APPLICATION OF SIMULATION IN METALLURGY SUPPLY CHAIN OPTIMIZATION

JIRSÁK Petr[1], KRŠŇÁKOVÁ Lenka[1], JANČÍK Jakub[1], HOLMAN David[2]

[1]*VSE - University of Economics, Prague, Czech Republic, EU, petr.jirsak@vse.cz*
[2]*SKODA AUTO University, Mlada Boleslav, Czech Republic, EU, david.holman@savs.cz*

Abstract

This article focuses on combination of the Value Stream Mapping and computer simulation within metallurgy supply chain optimization. The authors´ aim is to build up a conceptual model and verify it so that impacts of supply chain optimization by means of lean concept could be properly identified. Production process planning and management in metallurgy is characterized by high size batches due to technologically-economic reasons. However, high size production batches could hardly correspond with current customer requirements as customers want to avoid holding a high level stock of incoming material in their warehouses and associated costs. Searching for optimal parametrization of an interface between supplier production and distribution process and customer requirements is an inevitable task today for companies out of the metallurgical sector. Thus, Value Stream mapping and computer simulation can enable identification of real opportunities for time and cost reduction in a supply chain and can help refuse insular solution that would only increase short term effectiveness and efficiency of one company to the detriment of other supply chain elements.

Keywords: Value Stream Map, simulation, stock, lean, metallurgy

1. INTRODUCTION

The aim of this paper is to outline conceptual model that helps to appraise actual supply chain performances in metallurgical sector corresponding with the idea of lean thinking. The model comprises of lean approach, Value Stream Mapping as an essential lean tool [1] and a simulation method. Metallurgical sector has quite specific nature of production and logistics processes unlike to other sectors being replenished from the metallurgic sector downstream of supply chains. This causes disturbances in their mutual interfaces. However, time based competition is critical competitive advantage among supply chains of today markets [2] even in metallurgical sector.

Suppliers of metallurgical companies are allocated in remote distances outside Europe with delivery time exceeding month while their customer delivery time is estimated to be within days. Thus, metallurgical companies store material within their inbound logistics unlike to their customer which are usually of European base and want to keep low level of stocks.

There are quite limited number of inputs in a metallurgical supply chain e.g. iron ore, scrap iron, limestone, coke, water, air, electricity that enter the process and are transformed into high number of outputs (products) e.g. tubes, pipes, rails, traverses, metal sheets, profiles, girders. Combination of grades, shape, sizes, heat treatments and surface treatments enables creation of thousands of SKUs. Such nature is quite different from customers of the metallurgical sector as they source hundreds or even thousands of part numbers (PN) from their suppliers to build up one product, which might have tens, hundreds or more of the variants.

In general, metallurgy production process embraces melting, casting and then forging, cutting, machining, etc.

Some of these process steps e.g. welding and casting are associated with high investment as the process is done in technically and technologically sophisticated apparatus devices of high value. Thus, they are commonly supposed to be in operation any time to bring benefits by means of produced volumes regardless actual quantity demanded. Moreover, change over times are quite lengthy (hours) and so high size batches are preferred to diminish wasted time of change overs and to increase value added time of production and so the process productivity.

Those production process steps of which transformation has to be done under the same condition due to technological specifications e.g. temperature to provide required quality of outputs or which has some technological limitations e.g. liquid metal cannot be stored, are quite closely linked into sub process clusters. However, outside these clusters it lacks integration and coordination which leads to establishment of work in process and buffer stocks due to different optimal batch requirements.

Concerning aforementioned features of metallurgic production process it could be concluded that the production process is technologically sophisticated whereas it is quite simple from logistic process points of view due to low number of inputs and simple material flows. Metallurgical production process is commonly high size batch oriented so that maximum insular utilization of resources is achieved to reduce cost per ton or piece. Thus, production process is prone to be of mass rather than lean orientation.

However, customers of metallurgical companies which are exposed to individual customized demand and also fierce competition cannot dare to discontinue material flow by high size batches within transportation and manipulation processes, frequent storing, reworking, inspection etc. Such companies require frequent deliveries of short delivery times and of small batches. Therefore, such inconsistency of flow and performances might occur in an interface in supplier customer relationships. Despite the fierce competition on supply side force suppliers to meet customer requirements e.g. time and frequency of delivery, batch size etc.

