Information Systems for Steel Production: The Importance of Resilience

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Abstract. In this initial research work we show the industrial need to analyze production systems with respect to their resilience. In the LOISI project enterprise models will be developed to support the analysis and management of resilient production processes for half-finished steel products. We describe the software models currently developed and the conceptual integration. We briefly reflect on challenges to be met in a demanding industrial setting.

Keywords: Production process · Discrete-time simulation · Operations research · Logistics · Industry case

1 Introduction

In this paper we report on initial considerations of the research project LOISI (Logistics Optimization In Steel Industry). LOISI has started in October 2016 and runs for 3 years. The overall goal of the project is to support the modelling, analysis and design of resilient production logistics processes.

In the project multiple and intertwined models are developed as no single model can capture all aspects, which are of relevance [13]. The developed models are focusing on the logistics sub-system of a steel production system, to support the analysis of the system's behaviour in various settings with respect to *resilience*.

Resilience can be generally defined as the ability of a system to (proactively) resist disruptive events, returning to its equilibrium state. In production and logistics contexts, typical disruptions refer to a breakdown of a machine, a material handling device respectively. Consequently and since *"the question on 'how to assess the supply chain resilience' still has no answer"* [2, p. 19] the project aims to formalize requirements for resilient operations for the given logistics system and to provide tools that support the analysis of the system's behaviour with respect to to-be-defined key performance indicators (KPIs).

Published by Springer Nature Switzerland AG 2019
C. Debruyne et al. (Eds.): OTM 2018 Workshops, LNCS 11231, pp. 45–54, 2019.
https://doi.org/10.1007/978-3-030-11683-5_5

This in turn requires to build and interconnect information systems that support adaptation and minimization of the reaction time for meeting exceptional situations despite the growing complexity of production processes, due to the increasing flexibility and product variety.

The paper is structured as follows. First, the industrial application domain and its challenges are briefly described. Then the solution approach and the developed models are discussed in detail. Finally, we conclude the current developments of this initial research work.

2 LOISI Industrial Challenges

In this section we introduce the motivating industry case, its challenges, and describe the relevance of resilience, as well as its potential, in industrial application fields.

To retain the production of semi-finished steel products in high-wage regions steel companies specialize in production of a wide variety of high quality products. The considered system starts at the continuous caster and ends when products are leaving the facility. The metallurgical details are out of scope, we focus on information systems for production processes, including intra-logistics, storage and cooling.

Every product type may be produced using one of multiple alternative processes and process routes. Alternatives include additional work-steps for rework, re-classifications of products (downgrading products with properties out of quality-parameter limits). The term *process route* is used to emphasize that besides having different process steps, which are required to meet or change desired quality parameters, different process routes also result in different physical flows.

2.1 Industry Case

Higher quality steel production results in more stringent process requirements for processing, transport and storage of (semi-finished) products. Process control ensures to keep the production for each product type within well defined parameter boundaries (e.g. weight percentage of alloy). Additionally, the wide variety of product types results in a high variety of process routes. These two factors lead to disproportionately high volatility and dynamic process changes. Ad-hoc changes of process routes are required, if products do not meet the quality-parameter limits. Steel quality is measured along a multi-dimensional chemical analysis with steel type and product-quality level dependent sets of limits for the chemical composition/parameters. The quality is further influenced by surface conditions and the micro-structure of the material.

Typical, frequent changes include additional surface treatments and inspections. Of importance to the work here are controlled storage and cooling procedures. The time of cooling and the temperature of the surrounding environment in hot-storage places influences the quality, and can be used to improve the parameters of the products.

The execution of alternative process routes may not only be triggered by steel quality issues, but by a high number of disruptions such as failing machines, overfull storage areas, broken transport means or shifting demands of customers.

2.2 Resilience of Production Systems

From a logistics point of view, dynamic change of process routes constitute a disruption since additional machines' or material handling devices' capacities are used. Processes of warehouse and intra-logistics not only interconnect the continuous production with customer demands. Moreover, the internal logistics in this context has to support resilient behaviour and becomes the crucial factor of competitiveness for a resilient production.

The impact of disruptive events on the performance of the enterprise is depicted in Fig. 1 below. This figure shows the throughput over time as it experiences some form of spontaneous disruption. In the graph, the event becomes visible as a sudden drop of the key performance indicator (KPI) *throughput*. Over time, due to recovering activities, it returns to the value that the system had attained before the disruption event. In this figure a single performance indicator (*throughput*) is used. However, the principle holds true for the overall Performance Measurement Systems (PMS) with multiple dimensions of KPIs, developed in LOISI.

