A MODELING FRAMEWORK FOR THE RESILIENCE ANALYSIS OF STEEL MILL LOGISTIC SUPPLYING SYSTEMS

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Abstract

The objective of this paper is to come up with a concept of dynamic resilience modelling for the complex logistic systems with the example of logistic system of metallurgical plant. Based on the assumptions of service engineering, we propose a general model of logistics system, consisting of two parts representing both, the inward and the outward logistics in steel industry. This dynamic model takes into account different possible disruptive events, especially disruption in supply process (upstream operations) and unforeseen changes in demand (downstream processes). As a measure of resilience we have taken the production loss (disruption impact) and the recovery time needed to return to the required performance level (disruption time).

Keywords: Resilience, multi agent, simulation

1. INTRODUCTION

The subject of the research is the logistic system of a steelworks located in Central Europe. Logistics processes concerning company's activities in the area of procurement of basic raw materials providing continuity of operation, inventories' levels control and maintenance as well as internal transport within plant's premises, were subjected to analyzes and researches. Each of the listed processes can differ from others from the point of view of character of changes and the level of its complexity. Each of these processes has high level of complexity of processes themselves, as well as limitations deriving from the specifics of performance of such kind of plants, restrictions deriving from legal regulations (long-term contracts, obligatory inventories' stocks, environment protection) and commercial agreements (contracts with suppliers and forwarders). Proper controlling of these processes can contribute to rationalization of costs connected with company's activity. In the times of market-economy, all decision making processes play the key role in managing a company or organization. The more and more complicated level of production and logistics processes, the growing competition or budget restrictions are some of the factors forcing the managements of companies to conduct continuous, dynamic and rational planning. Unfortunately, significant fluctuation in the demand for iron ore in many metallurgical companies can be seen [28]. The fluctuation is caused by variability of demand for metallurgical commodities. The primary reason is not only the ever increasing competition, but mainly the recent world economic crisis. Prediction of iron ore demand becomes extremely difficult in such situations. The regularity of deliveries of raw materials is an important factor in maintaining the continuity. Research has shown that assumed level of the stock does not fill out gaps, arising from different types of disruptions, in the supply of raw materials. Analysis of the historical data, regarding the real level of reserve of raw materials, has shown that company has not kept stocks at a required level [13]. Therefore, we propose the model for resilience evaluation of logistics systems based on resilience engineering. As a measure of resilience we have taken the production loss and the recovery time needed to return to the required performance level. The model has been verified on the example of a steel mill located in Central Europe.

2. RESILIENCE ENGINEERING

The word resilience means the tendency or ability to spring back (bouncing back), and thus the ability of a body to recover its normal size and shape after being pushed or pulled out of shape, and general any ability to recover to normality after a disturbance. It means to be able to withstand shocks and deviations from the intended state and go back to a desirable or acceptable state. The authors of ReSIST document [27] concluded that a useful meaning to apply to resilience for current and future systems is ability to deliver, maintain and improve service when facing threats and evolutionary changes. Their concern is often one of balance, as they see excessive emphasis on static means for achieving safety, designed in response to accidents, while they see a need for a culture of self-awareness, learning how things really work in the organization (real processes may be very different from the designed procedures), taking advantage of the experience in dealing with anomalies, paying attention to the potential for unforeseen risks, fostering fresh views and criticism of an organization's own model of risk.

Since for most systems of interest the resilient behavior is non-deterministic in practice, we are no longer interested in whether the system will rebound from a disturbance but in the probability of it successfully rebounding; or the distribution of the time needed for it to return to a desired state. Thus in fault-tolerant computing we talk about the "coverage" factor of a fault-tolerant mechanism, and we can talk about the distribution of the latency (time to detection) of a component fault or data error [5].

