MasDISPO_xt

Process Optimisation by Use of Integrated, Agentbased Manufacturing Execution Systems Inside the Supply Chain of Steel Production

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Abstract: The production of steel normally constitutes the inception of many supply chains in different areas of industry. Steel manufacturing companies are strongly affected by bull whip effects and other unpredictable influences along their production chains. Improving their operational efficiency is required to keep a competitive position on the market. Hence, flexible planning and scheduling systems are needed to support these processes, which are based on considerable amounts of data, hardly processable manually anymore. MasDISPO_xt is an agent-based generic online planning and scheduling system for the observation on MES-level of the complete supply chain of Saarstahl AG, a globally respected steel manufacturer. This paper concentrates on the horizontal and vertical integration of influences of rough planning on detailed and the other way around. Based on model-driven engineering business processes are modeled on CIM-level, a service oriented architecture is presented for the interoperability of all components, legacy systems and others wrapped behind services. Finally, an agent-based detailed planning and scheduling ensuring interoperability in horizontal and vertical direction is approached effectively.

1 INTRODUCTION

The production chain of Saarstahl AG consists of a multitude of specialised and complex metallurgical manufacturing processes with a lot of dependencies among them. First, a blast furnace factory produces hot metal from iron ore, coke and limestone as raw materials for the steel production. In fixed intervals distributed over the day, a determined quantity of hot metal is sent by rail to the steel works for the next production step. Inside the melting shop, steel of different quality grades is produced, according to concrete customer orders and requirements. It is cast at continuous casting plants into billets. Afterwards, these billets are delivered to the rolling mills. Here, steel bars or wire rods of different shapes and formats are produced. In fixed, cyclic rolling campaigns of limited capacities certain formats are produced. After rolling, follow-up manufacturing steps concerning steel bars are arrangement, pickling, annealing and saw cutting; wire rods probably need a annealing and a pickling. Finally, the products are delivered to the customers – mostly suppliers of the automotive, shipbuilding or aerospace sectors.

MasDISPO_xt schedules the execution of each concrete order along the production chain. It monitors production on a rough—in weeks—and detailed—in days and hours—level, and executes an online detailed planning and scheduling for the different manufacturing steps in each single factory. It has to detect problems in the production and handle them in order to return to normal production. The rough working plan for each manufacturing level is calculated on demand, before final order commitment.

The overall process chain is characterized by changes in customer orders and it is affected by production setbacks or problems. Therefore, steel manufacturing companies must be flexible and dynamic, by adapting production plans fast in order to meet customer requirements while still being cost-efficient.

These are requirements which need to be covered in almost every industrial sector, hence, there are a lot of commercial systems handling this. Existing solutions are dominated by centralized decision making

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processes, mostly data driven and often not modeling the business processes they should. ERP systems like APO (Bartsch and Bickenbach, 2002) or APS (Advanced Planning and Scheduling) are suitable for a rough planning, only. Big software companies have adopted the strategy to provide integration mechanisms for MES-level solutions (SAP, 2004) like the presented solution.

MasDISPO_xt, a decentralised agent based approach, is the proposed solution of this paper. In MasDISPO_xt, every order is modeled as an agent. The agent calculates and observes its own schedule from order entry, across rough and detailed planning, and monitors the production up to the point of delivery. It responds to changes during planning, scheduling and production by dynamically adapting the schedules. Also, each aggregate of any factory is also modeled as an agent which also calculates its schedule autonomously based on further local knowledge and restrictions.

The complete production chain is very complex and could not be addressed with the appropriate detail in the context of only one paper. Therefore, this paper concentrates on the horizontal and vertical integration of solutions provided for detailed planning into a global perspective regarding rough planning and the other way round. As a presetting, rough planning influences detailed planning and vice versa a rearranged detailed planning might impact the rough layer – probably on several manufacturing levels. Existing ERP solutions cannot provide such integrations very suitable – the motivation for the presented approach.

2 PLANNING AT SAARSTAHL AG

Steel production in general is a very complex, dynamic and disassembling process. It starts inside the blast furnace as hot metal and ends up in vast number of products of different kinds. On each manufacturing step, there are lots of restrictions regarding quality, size, dimension and others which determine the campaigns and batch units on each processing step. Of course, time restrictions also have to be kept. Hence, a delay on a certain step might have cascading effects along different branches of further processing. As mentioned, the average order backlog of Saarstahl is about 17500 – each order composed of several order position and each position with up to 50 processing steps. Hence, it is a challenge to keep planning and scheduling under control.

Competitive orientation concerning product concepts, technology and others are discussed per annum and give a direction for human resource planning or machinery on a tactical level. In planning levels regarding sales, the global production capacities for the different production phases are booked. After that, the planning process continues by planning at lower levels. For each factory, the global planning level provides the lower level with a set of orders for a specified time horizon. These assigned orders are planned in more detail while going down in planning levels down to physical production systems. All these influences are correcting variables from 'above' often given just once.

