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APPLYING DECISION-ORIENTED ACCOUNTING PRINCIPLES FOR THE SIMULATION-BASED DESIGN OF LOGISTICS SYSTEMS IN PRODUCTION

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ABSTRACT

In this contribution, we focus on the configuration of logistics systems embedded into production processes. To evaluate the dynamic behavior of alternative configurations, Discrete-Event Simulation (DES) proofs helpful. Emphasis is typically put on physical performance measures. However, as configuration decisions have significant financial impact to the firm, an additional monetary impact assessment is usually performed. This requires cost accounting techniques that appropriately incorporate system complexity into the financial model. To this end, we propose a novel approach to extend the applicability of DES for configuration problems. The basic idea is to incorporate technical consumption or engineering production functions into Riebel's Generic Direct Cost Accounting and to add both methods to a standard DES modeling. Consequently, the informational value of DES is significantly improved. Misleading decision support can be avoided and insights into the relationship between processes and the value structure are achieved. Both of which contribute towards improved configuration decisions.

1 INTRODUCTION

Product heterogeneity, make-to-order production and high-tech production facilities have made the design and configuration of logistics systems in production a complex planning task. To this regard, Discrete-Event Simulation (DES) has become a widespread tool for accurately modeling and analyzing system behavior on a high level of detail. As a tool originating from engineering research, it is focused on the technical system. System analysis usually confines to technical targets, inducing two problems for decision making. First, a situation with conflicting technical targets leads to an inferior decision situation prohibiting the selection of alternatives. Here, only a monetary assessment can resolve the conflict without applying subjective elements. Second, as the design and configuration of logistics systems can significantly affect the cost structure and financial position of the firm, a decision is usually based upon managerial objectives. Simulation researchers have addressed these problems over the last 15 years, presenting new approaches such as Cost Simulation or Simulation Based Costing. The ultimate goal is to bridge the gap between simulation modeling and management accounting. Scientific publications have abated in the last 5 years, suggesting the topic was thoroughly explored. However, newly published papers on Discrete-Event Simulation show no increased tendency to include financial values in the analysis; the proceedings volumes of the annual Winter Simulation Conferences provide evidence. In practice, the new approaches seem to be hardly in use. The chair of a leading consultancy firm for simulation services in Germany assumes the percentage of simulation studies applying the new approaches in the lower single-digit area.

This contribution focuses on the applied cost accounting systems, as these constitute the major obstacle to their application. In chapter 2, the decision situation for the design of logistics systems will be explained. Here, we restrict our analysis to configuration, which yields a medium-term tactical planning task. Structural design aspects are excluded, allowing to focus on intra-periodical cost accounting systems only. In chapter 3, we present three important accounting methodologies. One of them, Activity Based Costing, is predominantly utilized in simulation-based accounting, whereas the other two constitute established concepts without many applications in the field of simulation. Chapter 4 treats a new approach, which builds on the analysis towards simulation-based accounting. Its potentials are validated in a case study at a German steel mill. The work closes with a summary in chapter 5.

2 DESIGN OF LOGISTICS SYSTEMS

2.1 Technical Configuration

The technical configuration of logistics systems comprises all decisions related to the definition of structural and process parameters of an existing or planned system with regard to one or more predefined goals. It is a tactical planning task with a medium-term planning horizon (months to years). It succeeds the strategic system design planning, where the system's elements and its basic relations are initially defined. In contrast to strategic design, the focus of the technical configuration is on operations rather than structure. However, design and configuration of a system can be heavily interdependent, often necessitating a simultaneous strategic-tactical planning. The outcome of the configuration process is an operational system with defined structures and processes. In the following short-term operational planning phase, the system can be applied to real-life conditions. Configuration is mainly a nonstandard, project-related planning, segregating from repetitive tactical planning tasks like Master Planning.

