Operational Measurements for Evaluating the Transformation of Production-Logistics System and Their Reflecting in Simulation Software

Piotr Cyplik, Lukasz Hadas and Pawel Pawlewski

Abstract The aim of the article is to present performance metrics and indicators of a production-logistics system at the operational level and their use for evaluation purposes in simulation experiments carried out in Simulation Software. The authors reviewed logistics and production system performance metrics and indicators as arranged in the category of flow and stock management. A survey questionnaires served as a basis for investigating the evaluation of logistics and performance systems (a system of metrics and indicators) with a view to identifying the ways in which the requirements of companies could be met in this respect, i.e. how they have a real impact on the decision-making process (research sample—372 enterprises surveyed on the operational and tactical level). The final part of the chapter demonstrates the authors' evaluation system its and modeling in Simulation Software. In the conclusion, the authors offer guidelines on how to capture and analyze the results of simulation experiments to be able to satisfy the requirements of competition-driven market.

Keywords Transformation of production-logistics systems • Simulation software • Metrics and indicators for evaluation purposes • Operational level

1 Introduction

The process of creating goods and/or services through combination of material, work, and capital is called production. Production can be anything from production of customer goods, service production in consultancy company, music or energy production (Bellgran and Safsten 2010).

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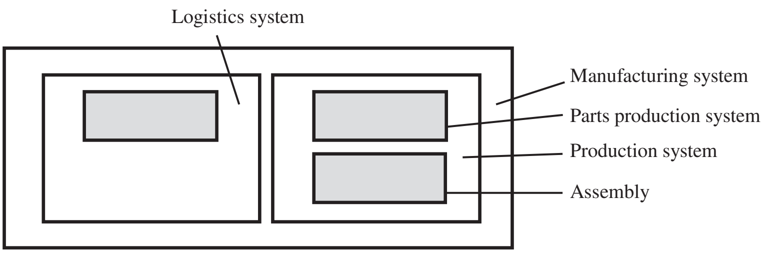

Fig. 1 A hierarchical respective on production system (*Source* Rogalski 2011)

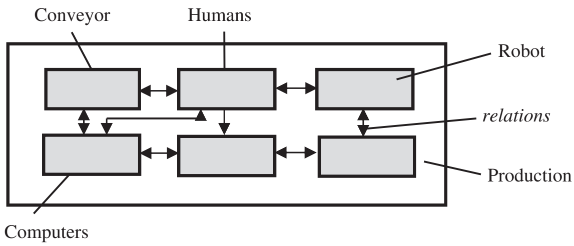

Fig. 2 Example of elements in production system (a structural perspective *Source* Rogalski 2011)

There is clear connection between production of goods and services. Consumption constitutes superior driving force for all production. Produced goods must in some way be distributed for consumption. Production of goods is therefore often of no interest, if not combined with production of services, as for example within the area of logistics (Rogalski 2011).

Production system is often used as synonymous with manufacturing system and assembly system. The Authors of this chapter assume a hierarchical perspective on the production system put forward by Bellgran and Safsten (Bellgran and Safsten 2010), as presented in Fig. 1.

Production system can be defined as by Eversheim (Eversheim 1992) as an "independent allocation of potential and resource factors for production purpose", which in addition to the elements of the technical production process, also includes organizational elements for the planning and controlling of the production process. Accordingly, it has a specific system organization that creates specific links between the elements of a production system in order to achieve the optimal factors combinations to complete the task (Kern 1980).

A production system comprise a number of elements between which there are reciprocal relations. Commonly mentioned elements are premises, humans, machines, and equipment (Löfgren 1983). Software and procedures might be added to the listed system elements according to Chapanis (Chapanis 1996). A structural perspective of a production system can be used to describe the different system elements and their relations, see Fig. 2.

