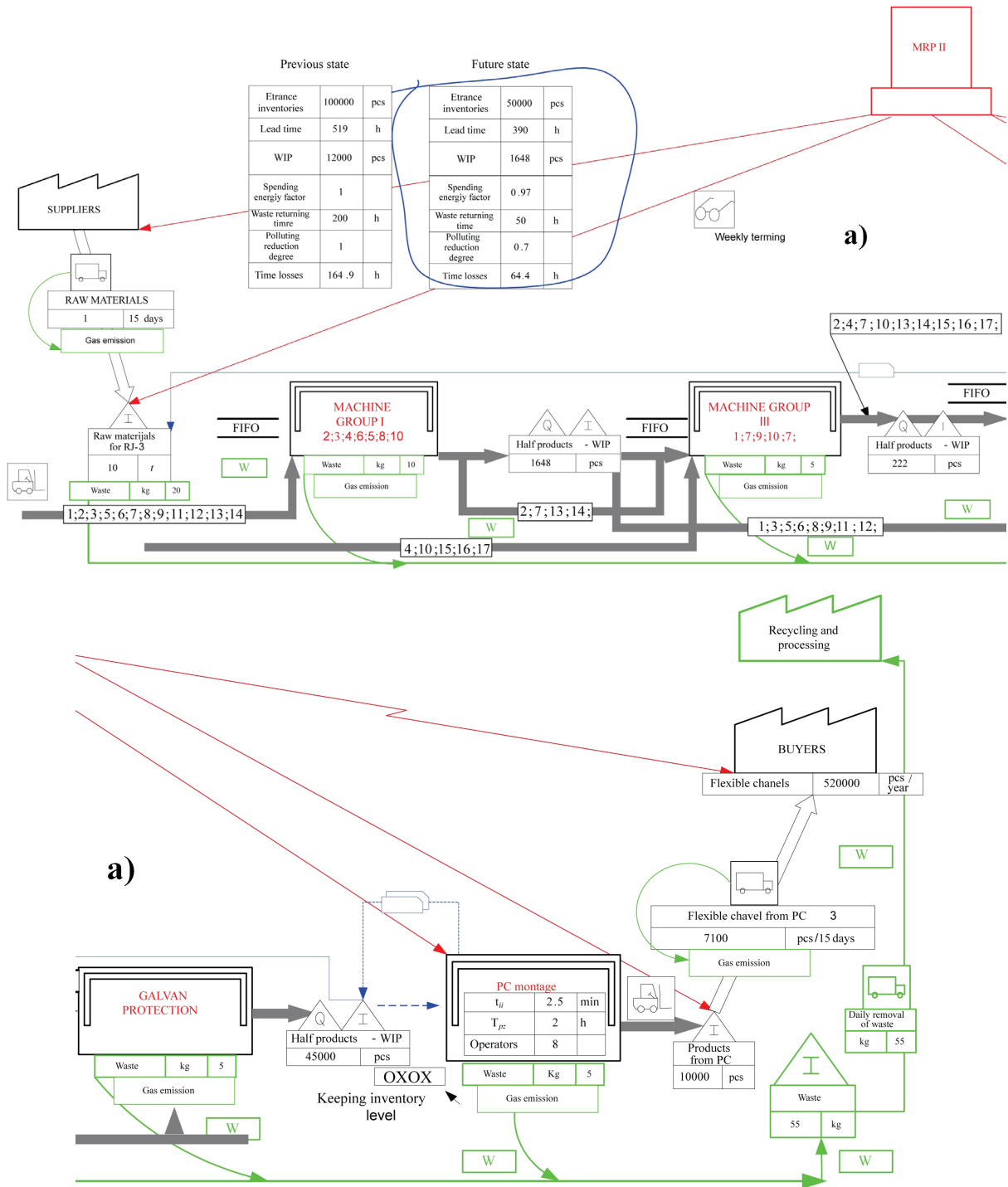
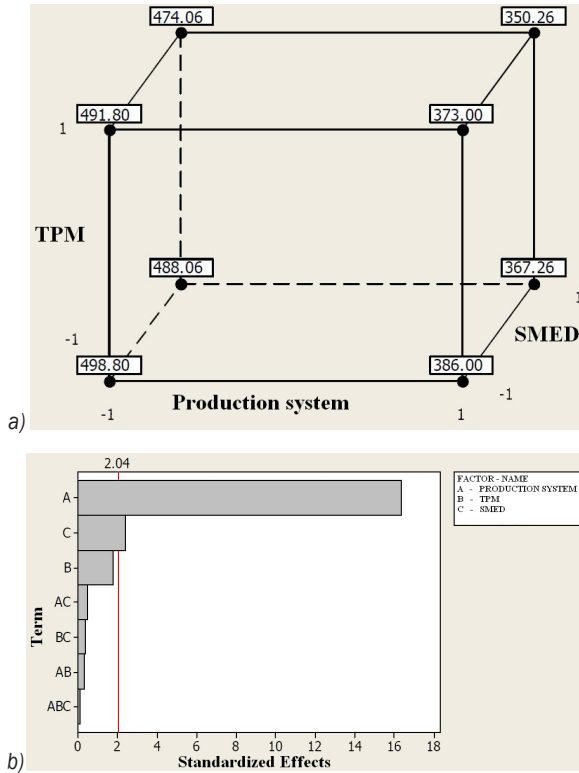