Nonetheless, it is not achieved by reduction of waste such as inadequate coordination and balancing of supplier and customer production and logistics processes, diversion form economies of scope, management of processes regarding external variability and reduction of internal variability etc. across supply chain. But, barriers in term of MUDA and MURA waste are overcoming by high cycle and buffer stocks being placed into the interfaces of a supply chain which are between two companies as well as between two process clusters inside one company.

Therefore, planning and materialization of production and logistic processes are realized and optimized insularly within each process regardless the previous and subsequent processes and supply chain elements.

Thus, metallurgy supply chains are characterized by symptoms of Mass approach within production and supply chain management processes.

Typically hereinafter drawbacks could be identified:

- production of high size batches,
- overstock,
- lack of material and information flow transparency and visibility,
- insular measuring of productivity,
- insufficient adherence to customer demand changes and requirements,
- rigid and demanding material and production planning,
- constant changes,
- overloaded people,
- occurrence of 9 source of waste.

Some of the aforementioned symptoms were identified within a production process across industrial and service sectors already long time ago particularly due to unprecedented success of Toyota Motor Company in 70s´ and 80s´. Since than many researchers and practitioners have devoted their time and resources to analyzing the Toyota Production System and comparison of their initial state and condition with other companies and sectors to identify applicability and impacts of transition from Mass to Lean. It was proved that companies adopting lean had better results than those that didn´t [1]. In 1996 new tool Value Stream Mapping (VSM) enabling mapping of value streams, particularly the scope of activities that should be managed and analyzed collectively to gain synergy in achieving mutual benefits, regarding value added, business value added, non-value added activity, lead tines, cycle times, change over times, EPEx, number of staff, WIP, tact, etc. was introduced by Womack [3]. VSM serves for identification diagnosis of symptoms, identification of desired state, implementation and maintenance of a new state [1]. The initial aim of VSM is to visualize material flow from final customer to the raw material supplier bringing the following benefits [4]:

- visualization of entire flow,
- visualization of relationship between material and information flow,
- visibility of decisions,
- identification of waste,
- establishment of common language,
- clarification of relationship between lean concept and particular lean tools,
- standardization of procedures in lean process improvement.

However, VSM is commonly used for mapping internal processes rather than entire supply chain as initially founders intended. It is due to prevailing of quick win narrow scoped lean projects e.g. 5S over improvements of complex process consisting of external suppliers, focal company and customers at least. Such simplification of lean and its tools commonly leads to improvements within narrow process scopes and doesn´t properly treat the interfaces between processes. Using VSM as a blue print for lean improvements enables significant benefits even in metallurgical supply chain such as 75 % of lead time and 5 % cycle time reduction [5].

VSM encompasses both material and information flow, however, lead time, cycle times and other lean indicators being measured in the focal process and expressed its in data boxes are only of material flow. Therefore, gained results could not properly reflect total lead time of the focal company which starts by identification of a material requirement and not by ordered or received material. Hence, material planning is not visible in a traditional VSM which hides the lead time that has to be covered either by stocks in a supply chain causing waste or by extension of customer delivery time which decreases supply chain competitiveness. The reason for that could lay in the fact that majority of practitioners considered planning as a value adding activity [6] and so it is not the object of reduction as it would worsen the lean KPI e.g. PCE.

Initiators of VSM emphasize that VSM should be created on site in operation and by simple tools such as pencil and paper [1] enhancing complete concentration on flows rather than on tools and also make simply changes of VSM drafts.

Benefits of VSM has been proved across industrial and service sectors [6], [7], [8] however, there are also possible negative impacts identified based on published papers dedicated to VSM: process measurements , people qualification, clarity of procedures, integration between processes, high product mix, process stability, product modularity, intuitive processes, production flexibility, map obsolescence and other problems [3].

It is highly important to follow guideline composing of three critical aspects: product, process and people to avoid failure of VSM and VSD application. Suitable products are those of initial stages of product life cycles falling into category A and being grouped with other products of the same nature regarding supply chain flow. Right product is the one which is stable, standardized and measurable. Proper person has to be skilled and qualified in VSM tools and should understand the role of VSM within company management system. [3]

The company processes are exposed to frequent changes due to customer requirement changes, product changes etc. Thus, initial maps created within on site analyses of operation and then developed in brainstorming meeting should be modeled in some simulation software so that several future scenarios could be simulated. The main reason is that simulation offers great advantage in capturing both stochastic and dynamic aspect of business processes [9].Based on previous text and depicted problems associated with metallurgical sector authors have formulated hereinafter conceptual model.