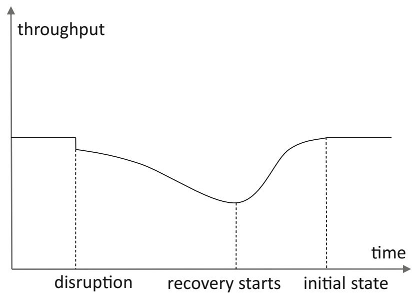

Fig. 1. Impact on throughput of a production system after disruption [6]

Figure 2 gives an impression of small events impacting multiple performance indicators used along a production process. Different performance indicators will react differently to the same event. Additionally the same event will show up in multiple places of the PMS along the process.

Due to the magnitude of the performance indicator change, the triggering event is easily detectable and the performance measurement system needs to be analyzed only for a short timer-period to learn about the event.

This figure implicitly highlights, that short-time extreme events are easier to detect than long-time trends. That has implications for resilience related activities that aim at retaining or sustaining normal performance. If the performance measurement system allows identifying the event's source, the underlying reason in the performance change can be addressed immediately.

For long-term trends a long period of time, likely being cluttered by a number of extreme and not extreme events, needs to be analyzed. In addition to being hard to detect, there is often not a single cause for long term trends. Selecting the right strategy for resilience is much harder. A strategy, or a set of strategies, need to be applied for no obvious reason and their suitability/success and also negative consequences are much harder to estimate as consequences get not visible immediately.

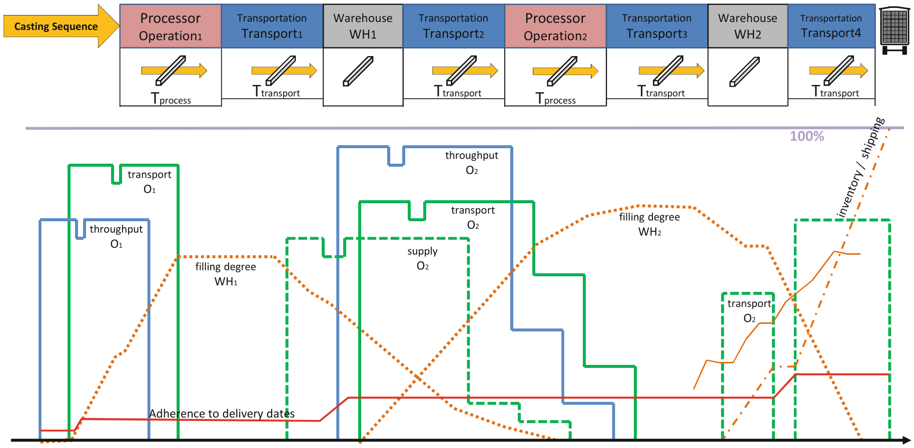

Fig. 2. Time dependent performance of multiple indicators, exemplifying contradicting reactions to events.

However, due to the system's complexity and not fully transparent interdependencies, some events may have severe impact on entirely different and unexpected processes or resources. There are effects, which result in a slow deviation of the measured performance from the normal level, that cannot easily be detected. This implies, that focused activities to establish "normal" performance levels cannot simply be started if the reason for the performance change is not clear.

On abstract level, resilience may be reached through robust (e.g. by using buffer), and flexible (e.g. more means for transport, alternative paths), adaptive processes (e.g. transport route optimization, based on the current situation).

2.3 Modelling Resilience

Multiple approaches exist to model resilience of production systems. Analytic models of the system are using either discrete-time or continuous-time Markov

Chains (see [5]). Other approaches use system dynamics models [9]. That approach incorporates a general formulation of resilience (i.e. for all kind of systems) and includes three measurements of resilient systems [4]:

- amount of change the system can undergo and still remain in the same configuration (same system state)
- degree to which the system is capable of self-organization
- degree to which the system can build the capacity to learn and adapt.

With respect to the development of a performance measurement system for resilience, there are two key questions: what system state is being considered (*resilience of what*) and what disturbances are of interest (*resilience to what*) [4]. Especially the former is of high interest for any enterprise as long as the system is in a favorable *configuration*. Configuration refers to a diversity of system states that are possible under a particular regime of actors, processes and functions. As a result resilience often requires the need to change configurations.

