MODELING OF THE MANUFACTURING SYSTEMS STATE IN THE CONDITIONS OF THE LEAN PRODUCTION

KONSTANTIN DYADYURA[1], LIUDMYLA HREBENYK[1], TIBOR KRENICKY[2], TADEUSZ ZABOROWSKI[3]

[1]Sumy State University, Ministry of Education and Science of Ukraine, Sumy, Ukraine

[2]Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Slovakia

[3]Polish Academy of Sciences Branch in Poznan, Poland

DOI: 10.17973/MMSJ.2021_6_2021024

e-mail: tibor.krenicky@tuke.sk

This article investigates the hierarchy of the manufacturing system, which consists of a set of interrelated processes aimed at converting information, knowledge, energy, materials, and other resources into value for the consumer based on the principles of lean production. Modern manufacturing systems are becoming more and more complex to manage. The problems that need to be solved are associated with a significant number of time-varying parameters, large time delays, high non-linearity of processes, and a complex relationship between input and output parameters. Depending on the parameters of internal components and characteristics of external conditions, the state of manufacturing systems can change in an unpredictable manner. The paper considers many types of discrete states in which the system can be. The estimation of the probability of finding the manufacturing system in any of the given states was carried out using discrete Markov analysis. The article also presents the results of studies of possible transitions between states in which the production system is presented in the form of a transition matrix.

KEYWORDS

Lean production, value stream, manufacturing systems, manufacturing process, resource, markov techniques

1 INTRODUCTION

With globalization and the ever-increasing demands and expectations of customers and other stakeholders, organizations are forced to continually adapt and improve their business organization. A systematic approach is a guiding principle in solving existing and emerging problems. Organizations are participants in the creation and users of various systems. The system can be considered a product or services provided that ensure this product. There is a wide range of systems [Zaloga 2019], differing in terms of purpose, scope, complexity, scale, novelty, adaptability, quantitative characteristics, location, a fragment of a lifetime, and evolution. The modern development of technologies, including information technologies, allows the use of a large number of heterogeneous complex systems consisting of interacting subsystems, as a result of which they acquire emergent properties. Complex manufacturing systems, as a rule, include, in addition to a set of hardware, software, and operational personnel [Bochen 2009, Zaloga 2020]. Every system has a life cycle. The life cycle of a product and the life cycle of a system that is associated with it may have common stages and phases. Life cycles vary according to the nature, purpose, product and system use, and prevailing circumstances. Modern business seeks to ensure the sustainability of the system life cycle processes [Modrak 2020]. Complex systems are characterized by many states. Each state is determined by a specific set of parameters. A change in the values of parameters that characterizes a separate element of the system can lead to a change in the output parameters of the system as a whole and its state. The latter, along with the presence of complex functional dependencies, greatly complicates formalization in describing the processes of functioning of such systems. The Lean Manufacturing Management System (LMMS) is the control system in relation to the manufacturing system, ensuring the alignment of value streams with customer order streams. The work of the LMMS is aimed at continually improving the capabilities and flexibility of the manufacturing system. The LMMS like the manufacturing system can exist in various states, each of which is determined by a specific combination of the states of its elements. In the case of a large number of states and transitions when making decisions about system optimization, there is a high probability of errors and distortions. Markov analysis is one of the analytical methods that can be applied to any system to analyze its states. Despite the fact that from a theoretical point of view, the analysis of the state space is flexible and universal, solving difficult practical problems of integrating capabilities for manufacturing systems requires special methods. The functioning of any manufacturing system as a set of interrelated processes that transform information, knowledge, energy, materials, and other resources are determined by the needs of the consumer. The application of the concept of lean manufacturing in the functioning of manufacturing systems involves a certain way of thinking, considering any activity in terms of value for the consumer and reduction of all types of losses. With the development of modern industry, management objects become more and more complex. This creates many new problems that can be associated with a significant number of time-varying parameters, long-time delays, high non-linearity of processes, and complex relationships between input and output parameters. In the context of sustainable development, the information gathered about the manufacturing process of an industrial product is critical to the life cycle of that product and the organization of its production. The key to sharing information is ensuring data interoperability. Production management, taking into account the concept of lean production, is considered as a function of directing or regulating the flow of goods in the entire production cycle from the purchase of raw materials to the delivery of final products, including the impact on resource management. An original approach to multipurpose optimization of lean and resource-efficient manufacturing systems is proposed in the works of some authors [Solke 2018, Greinacher 2020, Mourtzis 2018]. In such systems, the assessment of production efficiency using the system of economic and environmental indicators, which is described in the works of some authors [Jordan 2019, Darestani 2019, Leong 2019], can be used in the development of a production process management system that relies on the concept of lean manufacturing. In some researches [Panda 2014, 2018a,b, 2019; Valicek 2016 and 2017, Macala 2009 and 2017; Pandova 2018, Flegner 2019 and 2020, Markulik 2016, Prislupcak 2014] developed a method for assessing the individual properties of a system, which allows determining the parameters of the operating state and longevity of functioning, including manufacturing systems. Some authors [Yılmaz 2020, Zhang 2019, Gelmez 2020, Razali 2020, Kopylov 2020] offered an interesting and accessible research tool that involves the creation of a value stream mapping (VSM) using estimates of lean manufacturing in combination with discrete event modeling. Some authors [Jbara 2019, Asokan 2020] used another compact conceptual approach – Object-Process Methodology (OPM), which is considered as an up-to-date methodology for modeling the components of complex, multidisciplinary dynamic systems and for decision support using information technologies. The relevance of the problem study ensuring the functionality of manufacturing systems is confirmed by numerous studies in this area, in particular, the works of other authors [Thomassen 2019, Arvidsson 2018].