2. DESCRIPTION OF THE CONCEPTUAL MODEL AND SIMULATION MODEL

VSM has been proved as a powerful weapon in transition process from Mass to lean and significantly help overcome Muda, and Muri waste. However, authors want to confirm proposed conceptual model depicted on **Fig. 1** enabling incorporation additional aspects into transition from Mass to Lean concerning usage of VSM. Particularly, unlike to common practice across industries including metallurgy information flow is expressed within VSM but separately from the material flow without any impact on lead time. Thus, gained value stream map lead time hides a role and an impact of planning on supply chain processes. Authors propose to incorporate planning into material flow as an ordinary process step that is directly reflected in lead time. This step is labeled as vertically integrated VSM in **Fig. 1**.

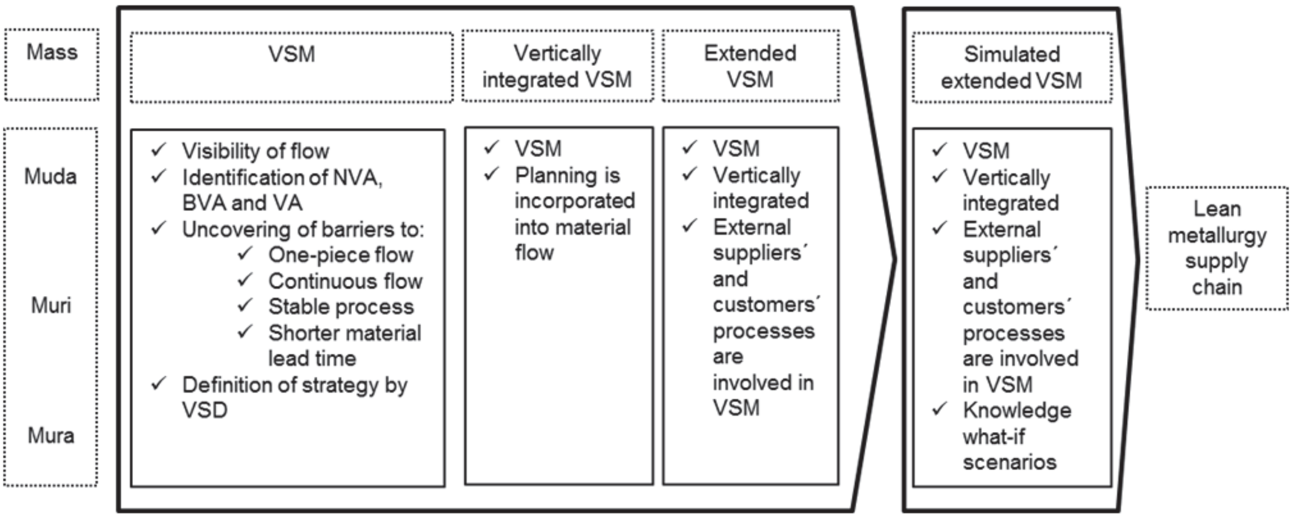


Fig. 1 Conceptual model

Moreover, VSM is commonly used in mapping of production and of quite narrow scope process so that the proposed changes and improvements arising from that could be quick win projects especially at the initial steps of transition from Mass to Lean. Furthermore, VSM is limited by direct visibility and scope of a particular silo or functional manager regarding real process interface that would enable holistic optimization. For instance, when a replenishment process of a production process is divided into three separated sub processes and hence three streams are created such as procurement, transportation and inventory management, application of lean tools is limited within these sub processes or ego battle among functional managers regardless real total benefits. Thus, authors propose cascade VSM that would guarantee overlapping of narrow level VSM interfaces by more general VSM ones. Such extension of scope id shown in **Fig. 1** under Extended VSM label. In addition to that, VSM is not only an operational short term lean tool enabling identification of waste that could be reduced quickly e.g. by implementation of 5S. VSM and particularly VSD is a strategic tool outlining transition from Mass to Lean. Today business world of frequent changes requires making scenarios about future condition in terms of customer demand, supplier performances, internal material structure or volume variability etc. Therefore, VSM and VSD should be combined with simulation as then it can identify complex system behavior under current state condition or under variety of possible future conditions. Hence, authors propose to combine extension of VSM with application of process simulation, see **Fig. 1**.