3 LOISI for Resilient Production

In this section we discuss in more detail, how we analyze and model resilient production processes in the steel industry.

3.1 Resilience in LOISI

In the project reported here, we develop a performance measurement system (PMS) that allows us to capture the *steady-state*, the mentioned disturbances and the resulting exceptional performance along multiple dimensions.

In `LOISI` we have decided to use simulation, not only to evaluate different strategies for improving resilience (dispatching rules for logistics decision - see below), we also use it to determine performance measurement values describing the steady-state within a statistical range of indicator values.

We have defined a system configuration describing the usual amount of space available for storage, the usual manipulation rates of handling devices, transport duration and number of vehicles available, customer order mix (steel in different qualities) and demand (amount).

Having defined a set of performance indicators (around five indicators per dimension and five dimensions) we observe the overall system and "normal" variations in performance indicators for some time. We divide these indicators into the following five dimensions:

- of a warehouse
- of a machine
- of means of transport
- of a handling device
- or related to customer satisfaction.

3.2 Simulation of Resilient Production Processes

To have an integrated model of the relevant part of the enterprise system, we use *discrete event simulation.* This type of simulation environment allows to follow discrete parts along their individual production and logistics processes. Environments also allow to introduce some statistical distribution of e.g. failure or some variations in the order mix/order sequence. The model for analyzing the production system's behaviour with respect to resilience is implemented using Tecnomatix Plant Simulation Software.

The simulation environment enables us to use this configuration as a baseline by running the scenario without any extreme events and without any trends that bring the system into a unstable state. This establishes what is "normal" in terms of performance indicators.

The values of the performance measures are also examined over certain period of time after a disruptive events and also global trends. The simulation allows us to determine the delta of the performance and hence makes it easier to spot long-term deviations from normal performance.

The `LOISI` team has analyzed a real-world steel production system to produce a list of analyzed sub-systems that are relevant for modelling. For each of these (sub-)systems we have described their normal function, duration for applying the function, amount of steel to which this function can be provided, etc. For each of these, we have also described possible failure events, and some distribution of failure impact and failure probability.

By introducing defined sets of (failure) events, it is possible to understand causal relationships between the events and values of performance indicators. The reproducibility of simulation runs, allows analyzing short-term (extreme) events and long-term trends which are discussed in more details in the following.

3.3 Resilience to Short-Term Events

As indicated above, a common and important event in the "extreme, short-term" category is the breaking of a sub-system (e.g. transport vehicles). The simulation will use a statistical distribution of how long such a break down will take and when it occurs.

Another common event is, that the product quality parameters of the steel are not met. Again, using a statistical distribution, the severity will be determined.

Dependent on the type of event a number of measures to increase the resilience of production have been created. For sub-system break downs, where the casting process is stopped, special procedures are in place. This concerns the sub-systems close to the caster. Any breakdown here will impact procedures of the basic oxygen steel-making. Here a LD-Converter will blow oxygen through molten pig iron to convert a charge of iron (several dozen tons) into steel in less than 40 min. For these melted tons of steel care has to be taken (e.g. alternative production route and/or different processing in secondary metallurgy), if further processing is stopped.

The simulation environment allows to elaborate and quantify the effects of different alternative procedures to increase resilience. This is particularly important in situations, as described above, where failure tolerance is not low.

At the other end of the spectrum of severity level, are events where repair takes only few hours and no particular measurement is required.

For the events in between, the project team has elaborated resilience procedures. These include alternative process routes, modification of production sequences and increasing production capacity by introduction of additional shifts.

The identified procedures and measurements do not take inter-dependencies in the complex system into account, nor is it possible to provide a performance quantification of effects in alternative scenarios/configurations. The simulation will allow to elaborate different procedures and will indicate the changes of performance using the identified performance measurement system. It allows determining different procedures in different system configurations and with different events.

3.4 Resilience to Long-Term Trends

The situation is different with long term trends. The first difference is that, due to the missing event character, these are only visible by taking a look at long-term developments of the performance measurement system values. Known trends include an increase in customer orders with higher steel quality (as mentioned above). That implies an increase in "high quality" procedures which have longer and more controlled cooling phases.

Currently, only a rough bottleneck analysis can be made for the future production system with changed order mix. By using the controlled simulation environment it is possible to elaborate on alternative scenarios for the developments of customer orders.