Yet another dimension can be added to the description of a production system, namely a decision-making process. The decision-making process for a production

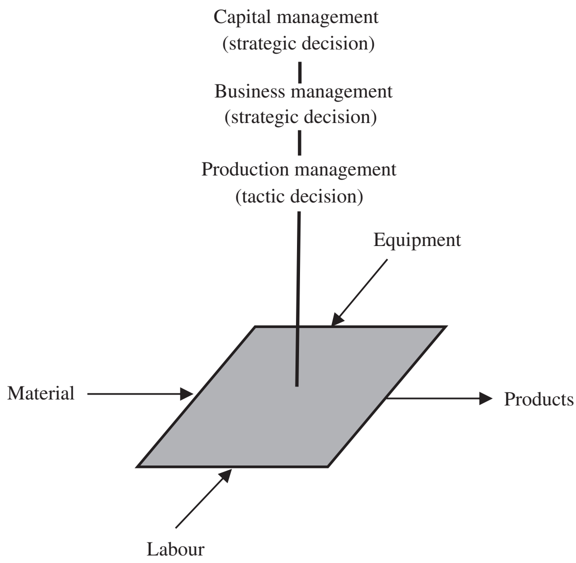

Fig. 3 Model of a production system including the decision making process (*Source* Rogalski 2011)

system adds capital management (owners), business management and production management to the description of a production system (Rogalski 2011), see Fig. 3.

Logistics activities in manufacturing companies can be divided into three fields: procurement logistics (in-bound), production logistics (in-plant) and distribution logistics (out-bound) (Baudin 2004).

The activities of production logistics are from dock to dock, meaning all activities from the receipt of goods to the dispatch. Its main purpose is to offer an efficient logistical support for production through material planning, i.e. planning, execution and control of material flows (Bullinger and Lung 1994).

Hence, efficient production logistics secures minimal inventory levels, short lead times, high flexibility of production and consistent (internal) customer orientation. Synchronization, flow and tact orientation, as well as the consideration of customer needs, are key requirements for eliminating wastes in form of excess inventory or waiting times due to material shortages (Droste and Deuse 2012).

On the tactical level a strong feedback between the production and logistics systems exists in each enterprise. A logistics system is a peer for a production system. They must both exhibit great similarities. Especially strong similarities ought to come into play in the area of planning. Irrespective of individual solutions applied in the field of production and logistics, both the systems are supposed to base their functioning on the same planning standard. This raises the problem of selecting a logistics strategy, understood as a general model of the functioning of the logistics system in an enterprise (Fertsch et al. 2010).

Based on these deliberations the authors assume that production-logistics system will be constructed as a set of elements of a production system, composed of premises, humans, machines, and equipment, software, procedures and the decision-making process, linked by mutual interrelations with a view to executing a logistics strategy and logistics system is understood by the authors as changes which are process and/or structural in nature. Process changes denote a modification in the operation of a production and logistics system as regards the mechanisms in control of material streams flow in order to meet the objectives of the logistics strategy which had been implemented. Structural changes denote a change in: type, number, location (arrangement into a layout) or capacity (throughput) of particular resources combining into production-logistics system. Structural changes are initiated by process changes (processes require resources) depending on the scope of individual works in process over time and their specialization (Boszko 1973).

Basic prerequisites for achieving an efficient production-logistics system are stability, transparency and standardization of processes (Droste and Deuse 2012). A multimodal modelling approach to manufacturing processes is an example of a major impact exerted by logistics processes on production processes. This concept defines a multi-layered model of behavior of a system of concurrent cyclic processes (Pawlewski 2014). Each process is “carried” by a physical system—in our case a logistics and production system.

A strong focus of production managers on logistics customer service as well as on lean and flexible qualities of internal and external supply chains along with cost pressures mean that at the operational level these managers evaluate production processes using measurement systems consisting of a set of both production and logistics metrics. This chapter demonstrates a selection of such metrics and indicators based on the study of the requirements of production company managers as well as a project involving mapping them in computer simulations.

2 Ratio Analysis

The main idea behind the ratio analysis is to measure the efficiency of the process. Process measurement may apply to three key elements

- input—information and materials on input,
- resources—resources used in the course of the process,
- results—the information and materials on output.

Ratio analysis is used for evaluating each of the above-mentioned attributes and process elements. The structure of metrics and ratios enables such an operation. Input data for calculating the value of a given metrics or ratio determine which process attribute will be evaluated.