Resilience Engineering is the latest departure from the popular image in which the typical path to disaster is a single and major failure of a system component - very often the human. The understanding of how accidents happen has undergone a huge development over the last century [1]. Accidents were initially viewed as the conclusion of a sequence of events, which involved "human errors" as causes or contributors. This is now being replaced by a systemic view in which accidents emerge from the complexity of people's activities in an organizational and technical context. These activities are typically focused on preventing accidents, but also involve other goals (e.g. effectiveness, throughput, productivity, efficiency, costs) which means that goal conflicts can arise, always under the pressure of limited resources (e.g. time, money, equipment). Accidents emerge from a confluence of conditions and occurrences that are usually associated with the pursuit of success, but in this combination (each necessary but only jointly sufficient) able to trigger failure instead. The iceberg model proposes that there are a certain number of incidents for each accident, and a certain number of near misses for each incident, and a certain number of unsafe acts for each near miss. The average ratio used is 1 accident for 10 incidents for 30 near misses for 600 unsafe acts (1:10:30:600) [16].

Sum up, one is simply the recognition of the multidimensionality of resilience. For instance, Westrum [37] writes: "Resilience is a family of related ideas, not a single thing. The various situations that we have sketched offer different levels of challenge, and may well be met by different organizational mechanisms. A resilient organization under Situation I will not necessarily be resilient under Situation II (these situations are defined as having different degrees of predictability). Similarly, because an organization is good at recovery, this does not mean that the organization is good at foresight".

The resilience model proposed in this work is based on a typical course of a service delivering process, interrupted by an occurrence of a threat leading to a disruption of the process continuity. Although the idea of vulnerability and resilience were introduced relatively recently, it appeared until now in area of engineered systems many serious studies, both theoretical and practical [1], [2], [3], [12], [15], [19], [29], [31]. Also in the area of logistics and supply chains has published a significant number of interesting works (e.g. [10], [11], [16], [18], [20], [23], [24], [25], [32], [33], [34], [35]). The common denominator of these works is, in our opinion, a process continuity oriented approach. This approach has been the subject of several our works (e.g. [6], [7], [8], [9] [13]).

3. RESILIENCE METRICS - A TWO-DIMENSIONAL APPROACH

We proposed the following basic definition of the main terms:

- Continuity - a system capability to deliver products or services at acceptable predefined performance level under the real work conditions (e.g. despite disruptive events).

- Disruptive event - an act of delaying or interrupting the process continuity (e.g. system failure, natural catastrophe, man-made fault).
- Vulnerability to a disruptive event - the degree to which a system is affected by a disruptive event. Vulnerability metric - expected loss given a disruptive event (e.g. disruption impact and disruption time).
- Resilience to a disruptive event -the ability of a system to absorb and withstand the disruption impact, and still continue to deliver products or services at acceptable predefined performance level.
- Resilience metric - a collective term describing “antivulnerability” of a system given a disruptive event.

Based on these assumptions, on the operational framework for resilience developed by Department of Homeland Security [17], and on the ideas described in [14], [21], [22], [26] we propose a general model of system operation in the case of disruptive event occurrence. The graphical interpretation of this model is shown in **Figure 1**.The thick line shows the course of an idealized system operation as changes its performance in function of time. Prior to the occurrence of a disruptive event the system was functioning at the recommended level of performance. Immediately after the occurrence of a disruptive event follows a sharp decline in system performance, until they reach a minimum level of performance PM. With the capacity to absorb the effects of a disruptive event system maintains its basic functions and gradually increase its performance. After the time $T_D(P_R)$ it achieves a requires performance level (indicated by dashed lines), which may lie between the acceptable performance level (indicated by dotted lines) and the recommended performance level (indicated by a solid line). A quantitative measure of the system resilience, according to our proposal, it is ordered pair (duplet): the total loss of performance caused by a disruptive event - disruption impact $C_D (P = P_R)$, and the time needed to return the system to the required level of performance - $T_D(P = P_R)$. Loss of performance is proportional to the area between the line showing the required performance and the actual course of the performance.