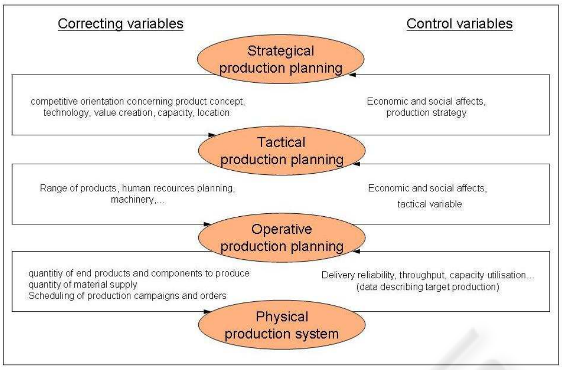

Figure 1: Control Cycle of planning influences and dependencies.

On the other hand, physical production systems might have any delays which has to adopted by the planning system above. Delivery reliability or throughput are measured constantly and influence the next level above. These control variables go up to the strategical planning on highest level. A cycle of interdependencies as shown in figure 1 is created. Flexibility across these different layers is needed to guarantee a flexible planning and production process.

The planning horizon on highest level is quite rough, the closer it gets down to production the shorter the horizon is. To realise this exchange of informations, smooth interfaces between the acting systems are needed. On a higher level planning level, usually normal ERP-systems are used. These systems probably also support also provide a adavnced planning system (APS) for a rough planning. Beneath, a so called MES is used for a detailed planning. The last level is the automation level covered by 'SPS' or 'SCADA' (Supervisory Control and Data Acquisition). A smooth vertical integration of these acting systems is needed to guarantee a fast exchange of informations which is especially needed in steel production since materials are often molten between two different processing steps and might not cool down.

Saarstahl is a historically grown company. Hence, a lot of obsolete legacy systems are running. Integrations as described above are especially regarding dynamic aspects viable unsatisfying by existing, commercial approaches. Driven by this need Saarstahl decided to develop own solutions and participate in research projects like the European funded project 'SHAPE' (Semantically-enabled Heterogeneous Service Architecture and Platforms Engineering) (SHAPE, 2008) dealing with these problems.

2.1 Solution

The main idea in order to be in a position of handling these problems is to model each single order position as a software agent. Every single compolo agent (*com*ission - *po*sition - *lo*t) calculates and observates its own schedule from order entry until invoicing. Instead of handling a vast number of restrictions subject to the manufacturing step in general only a few of which are relevant for a single order position are handled by the entity autonomously. A decentralised management of manufacturing control is received instead of a centralised, data driven approach.

Definition 1. *Having a finite set of* factories *F with elements f_i, where f_i is the factory number i,* aggregates *A with elements a_j, where a_j is the factory number j*

$$F = \{f_1, \ldots, f_n\} \; n \in \mathbb{N}$$
$$A = \{a_1, \ldots, a_m\} \; m \in \mathbb{N}$$

O being the finite set of all orders *to be planned, with elements identified with the letter o,*

$$O = \{o_1, \ldots, o_q\} \; q \in \mathbb{N}$$

L_i being the ordered list of elements of A which are the suitable aggretates for order o_i in order of preference,

$$L_i = \{a_x, \ldots, a_y\}$$

where

$$\begin{gathered} \mid L_i \mid \leq n;\; i = 1, \ldots, q; \\ a_x \in L_i \wedge a_y \in L_i \wedge \\ a_x \textit{ precedes } a_y \textit{ in the list } L_i \Rightarrow \\ a_x \textit{ is preferable over } a_y \textit{ for order } o_i \end{gathered}$$

L being the collection of preferences for all orders:

$$L = \{L_1, \ldots, L_q\}$$

and the functions C, being the function which associates an aggregte to its associated available capacity for a given period, and c, the function which associates each order to its required capacity on an aggregate,

$$C : M \to \mathbb{N}$$
$$c : O \to \mathbb{N}$$

the top level plannning problem for assinging aggregates can be defined *as the search for a set $\mathcal{P}$ that associates each order in O to aggregates in A following the preferences provided by L and making sure that the sum of all sizes provided by $c(x)$ of the orders associated to a specific furnace do not exceed the furnace's specific maximal capacity $C(a_j)$:*

$$\mathcal{P} = O \times A$$

where

$$\forall a_j \in A : \left(\sum_{x \in \{o \mid (o, a_j) \in \mathcal{P}\}} c(x) \right) < C(a_j)\,.$$

A solution $\mathcal{P}$ is produced by searching for each order $o_i \in O$ (sorted by arrival date) a factory $f_i \in F$ and an aggregate $a_j \in A$ with available capacity, following the list L_i. Furthermore, S_{o_q} is the finite set of processing steps with elements s_k, where s_k is the step number k necessary to meet customer requirements according o_q. H is the function assigning the number of different factories along the process chain of each single order position.