Fig. 7. Graphic depiction of the future state of the production system

$T_{cp}$ . The “F” value in the tables represents the Fisher criteria for significance evaluation. Residual value in relation to the order of data is shown in Fig. 9. The behavior of the main effects of factors (production system, SMED and TPM) in production cycle  $T_{cp}$  is presented in Fig. 10, and their interaction in Fig. 11.

From the figure it is clearly visible that by going towards the new layout and pull principle, towards “with”, SMED and TPM, the duration of a production cycle is shortened. The regression equation of the behavior of the duration of the production cycle  $T_{cp}$  is:



depending on the observed factors can be determined. The spatial layout of the plot comprised of  $T_{cp}$  with two factors is presented in Figs. 12 to 14.

**Fig. 8.** a) Spatial layout of the plan of the experiment; b) Pareto diagram of the influence of factors on production cycle

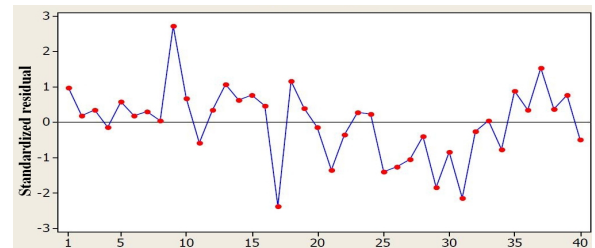
**Table 2.** A tabular presentation of  $T_{cp}$  in an effective production system

Effective Production System - EPS	TPM				Measurements
	without SMED		with SMED		
	519	500.3	499	480.3	1
	550	510	480	490	2
PUSH + existing layout	450	460	500	480	3
	470	450	470	430	4
	500	520	510	490	5
	-a, -b, -c (1)	-a, -b, +c (c)	-a, +b, -c (b)	-a, +b, +c (abc)	Code
	390	371.3	370	351.3	1
	400	380	380	360	2
Reconfigured EPS with PULL principle	410	360	370	355	3
	360	350	365	345	4
	370	375	380	340	5
	+a, -b, -c (a)	+a, -b, +c (ac)	+a, +b, -c (ab)	+a, +b, +c (abc)	Code

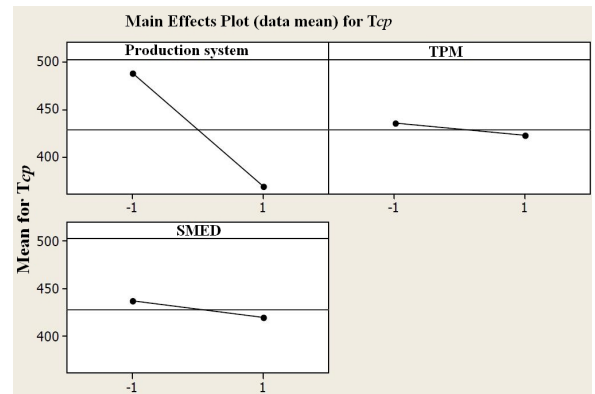
$$T_{cp} = 429 - 59.5 \text{ Production system} - 6.38 \text{ TPM} - 8.75 \text{ SMED} . \quad (1)$$

The regression analysis of the influence of factors is given in Table 4 from where the behavior of  $T_{cp}$