The literature review shows that despite the interest of the scientific community and stakeholders in the field of manufacturing systems management, there is currently no comprehensive methodology for assessing the various states of such systems in time, which could take into account a specific combination and change in the parameters of its individual elements (personnel, equipment, physical assets, and materials).

Based on the above, attention should be paid to the existence of four characteristics of manufacturing systems that can be considered as challenges for further research: comparability, scalability, availability, and uncertainty of data on the systems states. Further research in this area is necessary to develop schemes for scaling the application of new advanced manufacturing technologies. From the point of view of the authors of this work, the use of Markov methods can increase the reliability of modeling events and states of manufacturing systems with subsequent use in the development of regulatory documents for the management of production processes.

The purpose of this work is to improve the management system for the life cycle of manufacturing systems, taking into account the concept of lean manufacturing based on modeling changes in the states of complex systems.

2 MATERIALS AND METHODS

This paper examines manufacturing systems that are used in the specific conditions to provide products and/or services to users and other stakeholders. The process segments that make up the manufacturing system create end-user value. Process segments are a logical grouping of personnel, equipment, physical assets, and materials required to create value. Groups of resources such as people, equipment, physical asset and material that are involved, available or not available for a given process segment at a particular time are considered as a process segment opportunity. Process segment object models are represented using UML conventions (notation) in accordance with ISO/IEC 19501:2005. Value defines the required classes of personnel, equipment, physical assets and materials, as well as the amount of other required resources. The UML model defines that a class can have zero, one or more properties. The interrelated processes/operations of creating and moving of Value are accompanied by a change in the states of material (raw materials, materials, components, parts and assembly units, finished products), information and financial flows. For research of manufacturing systems some requirements are accepted, which include conditions for compliance with the principles of lean manufacturing [Iranmanesh 2019]:

- stream organization of processes, in which the movement of products is carried out directly from the output of the supplier process to the input of the consumer process, bypassing delivery to the warehouse and delivery from the warehouse (while the delivery function is performed by the logistic processes);
- management of the process system through the main characteristics of Value stream (process performance, machine cycle and cycle times (τ), product inventories, cycle times of reverse processes, process availability factors);
- improving the system of processes and their constant adaptation to the changing flow of orders.

The concept of lean manufacturing covers all levels of Value stream, starting with the interaction of organizations in the supply chain: inter-organizational level (level 1), organizational level (level 2), level of organizational processes (level 3) and level of specific operations (level 4) (Fig. 1). Value creation implies the process of changing product properties (movement in the space of product characteristics, from the input of the process to its output). The transfer of value implies the transfer of products from the output of the previous process to the input of the next one due to logistic processes (movement in physical space).

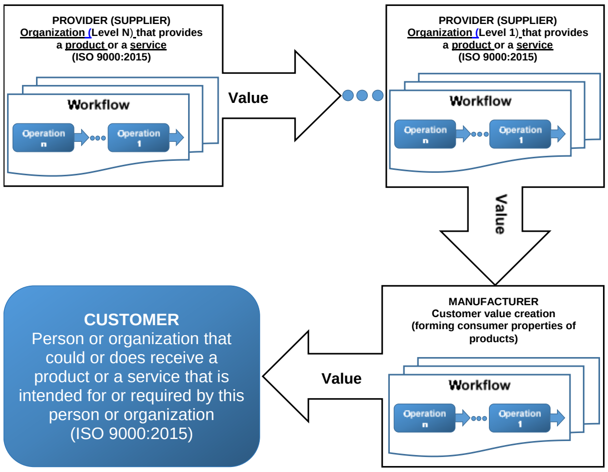


Figure 1. Value stream levels

Value stream (Fig. 2), which consists of elementary sequential or series-parallel chains (Fig. 3), including the processes of changing (creating) product properties and logistic processes of Value movement, is characterized by speed, continuity, uniformity, and is also accompanied by various types of losses. Processes/operations usually have different throughput. The concept of lean manufacturing should be harmonized with increasing the speed of Value stream, ensure its continuity, uniformity and eliminate waste. Equalizing throughput and synchronizing processes allows you to organize a continuous stream of Value creation and efficiently fulfill customer orders with the minimum required number of material and production assets in the shortest possible time (continuous processing without delays and expectations).

