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A Concept of Simulation-based SC Performance Analysis Using SCOR Metrics

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Abstract **– The paper discusses a common approach to describing and analysing supply chains between simulation specialists and supply chain managers, which is based on Supply Chain Operations Reference (SCOR) model indicators and metrics.**

SCOR is a reference model of supply chain business processes. It is based on best practices and used in various business areas of supply chains. Supply chain performance indicators are defined by numerous measurable SCOR metrics. Some metrics can be estimated with simulation models. For an efficient supply chain analysis, one should evaluate the conformity of SCOR metrics with simulation-based assessment of performance indicators.

Analysing projects in Supply Chain (SC) modelling area as well as analysing types of simulation results enables one to assess the conformity of the simulation-based performance indicators with SCOR model metrics of different levels.

Supply chain simulation modelling coordinated with the SCOR model expands the scope of simulation model applications for analysing supply chain performance indicators. It helps one estimate specific metrics with simulation results.

Keywords **– Performance measures, SCOR metrics, SCOR model, simulation supply chain, supply chain management.**

I. Introduction

To describe the supply chain (SC), professionals are recommended to refer to supply chain operations reference (SCOR) model. The SCOR model captures Supply Chain Council's consensus view of supply chain management. It provides a unique framework that links business process, metrics, best practices and technology into a unified structure to support communication among supply chain partners and to improve the effectiveness of supply chain management and related supply chain improvement activities [1]. The SCOR model is a descriptive one and may be used as a part of conceptual model for simulation-based analysis of dynamic behaviour of SC.

Supply chain simulation implies operating a model that suitably represents a supply chain. Simulation is an important tool to explain how supply chain performance indicators react in the face of controllable factors and environmental factors [2]. Simulation results after running models of this type make it possible to obtain estimates of various performance measures: productivity and throughput measures, resource utility measures, and service level measures [3]. The obtained simulation results are used for forecasting system behaviour or comparing two or more alternatives to organise the operation of the system [4].

As the goal of SC simulation analysis is to estimate performance indicators, these performance indicators should correspond to metrics introduced by the SCOR model. A range of papers (e.g., [5]) have indicated the necessity of effective communication among professionals in the area of supply chain analysis. Thus, identifying the compliance between SCOR model metrics and simulation results ensures the unambiguous interpretation of simulation results by SCM and simulation professionals. The choice of parameters and performance indicators of simulation model in accordance with SCOR metrics at the stage of conceptual modelling will allow creating a user-oriented tool for decision support in SCM.

II. Related Research

One of the topical studies dealing with the SCOR model and simulation is [6]. The authors introduce the process of SCOR template development for discrete event simulation software ARENA, as well as the application of this template for creating a model and obtaining simulation results. The simulation model is based on the processes of the SCOR model. As soon as SCOR processes are unified and described in detail, the process of simulation model creation is standardised and simplified as compared with a traditional approach. In the context, the traditional simulation approach, based on the concept of discrete-event system (DES), is adhered [7]. In [6], the authors demonstrate how the main disadvantage of the SCOR model, i.e., static nature, is overcome by the dynamics of ARENA simulation model. The authors conclude that their developed SCOR template is an effective tool for faster building of SC simulations. The provided solution is not generic, but the paper demonstrates that the SCOR model processes are rather accurately represented in a simulation model, and the analysis of a particular SC is automated. The authors provide a historical review of SCOR template development [8], [9]. Earlier versions of the template included only the processes of SCOR model level 2. The latest version has introduced level 3. The processes *Plan* and *Return* have not been considered. The latest version introduces examples of processes of level 3, such as *Make to Stock* and *Make to Order* (processes of level 3 in Source, Make, and Deliver). SCOR template-based simulation results provide performance measure estimates, such as *number of orders* and *inventory level*. At the moment, the SCOR model version 11.0 is actual, so the process *Enable* should be considered, as well as more attention should be devoted to SCOR model metrics [1]. The authors in [6], [8] and [9] continue the development of the SCOR model and simulation model association.

One of the first described attempts of implementing the SCOR model processes in simulation software is a dynamic decision support and management tool for supply chains named e-SCOR, developed by Gensym [10]. The tool architecture and functionality is described in [11]. The tool is used to design and analyse a supply chain, as well as determine SC validity. However, information about the software is insufficient at present.