Configuration can be subdivided into a static and a dynamic component. Static configuration refers to the definition of resource parameters necessary for operations. This task is necessary, since configuration details are omitted in strategic decision making to reduce problem complexity. Considering a production system, resource parameters may be the amount of staff to hire or qualify, the number of Kanban-cards in use or the speed of a conveyor belt. Dynamic configuration describes the definition of processes and methods for operational decision making, such as the allocation of personnel to machines, the order release process or sequence planning. As the resources and processes are connected in a common network, different parameter settings and process definitions can influence each other. In a logistics system usually a greater number of parameters and processes exists, leading to a variety of possible combinations. The configuration task is to identify and select the optimal combination that promises technical feasibility. However, to reduce problem complexity, often the entirety of combinations can be narrowed down to a denumerable number of insulated configuration settings. This yields a problem of choice, well accessible to Discrete-Event Simulation. Its power lies in the ability to model large dynamic-stochastic systems on a very detailed level, where analytical models fail due to modeling or solution reasons (Evans and Haddock 1992).

2.2 Assessment

However, a DES does not constitute a decision model, it only describes the behavior of the modeled system. Therefore, the interpretation and evaluation of a simulation experiment with a certain configuration requires an objective function. An objective function can be defined as a set of technical or monetary targets, which to reach leads to a desired state. Typically, technical targets, primarily quantity- and time-based, are used to control logistics processes in production. Figures include throughput times, machine utilization, inventory levels, quality and tardiness. Apart from process control, often the staff on the execution and lower planning levels are evaluated and paid according to the achievement of those targets. A direct measurement can be performed by the connected operating systems (level-one to level-three computers, cf. Lee et al. 1996). Conventional simulation studies are usually based on time- and quantity-based data, too (Harmonosky et al. 1999, Haarmann 1994, Klug and Fortmann 1994), which reflects the technical origin of the tool.

However, if more than one technical target exists, a multi-criteria decision-situation with two possible shortcomings results. First, different technical targets usually cannot be aggregated, as they are based on different measurements. Secondly, without knowing the financial impact of the targets on costs or revenues, the development of a hierarchy is not possible. Thus, multiple, coordinate targets for the configuration and control of a production system coexist. If these targets behave conflicting, a ranking and subsequent evaluation of different configuration settings is not possible. To overcome these shortcomings, numerous methods to handle multi-criteria decision-situations have been developed (Hwang and Yoon 1981). However, the majority of the approaches requires subjective inputs of the user, such as the choice of targets and their weighting or the final selection of one option among a list of efficient ones. A tactical planning, that is solely based on technical targets can lead to wrong decisions with respect to a monetary assessment. This can particularly occur, if the technical target system does not adequately reflect the financial impacts of the decision, for instance due to wrong weightings or the omittance of an important monetary factor. Non-proportional relationships between the quantity and the value structure also raise the need for a monetary assessment.

These arguments gain impact when adopting a managerial perspective. Companies are not controlled according to technical but to financial (monetary) targets. Companies ultimately strive to create value and make profits, whereas the production and selling of goods is only a means to achieve this fundamental goal. Therefore, all measures that can possibly affect profitability of the firm – such as the configuration of logistics systems – should be aligned to it. Technical targets only constitute derivative targets, that are supposed to have a positive effect on profitability. They are subordinate. The reason for their predominance in logistics systems is the fact that operational planning and control by monetary targets is often difficult to impossible. However, for the tactical configuration of a system, which can have significant impact on profitability, management usually takes the decision based on a monetary figure such as total costs, contribution margin, capital value etc. Apart from their discussed deficiency towards ranking and evaluation, technical targets never allow to assess the total profitability (e.g. cost effectiveness, return on investment) of a decision. This raises the question of how to convert the multi-criteria technical target system, which is capable of measuring the system's performance in many different dimensions, into a single-criteria monetary target. Two aspects are of particular relevance.