**Fig. 9.** Residual times  $T_{cp}$



**Fig. 9.** Residual times  $T_{cp}$



Identical  $2^3$  factor analysis has been performed for the behavior of the raw material stock, semi-production and finished merchandise in storage. The final regression equation for stocks in the processes is:



$$STOCK = 294190 - 157840 \text{ Production System} - 9255 \text{ TPM} - 10140 \text{ SMED} \quad (2)$$

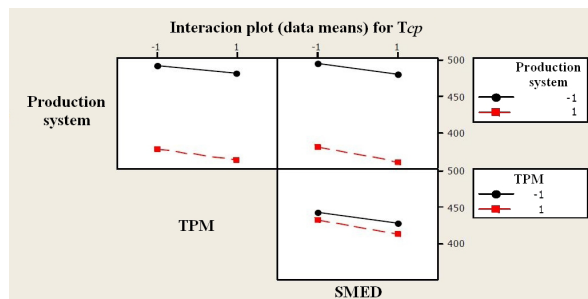


Fig. 11. Interaction of observed factors

Table 4. Regression analysis of the influence  $T_{cp}$  (Table from MiniTab)

Regression Analysis: $T_{cp}$ versus Production system; TPM; SMED					
The regression equation is					
$T_{cp} = 429 - 59.5 \text{ Production system} - 6.38 \text{ TPM} - 8.75 \text{ SMED}$					
Predictor	Coef	SE Coef	T	P	
Constant	428.655	3.459	123.91	0.000	
Production system	-59.525	3.459	-17.21	0.000	
TPM	-6.375	3.459	-1.84	0.074	
SMED	-8.745	3.459	-2.53	0.016	
S = 21.8788; R-Sq = 89.5%; R-Sq (adj) = 88.6%					
Analysis of Variance					
Source	DF	SS	MS	F	P
Regression	3	146414	48805	101.96	0.000
Residual Error	36	17233	479		
Total	39	163646			

### 3 DISCUSSION

The statistical part of the experiment has mainly been conducted on two primary performances: the duration of a production cycle  $T_{cp}$  and total production stock.

The first analysis proved the effect of the following factors: *EPS*, *SMED* and *TPM* on the duration of the production cycle  $T_{cp}$  and it was discovered that the use of reconfigured *EPS*, can potentially diminish the production cycle up to 20% (from 519 to approximately 390 hours). The production cycle will continue to diminish if we were to continue using the listed methods, principles and tools of the lean concept. The focus must be turned to *TPM* being that the technological equipment in the mentioned case is obsolete.

The second experiment analyzed the influence of the same factors on total stock and had shown the insignificant influence of factor “production tract” with pull principle. Inter-operational stock is lowered with this as well as other observed factors by about 3 times (from the average 472,000 to 156,648 pieces).

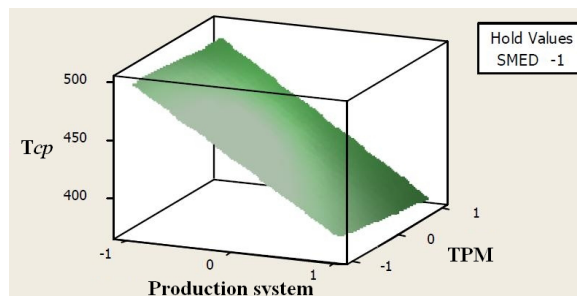


Fig. 12. Position of the plot  $T_{cp}$  - production system - SMED

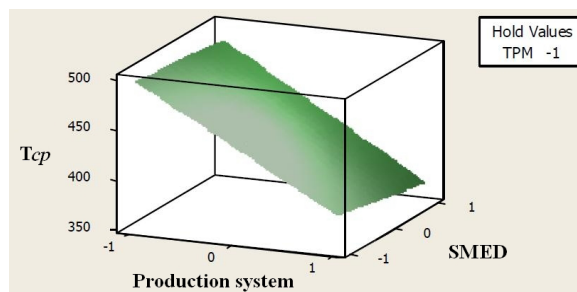


Fig. 13. Position of the plot  $T_{cp}$  - TPM - SMED

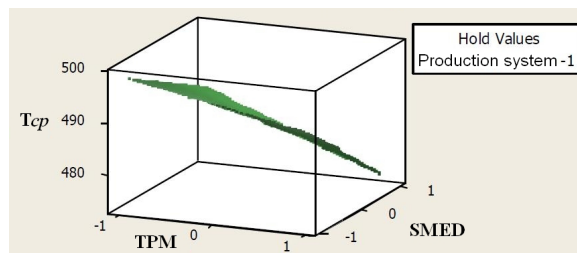


Fig. 14. Position of the plot  $T_{cp}$  - TPM - SMED

It can be concluded that with the result analysis it has been determined that the reconfigured *EPS* that has taken into consideration lean tools regarding the shaping of the material flows and spatial structure and the “pull” principle, has produced a more significant effect in relation to the other two factors. In the observed *EPS* it has been demonstrated that the influence of *TPM* is lower in relation to *SMED*. However, further improvements need to be directed towards these two factors of the lean concept. They

are definitely important in future work, especially concerning *TPM*.