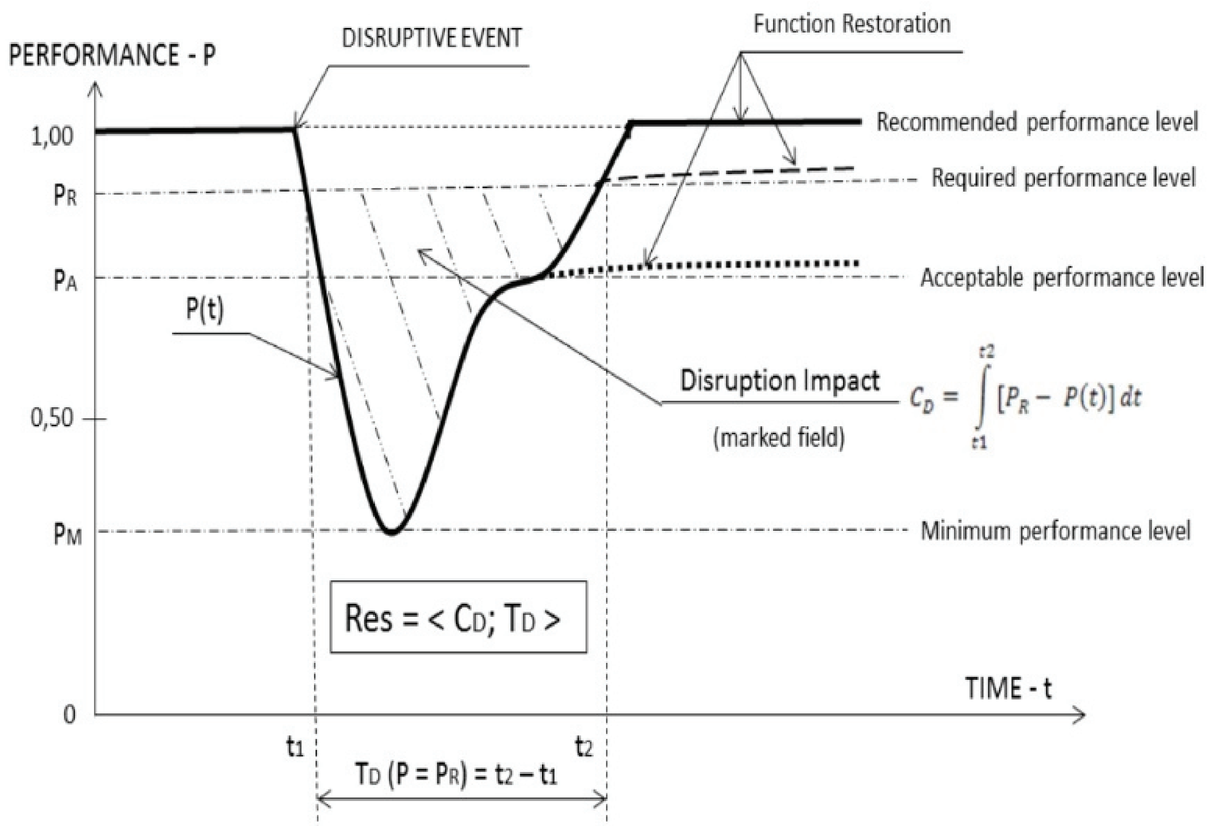

Figure 1 Disruption time history with resilience metrics

As shown in **Figure 1**, this loss is greater if the required performance level is located at P = 1.00 (100%), or less if we accept the lower level of performance (e.g. 80%). General metrics for resilience can be described by two-dimensional variable (duplet):

$$Res = \langle C_D\, ;\, T_D \rangle \tag{1}$$

with:

disruption impact:

$$C_D = \int_{t1}^{t2} [P_R - P(t)]\, dt \tag{2}$$

disruption time

$$T_D = T(P = P_R) = t_2 - t_1 \tag{3}$$

and required performance level

$$P_A \leq P_R \leq P_{1,00} \tag{4}$$

where:

$P(t)$ - performance level at the time t, t_1 - begin of disruption, t_2 - end of disruption.