2.1. Simulation model

Presented supply chain simulation model embraces 3 companies named company A, B and C each consisting of the following processes: material planning, replenishment, production planning and manufacturing, storing and customer order replenishment. Company A represents metallurgical company and a company B and C acts as primary and secondary demand of the company A.

The model is graphically expressed on **Fig. 2**. Fundamental inputs and data used in simulation are expresses either in **Table 1** or in **Fig. 1**. Its structure corresponds with essential rule of value stream mapping models and is compliant with metallurgical supply chain. The model and the simulation is done in visual dynamic simulation software Witness provided by Lanner Group which is highly suitable for simulating logistic and production processes in order to optimize them. Witness is and objective oriented simulation software in which a model is built on by predefined objects (part, buffer, machine, labor, layout, conveyor, path, tracks, vehicles, variables, attributes, charts etc.) and rules. They help to connect all the objects of a particular model so that the model corresponds to the system which the model should represent. The main supply chain processes of the model are characterized aforementioned:

Demand - customers demand two products of different demand both of which has normal distribution nature, thus in 50 % of cases 160 pcs of product 1 and 80 pcs of product 2 is demanded. Customers demand products only throughout 8 hour shift per day. Detail of the demand pattern is expresses in **Table 1**.

Table 1 Simulation model demand characteristics

Shift							1
Simulation time [weeks]							48
Demand distribution patterns [%]	3	7	15	50	15	7	3
Relative demand value patterns to average daily demand [%]	70	80	90	100	110	120	130
Average daily demand product 1 [pcs]							160
Average daily demand product 2 [pcs]							80
Rate of annual demand decline [%]							10

The model is simulated under the condition of declining demand, particularly by 10 %, 20 % and 30 %, as then the impact of fixed costs such as of the planning process or of batch size changes are more visible. Moreover, today market environment is more compliant to unpredictable and frequent changes of ups and downs rather than continuous economic and also demand growth.

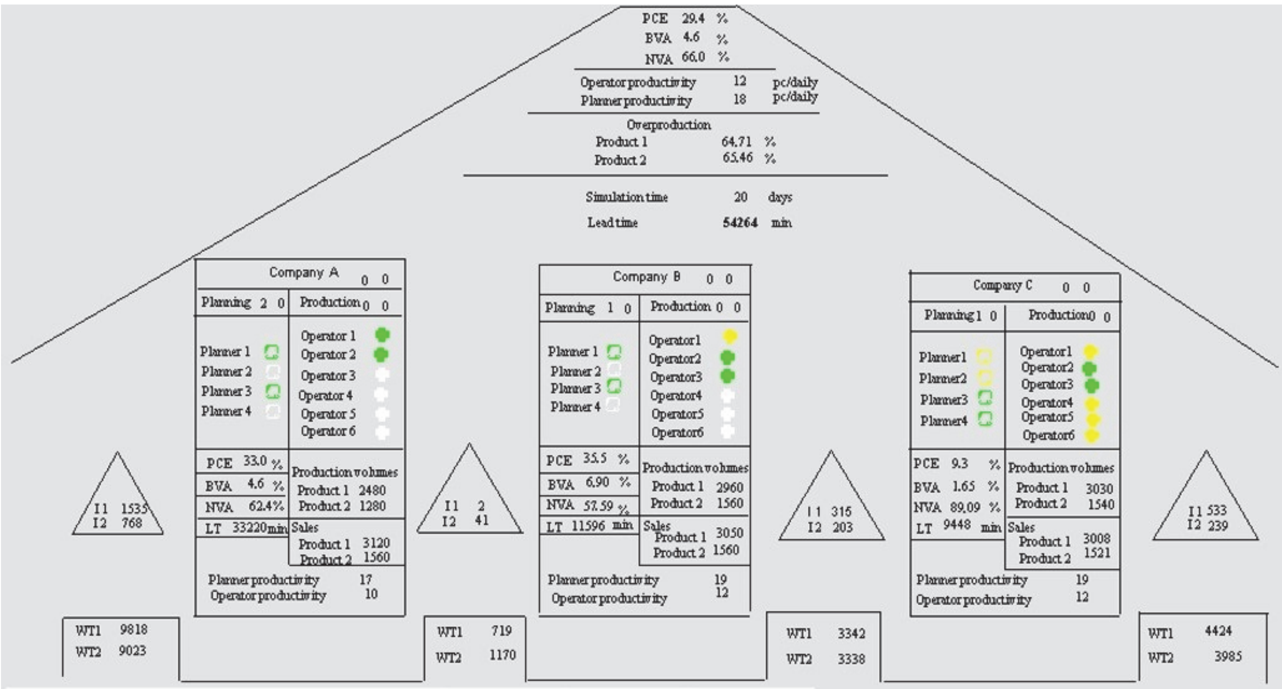
Customer order replenishment - supply chain end customers and company B and company C are replenished based on vendor managed inventory that is common in metallurgic supply chains as it enables overcoming of discrepancy between customer and supplier planning and operation practice. Thus, customers are replenished from a warehouse that is allocated at their facility and stock is replenished based on Re-order-point (ROP) concept and SLA agreement, 99 % in this model, between a customer and a supplier. Warehouse is expressed by triangle symbol between companies as used in VSM. This process is assigned to value added process.