There are some latest projects in the area of integration of SCOR and simulation models, e.g., described in [12]. The authors introduced an integrated platform supporting an end-to-end supply chain transformation named IBM SmartSCOR Platform. The platform comprises a number of modules for the analysis, including SCOR and other Supply Chain Council (SCC) reference models, as well as the SC simulator based on a discrete-event simulation engine. The SC transformations include both managerial activities and Information Technology (IT) oriented activities that are supported by the SmartSCOR Platform. The authors provided examples of Platform application for a transformation project of SC for a manufacturing enterprise, which gave a significant positive economic effect, and for an internal IBM project related to SC network rationalisation. Project at the time of this article was in the process of implementation. One of the important conclusions formulated by the researchers in the section *Supply Chain Process Analysis* was that the problem of inefficient business process modelling (BMP) application for an SC analysis is neither associated with the BMP approach itself, which is modelling-oriented, nor with simulation software, but rather with "in the process of understanding specific processes and expressing them in a logical way". Therefore, the authors proposed leveraging the existing simulation tools with reference models for better results. Better cooperation and result interpretation for business process diagnosis also implies the unified performance indicator framework.

The framework that follows the SCOR model and integrates discrete-event simulation software Arena and EXCEL spreadsheets is considered in [13]. The authors intended to facilitate SC simulation model construction by creation of reusable components. The proposed framework is implemented as a hierarchical three-level structure based on the SCOR model hierarchy. The first – highest – level is the simulation model; the second level is formed by SC participant submodels and the third level – by process submodels of each participant. The authors defined simulation modules corresponding to Process Elements and, therefore, these modules could be used for various types of SC configuration. The extensive information about simulation model is provided, as well as performance measures are described in detail. Simulation framework provides performance measures that exactly correspond to the SCOR model metrics. Both the simulation model and the performance measures were SCOR model-based, so despite the fact that the authors did not explicitly focus on the formulation of a conceptual model the concept was actually proposed.

To summarise the state of the art: there are a considerable number of articles and projects devoted to the merging of the concepts of the SCOR model and simulation. The authors mainly introduce frameworks where the SCOR model and simulation tool are cooperating with various strength of interaction, or create simulation models interpreting SCOR processes of the highest level as business processes. Most publications do not contain explicit recommendations about the use of the SCOR performance attributes to define the types of simulation results in the form acceptable for SC managers and simulation professionals. The suggestions on how to fill this gap on a conceptual level are provided in the following sections.

III. The SCOR Model in Conceptual Modelling for Simulation

A. SCOR Model Metrics

As mentioned before, the SCOR model is a standard tool designed for professionals to describe a supply chain. The SCOR model by definition is descriptive, qualitative and static. However, this model includes quantitative indicators for process quality of the SC. These indicators are the metrics of the attributes defined in Performance section of the SCOR model. Metrics measure the ability of a supply chain to achieve strategic attributes [1]. Metrics are organised as a hierarchy; lower-level metrics are used for metric diagnostics at a higher level. The metrics are fully determined at the third lowest level of the hierarchy.

B. Simulation in SCM

SCM addresses different types of problems according to the decision horizon concerned [14]. Not all of the problems can be solved using descriptive reference models. Complex problems in SCM, for example, cost optimisation, logistics facility location problems, or inventory management strategy choice in the SC, are often solved using operation research (OR) problem-solving techniques and methods [15]. Simulation is a recognised method of solving OR complex problems in various areas of human activity [15], [16]. The main advantage of simulation can be considered the ability of obtaining quantitative estimates of multi-factorial logistic strategies, taking into account SC dynamics. The present paper focuses on discrete-event simulation models in OR, further described as just "simulation". In a discrete-event simulation approach, the system dynamics is modelled as a series of discrete events, at which the state of the system changes [17], [18].

C. Conceptual Modelling for Simulation

The creation of a simulation model usually starts with the formulation of the problem, development of a conceptual model of the system or the process and input data collection. A conceptual model, according to Robinson [5], comprises not only model requirements relative to objects that are included or not included into consideration, determination of generic goals and objectives of the project and simulations in particular, but also identification of the model inputs (experimental factors) and model outputs (responses) [16]. In practice, the conceptual model usually combines heterogeneous models, i.e., descriptive, graphical models, diagrams of processes and logical diagrams and management algorithms.

The process of conceptual modelling also involves the creation of system description. System description is based on information about the real object associated with a specific problem. Reasonable assumptions and necessary simplifications are made for conceptual model formulation.

One of the main conceptual modelling principles is the creation of a model description. This document is essential for all project participants. The document may include both diagrams and text. The most important is that this document is intended for non-professionals in programming or modelling, it is clear both for SC managers or customers and simulation specialists. Thus, an informative conceptual model is a solution to avoid misunderstanding among professionals involved in various spheres of activity [16].