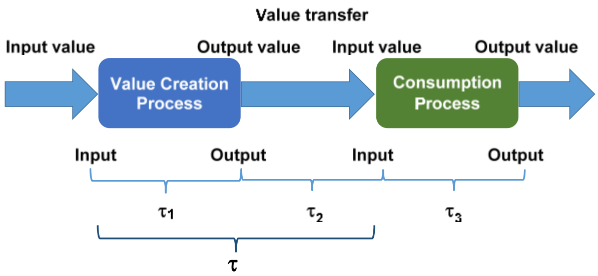


Figure 2. The structure of an elementary action to create and transfer of value (sequential chains)

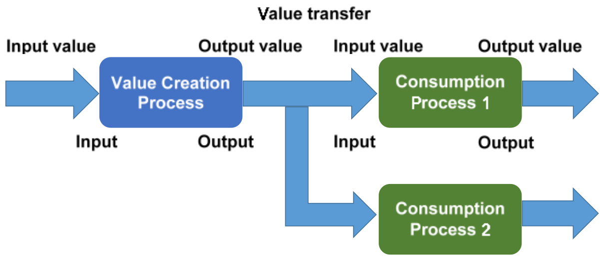


Figure 3. The structure of an elementary action for creating and moving value (series-parallel chains)

A flow occurs when a set of orders is formed as a sequence of orders with a certain period of time, consistent with the takt time of the processing system. The value stream is defined as the ratio of the value that crosses the output of the process to the time in which this value is created. The process adds value to the output to the value that has been delivered to the input of the process. The value stream characterizes the rate of value creation and its movement from the output of one process to the input of another.

The organization of the system of processes in the form of a value stream allows you to improve indicators of cost, speed, flexibility, level of losses, time production cycles, labor productivity, and also creates conditions for a systematic increase in organizational performance indicators and the basis for continuous improvement. Continuous improvement of the value stream is aimed at increasing the satisfaction of all business stakeholders (shareholders/owners, management, personnel, consumers/customers) and ensuring resilience to fluctuations in market demand by synchronizing processes and reducing losses both in the processes themselves and in the transition from one value creation process to another (reduction or elimination of redundant logistics, control/verification processes, actions with inappropriate products, process outsourcing).

Changes in state and transitions between them are a consequence of a different degree of reproducibility of the results of processes of manufacturing systems (effects that form the consumer properties of products, movement and consumption) under the same conditions. Analysis of the statechart diagram allows to determine what properties the resources (personnel, equipment, physical assets, and materials) will have for providing the required Value.

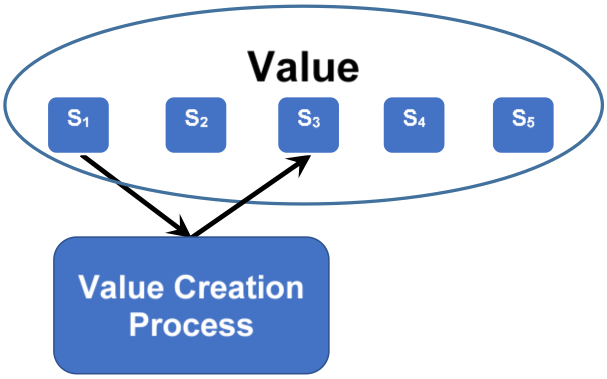
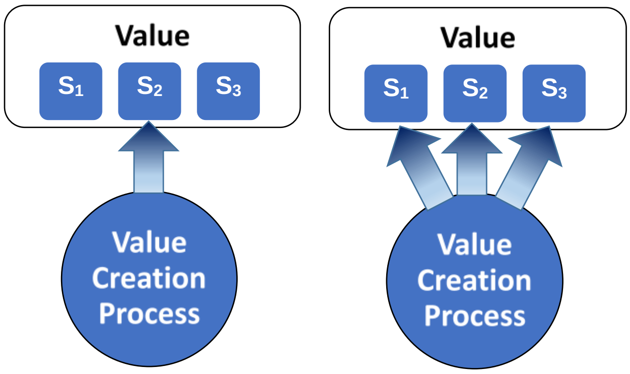