Of importance to long-term resilience are alternative process-routes. As mentioned above the term process-route is used to indicate that any production process has an important physical component, where the steel half-finished goods have to be routed differently through the shop floor.

The usage of alternative routes for certain product types results in a different system load when still meeting the desired quality standards and fulfilling operational constraints (such as landing at the correct loading point). An alternation of a production sequence is likewise resulting in changed usage of resources which may affect customer satisfaction. The enhancement of the system capacity can be obtained by enlargement of storage area. However, this is facing the disadvantage of increase of handling effort and being limited by spacial constraints.

To conquer the challenge of these developments, an optimization tool called HeuristicLab [11,12] is used to optimize the process routes. This optimization supports users by choosing the best route dependent on the product's state and the overall state of the production system.

Another way to enhance resilience (in particular for long term trends), is that the overall production system configuration is altered. Typically production system functionality is improved by applying changes and re-executing the model and analyzing the disturbance effect again. Mathematical optimization of certain input parameters (production plan etc.) or policies appears to be a promising tool for remaining in favorable domain or changing the domain if any disruption occurs.

By using simulation models and automatized decision-making in operational planning through mathematical optimization we expect a better utilization of the logistical system as well as more stability of the system with respect to disruptive events, and long term trends. This is realized (also) by providing simulation models and optimization models [1,3].

Needless to say, short-time events and long-term trends will be analyzed together and effects of bottle-neck sub-system breakdowns will be explored.

3.5 Modelling Considerations

Enterprise Modelling (in general) is used for integration and knowledge transfer [13]. In this project, simulation is used to provide a behaviour oriented enterprise model. The simulation model, build in `LOISI`, allows to gain better understanding of (future) scenarios, with particular systems configurations like number of transport vehicles, amount of steel that can be stored and the overall conception of interconnected material flows.

For users of the developed models, the knowledge gain lies in the results of the analysis of impacts of events and trends on the performance of the enterprise system and its subsystems. Besides this, the developed performance measurement system will have to prove its usability in the scenarios and will then be integrated in the running information systems.

In order to develop the models, we have defined objective functions and identified appropriate degrees of abstraction that help to reach our targets while allowing to model as simple as possible. The selection of proper abstraction level is a general question for the analyses of any behavioural aspect of a system (cf. [10]). There is no general answer as it is depending on the goal.

In any case we face the challenge that the degree of abstraction is neither particularly obvious nor a static factor, but changing and adapting throughout the project. Some initial research on business process modelling focuses on support for the process and less on the results [7].

However, this support for the process, with respect to resilience, has not been researched in full detail. In one approach the authors additionally carried out a study to evaluate the concept of resilience in general, and they proposed a *resilience analysis method* [9]. The effect of varying abstraction levels on the validity of the resulting quantification of resilience of any state has not been addressed in the steel production processes. A driving fact for a higher degree of abstraction might always be the generality of a model for applying it to difference scenarios or even in different domains. On the contrary a very detailed model might serve better for observing detailed performance indicators in the specific manufacturing system.

4 Conclusion

In LOISI we are building multiple models (simulation, performance measurement system, optimization) to support analysis and decision making with respect to resilient production and intra-logistic processes.

The engineered models will consequently be used in corporate information systems as well as in business intelligence tools to provide decision-support in real world systems. The development of the models supports users in gaining a common understanding [8]. The understanding is needed so that the independent models (conceptually) fit together.

This common understanding is also of importance for being able to articulate future trends that need to be handled in the production system. It includes the derivation of knowledge about the characterization of the systems state by quantification of its behaviour, the formulation and the evaluation of alternative utilization concepts to sustain in a favorable configuration that is efficient and robust to disruptions. Furthermore, we expect insights how to translate the trends adequately into probable scenarios which requirements in some form exceed the production systems capacities.

Challenges we will address in the (near) future, include the interfaces to real world information systems. The challenge lies in making the different models inter-operable with the existing systems to properly process information or data as well as redistribute it accordingly.

This challenge is already addressed partially. On conceptual level all models take the same point of view. On technical level, the provider of the real world information system is part of the project team. Part of the PMS is already implemented in the software.

Acknowledgement. The research described in this paper has been funded by the Governments of Upper Austria, Styria and the FFG: FFG Project "Logistics Optimisation in Steel Industry (LOISI)" Contract nr.: 855325.

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