Twarog (Twarog 2003) defines a metric as an economic and logistics category reflecting the events and facts pertaining to the company management and its environment, as expressed in certain units of measurement. In other words, a metric is a measure which characterizes a given phenomenon. Another definition Twarog (Twarog 2003) puts forward for a metric is that it is an economic category reflecting the events and facts pertaining to the flow of materials and related information in the company’s logistics system and in the supply chain. A metric is a relative number expressing a variable ratio of certain statistical values. From the point of view of logistics, metrics are used for measuring performance efficiency of logistics systems and for a quantitative determination of objectives. According to Kisperska-Moron (Kisperska-Moroń 2000), ratio analysis consisting in the use of logistics factors in measuring the performance of processes in enterprises or in supply chains requires defining a framework for measuring and analyzing the efficiency of logistics systems (the production system is included in the logistics system). The ratios should have an appropriate structure so that described results could be achieved. The features of a well-structured metric are as follows (Twarog 2003):

- adequacy—a metric should clearly reflect the situation in the organization,
- validity—a measurement should be valid in terms of time,
- relevance—information given by ratios should be relevant from the point of view of the organization,
- accuracy—the results of ratio analysis should provide the grounds for measuring processes and the system and for making decisions on this basis,
- scope—should include the highest number of states within the organization,
- comprehensiveness—should enable the evaluation of the system and processes right from their start (input) to the end (output),
- comparability—ratios should enable the comparison of processes over time,
- unification—ratios should be identical for as many processes in the supply chain as possible,
- comprehensibility—ratios should be understandable by both their authors and the reviewers,
- compatibility—ratios should enable the creation of a system of indicators,
- costs and profits—the costs of establishing the value of metrics should be justified in the terms of the metric's objective.

A system of logistics metrics and indicators must be created with the use of logistics approach. It must also reflect the essence of logistics. It is therefore necessary to connect the metrics in an arithmetical or logical way. The cross-referencing of indicators may occur on two planes (Pfohl 1998).

- phase—based on material flow phases (supply, production, distribution),
- systemic—based on logistics systems (inventory management, warehouse management).

3 Basic Operational Metrics and Indicators of a Production-Logistics System: Selection Method

The Authors suggested a three-staged method of selecting production-logistics system metrics and indicators for evaluating the system transformation:

1. Stage one—questionnaire survey on the use (if any) of production-logistics evaluation systems in enterprises—along with the extent to which they meet the expectations set for them (and have a real impact on decision-making).

Table 1 Number and volume of fractions in individual layers for surveyed enterprises from Group C—processing industry (based on the basic classification of activities employed by Central Statistical Office)

No. of subsets	Subset feature (employment)	Subset size (Nh) (number of enterprises)	Number of sample elements (nh)
1	0–9	282,839	121
2	10–49	26,025	11
3	50–249	6,461	3
4	≥250	1,466	1
In total		316,791	136

2. Stage two—expert selection of operational metrics for an in-depth study.
3. Stage three—carrying out an in-depth study of the relevance of individual metrics in the process of transforming a production-logistics system.

3.1 Stage One: Questionnaire Survey

The first stage involved conducting a questionnaire survey among production enterprises based in Poland. This phase was intended to identify state-of-the-art and relevant fact pertaining to the area under investigation. The scope of study is outlined below:

Objective scope of the study was to determine the extent, to which production-logistics evaluation systems are applied in enterprises along with the extent to which they meet the expectations set for them (and have a real impact on decision-making).

Subjective scope of the study—the survey was conducted among Polish enterprises belonging to Group C (processing industry), according to the Polish Classification of Activity employed by the Polish Central Statistical Office (GUS). The enterprises subject to the survey would be small, medium and large companies (as classified by GUS based on the number of employees).

Geographical scope—the Authors of this chapter were interested in Polish enterprises. The survey covered entire Poland.

Timeline—the first half-year of 2013.

The survey involved 372 enterprises, although the minimum size of the sample (with the maximum error of estimate at 10 % and confidence coefficient set at 98 %) was 136 enterprises, as divided into fractions presented in Table 1.