Figure 4. The state diagram of Value

Figure 4 shows a statechart diagram of variations of Value. Value can be in state S_1, S_2, S_3, S_4, or S_5. Value Creation Process changes Value state from S_1 to S_3. Value Creation Process with a resulting link that creates Value with n-states S_1–S_n (without specifying a specific state) means that the probability of forming Value in any particular state should be 1/n. In the diagram (Fig. 5a), the resulting relationship between Value Creation Process and Value having three states will mean that Value Creation Process can create each Value state with equal probability P_r = 1/3. The diagram (Fig. 5b) illustrates a more complex way of expressing the same situation. In general, the probabilities of a particular connection are not equal.

It is usually assumed that transitions between states occur at certain intervals with an appropriate transition probability (Markov chain with discrete-time). In practice, this most often occurs if the system is analyzed at regular intervals to determine its condition. In some applications, transitions are governed by exponentially distributed random time intervals with appropriate transition rates (continuous-time Markov chain). It. typically used for reliability analysis.

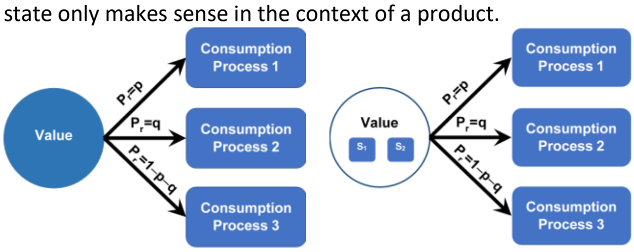


a) Value can be found in three different states: s1, s2, s3. Value Creation Process creates Value

b) Value Creation Process create states s1, s2 or s3 for Value

Figure 5. Equivalence the relevant and the resulting positions state-determining Value

Graphically, along with each "spokes" connections with probabilistic properties, there should be annotations in the form P_r = p, where p is transition probability is a numerical value of the probability or a parameter that should indicate the probability of the defining priorities among of a huge number of possible areas of engagement and implementation of concrete projects. The diagram in Fig. 6a illustrates particularly well the probabilistic consumer fanning relationship by which Value is consumed, with certain probabilities for Consumption Process 1, 2, or 3. The diagram in Fig. 6b represents the additional fact that Value can be in state S_2. The Value state means the space of product characteristics (quality, production time, service delivery time, reliability, safety, and others). Value state only makes sense in the context of a product.



a) Value is consumed by Consumption Process 1 with probability p, Consumption Process 2 is with probability q or Consumption Process 3 is with probability 1–(p–q)

b) Value in state s2 is consumed by Consumption Process 1 with probability p, Consumption Process 2 is with probability q, or Consumption Process 3 is with probability 1–(p–q)

Figure 6. Values, with or without defined states, as sources and receivers of probabilistic branching

In this work, for research on the manufacturing system, the methodology of state space analysis based on the methods of Markov analysis was used, which is a graphical representation of the functioning of the system and simulates aspects of the behavior of the system in time. A time-homogeneous Markov process is completely characterized by the matrix of transition intensities $Q = [\lambda_{ij}]$ and the vector of initial probabilities at the time $\tau = 0$. The transition rate λ_{ij} is determined by the productivity process. Productivity process Value stream is specified by the speed of elementary actions to create and move value into the stream.

$$\lambda = \frac{V_2 - V_1}{\Delta\tau}, \tag{1}$$

where V_1 is Value at the input of Consumption Process; V_2 is Value at the input of Value Creation Process; $\Delta\tau$ is the time of Value creation of in Value Creation Process and its movement to the input of Consumption Process (the time between the moments of two consecutive inputs of the processes). The probabilities of transition from one state to another in the time interval $\Delta\tau$ ($\Delta\tau$ is taken to be small) are given by the values $\lambda \cdot \Delta\tau$. The probabilities corresponding to individual states can be obtained on the basis of the transition matrix or by solving the differential equations. The graphical display of the transition intensity matrix is a statechart and transition diagram. Consider an ordered set of states Value S_0, S_1, S_2,..., S_k (Fig. 7). The object of management of the integrated quality management system and lean production is a system of interrelated processes.

