System Approach to the Mass Production Improvement

Irina Makarova, Vadim Mavrin, and Ksenia Shubenkova(✉)

Kazan Federal University, Naberezhnye Chelny, Russia
{kamivm,vadim_mmite}@mail.ru, ksenia.shubenkova@gmail.com

Abstract. The ways of increasing the efficiency of production processes in automotive industry are presented in the article. These ways can be realized by modern optimization methods and tools. Analysis of activity of enterprises implementing strategies of production development, shows that only comprehensive solutions can lead to real improvements. The results of simulation experiments revealed the best combination of input factors values that helped to improve each of factors, compared to existing solutions.

Keywords: Mass production · System approach · Simulation · Modeling · Optimization of technological processes · Assembly line

1 Introduction

In the last two decades information technology has been actively involved in almost all spheres of modern society. In a vision of the future of manufacturing, the pervasive networking of people, things, and machines will create completely new production environments. Manufacturers, researchers, and governments are working together to explore and implement this vision for tomorrow's networked factory, which is embodied in Germany's "Industry 4.0" concept – the Siemens term for fourth Industrial Revolution, when the real and virtual worlds are now beginning to merge in production. Increasing digitalization and networking is changing the entire industrial production chain, and the volume of data worldwide is exploding. In order to properly analyze and be able to use huge volumes of data, we must first develop systems that enable us to understand their content. A precondition for this is to know how devices and systems function and which kinds of sensor and measurement technology can be used to access the most useful data.

The current state of technics and technologies allows us to create tools and methods not only for managing technical and organizational and technical systems, but also devices for analyzing the state of human functional systems and affecting them. This makes it possible to correct and optimize human activity both indirectly, using the recommended loads and parameters, and in real time, which allows creating a comfortable working environment, as well as increasing the safety and efficiency of labor, increasing the efficiency of production systems and product quality.

T. Březina and R. Jabłoński (eds.), *Mechatronics 2017*, Advances in Intelligent Systems and Computing 644, DOI 10.1007/978-3-319-65960-2_13

2 Features of Mass Production and Ways to Increase Its Efficiency

Automotive industry belongs to those sectors of economy which largely determine the development of other industries where automotive equipment is used, because automotive vehicles solve the problem of population mobility and carry out door-to-door cargo deliveries. High level of motorization and market globalization make manufacturers to look for new solutions, constantly to improve both the car's design and production technology. Because it is possible to sustain significant competition in the markets only by the continuous development and application of innovative solutions.

2.1 Production Systems and the Theory of Constraints

When creating production control systems, it is necessary to take into account features of managed subsystems, whose activities were determined by components of different types. The efficiency of the production system can be assessed with the help of quality indicators and the volume of output, as well as the costs of resources for its production. Complex indicators of effective work allow managing by the usage of feedback.

Since production systems operate under conditions of limited resources, it is important to determine what hampers efficiency's increasing and what actions can improve processes. To construct effective control the Theory of Constraints (TOC) can be used. The paradigm of this theory was first used by Goldratt. According to TOC constraints can be internal or external to the system. Types of (internal) constraints: (1) Equipment: The way equipment is currently used limits the ability of the system to produce more salable goods/services; (2) People: Lack of skilled people limits the system. Mental models held by people can cause behaviour that becomes a constraint; (3) Policy: A written or unwritten policy prevents the system from making more (Fig. 1).

The concept of the constraint in Theory of Constraints is analogous to but differs from the constraint that shows up in mathematical optimization. In TOC, the constraint is used as a focusing mechanism for management of the system.

As a rule, it is easier to influence internal constraints by improving the processes at the enterprise. Although TOC is not a rigorous mathematical theory, the authors of numerous studies use this concept to optimize production processes using simulation models. For example, multiobjective optimization and build-to-order supply chains modeling can be used for improvement of the automobile production [1]. Bottlenecks in a production line is one of the main reasons that impede productivity. The approach proposed in [2] combines in a semi-automatic way simulation-based bottleneck detection methods. This approach consists of a two-step procedure: analyzing the system and then generating scenarios testing the system's sensitivity against changes. The authors of the research [3] have investigated bottlenecks in production line using Goldratt and Cox's theory of constraints with a simulation based heuristic method. One of the bottlenecks in production line can be the machine failures. Gopalakrishnan M. et al. [4] propose to solve this problem by integration of dynamic maintenance strategies into scheduling of reactive maintenance using Discrete Event Simulation.