I. The design and nature of the **accounting system** determine its ability to incorporate the characteristics of the logistics system and to support configuration decisions. For instance, if accounting confines to mean values for labor rates, then wage distinctions between different workers or daytimes are impossible. Thus, different configuration settings that build on these distinctions cannot be adequately evaluated. In general, the better the accounting system is capable of reflecting the underlying system in terms of resources, processes and dynamic behavior, the better the quality of the monetary assessment. However, some technical targets become an irrelevant factor on a monetary level, while others are not accessible to monetary measuring (see II.).
II. In a hierarchical target system, subordinate technical targets may also be interpreted as **restrictions**. This approach is especially useful for technical targets that are difficult to measure in monetary units, e.g. quality or customer service objectives. The target is provided with a minimum or maximum aspiration level, which has to be reached with a certain probability.

In this contribution we will focus on the first aspect. Simulation researchers have recognized the shortcomings of conventional, purely time- and quantity-based simulation studies and developed new approaches, such as Simulation Based Costing or Cost Simulation. These approaches incorporate a costing methodology to realize a monetary assessment of different simulation experiments. The aim is to improve the decision-support process of the management and technical staff. However, apart from some necessary technical standardizations and adaptations between the accounting and the simulation model, the choice and design of the accounting model have a major impact on the tool's quality. In the next section, we will discuss the suitability of the predominant accounting model in use with simulation, and present a novel approach to address existing conceptual shortcomings thereafter.

3 ACCOUNTING PRINCIPLES

Configuration of logistics systems is usually subject to singular, project related planning (e.g. process optimization, organizational issues, make-or-buy decisions). To evaluate, whether a configuration setting dominates a set of others, only relevant costs (and revenues) are to be taken into account. This concept is defined as Relevant Costing; in the German field of accounting it is known as decision-oriented accounting (Weber and Weißenberger 1997). The relevant costs depend upon the factual scope and the time frame of the decision. A decision-oriented accounting has to meet two requirements:

I. Future-orientation: As a decision can only affect future spending, costs or revenues that have already materialized (also named sunk costs) are irrelevant.
II. Incremental: Only costs or revenues, that are incurred or changed due to decision are relevant. Common costs, i.e. costs that are identical for all decision alternatives, or committed costs, which refer to future expenses depending upon an existing obligation (a past decision), are therefore irrelevant.

The American approach of Relevant Costing goes so far as to require cash flow-orientation, which would exclude costs such as depreciation (Shillinglaw 1972). Some German approaches are cash-based, too (Riebel 1994). This resembles investment accounting in German accounting methodology, which is solely based on cash flows. However, in this contribution we confine to intra-periodical cost accounting, where depreciation constitutes a decrease in the value of an asset. This could possibly be caused by a decision.

3.1 Activity-Based Costing

Activity-Based Costing (ABC) was introduced by Johnson and Kaplan (1987) and Cooper and Kaplan (1988) and aimed to improve the established costing systems (Direct Costing, Standard Costing). Numerous modifications, such as Process Costing for administrative activities by Horváth and Mayer (1989) enhanced the area of application and publicity of the concept. The basic principle of ABC is to allocate indirect costs to cost units based on defined cost drivers rather than on simple volume- or value-figures (e.g. direct labor costs). The cost drivers are time- or quantity-based and measure the intensity of an activity (e.g. number of setups or transports, working time) that is been processed by a product. The higher the intensity (e.g. the more working time the product requires), the greater the share of indirect costs to be allocated to the product. The aim is to provide a fair allocation in contrast to "traditional" absorption accounting techniques.