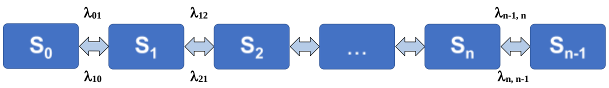


Figure 7. Sequence of Value states

It is obvious that for any moment the sum of the probabilities of all states is equal to one:

$$\sum_{i=0}^{3} p_i(t) = 1 \tag{2}$$

Then the probability Pr of the state s0 is determined by the expression:

$$P_r(S_0) = \frac{1}{1 + \frac{\lambda_{01}}{\lambda_{10}} + \frac{\lambda_{01}\cdot\lambda_{12}}{\lambda_{21}\cdot\lambda_{10}} + \ldots + \frac{\lambda_{01}\cdot\lambda_{12}\cdots\lambda_{n-1,n}}{\lambda_{n,n-1}\cdots\lambda_{21}\cdot\lambda_{10}}} \tag{3}$$

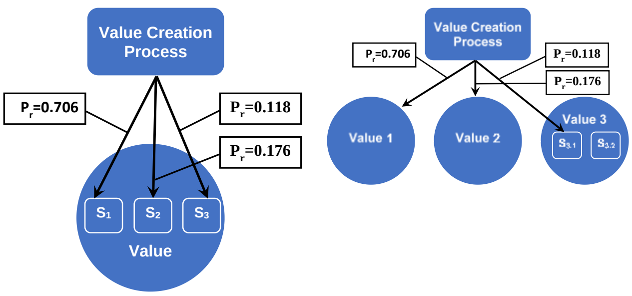
The formulas for determining the probability Pr of states S_1, S_2, Sn are below:

$$\begin{gathered} P_r(S_1) = \frac{\lambda_{01}}{\lambda_{10}} \cdot P_r(S_0), \\ P_r(S_2) = \frac{\lambda_{12}\cdot\lambda_{01}}{\lambda_{21}\cdot\lambda_{10}} \cdot P_r(S_0), \\ P_r(S_n) = \frac{\lambda_{n-1,n}\cdots\lambda_{12}\cdot\lambda_{01}}{\lambda_{n,n-1}\cdots\lambda_{21}\cdot\lambda_{10}} \cdot P_r(S_0) \end{gathered} \tag{4}$$

The degree of discreteness of data presentation is determined by their intended purpose. Each specific practical implementation may require its own degree of discreteness of data presentation for each state. To facilitate calculations, you should build a state diagram with the minimum possible number of states. The models in question are suitable for all categories of production processes/operations (maintenance, quality control, inventory management, inventory utilization, etc.) in accordance with IEC 62264-1:2013.

3 RESULTS AND DISCUSSION

Consider $P_1(t)$, $P_2(t)$, $P_3(t)$ is the probability that at time t Value will be in state 1, 2 and 3 in accordance with Figure 8. Using formulas 3 and 4 with transition rate $\lambda_{12} = 1$, $\lambda_{21} = 4$, $\lambda_{23} = 2$, $\lambda_{32} = 3$ (the values in question are abstract representations without indicating any special data types), we calculate that $P_1 = 0.706$, $P_2 = 0.176$, $P_3 = 0.118$. These calculations represent a general approach to managing a project or value creation process. Figure 8 presents options of probability that define Value state. Value is understood as what people want to own, use, what they want to consume, exploit, and what they want to exchange. The diagram (Fig. 8a) presents Value Creation Process, which can create Value in three possible states – S_1, S_2 or S_3 with their relevant probabilities 0.706, 0.176, and 0.118, which are indicated along each of the resulting "spokes" connections. The diagram (Fig. 8b) presents Value Creation Process that can create one of Value 1, 2, or 3 in state $S_{3.1}$ with probabilities specified along each of the resulting "spokes" connections. Value for the inner consumers is determined by the implementation of the requirements for the supply of products of the required quality, at the right time and place, in the required quantity. Value stream is formed as a repetitive sequence of value creation and movement from the inputs of the first processes to the outputs of the last, synchronized with the flow of orders, and is the result of the activity of a system of processes that create value and moving services in time and space from suppliers to consumers. Potential Value states are identified, analyzed, and considered to help ensure stakeholder compliance and provide alternatives for choosing the most beneficial course of action at any point in the product lifecycle. Throughout the product life cycle, bi-directional traceability is maintained between the needs and requirements of interested parties, between interested parties and sources, organizational strategy, problems and business or destination opportunities.