$$S = \{s_1, \ldots, a_l\} \; l \in \mathbb{N}$$
$$H : S_{o_q} \times S_{o_q} \to \mathbb{N},$$

$$h(s_k, s_{k+1}) \mapsto \begin{cases} 0: & f(a_{s_k}) = f(a_{s_{k+1}}) \\ 1: & f(a_{s_k}) \neq f(a_{s_{k+1}}) \end{cases};$$

$f(a_{s_k})$ maps step s_k on aggregate a_{s_k} to factory i

$$min \left(\sum_{S_{o_q}} \sum_k h(s_{s_k, s_{k+1}}) \right)$$

By minimizing this function transportation costs will be optimised. Of course, this is not the single objective. Along the complete process chain, there are several and also conflicting goals. But this is not addressed in this paper.

This general definition is valid across the complete supply chain for every single order position in each local subsystem. Additional restrictions and others are takeninto account while going down on more detailed level. The degree of detailedness also define the framework for information exchange. The goal is to exchange the least data as possible but at least what is necessary to guarantee transparency as demanded.

How are existing legacy systems be integrated into workflow and how are interactions realised? This is solved by use of a *Service Oriented Architecture* (SOA). An extract of the complete process chain is choosen to explain the approach in more detail. The extract concentrates on the phase of production report of the steelwork until preparation of rolling. In this phase, all compolo agents release semi finished products of the steelwork in order to find potential better assignments especially concerning time and quality.

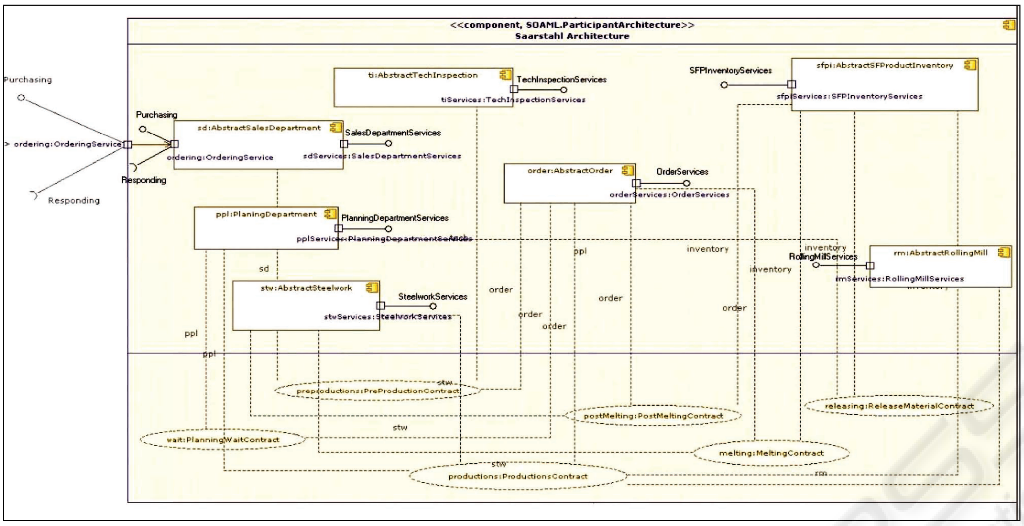

Figure 2: Service Oriented Architecture of Saarstahl AG.

The planning process is formalized via business process modeling notation (BPMN) using ARIS (IDS Scheer AG , 2008) on computation-independent model (CIM level). A model transformation to PIM level (platform-independent model) is done using SOAML (OMG, 2008). Another model transformation is done on PIM level to *PIM4Agents* (Hahn et al., 2007). The metamodel of agent aspect is centered on the concept of an *agent*, the autonomous entity capable of acting in a specified environment. The last transformation is going down to platform specific model (PSM). On this layer, a detailed planning as described in (Jacobi et al., 2007) is fulfilled.

Since there are a lot of legacy systems running, information exchange between these systems has to be arranged. On each level certain services are already specified. A service oriented approach is straightforward. Legacy systems are wrapped behind services. Figure 2 depicts an extract of the generated service oriented architecture for the described phase.

3 CONCLUSIONS

A need for flexible integrated planning systems with a clear workflow and a fast information exchange is undeniable. By use of a SOA, vertical integration but also horizontal integration of information exchange is eased. Response times are reduced by use of services provided by orders or aggregates both modeled as agents. Informations are exchanged without detours anymore. No informations are lost, because services are embedded in specified protocols which ensure completeness.

The described examples of this paper state a subset of the different problems which need to be solved along production inside the supply chain. An automatic and responsive planning system is needed. The decentralised approach with multiagent systems make the system easier to handle, really models the demanded business processes and is able to manage the huge data amount along production – requests which are not always met by the existing centralised approaches. By use of SOA, a more flexible environment easily to extent is received.

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