However, in order to present a fair allocation, which assigns costs to its originator, a proportional relationship between costs and the cost-driver as well as the cost-driver and the cost unit is required (Glaser 1995). This assumption would be fulfilled, if an increase in production output of a plant would lead to a proportional increase in the plants' personnel costs, so that the unit costs remain the same. In reality, these kinds of relationships are hardly given. In fact, the reason for declaring costs as indirect usually results from the lack of a proportional relation to the cost unit. As an absorption accounting system itself, ABC inherits the same conceptual deficiencies of full cost accounting in general, regardless of its sophisticated cost allocation techniques (cf. Riebel 1994, Küting and Lorsen 1991, Kloock, Sieben, and Schildbach 1999). Cost allocation in general contradicts an incremental costing, as a direct relation between the costs and the decision is made intransparent through allocation and cannot be verified. Furthermore, ABC focuses on the calculation of unit costs, which is hardly a key figure for evaluating plant configuration (or plant design). An assessment of different configuration settings based on unit costs can lead to wrong implications; for instance, an increase in output may result in decreased unit costs due to a smaller allocation rate, while the total personnel costs are fix and remain constant. In this case the cost model suggests savings that cannot be realized. In fact, the increase in output may only affect variable costs and revenues.

Despite its obvious inappropriateness, ABC is the predominant accounting technique for simulation studies (Table 1). This is probably due to the fact, that simulation and ABC make use of the same entities of the underlying real system, the processes (von Beck and Nowak 2000, Spedding and Sun 1999). The cost and the simulation model are either part of an integrated model (Cost Simulation) or the cost model is an on-dock module, which receives detailed simulation output data after each simulation run (Simulation Based Costing). The goal of the approaches is to provide a more accurate description of the processes compared to isolated ABC, where the dynamic behavior and stochastic elements (e.g. varying process times) can be included. To this end, the use of simulation shall contribute to an increased accuracy of ABC.

Table 1: Prior work on Cost Simulation and Simulation Based Costing

Cost Simulation	**Simulation Based Costing**	**Others**
Strugalla (1994)	Haarmann (1994)	Kersten (1996): simulation based capital Budgeting
Klug (1994), Klug (1995)	Lorenzen (1997)	
Rauh (1998)	Takakuwa (1997)	Wollenweber (Verein Deutscher Ingenieure 2001): no information on cost model
Blömer, Günther, and Kaminiarz (1999)	Zülch and Brinkmeier (1998)	
Spedding and Sun (1999)	Rauh (1998)	
Eversheim and Fuhlbrügge (1994)	Harmonosky et al. (1999)	
Ciupek (2004)	Feldmann, Collisi, and Wunderlich (1999)	
	Von Beck and Nowak (2000)	
	Lee and Kao (2001)	
	Wunderlich (2002)	
	Feldmann, Christoph, and Wunderlich (2003)	

All approaches depicted in Table 1 apply to simulation-based configuration of logistics systems. Apart from Kersten (1996) and Wollenweber (Verein Deutscher Ingenieure 2001) all authors have committed to ABC. The great majority allocates depreciation, personnel costs and other indirect costs (such as rent, insurance etc.) to cost units (orders, products) based on activity-drivers. Many of them label this a "fair allocation", although it is obvious, that the cost components do not behave proportional to the proposed cost driver (e.g. labor costs being measured by the duration of inspection for example in Feldmann, Collisi, and Wunderlich 1999). With respect to a configuration setting, these costs are neither incremental, nor are they necessarily future-oriented. A differentiated analysis about cost origins remains undone. None of the approaches nourishes the idea to identify real relations between the technical (process) system and the value structure. The focus is put solely onto products as cost units and the subsequent allocation of indirect and fixed costs.

3.2 Riebel's Generic Direct Cost Accounting

Paul Riebel's approach describes direct cost accounting, which strictly refrains from allocating indirect costs to products or orders (Riebel 1994). In contrast, costs (and revenues) shall be assigned to those objects, which evoke them with respect to a certain decision. For instance, the advertising costs of a product-family will not be affected if its production output is changed; thus, these costs are irrelevant for decisions concerning the product units, e.g. sequencing. However, once the entire product-family is erased from the assortment, they become a relevant cost factor. They constitute direct costs only on behalf of the reference object "product-family". Riebel proposes to develop a hierarchy of reference objects where all costs (and revenues) can be declared as direct with respect to the lowest possible reference level. Apart from costing this allows the assignment of contribution margins to different reference levels, e.g. product-families, cost centers, plants or business units.