2.2 Lean Manufacturing: Advantages and Problems

One of the methods to improve processes in high-tech industries that have become widespread is the concept of "lean manufacturing", developed for the automotive industry and first applied in automotive enterprises. However, as studies show [5, 6] the effects of this technology introduction are ambiguous and, in most cases, are rather negative. To improve and optimize technological processes any changes should be carried out with provision for ergonomic factors, adherence to the principles of ensuring quality and safety of the working environment.

The researches of many scientists in the field of ergonomics, labor protection, modeling of the production environment are devoted to identification of the factors that affect the quality of the working environment, the causes of overloading and the risks of occupational injuries [7–10]. Multifactor modeling, including also ergonomic factors, allows to increase efficiency in resource-limited settings [11], to predict subsequently the fatigue [12] and to prevent accidents on manufacture [13]. In addition, the usage of a virtual production environment in the process design allows solving the tasks of timely maintenance of equipment [14].

Analyzing the role of ergonomic studies in ensuring the sustainability of the production systems and the quality of working environment, the researchers note positive changes in companies that have implemented recommendations for changes in processes with account of ergonomic parameters [15]. However, it is also noted that this issue needs more attention, because this affects both the quality of the processes and the sustainability of production system, and on the psycho-emotional state of industrial workers and harmonious development of human potential [16, 17].

The solution of such problems is based on adequate information that is unique for each manufacturing enterprise. This information depends on a large number of stochastic factors. Thus, the anthropometric characteristics of personnel of any company are unique and they allow creating an adequate model of a person behavior in a working environment [18]. In order to ensure that used in the models information is adequate, it is possible

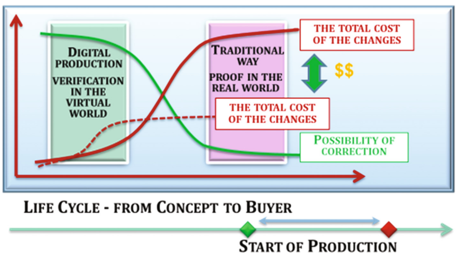


Fig. 1. Consequences of ergonomic mistakes

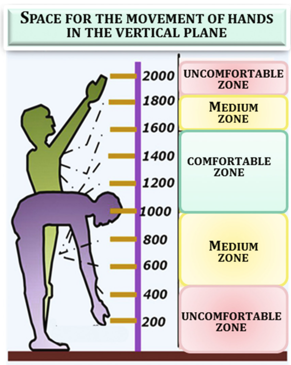


Fig. 2. Location of comfortable and uncomfortable work areas by height

to use monitoring of real production processes [19, 20]. Moreover, monitoring data can be used to assess the adequacy of the developed models during the simulation experiment.

3 Results and Discussion: Simulation Models to Manage Mass Production and Human Resources

3.1 Optimization of Technological Processes on the Assembly Line

Simulation models are used to determine the optimal parameters of technological processes when changing internal or external parameters of production. Input data for the development of the simulation model of technological processes are: typical manufacturing process; Teamcenter database (data on assemblies, products, equipment, tools, environment).

The structure of individual technological process is adjusted in accordance with the composition and structure of the unified technological process by analyzing the need for each operation and the technological transition with the consistent refinement of all solutions. Technological design consists in the development of standard technological processes, from which in the future it is possible to assemble various methods of assembling cars. This makes it possible to significantly reduce labor input and the time required for their introduction into production.

Mass conveyor production is based on the principle of the flow organization of technological assembly processes, providing:

- the division of the assembly process into a series of assembly operations, sequentially arranged in time and space, performed by the operators-assemblers;
- the usage of special transport devices to move the assembled units between assembly devices and to ensure a given assembly rate;
- the usage of special transport devices for supplying parts and assemblies to the main assembly conveyor;
- usage of special and unified tools and devices for mechanization and automation of the technological process;
- mechanical machining of parts and assembly of machine units in machine-assembly shops.

With this organization of production, assembly of the entire vehicle on the main assembly conveyor is carried out from the finished assembled units and aggregates, connected together by fasteners. The open architecture of the Teamcenter system allows you to connect to the PLM environment such systems as Matlab/Simulink and Rhapsody. In order to work with data in the usual formats, we can use the capabilities of dynamic integration with Microsoft Office software package. The obtained solutions are stored in the knowledge base and can be used in similar production situations.