In "*A tutorial on Conceptual Modelling for Simulation*" [5], a clear definition of conceptual modelling is proposed: "the process of abstracting a model from the real world". In other words, the conceptual model gives an idea about what we need to include into a model and what not, and provides the definition of requirements to the simulation model.

D. SCOR Model Metrics and Quantifying of Simulation Models

In conceptual modelling, it may be difficult to identify a complete set of measurable criteria, since the model is purely descriptive at this stage [7]. As soon as an urgent need for such performance indicators meets the practical needs of researchers, designers or other users of the model, it is obvious that when formulating requirements for the selection of specific indicators, it is reasonable to adhere to the SC professional user-oriented approach. Therefore, the requirement to ensure consistency between the specific SCOR model metrics and parameters, inputs and outputs of the simulation model may be considered a reasonable one. This takes into account the statement that "the performance goals are defined according to the performance attributes defined in the SCOR model" [14].

E. Conceptual Modelling for SC Simulation

There is, in large measure, a vacuum of research in the area of conceptual modelling for discrete-event simulation [7]. Therefore, the present paper focuses on potential closing of this gap by discussing the simulation modelling of supply chains on the basis of process descriptions implemented in a discrete-event or discrete-time paradigm to meet the needs of decision support in SCM. The SCOR model is assumed an information source for modelling. The SCOR model can be used as an element of the narrative part of the conceptual model, and SCOR model metrics are recommended as a study of choice of input types and scope as well as types of performance indicators of the simulation model. The consistency of SCOR model metrics and simulation model parameters, inputs, and outputs is considered in the following sections.

IV. SCOR Model Metrics

Since the goal of the paper is to provide a unified vision of the performance indicators of the real supply chain and SC simulation model for SCM professionals and simulation specialists, let us consider the *Performance Attributes* of the SCOR model. Considering performance attributes implies devoting special attention to quantifying these attributes by using SCOR model metrics. Every SCOR model process owns attributes, each attribute with metrics of the first, second and third levels. Table I shows some examples of attributes and metrics corresponding to higher level processes.

Table I also gives an idea of the hierarchy of metrics. To assess the efficiency of the system, three levels of SCOR metrics are introduced. The upper level defines the generalised attribute characterising the operation of the SC as a whole, the lower level provides more specific attribute metrics.

For example, the attribute *Responsiveness* gives an idea about the estimated features of the SC, and the quality of the responsiveness is determined by the values of RS.1.1 – *Order Fullfilment Cycle Time* (*T*) metric.

RS.1.1 – *Order Fullfilment Cycle* Time (*T*) metric can be calculated using the formula:

$$T = \frac{x}{y}, \tag{1}$$

where x is the *sum of actual cycle* times *for all orders delivered* and y is a *total number of orders delivered*, units are days. The attribute gives an idea of the speed at which tasks are performed or the speed at which a supply chain provides products to the customer.

Considering this attribute and the corresponding metric in more detail gives an idea of the time of order movement through the system that is definitely associated with the performance measures of the simulation models. Simulation performance measures in more detail are considered in the next section.

Level 1 metric RS.1.1 – *Order Fulfilment Cycle Time* – is calculated as average cycle time for all orders delivered. Cumulative cycle time is calculated as the sum of particular cycle times, which are the metrics of Level 2, and finally each particular cumulative cycle time, e.g., production time or RS.2.2 – *Make cycle time* – metric value is calculated as the sum of all particular cycle times of a particular production cycle, which are the metrics of Level 3.

Level 3 SCOR metrics are described in detail for the needs of SC of different type, size and efficiency. A particular company requires only some of SCOR metrics, which are appropriate for this SC. In [19], the authors justify the choice of metrics needed for a certain case.

Therefore, the *Responsiveness* metrics provide an insight into the dynamics of the order movement along SC and can be used for the analysis of SC functioning quality.

Attribute that includes cycle time metrics implies a direct analogy, based on the method of calculating of these values, with the outputs of the conceptual model and performance measures of simulation models. There is less consistency between the other attribute *Reliability* and inputs of the conceptual model and parameters of the simulation model.

Reliability metrics represent the accumulated indicators of the quality of order execution.

If random factors, taking into account the quality of execution of the operation, are included into the simulation model, the quality of the operation is assessed by, for example, level 2 metric RL.2.4 – *Perfect condition* – which gives an estimate of the value of the corresponding probability. Interpretation of this metric as a probability of obtaining a good or poor result is based on the method of calculating of this value. The value can be used to determine the input of the conceptual model and, consequently, a parameter of the simulation model.