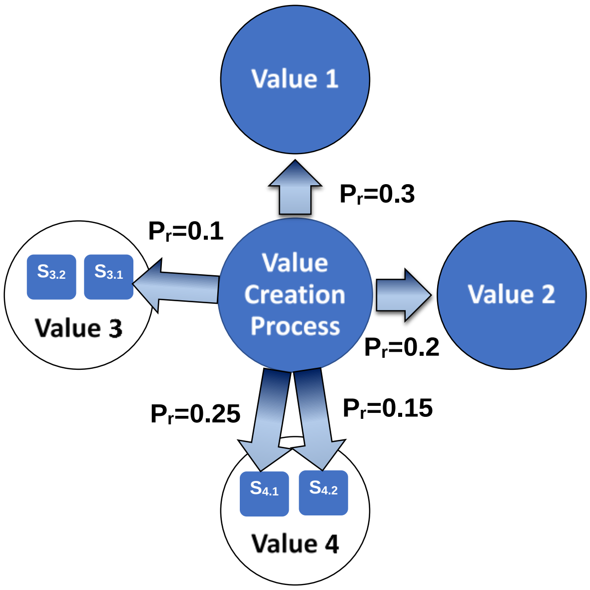


a)	b)
Value Creation Process creates Value in state S_1 with probability 0.706, Value in state S_2 with probability 0.176 or Value in state S_3 with probability 0.118. A similar deterministic case: Value Creation Process creates Value only in state S_1, S_2 or S_3.	Value Creation Process creates Value 1 with probability 0.706, Value 2 with probability 0.176 or Value 3 in state $S_{3.1}$ with probability 0.118. A similar deterministic case: Value Creation Process creates only Value 1, 2 or 3 in state $S_{3.1}$.

Figure 8. Creating a probabilistic state-determining Value

The diagram in Fig. 9 presents the probable resulting relationship by which the Value Creation Process creates Value 1, Value 2, or Value 3 in the $S_{3.1}$ state, or Value 4 is state in the $S_{4.1}$ or $S_{4.2}$ state $S_{4.2}$.

There is a wide range of manufacturing systems that differ in terms of purpose, scope, complexity, scale, novelty, adaptability, quantitative characteristics, location, lifetime fragment, and evolution.



Value Creation Process creates Value 1 with probability 0.3, Value 2 is with probability 0.2, state $S_{3.1}$ Value 3 is with probability 0.1, state $S_{4.1}$ Value 4 is with probability 0.25, state $S_{4.2}$ Value 4 is with a probability of 0.15.

Figure 9. Value State Sequence Model

The product life cycle model is formed as a sequence of Value states, which can be appropriately superimposed and/or repeated for the area of the considered manufacturing system, depending on scale, complexity, changing needs, and capabilities. The changing nature of impacts on the manufacturing system (changes in the environment, new opportunities for the implementation of system elements, changes in the structure and responsibilities in the organization) requires continuous analysis of Value states and decision-making for each use of process resources. By managing the many exogenous influences on the manufacturing system, the use of Value State Sequence models allows you to take into account the accumulated changes at each stage of the product life cycle. Value State Sequence Models in this paper can be used by any organization to acquire, use, create, or supply products. They can be applied at any level of the manufacturing system hierarchy and at any stage of the product life cycle. Organizations can apply this approach to modeling steady-state and add procedures, methods, tools, and to its provisions.

Organizations must implement value stream improvement based on planned risk actions. Improving the value stream must be considered with unconditional customer satisfaction and a guaranteed level of safety. At all stages of operating activities, it is necessary to ensure the search and reduction of losses in the value chain, aimed at continuous cost reduction.

For the implementation of most projects, it is necessary to change the scheme of the organization's processes (adding new ones, outsourcing, splitting, merging) or changing individual processes. The general requirement for the result of such changes is the observance of the principle of "built-in quality", i.e. such a state of the process, the risks of the appearance of nonconforming products in which do not exceed the predetermined ones. Based on the requirements of consumers for products and services, the organization should detail the requirements for the volume of production, the rhythm of production and supply, the size of the supplied batches, where applicable. The detailed requirements for products and services should be considered as part of the design input.

4 CONCLUSIONS

When designing products and processes, it is necessary to apply the principles, methods, and tools of lean production to find and reduce waste. Manufacturing systems that are built on the principles of lean manufacturing and are organized using a process approach to coordinate value streams, require continual improvement. To make informed decisions for the effective organization of processes at all stages of the product/service life cycle, reliable technical and economic information is required, which takes into account the change in the hierarchical structure of the manufacturing system in the context of varying stakeholder's requirements. The lack of unified approaches to assessing the dynamic behavior of the manufacturing system when internal and external conditions change leads to significant unjustified costs of information, material, and energy resources. To meet all stakeholder's requirements for the effectiveness of modern manufacturing systems, it is necessary to develop unified approaches that could reliably predict and manage processes at all stages of the product/service life cycle. The paper shows the advantages of using Markov analysis in modeling discrete states of processes in dynamically complex open manufacturing systems. The use of this approach based on state-transition diagrams allows controlling of the capabilities of processes to reduce costs, increase business profitability, reduce order lead time, and increase labor productivity. Despite the recognized advantages, this method has some limitations that range its use. In particular, the transition probabilities or the intensity of the transition between the states of the system can change over time. Moreover, it is difficult to predict the direction of subsequent changes in the conditions of degradation/adaptation of the system, or at the moment when the subjective component is included when managers make certain decisions. The modeling accuracy in these cases is determined by the availability of the necessary data, their constant replenishment, and verification. The research results may be of interest in the development of guidelines for manufacturing process managers and are intended to expand the arsenal of methodological approaches for future scientific research of the behavior of manufacturing systems. This approach will further be the basis for setting the overall goals of the organization in the field of quality and lean production.