4. STELL MIIL LOGISTIC SYSTEM RESILIENCE - CASE STUDY

The problem of disturbances in the supply of raw materials was analyzed and modelled and simulated in the papers [9], [13] with use of Agent Based Modelling (ABM). Agents are decision-making elements, and disturbances is modeled in the form of in supply disruptions (inward logistics - representing upstream operations), as well as demand variability (outward logistics - representing downstream processes). Disturbances tend to be rare random events, however, have a significant impact on the functioning continuity of the logistics system, especially at the operational level. Consideration of such cases is possible by combining different modelling methods, namely the method of system dynamics, discrete event simulation and agent-based techniques. **Figure 2** shows the model of logistic system of the steel mill using agent-based techniques implemented in in AnyLogic Simulation Software.

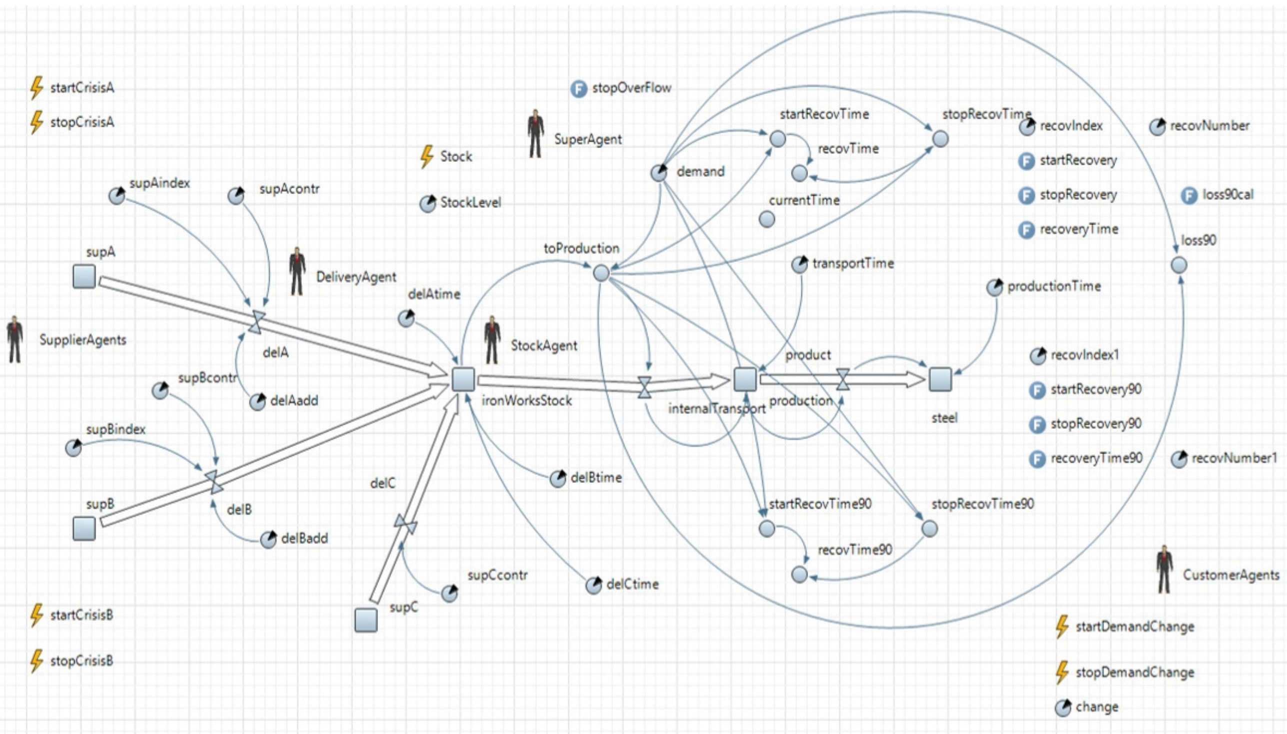

Figure 2 Model of logistic system of the steel mill using agent-based techniques

Provide information about the increased demand is the responsibility of Customer Agent (the right part of the model). This information does not reach directly to the agent responsible for the realization of supply, but to an agent acting the primary role in relation to the other two, namely Super Agent (visualized in the upper part of the **Figure 2**). Agent responsible for the level of inventories (Stock Agent) has knowledge only on stocks, and passes it to the Super Agent, otherwise take no action. Agent responsible for the implementation of supply (Delivery Agent) issues a request for custom agents supplying raw materials (Supplier Agents) on the basis of information from the Super Agent about the level of ongoing contracts. In the case of an interruption in the supply, he makes efforts to organize alternative supplies. Super Agent coordinates the actions of other agents, decide how to implement orders on the basis of knowledge about the size of demand, the inventory levels and the current state of supplies. Simulation tests cover a period of 100 days business activity and were carried out by one of the various possible scenarios.