Planning process - it is triggered when customer´s stocks fall below ROP, therefore material planning and then production planning is realized by means of two material and two production planners. Planning process is realized throughout two shifts a day, always by one material and production planner in each shift. Detail process data box is provided in **Fig. 2** below VSM. Planning process is considered to be business value added process.

Production process - this process is provided by 6 parallel work station with assigned production batch and changeover time between product 1 and product 2. Company A operates on 3 shifts, 2 operators in each of them. After finishing production process, outputs are delivered to a customer stock. Production process is measured as a value added process as a whole.

Storing - stocks between companies are based on vendor managed inventory concept, average level of supply chain stocks of each supply chain element is visible in VSM in **Fig. 2**. In addition to that model involves work in process (WIP) between replenishment and production process in each company.

Supply chain performance is measure by using lean KPI e.g. process cycle effectiveness (PCE), lead time, value added time, business value added time, non-value added time, productivity etc.



input/company	A	B	C
available time/shift	480 min	480 min	480 min
number of material planners	2	2	2
number of production planners	2	2	2
number of operators	6	6	6
P/T material planner product 1	3.2 min	3.2 min	3.2 min
P/T material planner product 2	3.2 min	3.2 min	3.2 min
P/T production planner product 1	3.2 min	3.2 min	3.2 min
P/T production planner product 2	3.2 min	3.2 min	3.2 min
P/T production operator product 1	9.6 min	9.6 min	9.6 min
P/T production operator product 2	9.6 min	9.6 min	9.6 min
C/O of operator	60 min	20 min	0.5 min
production batch 1	20 pc	10 pc	1 pc
production batch 2	20 pc	10 pc	1 pc
ROP outbound product 1	511 pc	511 pc	511 pc
ROP outband product 2	220 pc	220 pc	220 pc
Delivery time product 1	0.9 shift	0.9 shift	0.9 shift
Delivery time product 2	0.4 shift	0.4 shift	0.4 shift
inbound batch 1	1534 pc		
inbound batch 2	767 pc		
ROP inbound product 1	1128 pc		
ROP inbound product 2	564 pc		
Delivery time in product 1	5 days		
Delivery time in product 2	5 days		

Fig. 2 Simulation model description

3. APLICATION OF THE CONCEPTUAL MODEL

Authors have built up a simulation model and subsequently have simulated supply chain processes during 8 weeks, 5 days a week and 3 shifts each of 8 hours a day of operation. The model has been created regarding proposed conceptual model enabling application of VSM including planning process, extended supply chain scope and simulation of scenarios. The conceptual model has been verified for instance by testing the impact of batch sizes on supply chain performances and the impact of demand decline on supply chain performances which are presented here.

Increase of production batch is a common practice technique that is used by production managers to improve production process productivity as it reduces number of change over time and extends the actual time of operators´ time in operation. Results are shown in **Table 2**, current state proportion expresses the structure of the lead time. Due to the limited space here, the **Table 2** only involves results of the whole supply chain and not the detail ones of the company A, B and C. However, the model enables identification of impacts on both sides either on particular company of a supply chain or on the whole supply chain when a batch size is changed e.g. doubled in each of the supply chain party or halved as in this model.