Table 2 answers to what extent the existing system for evaluating the production and logistics area in the enterprise (a system of performance metrics and indicators) meets its requirements—namely what is its real impact on the decision-making process at the operational level of management (impact on the daily performance specific functions).

The most common answers given by respondents to these questions was: I have no such knowledge (35.2 % of answers). It is an evidence of a lack or a gap

Table 2 To what extent the existing system for evaluating the logistics and production area (a system of metrics and indicators) meets the requirements imposed on it—namely what is its real impact on the process of decision-making at the operational level of management (daily performance of specific functions)

No.	Possible answer	Number of answers	Percentage of answers
1	Complete overview of the situation in the context of pursued strategy (global and functional) and the extent to which resources are engaged (machinery and human) as well as their costs (arranged into categories)	51	13.7
2	Knowledge on process total costs	42	11.3
3	Knowledge on the process results (the status/extent of on-time order delivery expressed as %: shipments, service, etc.)	52	14.0
4	General knowledge on the extent to which the resources are engaged (machinery and human resources)	57	15.3
5	No knowledge on the performance efficiency of executed processes at this level—no metrics and ratios clearly assigned to this level	22	5.9
6	No access to this management level	131	35.2
7	Not met at all, because there is no formalized evaluation system for this area from a strategic point of view	17	4.6
	Total	372	100

in knowledge on management systems at enterprises. General knowledge on the extent to which resources are used (machinery and human resources) was reported in 15.3 % of cases. 14 % of respondents has general knowledge on the results of realized processes (the status/extent of order delivery expressed as percentage of on-time shipments, service, etc.). A comprehensive view of the situation as regards the strategy implementation (global and functional strategies) and the extent to which available resources are engaged (machinery and employees) as well as the costs (arranged into categories) is held in 14 % of cases. Knowledge on the total costs of the process was reported by 11 % of companies. It should be stressed at this point that 4.6 % of respondents declared that no formalized evaluation system had been put in place for this area in their enterprise and 5.9 % of respondents lack any knowledge on the performance efficiency of the processes realized at this level—there are no performance metrics and indicators have been clearly assigned. The level of knowledge of surveyed enterprises regarding the evaluation system in the area of production and logistics is nowhere near satisfactory.

Another question concerned the tools and techniques applied in the enterprise for the purpose of assessing the production-logistics system. An analysis of the findings (Table 3) suggests that every fifth enterprise (72 of 372) has no formalized evaluation system deployed for this area.

Table 3 What tools and techniques are used by enterprises for evaluating the logistics and production system?

No.	Possible answer	Number of answers	Percentage of answers
1	SCOR model	10	1.5
2	Balanced scorecard (BSC)	34	5.2
3	Cost centre analysis (MPK)	235	35.7
4	Activity based costing (ABC)	32	4.9
5	Simulation tools	13	2.0
6	Internal system dedicated for process evaluation	248	37.6
7	None—no formalized evaluation system deployed in the company	72	10.9
8	Other	15	2.3
	Total	659[a]	100

[a]respondents could choose more than one tool or technique

In other enterprises an internal system dedicated for process evaluation is used in 37 % of cases, yet such solutions are not treated as objective. As regards other tools, the analysis of cost centers is quite popular (27 % of answers). The remaining tools and techniques can be regarded as being at the preliminary stage of implementation. What also comes to the forefront as regards the survey results is the popularity (between 10 and 20 %) of ABC method (16 %) and simulation processes (22 %) compared with SCOR (11 %) and BSC (9 %).

3.2 Stage Two: In-depth Study

The results obtained in the first phase had an impact on the second phase. Hundreds of performance indicators of the production-logistics system discussed in the literature on the subject (Supply Chain Operations Reference (SCOR®) Model, Overview—version 10.0, Supply Chain Council. http://supply-chain.org/f/SCOR-Overview-Web.pdf. Access April 2012) were analyzed based on interviews with managers (at companies having production and logistics evaluation systems put in place); as many as 46 indicators were shortlisted for further in-depth study. This phase was intended to provide a detailed (precise) picture of subject of study along with its distinctive features and situations.