Usage of simulation models allows you to isolate operations that need optimization, determine the required number of employees, and optimize their load. Usage of the obtained solutions allows to reduce the assembly time at the conveyor positions, and, accordingly, the cycle time by 6%, while the optimal loading of personnel leads to a reduction in the number of errors.

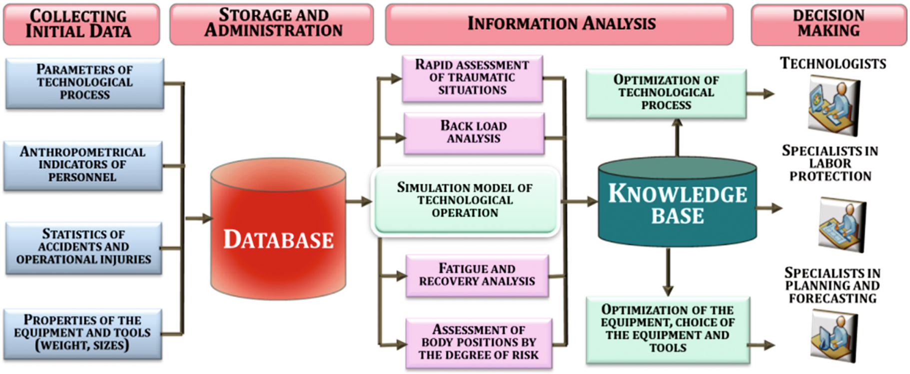


Fig. 3. Conceptual scheme of DSS

3.2 Ergonomics of the Workplace: The Impact on the Efficiency of Processes

As the researches have shown, all changes in technological processes will be inefficient without provision of ergonomic parameters. Therefore we have highlighted the factors, that have an impact on both quality of assembly operations and on safety of their execution.

Analysis of frequency of the injury occurrence showed, that in groups the most at risk are represented by workers ages 45 to 55 and 18 to 30 years, moreover the number of men, that was affected, is 62% of all injuries, that may be explained to their employment in jobs with more heavy loads. Studies have shown, that workers of assembly production in the first 2 months of work is the most vulnerable for risk a injuries, so need to more closely monitor the safety of young workers. Position analysis of the condition of convenience of work on the first main assembly line (Fig. 2) have shown, that the majority of assembly operations and auxiliary operations at its second position are carried out in a less convenient area - at a height less than 900 mm, therefore it is potential "bottleneck". There are assembly tables, some types of containers and frames of the truck in this area.

The modeling of the operators in assembly production is carried out using information on working processes of real production and begins with conducting the experiment of two-dimensional layouts of work areas in an interactive three-dimensional system Tecnomatix Jack. After that an interactive layout reproduced with using three-dimensional objects of trucks from engineering data system "Teamcenter Engineering" and three-dimensional models of tools, tooling and equipment created in CAD "Unigraphics NX". Virtual operators-assemblers are added in an interactive three-dimensional model. The number of virtual operators-assemblers corresponds to the actual number of workers in this area. Verification of weights of all active objects is carried out in a three-dimensional environment. Only those elements of the production system that have a significant influence on the explored objects are taken into account when creating a model (Fig. 3).

The problem of determining the optimal control is to find such optimal values of input factors X (X_1 – the manufacturability of the assembly of the car, X_2 – ergonomics of equipment, tools and tooling, X_3 – operator qualification, X_4 – anthropometric data of operator, X_5 – gender of operator) in which value of function Y (ergonomic assessment for assembly operations) will be minimal, that means better working conditions from the ergonomics point of view:

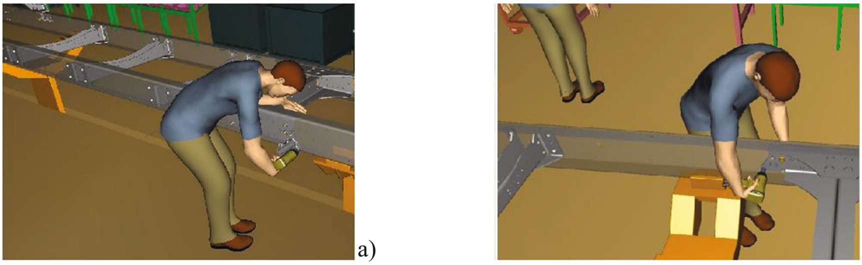
$$Y(X_1, X_2, X_3, X_4, X_5) \rightarrow \min \quad (1)$$

At the planning stage of the experiment, the boundary values of the factors were determined (Table 1).