**Table 5.** Display of achieved results with the use of lean concept

No.	Process measurement characteristics	Pre lean (level "-1")	Post lean (level "+1")	Improvements
1	Duration of production cycle $T_{cp}$ [h]	519	390	Lowered by 1.33 times
2	The stock level of semi-production [pcs]	12000	1648	Lowered by 7.2 times
3	The level of stock in the input storage [pcs]	100,000	50,000	Lowered by 2 times
4	The level of stock in finished merchandise storage [pcs]	270,000	60,000	Lowered by 4.5 times
5	The degree of space use <i>EPS</i>	Concentrate storages around work units		Increased by 1.2 times
6	Technological development time	45.49	45.49	Same
7	Efficiency of $T_{cpp}/T_{cpn}$	1.62		Increased
8	Effectives – degree of the flow of the order $P = T_{cp} / \sum T_{ii}$	$519 \times 60 / 45.49 = 684$	$390 \times 60 / 45.49 = 514$	Increased
9	The degree of organization functionality $F=1/P$	0.0014	0.0019	Increased
10	The No. of operator in the work process	32	32	Same
11	Passive times [h]	169.9	64.4	Lowered by 2.6 times
12	The consumption of hot water and electrical	3%		Lowered

This is not considered to be the end of perfection in such a shaped spatial structure of the work unit and an effective production system. The focus can be directed towards rising of the automated transport to the machines.

In the end, it is important to stress that by using graphic tool Sigma Flow VSM, simulation tool Simul8 where the simulation has been performed in 10 replications and was based on an eight hour work day, five days a week and statistical 23 analysis with this experiment possible improvements to the system are presented, and total improvement results are shown in Table 5.

## 4 CONCLUSION

This paper describes the development of the systematic methodology for the implementation of the lean concept in the industrial systems. An effective production system is one of the representatives of the concept of production systems where such material flows have been established that they can be compared to the production in the process industry. The main idea in this paper was conducted in two directions; the first was meant to help the critics to in such or similar situations, use new initiations for upgrading the efficiency by using lean concepts and to become competitors in the global market, and the second to show the increase of efficiency and effectiveness of EPS and to lower the stock and production cycle in relation to the time, up to the moment of observation. It is important to mention the limitations that showed themselves during the research and were characterized through non-accepting of changes by the employees, mostly due to fear of losing their jobs. Although, the work itself showed that the efficiency was increased without the change in number of employees. Realization of the research through time period made employees and other critics to change their opinion in great measure as well as to accept the changes in a positive way. By developing procedures, steps and phases of implementation of the lean concepts in the mentioned area there are realistic chances for further research that will include the lean concept and the concept of an effective system into one integrated concept for molding the production system.

## 5 REFERENCES

- [1] Womack, J., Jones, D. (1990). *Machine that change the world*. Macmillan Publishing, New York.
- [2] Womack, J., Jones, D. (1996). *Lean Thinking: Banish Waste and Create wealth in Your Corporation*. Simon&Schuster, New York.
- [3] Taiichi, O. (1988). *Toyota Production System: Beyond Large-Scale Production*. Productivity Inc., Portland.
- [4] Shigeo, S., Dillon, A. (1989). *A study of the Toyota production system from an industrial engineering viewpoint*. Productivity Press, Portland.
- [5] Tennant, G. (2001). *Six Sigma: SPC and TQM in Manufacturing and Services*. Gower Publishing, Hampshire.
- [6] Pyzdek, T., Keller, P. (2009). *The Six Sigma Handbook*. McGraw-Hill Companies, Inc., New York.
- [7] George, S., Weimerskirch, A. (1998). *Total Quality Management: Strategies and Techniques at Today's Most Successful Companies*. John Wiley and Sons Inc., Toronto.