The aim of the in-depth study conducted by the authors of this chapter on a group of 30 production and logistics managers working in the sector of machine production was to identify key performance assessment indicators currently used to assess the production-logistics system. The second aim of the study was to find out which of the indicators would production managers opt for if they had appropriate information and technological tools at their disposal. Yet another goal of the study was to answer the following question: changing the value of which indicators will directly affect corrective measures introduced by production managers? The research was based on basic assumptions of the Delphi method. The Delphi method is based on a structured process for collecting and distilling knowledge from a group of experts by means of a series of questionnaires interspersed with controlled opinion feedback (Adler and Ziglio 1996). Linstone and Turoff (Linstone and Turoff 1975) say that Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem. The method takes its name from the Oracle at Delphi, an ancient Greek soothsayer able to predict the future, and was originally developed at the RAND Corporation by Dalkey and Helmer (Dalkey and Helmer 1963) as a tool for forecasting likely inventions, new technologies and the social and economic impact of technological change.

The members of the expert team were not selected randomly. The authors of the research turned for help to experienced production managers (with a minimum of three years of experience in a managing position). The subjects analyzed were six big businesses, 18 small and medium-sized businesses, and six microbusinesses (in these cases of which the owners of the businesses were interviewed).

In order to conduct a study based on an in-depth interview, a study questionnaire was prepared. Considering the aim of the study, the most important part of the questionnaire was a table presenting the use of specific assessment indicators of production-logistics system (see Table 4).

Every manager was to be interviewed about 46 performance assessment indicators of the production-logistics system. The preliminary list of indicators had been prepared by the authors with reference to the literature (Twarog 2003) of the subject and their personal experience in this area. While preparing the list of indicators, proper care was taken to eliminate indicators of similar value (e.g. only one indicator was selected from a group containing Perfect Order, Vendor Delivery Performance, On Time In Full).

Descriptions of all listed indicators that were used in the questionnaire included a name of an indicator, its verbal definition and its calculation formula. Additionally, the managers determined how changes of the indicators currently used in their companies affected the decisions concerning implementing corrective measures into the production-logistics system. The authors of the study also analyzed the experts' opinions on the role of indicators, which are not currently used in the company, but which should be used according to the respondents.

After gathering research results from all the experts, steps to judge conformity of experts' opinions were taken (compare Table 5). With this end in view relative classification dispersion rate was used. The following formula depicts it (Martino 1970):

$$\mathrm{h_r} = \frac{\mathrm{k}}{\mathrm{k}-1}\left(1-\sum_{\mathrm{j}=1}^{\mathrm{k}} f_{rj}^2\right) \quad 0 \le \mathrm{h_r} \le 1, \tag{1}$$

where:

k Number of categories distinguished in the rth question
$\mathrm{f_{rj}}$ Frequency of occurring the jth category in the rth question

The formula measures conformity of experts' opinions, the closer h is to 0, the higher is conformity of experts' opinions.

Table 4 A sample table presenting the use of specific performance assessment indicators of the production-logistics system, completed by experts

Indicator: (name)					
Definition					
Formula					
	The influence of the indicator value on introducing adjustment procedures in the production- logistics system				
	None—the indicator in not used	Rather small—indicator of local importance, useless for decision making	Quite big—indicator helpful for decision making	Big—indicator important but not critical for decision making	Very big—key indicator for decision making
Currently used					x
To be used in the future					x

Table 5 Results of the expert opinion analysis for the vendor delivery performance (VDP) indicator

Indicator: Vendor delivery performance

Definition: shows the percentage of order completed on the first confirmed delivery date and in full

Formula: the number of orders completed on the first confirmed date and in full/the number of all orders to be completed within a specific period of time

	The influence of the indicator value on introducing adjustment procedures in the production-logistics system				
	None—the indicator in not used	Rather small	Quite big	Big	Very big
Currently used		1	3	2	24
To be used in the future			2	2	26