ACKNOWLEDGMENTS

This work was supported by the projects VEGA 1/0823/21, VEGA 1/0226/21 and KEGA 025TUKE-4/2020 of Scientific Grant Agency of the Ministry of Education, science, research and sport of the Slovak Republic and the Slovak Academy of Sciences.

REFERENCES

[Arvidsson 2018] Arvidsson, R., et al. Environmental Assessment of Emerging Technologies: Recommendations for Prospective LCA: Recommendations for Prospective LCA. J. Ind. Ecol., 2018, Vol. 22, pp. 1286–1294.

[Asokan 2020] Asokan, V.A., Yarime, M., Onuki, M. A review of data-intensive approaches for sustainability: methodology, epistemology, normativity, and ontology. Sustain. Sci., 2020, Vol. 15, pp. 955–974.

[Bochen 2009] Bochen, J., Gil, J. Properties of pore structure of thin-layer external plasters under ageing in simulated environment. Construction and Building Materials, 2009, Vol. 23, Issue 8, pp. 2958-2963.

[Darestani 2019] Darestani, S.A., Shamami, N.H. Performance evaluation of lean production based on balanced score card method using ANP and SIR: a case from Iranian home appliance industry. OPSEARCH, 2019, Vol. 56, pp. 717–738.

[Flegner 2019] Flegner, P., Kacur, J., Durdan, M., Laciak, M. Processing a measured vibroacoustic signal for rock type recognition in rotary drilling technology. Measurement, Journal of the International Measurement Confederation, 2019, Vol. 134, pp. 451-467.

[Flegner 2020] Flegner, P., Kacur, J., Durdan, M., Laciak, M. Statistical Process Control Charts Applied to Rock Disintegration Quality Improvement. Applied Sciences, 2020, Vol. 10, No. 23, pp. 1-26.

[Gelmez 2020] Gelmez, E., Özceylan, E., Mete, S., Durmuşoğlu, A. An Empirical Research on Lean Production Awareness. The Sample of Gaziantep. JGBC, 2020, Vol. 15, pp. 10–22.

[Greinacher 2020] Greinacher, S., Overbeck, L., Kuhnle, A., Krahe, C., Lanza, G. Multi-objective optimization of lean and resource efficient manufacturing systems. Prod. Eng. Res. Devel., 2020, Vol. 14, pp. 165–176.

[Jbara 2020] Jbara, A., Bibliowicz, A., Wengrowicz, N., Levi, L.N., Dori, D. Toward integrating systems engineering with software engineering through Object-Process Programming. Int. J. Inf. Technol., 2020, p. 135.

[Jordan 2019] Jordan, E., Kusar, J., Rihar, L., Berlec, T. Portfolio analysis of a Lean Six Sigma production process. Cent. Eur. J. Oper. Res., 2019, Vol. 27, pp. 797–813.

[Kopylov 2020] Kopylov, M.V., Kleymenova, N.L., Bolgova, I.N., Lobacheva, N.N. Development of the Basis of the Quality Management System of an Enterprise Financial Activity on the Principle of Lean Production. In : Proc. of the Int. Science and Technology Conf. "FarEastCon 2019", 2020, 172, pp. 581–589.

[Leong 2019] Leong, W. D., Lam, H. L., Ng, W.P.Q., Chun, H. L., Chee, P.T., Sivalinga, G.P. Lean and Green Manufacturing—a Review on its Applications and Impacts. Process. Integr. Optim. Sustain., 2019, Vol. 3, pp. 5–23.

[Macala 2009] Macala, J., Pandova, I., Panda, A. Clinoptilolite as a mineral usable for cleaning of exhaust gases. Mineral resources management, 2009, Vol. 25, No. 4, pp. 23-32.

[Macala 2017] Macala, J., Pandova, I., Panda, A. Zeolite as a prospective material for the purification of automobile exhaust gases. Mineral resources management, 2017, Vol. 33, No. 1, pp. 125-138. ISSN 0860-0953.

[Modrak 2020] Modrak, V., Soltysova, Z. Management of Product Configuration Conflicts to Increase the Sustainability of Mass Customization. Sustainability, Vol. 12, No. 9, Art.No. 3610.