- [8] Vujovic, A., Krivokapic, Z., Sokovic, M. (2011). Improvement of business processes performances trough establishment of the analogy: Quality management system – Human organism. *Strojniški vestnik - Journal of Mechanical Engineering*, vol. 57, no. 2, p. 151-161, DOI:10.5545/sv-jme.2009.177.
- [9] Kušar, J., Rihar, L., Duhovnik, J., Starbek, M. (2008). Project management of product development. *Strojniški vestnik – Journal of Mechanical Engineering*, vol. 54, no. 9, p. 588-606.
- [10] Žargi, U., Kušar, J., Berlec, T., Starbek, M., (2009). A company's readiness for concurrent product and process development. *Strojniški vestnik – Journal of Mechanical Engineering*, vol. 55, no. 7/8, p. 427-437.
- [11] Preiss, K., Patterson, R., Field, M. (2004). *The future directions of industrial enterprises*. Zandin, K. Maynard's Industrial Engineering handbook. McGraw-Hill Companies, Inc., New York, p. 135-163.
- [12] Page, J. (2004). *Implementing Lean Manufacturing Techniques*, Hanser Gardner, Cincinnati.
- [13] Feld, W. (2000). *Lean Manufacturing: Tools, Techniques, and How to Use Them*, St. Lucie Press, Florida, DOI:10.1201/9781420025538.
- [14] Arsovski, S., Arsovski, Z., Mirovic, Z. (2009). The integration role of simulation in modern manufacturing planning and scheduling. *Strojniški vestnik - Journal of Mechanical Engineering*, vol. 55, no. 1, p. 33-44.
- [15] Rother, M., Shook, M. (1997). *Learning to See – value stream mapping to create value and eliminate muda*. Lean Enterprise Institute, Cambridge.
- [16] Radošević, M., Čosić, I., Soković, M., Božičković, R. (2011). Visual stream mapping – Visualise before acting. *XV International Scientific Conference on Industrial Systems*, p.44-47.
- [17] Abdulmalek, F., Rajgopal, J. (2007). Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study. *International Journal of Production Economics*, vol. 107, no. 1, p. 223-236, DOI:10.1016/j.ijpe.2006.09.009.
- [18] Law, A. (2006). *Simulation Modeling and Analysis*, 4<sup>th</sup> ed. McGraw-Hill, New York.
- [19] Chung, C. (2003). *Simulation Modeling Handbook: A Practical Approach*. CRC Press LLC, Florida, DOI:10.1201/9780203496466.
- [20] Rihar, L., Kušar, J., Duhovnik, J., Starbek, M. (2010). Teamwork as a precondition for simultaneous product realization. *Concurrent engineering – research and applications*, vol. 18, no. 4, p. 261-273.
- [21] Raigopal, J. (2004). Principles and applications of operationa research. Zandin, K. *Maynard's Industrial Engineering handbook*. McGraw-Hill, New York. 1677-1694
- [22] Detty, B., Yingling, C. (2000). Quantifying benefits of conversion to lean manufacturing with discrete event simulation: a case study. *International Journal of Production Research*, vol. 38, no. 2, p. 429-445, DOI:10.1080/002075400189509.
- [23] Fetvacı, C. (2010). Genereation simulation of involute spur Gear machined by pinion-type shaper Cutters. *Strojniški vestnik - Journal of Mechanical Engineering*, vol. 56, no. 10, p. 644-652.
- [24] Tan, Y., Takakuwa, S. (2011). Use of simulation in a factory for business continuity planning. *International Journal of Simulation Modelling*, vol. 10, no. 1, p. 1-48, DOI:10.2507/IJSIMM10(1)2.172.
- [25] Fandino Pita, N., Wang, Q. (2010). A simulation approach to facilitate manufacturing system design. *International Journal of Simulation Modelling*, vol. 9, no. 3, p. 113-168, DOI:10.2507/IJSIMM09(3)4.162.
- [26] Zelenović, D., Čosić, I., Maksimović, R. (1998). *IISE – approach in development of effective manufacturing systems – companies, group technology and cellular management*. A state of the art synthesis of research & practice, Cluwer pres, New York.
- [27] Božičković, R. (2005). *Lean concept in efective manufacturing systems*. PhD Thesis, University of Novi Sad, Novi Sad.
- [28] Božičković, R., Čosić, I., Božičković, Z., Radošević, M. (2011). An application of simulation and graphic tools in lean production. *XV International Scientific Conference on Industrial Systems*, p. 483-489.