By judging experts' opinions conformity for VDP, relative classification dispersion rates were calculated in the following way:

$$h_{VDP,\,(1)} = \frac{5}{4}\left[1 - \left(\left(\frac{0}{30}\right)^2 + \left(\frac{1}{30}\right)^2 + \left(\frac{3}{30}\right)^2 + \left(\frac{2}{30}\right)^2 + \left(\frac{24}{30}\right)^2\right)\right] = 0.43 \tag{2}$$

$$h_{VDP,\,(2)} = \frac{5}{4}\left[1 - \left(\left(\frac{0}{30}\right)^2 + \left(\frac{0}{30}\right)^2 + \left(\frac{2}{30}\right)^2 + \left(\frac{2}{30}\right)^2 + \left(\frac{26}{30}\right)^2\right)\right] = 0.3 \tag{3}$$

These rates were calculated in an identical way for other indicators as well. Table 6 presents the classification of results for 46 selected indicators arranged according to the criterion of the impact of the indicator's value on introducing corrective measures into the production-logistics system. The table contains the most frequent experts' responses and the dispersion indicator value. Wherever two values are assigned to one indicator, it means that the number of experts' responses to the two criteria were identical.

The observations prove previous research that large enterprises use the most complex structure of performance assessment indicators of the production-logistics system, whereas the structure used by microenterprises is the least complex. It needs to be kept in mind, however, that for the first 15 indicators, managers of SMEs, as well as microenterprises considered the introduction of these indicators as necessary in the future. Relative classification dispersion rate is included in the range of $\langle 0,\ 1\rangle$. The lower its value, the greater the conformity of the advisors' opinions. The authors' conclusion based on the results is that for the first four indicators the compliance level concerning the significance of impact of the indicator value on introducing corrective measures in the production-logistics system is big. For the next 11 indicators, however, the compliance level proves to be acceptable (the dispersion rate for their use in the future is lower than 0.75).

Table 6 Results of a pilot study of preferences of the Polish production managers concerning the choice of performance assessment indicators of the production-logistics system

No.	Indicator	Currently used/to be used in the future	None—this indicator is not used	Rather small	Quite big	Big	Very big
1	Single order lead time	Currently used					0.43
		To be used in the future					**0.23**
2	Timeliness of the production process (Vendor Delivery Performance)	Currently used					0.43
		To be used in the future					**0.3**
3	OEE—overall equipment effectiveness	Currently used					0.46
		To be used in the future					**0.37**
4	DDT—Dock to Dock time	Currently used					0.49
		To be used in the future					**0.37**
5	Precision (quality of production planning)	Currently used					0.53
		To be used in the future					**0.49**
6	Stock intensity, namely the level of work-in-progress	Currently used					0.53
		To be used in the future					**0.53**
7	Cost of processing incoming order	Currently used					0.82
		To be used in the future					**0.58**
8	Cost of wrong deliveries or complaints caused by a wrong instruction	Currently used					0.74
		To be used in the future					**0.58**
9	Finished goods inventory turnover	Currently used				0.71	
		To be used in the future					**0.63**
10	WIP inventory turnover	Currently used					0.77
		To be used in the future					**0.68**
11	Inventory—percentage > X days	Currently used	0.81				
		To be used in the future					**0.68**
12	Obsolete inventory—%	Currently used	0.34				
		To be used in the future					**0.7**

(continued)

Table 6 (continued)

No.	Indicator	Currently used/to be used in the future	None—this indicator is not used	Rather small	Quite big	Big	Very big
13	Production process throughput	Currently used	0.85				
		To be used in the future				**0.7**	
14	Tact time	Currently used		0.85			
		To be used in the future				**0.73**	
15	Efficiency (intensity) of the flow	Currently used	0.88				
		To be used in the future				**0.73**	
…	…	…	…	…	…	…	…
46	Share of LT in DDT	Currently used	**0.80**				
		To be used in the future	**0.86**				

Table 7 Analysis of logistics states and of the entire production-logistics system