Table 1. Boundary values of parameters

Parameter	Value	Description
X_1	0	Without changes
	1	With the change of assembly technology
X_2	0	Without changes
	1	The usage of more ergonomic equipment, tools and equipment
X_3	0	Inexperienced worker
	1	Experienced operator
X_4	5	Low height and weight
	50	Average height and weight
	95	High height and weight
X_5	0	Man
	1	Woman

After building models of Assembly operations for all combinations of factors ergonomic analysis was performed by using built-in tools Tecnomatix Jack and scientific methods of ergonomic analysis (Figs. 4 and 5): (1) the tool "RULA" (Rapid Upper Limb Assessment) – a quick evaluation of traumatic situations; (2) the tool "Lower Back Analysis" – analysis of load on the back; (3) the tool "OWAS Posture Evaluation" – evaluation of those provisions body of according to risk; (4) the tool "Fatigue and Recovery" – analysis at degree of fatigue and recovery; (5) the tool "NIOSH Lifting Analysis" – analysis of lifting tasks/lowering.



a) b)

Fig. 4. Checking of the technological effectiveness of the assembly operation: (a) securing the part from the outside of the frame, (b) securing the part from the inside of the frame

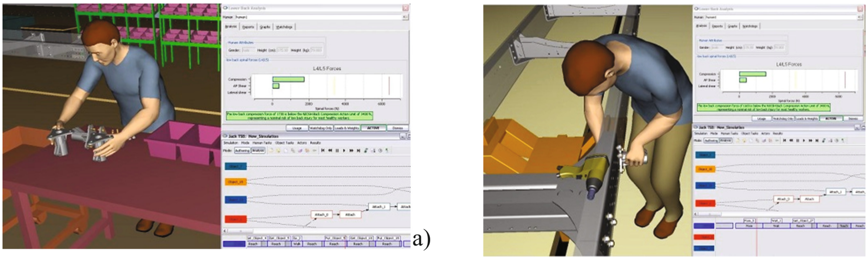


Fig. 5. Analysis of the back injuries in the state (a) «preparation of rear wing holders»; (b) «mounting the rear wing holders to the frame»

The results of the economic analysis are displayed in the summary Table 2.

Table 2. Summary table

Parameters		Solutions						Optimal solution
		$X_4 = 50$ $X_5 = 0$	$X_4 = 5$ $X_5 = 0$	$X_4 = 95$ $X_5 = 0$	$X_4 = 50$ $X_5 = 1$	$X_4 = 5$ $X_5 = 1$	$X_4 = 95$ $X_5 = 1$	$X_4 = 50$ $X_5 = 1$ $X_1 = 1$ $X_2 = 1$
Load on back H:	Rookie	1380,8 **(+37%)**	1148,7 **(+14%)**	1631,6 **(+62%)**	1143,0 **(+13%)**	1059,3 **(+5%)**	1514,6 **(+50%)**	1009,44
	Experienced worker	1380,8 **(+37%)**	1148,7 **(+14%)**	1631,6 **(+62%)**	1143,0 **(+13%)**	1059,3 **(+5%)**	1514,6 **(+50%)**	
Ergonomic evaluation:	Rookie	2,50 **(+22%)**	2,62 **(+28%)**	2,65 **(+29%)**	2,32 **(+13%)**	2,42 **(+18%)**	2,60 **(+27%)**	2,05
	Experienced worker	2,60 **(+37%)**	2,72 **(+33%)**	2,85 **(+39%)**	2,42 **(+18%)**	2,52 **(+23%)**	2,65 **(+29%)**	
Recovery time, sec.:	Rookie	28,2 **(+14%)**	26,7 **(+8%)**	27,3 **(+11%)**	26,4 **(+7%)**	26,7 **(+8%)**	27 **(+10%)**	24,6
	Experienced worker	28,8 **(+17%)**	28,5 **(+16%)**	29,1 **(+18%)**	28,2 **(+15%)**	28,5 **(+16%)**	28,8 **(+17%)**	

4 Conclusions

Analysis of activity of enterprises implementing strategies of production development, shows that only comprehensive solutions can lead to real improvements. This is consistent with numerous studies of different authors. Simulation modeling is an optimal method, that allow to compare at the design stage of production different variants of technological processes, to identify problem areas and choose the best solution. In addition, such models allow to conduct experiments for finding most effective and safe variations of organizing staff work. The results of simulation experiments revealed the best combination of input factors values that helped to improve each of factors, compared to existing solutions. In order to identify, if this combination of these factors is a best management decision, as it is established in the experiment on simulation model, it is necessary to perform a feasibility study of this solution, since financial costs is necessary for variations of some factors and also to develop measures for safe use recommendations.