Riebel utilizes a very strict cash-based cost definition. The assignment of depreciation to reference objects is therefore not possible. This aims towards an inter-periodical accounting methodology alike investment accounting. In fact, Riebel claims the discrepancies as overcome (Riebel 1994). However, Riebel's Generic Direct Cost Accounting is a static approach, where the dynamic setting of long-term decisions cannot be adequately reflected (Ewert and Wagenhofer 2005). Hence, we restrict Riebel's principles to intra-periodical (i.e. usually one year or less) cost accounting and allow for a cost definition, where non-cash items such as depreciation can become a relevant factor. In general, Riebel's principles require a soft interpretation for an implementation into practice (Weber and Weißenberger 1997).

Despite its conceptual coherence, which has been attested by researchers (Ewert and Wagenhofer 2005, Eisele 2002, Männel and Hummel 1993), the concept has found little application in simulation based costing analysis. Although Klug (1994) and Klug and Fortmann (1994) mention Riebel's approach for simulation based costing, their implementations solely describe the use of Activity Based Costing methods. From a modeling point-of-view, this is not evident, as the model structures of Riebel's Generic Direct Costing and DES have similarities, too. The standard reference objects, such as components, products, transport devices, machines or cost centers, are usually objects of a simulation model as well. Compared to ABC, the efforts to adjust a standard simulation model to a cost simulation model applying Riebel's costing are less.

With regard to configuration, Generic Direct Cost Accounting analyzes total and reference object costs (and revenues). The direct unit costs usually contain material costs and define a lower price limit for operational decisions. The approach visualizes how different configuration settings change the cost (and contribution margin) structure of the system. It is strictly future-oriented and incremental. In contrast to ABC, the assessment is based upon total cost differences, which can be traced to direct cost savings of reference objects without fearing distortions due to allocations.

3.3 Consumption and Engineering Production Functions

Unlike ABC or Riebel's Generic Direct Cost Accounting, consumption or engineering production functions do not constitute a complete cost accounting system. They merely allow to describe relationships between input factor consumption and outputs. The concept of consumption functions was first introduced by Gutenberg in 1951 (Gutenberg 1983). He claimed a functional relationship between a machine's power setting, the amount of raw materials required on the machine (energy, lubricants, material) and the output quantity generated over a fixed time interval. The consumption function $r_i=f(d)$ measures the consumption of a particular factor i for a given machine power setting d, resulting in the production of one output unit. In contrast to constant production coefficients in earlier works, the consumption function leads to variable relationships between input and output quantities, such as s-shaped curves (Steven 1998). However, Gutenberg's analysis remains quite theoretical with little applicability for industrial settings. Heinen (1985) decomposes the transformation process further and describes it as a number of single elementary activities, each for which consumption functions can be formulated. The entire process to manufacture an output unit therefore is a combination of different, repeatedly executed elementary activities. This allows a more realistic modeling of input-output-relationships (Steven 1998). The derivation of consumption functions is usually an inductive process based on empirical observations.

Research on Engineering-Production-Functions (EPFs) occurred parallel in the USA; they were first introduced by Chenery (1949). EPFs explore the technical (mechanical, biological or chemical) system of the process and determine input-output-relationships with respect to process-inherent technical parameters. EPFs are commonly derived based on scientific laws (e.g. physical laws of mechanics), which yields a deductive approach. The operation of a gantry crane shall illustrate the differences between the three concepts. A gantry crane can displace an object on a plane by lifting it, horizontally moving it in x- and y-axis and dropping it at the desired spot.