Performance measures/ratios	Logistics states		Entire production-logistics system (a mix of logistics states)
	Movement (flow)	Stock	
Reliability (timeliness of the production process)	√	X	√
Responsiveness (single order lead time)	√	√	√
Cost of processing incoming order	√	√	√
Stock intensity, namely the level of WIP inventory	X	√	√
Cost of wrong deliveries or complaints caused by a wrong instruction	√	√	√
Precision (quality) of production planning	√	√	√
Finished goods inventory turnover	X	√	√
Obsolete inventory—percentage	X	√	√
WIP inventory turnover	√	√	√
Production process throughput	√	X	√
Tact time	√	X	√
Dock to dock = lead time	√	X	√
OEE—overall equipment efficiency	√	X	√
Flow efficiency (intensity)	√	X	√

3.3 Stage Three: The Use of Logistics and Production System Performance Measures and Indicators for Analyzing Logistics States

A production and logistics of an enterprise with a diversified production structure, a wide range of products and multi-variant customer service strategy can be described by way of a combination of logistics states such as stock (warehousing) and movement (flow). Planning and shop floor control systems developed based on the planning logic such as MRP, JIT or TOC are also such a combination (Hadaś and Cyplik 2010) of the flow logic (push, pull) and buffering (stock buffer and time buffer), creating the company's manufacturing system. The system of metrics and indicators should enable a comprehensive analysis of logistics states in the course of the transformation of the production-logistics system with a view to enhancing its efficiency in using the resources (production criterion) and the level of customer service (logistics criterion) (see Table 7).

Performance measures and indicators differ in character; some of them refer only to "flow" or "stock" states and some of them apply to both. All of the metrics and ratios brought together evaluate the mix of logistics states in a logistics and production system of an enterprise.

4 Project of Reflecting Measures and Indicators of Efficiency of Production-Logistics Process in a Simulation Model

The Authors of this chapter developed a simulation model of an enterprise with a multi-divisional production structure, capable of processing a number of value streams (group technology) and pursuing a diversified customer service strategy. Simulation works were performed with the use of Simulation Software tool. Simulation Software is an advanced tool, which enables the execution of simulation experiments, which are a valuable source of information on the behaviour of dynamic production-logistics systems. Analysis methodology for such a production-logistics system was based on short-listed metrics and indicators selected by the managers at production companies. The project of reflecting all of the measures and indicators selected at the research level by the Authors required:

- Defining key input data (variable for particular simulation scenarios),
- The scope of mapping analyzed processes in the simulation model,
- The scope and logic of monitoring simulation parameters,
- The scope of reporting or calculating final performance measures and indicators (based on input and output data from Excel and Simulation Software).

Of course there are alternative methods of reflecting the parameters which describe the processes under review. The Table 8 shows the project of reflecting measures and indicators of efficiency of production-logistics process in a simulation model.

5 Summary

This chapter was aimed at presenting a set of performance metrics and indicators for evaluating the performance of a production-logistics system and showing a method of their mapping in the simulation environment. The data contained in Table 7 confirm that this objective has been accomplished. The set of performance metrics and indicators provides the basis for analyzing, in line with standard requirements, the application of a simulation tool in business practice for the purpose of analyzing the production-logistics systems in market conditions.

Further study will involve working on the results of the simulation of the behavior of a logistics and production system under transformation. The data contained in Tables 7 and 8 was used for simulation experiments mapping production-logistics processes; the following assumptions have been made for the purpose of further analysis:

- the results of the transformation of the production-logistics system states are known on a fixed control date (among others the status of production orders, the number of available machines, the size of work station buffer, etc.),
- states of production-logistics systems on fixed control dates are clearly defined, namely measurable.