Table 1 Two-dimensional vector $Res = \langle C_D ; T_D \rangle$ for 90 selected scenarios (C_D %; $T_D day$)

O	O1			O2			O3		
V/S	V1	V2	V3	V1	V2	V3	V1	V2	V3
S1	⟨97.1; 70.0⟩	⟨94.4; 70.0⟩	⟨91.8; 70.0⟩	⟨100; 100⟩	⟨98.1; 89.0⟩	⟨95.3; 82.3⟩	⟨100; 100⟩	⟨100; 100⟩	⟨99.8; 99.0⟩
S2	⟨99.3; 86.7⟩	⟨98.7; 86.1⟩	⟨98.1; 85.7⟩	⟨100; 100⟩	⟨98.9; 89.0⟩	⟨98.1; 82.3⟩	⟨100; 100⟩	⟨100; 100⟩	⟨99.8; 99.0⟩
S3	⟨96.0; 86.0⟩	⟨92.1; 81.0⟩	⟨88.1; 76.0⟩	⟨100; 100⟩	⟨96.0; 86.0⟩	⟨92.1; 81.0⟩	⟨100; 100⟩	⟨100; 100⟩	⟨97.0; 87.3⟩
S4	⟨96.5; 94.2⟩	⟨95.9; 90.0⟩	⟨95.9; 85.8⟩	⟨99.9; 100⟩	⟨99.9; 99.5⟩	⟨99.9; 92.5⟩	⟨100; 100⟩	⟨100; 100⟩	⟨100; 100⟩
S5	⟨90.7; 56.0⟩	⟨86.9; 51.0⟩	⟨83.2; 46.0⟩	⟨94.3; 75.0⟩	⟨90.6; 70.0⟩	⟨86.8; 65.0⟩	⟨99.0; 90.1⟩	⟨95.3; 84.8⟩	⟨91.5; 79.8⟩
S6	⟨96.5; 65.6⟩	⟨96.1; 60.9⟩	⟨95.9; 55.9⟩	⟨96.3; 84.2⟩	⟨95.7; 79.9⟩	⟨95.5; 74.9⟩	⟨99.6; 98.5⟩	⟨98.7; 92.4⟩	⟨95.7; 87.2⟩
S7	⟨90.7; 56.0⟩	⟨86.9; 51.0⟩	⟨83.2; 50.6⟩	⟨94.4; 70.0⟩	⟨90.7; 60.6⟩	⟨86.9; 55.6⟩	⟨99.0; 94.0⟩	⟨95.2; 74.0⟩	⟨91.5; 61.9⟩
S8	⟨94.9; 71.8⟩	⟨94.6; 70.5⟩	⟨94.4; 65.5⟩	⟨98.3; 80.2⟩	⟨98.2; 62.9⟩	⟨94.9; 57.6⟩	⟨100; 100⟩	⟨100; 100⟩	⟨100; 100⟩
S9	⟨92.8; 82.5⟩	⟨88.3; 77.5⟩	⟨83.8; 72.5⟩	⟨96.4; 94.5⟩	⟨91.9; 89.4⟩	⟨87.4; 84.4⟩	⟨100; 100⟩	⟨96.6; 94.5⟩	⟨92.1; 89.4⟩
S10	⟨95.8; 84.5⟩	⟨95.1; 92.6⟩	⟨94.9; 92.6⟩	⟨97.7; 96.5⟩	⟨97.1; 94.9⟩	⟨96.8; 94.9⟩	⟨100; 100⟩	⟨100; 100⟩	⟨100; 100⟩