[Mourtzis 2018] Mourtzis, D., Fotia, S., Vlachou, E., Koutoupes, A. A Lean PSS design and evaluation framework supported by KPI monitoring and context sensitivity tools. Int J Adv Manuf Technol, 2018, Vol. 94, pp. 1623–1637.

[Panda 2014] Panda, A., Duplak, J. Comparison of theory and practice in analytical expression of cutting tools durability for potential use at manufacturing of bearings. Applied Mechanics and Materials, 2014, vol. 616, pp. 300-307. ISSN 1662-7482.

[Panda 2018a] Panda, A., Dobransky, J., Jancik, M., Pandova, I., Kacalova, M. Advantages and effectiveness of the powder metallurgy in manufacturing technologies. Metalurgija, 2018, Vol. 57, No. 4, pp. 353-356. ISSN 0543-5846.

[Panda 2018b] Panda, A., Olejarova, S., Valicek, J., Harnicarova, M. Monitoring of the condition of turning machine bearing housing through vibrations. The International Journal of Advanced Manufacturing Technology, 2018, Vol. 97, No. 1-4, pp. 401-411. ISSN 0268-3768.

[Panda 2019] Panda, A., et al. Development of the method for predicting the resource of mechanical systems. The International Journal of Advanced Manufacturing Technology, 2019, Vol. 105, No. 1-4, pp. 1563-1571. ISSN 0268-3768.

[Pandova 2018] Pandova, I., et al. Use of sorption of copper cations by clinoptilolite for wastewater treatment. Int. J. of Environmental Research and Public Health, 2018, Vol. 15, No. 7, pp. 1-12. ISSN 1661-7827.

[Prislupcak 2014] Prislupcak, M., Panda, A., Jancik, M., Pandova, I., Orendac, P., Krenicky, T. Diagnostic and Experimental Valuation on Progressive Machining Unit. Applied Mechanics and Materials, 2014, Vol. 616, pp. 191-199.

[Razali 2020] Razali, N.M., Rahman, M.N.A. Value Stream Mapping – A Tool to Detect and Reduce Waste for a Lean Manufacturing System. In: Proc. of the Int. Manufacturing Engineering Conf. & The Asia Pacific Conf. on Manuf. Systems, iMEC-APCOMS 2019: iMEC-APCOMS 2019, 2020, pp. 266–271.

[Solke 2018] Solke, N.S., Singh, T.P. Analysis of Relationship Between Manufacturing Flexibility and Lean Manufacturing Using Structural Equation Modelling. Glob J Flex Syst Manag, 2018, Vol. 19, pp. 139–157.

[Thomassen 2019] Thomassen, G., Van Dael, M., Van Passel, S., You, F. How to assess the potential of emerging green technologies? Towards a prospective environmental and techno-economic assessment framework. Green Chem., 2019, Vol. 21, pp. 4868–4886.

[Valicek 2016] Valicek, J., et al. A new approach for the determination of technological parameters for hydroabrasive cutting of materials. Materialwissenschaft und Werkstofftechnik, 2016, Vol. 47, No. 5-6, pp. 462-471.

[Valicek 2017] Valicek, J., et al. Identification of Upper and Lower Level Yield strength in Materials. Materials, 2017, Vol. 10, No. 9, pp. 1-20. ISSN 1996-1944.

[Yılmaz 2020] Yılmaz, Ö.F., Özçelik, G., Yeni, F.B. Developing a Customer Oriented Lean Production System Using Axiomatic Design and Fuzzy Value Stream Mapping. In Customer Oriented Product Design Intelligent and Fuzzy Techniques, Springer, 2020, pp. 151-168.

[Zaloga 2019] Zaloga, V., Dyadyura, K., Rybalka, I., Pandova I. Implementation of Integrated Management System in Order to Enhance Equipment Efficiency. Management Systems in Production Engineering, 2019, Vol. 10, No. 4, pp. 221-226.

[Zaloga 2020] Zaloga, V., Dyadyura, K., Rybalka, I., Pandova, I., Zaborowski, T. Enhancing efficiency by implementation of integrated management system in order to align organisational culture and daily practice. Management Systems in Production Engineering, 2020, Vol. 28, No. 4, pp. 304–311.

[Zhang 2019] Zhang, K., Qu, T., Zhou, D., Thürer, M., Liu, Y., Nie, D., Li, C., Huang, Q, G. IoT-enabled dynamic lean control mechanism for typical production systems. J Ambient Intell Human Comput, 2019, Vol. 10, pp. 1009–1023.

CONTACTS:

RNDr. Tibor Krenicky, PhD.
Technical University of Kosice
Faculty of Manufacturing Technologies with a seat in Presov
Bayerova 1, 080 001 Presov, Slovakia
e-mail: tibor.krenicky@tuke.sk