Table 8 The project reflecting measures and indicators of efficiency of production-logistics process used for analyzing a production-logistics system in Simulation Software for the developed simulation model

Metric/indicator	Key input data	Key mapping in the simulation tool	Scope and logic of monitoring simulation parameters	Reporting and calculation
	Input data	Simulation program	Simulation program	Excel report
Single order lead time	Technological route, setup and process time	Production structure, parameters of production and logistics resources	Identification of the flow and storage of a single batch, lead time report for a single order	Archiving
Cost of processing incoming order	Cost data: Hourly rate of working and idle time of production and logistics resources	Production and logistics structure of an item under investigation	Resource working time (work, transport, changeover, etc.) Resource idle time (waiting to be processed)	Calculation in excel according to assumed settlement system of fixed and variable costs
Stock intensity, namely WIP inventory level	Key phases of the flow—“phases” of value stream, incrementing of the stream value	Production and logistics structure of entity under investigation	Identification of the value of input, output, length of stay (duration of) a given flow phase of the value stream for allocated streams	Calculation according to assumed unit of time (time scales), calculation according to incrementing value of inventory for respective phases
Value of wrong deliveries or complaints caused by wrong order instruction	Characteristics of probability distribution for individual phases of the decision-making processes	Expanding the flow model by a logical decision-making structure of order instruction & feedback	Monitoring the selection of paths with a specification inconsistent with deviation threshold	Percentage analysis of the selection of decision-making paths
Precision (quality) of production planning	Order schedule (quantity and right-hand deadline)	Production and logistics structure of a given entity	Monitoring order receipt time from production phases—inventory level	Calculation—value of order release time from right hand-side deadline

(continued)

Table 8 (continued)

Metric/indicator	Key input data	Key mapping in the simulation tool	Scope and logic of monitoring simulation parameters	Reporting and calculation
	Input data	Simulation program	Simulation program	Excel report
Finished product inventory turnover	Value of individual finished goods Schedule or probability distribution of the release of finished goods	Generator of the release from finished goods warehouse	Inventory level per individual finished goods	Calculation of the value of inventory level/sales figure
Obsolete inventory—%	Order schedule, schedule or probability distribution of release from finished goods warehouse, value of individual finished goods	Generator of the release from finished goods warehouse	Inventory level per individual finished goods Warehouse receipt time	Calculation, validity period, report date, warehouse receipt date, number of SKUs, value of SKU
Inventory—% > X days	Order schedule > X days	Generator of the release from finished goods warehouse	Inventory level per individual finished goods, Warehouse receipt time	Term input in warehouse, >X days
WIP inventory turnover	Order schedule, raw material value	Generator of the release from finished goods warehouse	Volume of release from finished goods warehouse	Calculation. Order schedule * value of raw materials/ volume of release * value of raw material
Timeliness of the production process	Order schedule (volume and right hand-side deadline)	Production and logistics structure of entity under review	Warehouse receipt time	Calculation—% number of orders with a "positive" receipt at the warehouse
Production process throughput	Mark-up	Production and logistics structure of an entity under review	Product units generated per hour	Mark-up * number of units / generated per h

(continued)

Table 8 (continued)

Metric/indicator	Key input data	Key mapping in the simulation tool	Scope and logic of monitoring simulation parameters	Reporting and calculation
	Input data	Simulation program	Simulation program	Excel report
Tact time	Technological route, setup and process time, time fund, order schedule	Production and logistics structure of an entity under review	Average work station time (cycle time)	Order schedule/time fund, tact time/cycle time
Dock to dock = lead time	Order schedule	Production and logistics structure of the entity under review	Warehouse release and receipt of material for an order	Archiving
OEE—overall equipment efficiency	Probability distribution of breakdown, shortage ratio	Production and logistics structure of the entity under review	Idle time, process time, setup time, break time	OEE calculation
Flow efficiency (intensity)	Technological route, setup and process time, order schedule	Production and logistics structure of the entity under review	Process time, setup time, Idle time, lead time	Process time total, setup time, per order/lead time

Based on the above mentioned assumptions for each predefined state of system on transformation control dates selected performance measures and indicators of the production-logistics system will be reviewed with the use of an expert method. The dispersion factor will be put to use after the review process—from the perspective of individual ratios. The aspects measured will be the relationship between the measure returned by an indicator on a fixed control date and the real state of the production-logistics system (this state is known thanks to designed simulation scenarios). The evaluation of the transformation process is equally important. It will be also possible to evaluate the effectiveness of suggested changes to the production-logistics system. Such a solution enables the creation of the final list of measures identifying the production-logistics system as well as its transformation efficiency.

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