- A Gutenberg consumption function would regard the crane as one entity and try to construct a relationship between its output, e.g. the number of crane movements per hour, its input, for example the electrical energy consumption, and the power setting, which could be a fraction of the maximum speed of the crane. However, the operation of the crane is characterized by a number of different actions (lifting, dropping, horizontal movement), which are subject to regular changes in speeds. A Gutenberg consumption function would therefore yield a poor approximation of the systems consumption structure.
- A Heinen consumption function would decompose the crane process into its elemental activities lifting, dropping, trolley movement (y-axis) and crane movement (x-axis). Here consumption functions incorporating different technical drivers can be modeled; i.e. the energy consumption for lifting depends upon the coil weight, while it might be

a function of the travel distance at a particular speed for the crane movement. However, the derivation requires detailed empirical observations of energy consumptions and activities.

- An engineering production function would decompose the system further and analyze the mechanical and electrical system of the different power aggregates of the crane. Here, the energy consumption could be obtained by calculating the physical work, which has to be provided by the electric motors with a (potentially varying) efficiency factor.

The example illustrates, that Heinen consumption functions and engineering production functions can significantly improve process analysis, as formerly hidden input-output-relationship become visible. Combining the functions with cost factors further allows to create a linkage between costs and processes, which – in contrast to ABC – relies on functional relationships rather than on simplified cost drivers. However, consumption functions and EPFs require detailed empirical or a thorough technical analysis of the processes. Until today, they have not encountered a strong dissemination in industry applications (for an overview see Wibe 1984).

4 CONFIGURATION WITH VALUE-ORIENTED SIMULATION

In chapter 3.1 we revealed that simulation approaches applying ABC show significant weaknesses, since ABC does not constitute a decision-oriented accounting method. This is particularly true for tactical decisions in the course of technical configuration. In the following, we will present a different approach for combining DES with accounting, which we define as Value-oriented Simulation. The term shall reflect the main idea of the approach to provide simulation-based tactical decision support based on managerial objectives. In analogy to the correspondent concept of Value-oriented Management, where management options are assessed according to their contribution to corporate value (Copeland, Koller, and Murrin 2000), Value-oriented Simulation builds a connection between the technical system and corporate objectives to improve tactical decision-making. Furthermore, the term is to separate our concept from the existing deficient approaches of Simulation Based Costing and Cost Simulation, and the definition of the Association of German Engineers Guideline VDI 3633 (Verein Deutscher Ingenieure 2001). The focus in this contribution is set onto the application of adequate accounting techniques. However, Value-oriented Simulation separates from existing methodologies in other aspects as well, which are treated elsewhere.

4.1 Applying Decision-oriented Accounting

As described, a full cost accounting system allocating indirect costs to units contradicts Relevant Costing. Therefore, direct costing systems, such as Marginal Costing (Kilger, Pampel, and Vikas 2007), multi-level fixed cost absorption (Agthe 1959) or Generic Direct Cost Accounting (Riebel 1994) are to be applied. For the purpose of simulation-based configuration planning, the use of Riebel's Generic Direct Costing is particularly beneficial. His approach suits well for project-related accounting as the definition and arrangement of reference objects is very flexible (Weber and Weißenberger 2002, Ewert and Wagenhofer 2005); according to Riebel, direct costs are relative as they can be assigned to different reference objects dependent on the decision situation. To this regard, costing systems which are pooling costs in cost centers, such as Kilger's Marginal Costing, are less flexible due to their foundation on established organizational structures.

Reference objects are usually assigned to objects of the simulation model; however, if particular cost-relevant aspects of the decision are not explicitly assumed in the simulation, reference objects can stand alone, too. They act as a cost pool, measuring costs for the object they represent and transferring them to the next higher hierarchy level. Riebel's approach positively affects the modeling phase of the study. By defining the reference objects and arranging them hierarchically, the modeler has to analyze the cost structure with respect to the decision. All relevant costs require a single reference object that provokes them, which leads to n-to-one-relationships. The developed hierarchy gives hints about possible measures with considerable effect on costs and helps to define the boundaries of the simulation model.