Table 2 Impact of batch size changes

KPI	current state proportion [%]	after batch double sizing [%]	after batch half sizing [%]
VA	19	29.9	11.3
BVA	3	4.1	3
NVA	78	66	85.6
LT	1	7.90	-5.20

The simulation has confirmed that the increase of batch size has caused increase of value added time, consisting of production time, by 54 %. The reason could be found in an extension of production time and a reduction of change over times in the total lead time. Thus, increasing of batch size seems to be good managerial decision from the provided outcomes as value added time is improved. However, the negative impact in terms of extension of supply chain lead time by 7.9 % caused by stock level growth cannot be overlooked as time is a competitive force of today. Furthermore, it would lead to lower agility of such supply chain as the EPEx would be increased. Reduction of batch size has enabled reduction of total lead time by drop of stock, however, reduction of VA has been achieved. Hence, increase of production batch size can help report efficiency improvements but on the expenses of future competitiveness. Thus, the benefits in identification of real impacts of the aforementioned managerial impacts has been identified by using model based on the proposed conceptual model.

Furthermore, the model has proved that decline of demand unlike to mid-term and long-term forecast and so as to production and logistics plans results in overproduction growth by 4 % and extension of total lead time although the reported productivity of the production process in each company remains unchanged. The overproduction has increases by less than 10 % as the supply chain system works on ROP, thus it reduces the magnitude of demand fall on overproduction. However, the predetermined batch sizes and system parameters based on estimations have caused the 4 % overproduction growth. Therefore, the simulation model has also provided identification of demand change on supply chain performances.

Finally, VSM based on the conceptual model has helped identification of 3 % of the total lead time hidden in planning unlike to traditional VSM.

4. CONCLUSSION

The aim of this paper has been achieved by confirmation of the proposed conceptual model by means of identification of impact of the two changes in supply chain on total supply chain performances. The authors have identified fundamental aspects of VSM which should be incorporated into supply chain appraisal and improvement based on VSM. Thus, authors´ intension is not to quantify a particular impact of changes in supply chain on its performances but to clarify how VSM can be used to achieve significant benefits in today highly competitive environment. Particularly, conceptual model has been proposed and verified based on example of problems that are commonly solved within supply chain management. VSM, incorporation of planning process and combination of VSM and simulations can help numerous companies from metallurgic sector to make changes in their supply chain with sufficient knowledge about their impact not only on their processes but also on their direct and indirect customer of their supply chain.

ACKNOWLEDGEMENTS

This paper and associated research was carried out as a part of the project financed by Internal Grant Agency of University of Economics, Prague, IG305025 and Internal Grant Agency SKODA AUTO University No. SGS022015

REFERENCES

[1] ROTHER M., SHOOK J., WOMACK J., JONES D. Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA. Lean Enterprise Institute: Cambridge, 1999.

[2] HARRISON A., HOEK R.V., SKIPWORTH H. Logistics Management and Strategy: Competing through the Supply Chain. Prentice Hall: New York, 2015.

[3] FORNO A., PEREIRA F., FORCELLINI F., KIPPER L. Value Stream Mapping: A study about the problems and challenges found in the literature from the past 15 years about application of Lean tools. International Journal of Advanced Manufacturing Technology, Vol. 72, No. 5-8, 2014, pp. 779-790.

[4] MARTICHENKO R., GRABE K.V., WOMACK J. Building a Lean Fulfillment Stream: Rethinking Your Supply Chain and Logistics to Create Maximum Value at Minimum Total Cost. Lean Enterprise Institute: Cambridge, 2010.

[5] BRUNT D. From Current State to Future State: Mapping the Steel to Component Supply Chain , International Journal of Logistics Research and application, Vol. 3, No. 3, 2000, pp. 259-271.

[6] JIRSÁK P., HOLMAN D. Productivity of Lean Logistics System. Logistics & Sustainable Transport, Vol. 3, No. 1, 2012.

[7] MALINDŽÁK D. Application of Logistic Principles in Metallurgical Production. Metalurgija, Vol. 51, No. 3, 2012, pp. 345-348.

[8] SAMOLEJOVÁ A., LENORT R., LAMPA M., SIKOROVA A. Specifics of Metallurgical Industry for Implementation of Lean Principles. Metalurgija, Vol. 51, No. 3, 2012, pp. 373-376.

[9] HLUPIC V., VREEDE G.J. Business process modelling using discrete-event simulation: current opportunities and future challenges. International Journal of Simulation, Vol. 1, No. 1-2, 2005, pp. 72-81.