References

1. Volling, T., Matzke, A., et al.: Planning of capacities and orders in build-to-order automobile production: a review. Eur. J. Oper. Res. **224**, 240–260 (2013)
2. Lemessi, M., Rehbein, S., et al.: Semi-automatic simulation-based bottleneck detection approach. In: Proceedings of IEEE WSC, 9–12 December 2012
3. Gundogar, E., Sari, M., et al.: Dynamic bottleneck elimination in mattress manufacturing line using theory of constraints. SpringerPlus **5**(1), 1276 (2016)
4. Gopalakrishnan, M., Skoogh, A., et al.: Simulation-based planning of maintenance activities by a shifting priority method. In: Proceedings of IEEE WSC, 7–10 December 2014
5. Tortorella, G.L., Vergara, L.G.L., et al.: Lean manufacturing implementation: an assessment method with regards to socio-technical and ergonomics practices adoption. Int. J. Adv. Manuf. Technol. **89**(9–12), 1–12 (2016)
6. McLean, R.S., Antony, J., et al.: Failure of continuous improvement initiatives in manufacturing environments: a systematic review of the evidence. Total Qual. Manag. Bus. Excell. **28**, 219–237 (2017)
7. Rane, A.B., Sunnapwar, V.K.: Assembly line performance and modeling. J. Ind. Eng. Int., 1–9 (2017). First Online: 02 March 2017
8. Santos, E.F., Santos Nunes, L.: Methodology of risk analysis to health and occupational safety integrated for the principles of lean manufacturing. In: Advances in Social & Occupational Ergonomics. AISC, vol. 487, pp. 349–353 (2017)
9. Gambatese, J.A., Pestana, C., et al.: Alignment between lean principles and practices and worker safety behavior. J. Constr. Eng. Manag. **143**, 04016083 (2017)
10. Zare, M., Croq, M., et al.: Does ergonomics improve product quality and reduce costs? Hum. Factors Ergon. Manuf. Serv. Ind. **26**, 205–223 (2016)
11. Kara, Y., et al.: An integrated model to incorporate ergonomics and resource restrictions into assembly line balancing. Int. J. Comp. Integr. Manuf. **27**, 997–1007 (2014)
12. Perez, J., Looze, M.P., et al.: Discrete event simulation as an ergonomic tool to predict workload exposures during systems design. Int. J. Ind. Ergon. **44**, 298–306 (2014)
13. Garcia-Herrero, S., et al.: Working conditions, psychological/physical symptoms and occupational accidents. Bayesian Netw. Model. Saf. Sci. **50**, 1760–1774 (2012)
14. Regazzoni, D., Rizzi, C.: Digital human models and virtual ergonomics to improve maintainability. Comput. Aided Des. Appl. **11**, 10–19 (2013)
15. Vinodh, S., Ramesh, K., et al.: Application of interpretive structural modelling for analysing the factors influencing integrated lean sustainable system. Clean Techn. Environ. Policy **18**, 413–428 (2016)
16. Dombrowski, U., Reimer, A., et al.: Occupational stresses on employees in lean production systems. In: Advances in Social & Occupational Ergonomics. AISC, vol. 487, pp. 215–226 (2017)
17. Widyanti, A., Larutama, W.: The relation between performance of lean Manufacturing and employee' mental workload. In: Proceedings of the IEEE International Conference on IEEM, 4–7 December 2016
18. Nadadur, G., Parkinson, M.B.: The role of anthropometry in designing for sustainability. Ergonomics **56**, 422–439 (2013)
19. Han, S.U., Achar, M., et al.: Empirical assessment of a RGB-D sensor on motion capture and action recognition for construction worker monitoring. Vis. Eng. **1**, 6 (2013)
20. Zunjic, A., Milanovic, D.D., et al.: Development of a tool for assessment of VDT workplaces – a case study. Int. J. Ind. Ergon. **42**, 581–591 (2012)