One part of the model describes the system of the iron ore supply, which can be implemented according to the different scenarios. Selecting the appropriate scenario of delivery is the responsibility of Delivery Agent. In the work [9] have been presented the results of simulation studies on the effects of interruptions in the supply of raw materials for the potential production of the plant, assuming a constant level of demand. This article assumes that the demand for products may vary, and one of our goals is to balance it. It is also assumed that we have sufficient capacity to balance demand, while the limitation may be the lack of raw materials due to various reasons contained in the scenarios. The scenario is the increase in demand (*V1* - variant x = 10% increase in demand, *V2* - variant y = 20% increase in demand, *V3* - variant z = 30% increase in demand) and/or break in supply (*V1* - variant a = 5 day interruption in supply, *V2* - variant b = 10 day interruption in supply, *V3* - variant c = 15 day interruption in supply). The scenarios we take into account all kinds of disturbances - disruptions in the supply chain, as well as events related to the variability of demand. The scenarios take into account a situation in which it was used only accumulated stock of material (buffer) to eliminate interference, and the inclusion of the agent's activities to minimize potential losses. The level of inventories at the beginning of the simulation period for each option *Oi* was *O1* - stocks for 1 day of typical production demand, *O2* - stocks for 5 days, *O3* - stocks for 10 days. For example scenario *S1* - assumes an increase in demand for 10% (*V1*), or for 20% (*V2*), or 30% (*V3*) with level of stocks for one day production (*O1*), or for 5 days (*O2*), or for 10 days (*O3*). Scenario *S2* is very similar like scenario *S1*, one diferent is that in scenario *S1* we do not run the additional supplies, but in scenario *S2* we run an additional delivery (1 day after disruption from extra supplier - extra transport time takes 3 days). Scenario *S3* assumes a break in supply, we do not run additional delivery, but in scenario *S4* we run an extra supply. Scenarios *S5* and *S6* assumes an increase in demand for 30 days, then interruption in supplies, and in scenario *S5* we do not run additional delivery, but in scenario *S6* we run extra supply. Scenarios *S7* and *S8* assumes a break in supply, then the increase in demand, and scenarions *S9* and *S10* assumes: *S9* - a break in supply during the growing demand, we do not run additional delivery, *S10* - a break in supply during the growing demand, with an extra supply. To determine the resilience of the logistics system to different types of disturbances, calculation based on formulas (1) to (4) for each scenario, and the results are summarized in **Table 1**.

The simulation results confirmed the assumption that stocks plays an important role in mitigating the effects of various types disturbances, but it is necessary to further analyze the costs of maintaining higher levels of inventory or unplanned supplement their level in situations of increased demand.

5. CONCLUSIONS

Continuity of production process is particularly important in the steel mills. This is determined by the requirements of the technological processes in which the unplanned interruptions are very costly. To implement the manufacturing process it is required to provide the relevant raw materials to the steelworks. Companies are equipped with large, in terms of weight and capacity, amount of all kinds of raw materials. The raw materials, that have the strategic importance for the investigated company are: iron ore, coke, fly ash, lime stone. In the case of researched object about seven million tones of iron ore is delivered and consumed in metallurgic process every year. Competition in the steel market requires also meet customer expectations. Decision making in this area requires tools that allows for analysis of the effects of a demand change on a continuity of the operation of the production system. We propose a general model of a complex logistics system, consisting of two parts representing both, the inward and the outward logistics. This dynamic model takes into account different possible disruptive events, especially disruption in supply process (upstream operations) and unforeseen changes in demand (downstream processes). The practical use of this concept is based on the agent-based approach. Implementation of the model has been made on the example of a steel mill, which logistic system is global. Simulation studies on this model were designed to evaluate the resilience of the whole logistics system to disturbances occurring in both its parts. As a measure of resilience we have taken the production loss as disruption impact and the recovery time. With the help of the proposed measures, the degree to which the supply network can be reconfigured using for example Lean strategies may be analyzed.

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