TABLE I
SOME ATTRIBUTES AND CORRESPONDING METRICS OF SCOR PROCESSES

ATTRIBUTE	LEVEL 1 METRIC	LEVEL 2 METRIC	LEVEL 3 METRIC
…	…	…	…
Responsiveness	RS. 1.1. Order Fulfilment Cycle time	RS.2.1 – Source Cycle Time	…
			RS.3.139 – Transfer Product Cycle Time
			…
		RS.2.2 – Make Cycle Time	…
			RS.3.114 – Release Finished Product to Delivery Cycle Time
			…
		RS.2.3 – Delivery Cycle Time	…
			RS.3.142 – Package Cycle Time
			…
		RS.2.4 – Delivery Retail Cycle Time	…
			RS.3.126 – Ship Product Cycle Time
			…
…	…	…	…
Reliability	RL. 1.1 Perfect Order Fulfilment	RL.2.1 – % of Orders Delivered in Full	…
			RL.3.35 – Delivery Quantity Accuracy
			…
		RL.2.2 – Delivery Performance to Customer Commit Date	…
			RL.3.32 – Customer Commit Date Achievement Time Customer Receiving
			…
		RL.2.3 – Documentation Accuracy	…
			RL.3.45 – Payment Documentation Accuracy
			…
		RL.2.4 – Perfect Condition	…
			RL.3.35 – Delivery Quantity Accuracy
			…
…	…	…	…

Therefore, the descriptive SCOR model provides the values of generalised performance measures of the SC as a basis for conceptual model formulation and parameter value determination of simulation model. The SCOR model also provides metric values that can be assumed the target values of functioning quality indicators of the SC. These quality indicators are based on benchmarking data in the reengineering of business processes, and the essence of reengineering is based on the analysis of practices [1].

V. SIMULATION-BASED ESTIMATIONS OF SUPPLY CHAIN PERFORMANCE MEASURES

The raw materials, products, information, and services are constantly moving in SC, and system permanently evolves over time. Thus, Supply Chain simulation models are dynamic. Furthermore, SC can have a huge number of random factors influencing its behaviour; as a result, simulation models incorporate randomness. In addition, the necessity to downsize the information volume about SC for simulation purposes results in discretization, and the system most commonly is analysed as a discrete-event system (DES) [18].

Most of SCs can be transformed into the simulation model through making valid assumptions and reasonable simplifications [20], [21]. The generalised approach to SC simulation results in simulation models comprising entities, attributes, process functions, resources, and queues. Moving objects within DES simulation approach are simulated entities. ‘Entities’ (e.g., customers) may be individualised by attributes. Entity process in the system consists of events and delays. During delay time, entity is either receiving service at some resource or waiting for service. Process functions define instantaneous actions for events, and both specified and unspecified delay times for entities [22].

The entity processes are described in general at the model construction stage, and then simulated according to model parameters at the model execution stage [22]. Model parameters may be interpreted either as simulation inputs or as experimental factors [16].

Based on the process concept, simulation models provide the accumulated results of particular entities, or observational results, as well as time persistent simulation results of processes. The examples of observational results are various cycle times and waiting times. Time persistent results are *work-in-process* (WIP), queue length, resource usage and other similar performance measures. To perform a thorough analysis, not only accumulated values are used but also several statistical measures, e.g., measures of central tendency, variation, confidence intervals etc., are employed.

VI. SCOR MODEL METRICS CORRESPONDENCE TO SIMULATION OUTPUTS AND INPUTS

The SCOR model is so versatile that it can be used at any stage of the simulation project: at the conceptual phase, modelling phase and at the experimental phase of a simulation project.

TABLE II
CONFORMITY OF SCOR MODEL LEVEL 2 METRICS WITH SIMULATION INPUTS AND OUTPUTS

ATTRIBUTE	LEVEL 1 METRIC	LEVEL 2 METRIC	SIMULATION INPUTS OR OUTPUTS
Responsiveness	RS. 1.1 – Order Fulfilment Cycle time	RS.2.1 – Source Cycle Time	Performance Measures
		RS.2.2 – Make Cycle Time	
		RS.2.3 – Delivery Cycle Time	
		RS.2.4 – Delivery Retail Cycle Time	
Reliability	RL. 1.1 – Perfect Order Fulfilment	RL.2.1 – % of Orders Delivered in Full	Parameters
		RL.2.2 – Delivery Performance to Customer Commit Date	
		RL.2.3 – Documentation Accuracy	
		RL.2.4 – Perfect Condition	
Cost	CO.1.001 – Total Cost to Serve	CO.2.001 – Planning Cost	Performance Measures
		….	
		CO.2.004 – Production Cost	
		….	
		CO.2.008 – Cost of Goods Sold	
Asset Management Efficiency	AM.1.1 – Cash-to-Cash Cycle Time	AM.2.1 – Days Sales Outstanding	Derived from Performance Measures
		….	
	AM.1.2 – Return on Supply Chain Fixed Assets	AM.2.4 – Supply Chain Revenue	
		….	
	AM.1.3 – Return on Working Capital	AM.2.6 – Accounts Payable	
		….	
		AM.2.8 – Inventory	
Agility	AG.1.1 – Upside Supply Chain Flexibility	AG.2.1 – Upside Flexibility (Source)	Derived from Performance Measures
		….	
	AG.1.2 – Upside Supply Chain Adaptability	AG.2.6 – Upside Adaptability (Source)	
		….	
	AG.1.3 – Downside Supply Chain Adaptability	AG.2.11 – Downside Adaptability (Source)	
		….	
	AG.1.4 – Overall Value at Risk (VAR)	AG.2.14 – Supplier's/Customer's/ Product's Risk Rating	
		….	
		AG.2.19 – Value at Risk (Return)	

Based on the Metrics section analysis [1], the most appropriate level 1 and level 2 metrics are displayed in Table II. SCOR model metrics can correspond both to simulation results (outputs), and parameters (inputs or experimental factors), as well as more complex metrics, technical and economic indices, can be derived from simulation performance measures. The compliance of SCOR metrics to simulation results seems natural, since both characterise the performance of the SC, e.g., RL.2.2 *Delivery Performance to Customer Commit Date* can be estimated by comparing the scheduled and simulated time of delivery to the customer. Metric RL.2.3 *Documentation Accuracy* can be interpreted in different ways for particular cases. This metric is evaluated as a simulation result, if events that cause the appearance of orders with inaccurate documentation are included in the process description of the SC. If such events are not scheduled in the model, then the observed value of this metric can only be used to determine the value of the random parameter. However, this parameter of delivery makes the simulation model more realistic.

It should be emphasised that of all the performance attributes *Responsiveness* and its metrics best of all fit simulation performance measures. The SCOR model *Responsiveness* is the speed at which a supply chain provides products to the customer. In simulation, the *cycle time* (CT) of a process is the average time entity of interest spends as WIP. The *total cycle time* is obtained as the sum of all delays, or all components of *cycle time* for every simulated entity. Thus, there is a direct correspondence between SCOR performance attribute metrics and typical discrete-event model output.

Level 2 metrics of performance attribute *Cost* match simulation outputs. Various *Cost* metrics provide SC monetary operating results. In general, simulation models do not estimate economic indicators. Some simulation programs, e.g., Arena by Rockwell Software, provide cost calculation during simulation run; such outputs can be attributed as optional.

Level 2 metrics of performance attribute *Reliability* describe the ability of SC to perform tasks as expected. *Reliability* focuses on the predictability of the outcome of a process [1]. In terms of simulation particular metrics, e.g., RL.2.3 *Documentation Accuracy* may be implemented as random factors influencing *production cycle time*. In turn, *production cycle time* performance measure corresponds to metric RS.2.2 – *Make Cycle Time* of performance attribute *Responsiveness*.

Performance attribute *Asset Management Efficiency* and its metrics can be associated with calculations based on simulation results, e.g., *cycle time* or *costs*. For example, AM.2.4 *Supply Chain Revenue* can be estimated by using a simulation result – accumulated throughput.

Agility is the performance attribute whose metrics cannot be directly associated with simulation model inputs or outputs. *Agility* is the flexibility of a supply chain in responding to marketplace changes to gain or maintain a competitive advantage [1]. Thus, this attribute value can be estimated through simulating scenarios that reflect market changes in complex simulation projects.

VII. CONCLUSION

Analysing projects in Supply Chain (SC) modelling area, as well as analysing types of simulation results enables one to assess the conformity of the simulation-based performance indicators with SCOR model metrics of different levels.

Supply chain simulation modelling coordinated with the SCOR model expands the scope of simulation model applications for analysing supply chain performance indicators. It helps one estimate specific metrics, using performance indicators provided by simulation models.

As the findings of the present article are of generic nature, it might be useful to continue the research by introducing a set of performance indicators, which correspond to SCOR model metrics, into case studies. Thorough analysis of SCOR model-based simulation results using, e.g., data mining techniques might provide deeper insight into SC performance and be the area of further research.

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