However, the greatest potentials of combining DES and Generic Direct Costing we see in the possibility to incorporate consumption and engineering production functions to increase the explanatory power of decision support. Consumption functions and EPFs establish a relationship between input factors and the output of a machine based on its technical parameters. The output can represent an assembled physical good, a change in characteristics of a good or a logistics activity, such as the transport of a good. Applying such functions can (positively) affect the structure of a Generic Direct Cost Accounting system in two possible ways:

I. Costs linked to an existing reference object can be measured more accurately. Consider a furnace (reference object 'furnace'), in which large objects (reference object 'objects') are heated through several gas burner. The amount of energy to be inserted depends upon the base and the target temperature and the geometry of the object. Without a technical function, mean values would have to be applied for the calculation of the energy consumption and costs (potentially based upon prior measurements). Once consumption functions or EPFs – determining energy consumption with respect to temperatures and geometry – are incorporated, a linkage between the two reference objects is created, leading to an endogenous calculation of costs. As a consequence, measures affecting the technical parameters of the objects precipitate in cost changes.

II. New reference objects can be established, which allow the assignment of costs to a lower hierarchy level. This is the case when a functional relationship allows to decompose an existing reference object. This case is represented by the crane example in section 3.3. By decomposing the crane process into its elementary activities, a new reference object hierarchy situated underneath the reference object 'crane' can be established. The new hierarchy supplies reference objects for the energy consumption and costs (Figure 3).

The flexibility of Riebel's approach facilitates the incorporation of consumption functions and EPFs. However, in a stand-alone (static) cost accounting system, their calculation would require great efforts. Furthermore, dynamic aspects that might play a role for the calculation (e.g. if system state parameters represent input factors to the functions) can hardly be accounted for. In contrast, a DES model can apply the functions during its standard routines and allows to consider dynamic and stochastic aspects as well. Finally, today's simulation packages on the market offer ample degrees of freedom to integrate mathematical relations.

Applying the discussed principles of Value-oriented Simulation leads to a significantly improved configuration planning. By combining Riebel's decision-oriented accounting with DES, the shortcomings of technical target systems can be overcome without jeopardizing the explanatory power due to lacking or distorting value information. On the contrary, the incorporation of consumption functions or EPFs allows for a better understanding of processes inside a system. The discussed problem of transferring the multitude of a dynamic system (chapter 2.2) and its various technical figures into a single monetary value can be further diminished.

4.2 Case Study

4.2.1 Setting

We will illustrate the potentials of the approach in a case study of a German steel manufacturer. Steel production processes are usually complex due to a high product heterogeneity, make-to-order production, many technical restrictions and a production network with various paths and loops (for an overview see Lee et al. 1996, Dutta and Fourer 2001). Therefore, plant design often requires dynamic planning tools such as DES (cf. Briggs 2008, Spengler, Labitzke, and Volling 2007, Fioroni and Franzese 2005, Brady 2001) in combination with sophisticated accounting techniques. Furthermore, steel production is characterized by high energy inputs (iron ore reduction, heating of slabs and coils, transportation of heavy items); rising energy prices for coal, gas and electricity have put a strong focus on energy-efficiency in the last years (Tang et al. 2001, Ameling 2007). This has raised issues for the reconfiguration of logistics systems in many steel mills, based on a more detailed measuring and analysis of energy consumption.

In this contribution we focus on a stockyard used for coil inventory between the hot rolling mill and the pickling plant, which is subject to a major reconstruction. The inventory is required due to an emancipated production scheduling of the plants and due to the need for annealing, which takes approximately three days. Although structural issues have been considered during the study, only aspects of dynamic configuration are reported here. To this end, measures are to be evaluated to improve the efficiency of the stockyard.

The stockyard is operated by two gantry cranes, which pick up hot coils from a dynamic lifting bar, move them in designated bin locations and put them on railway cars, which transport them to the pickling plant. The coils can be stored in layers of one to three. As the coils do not pass through the inventory in a first-in-first-out sequence, reshuffling activities cannot be avoided. Figure 1 gives an overview of the layout.

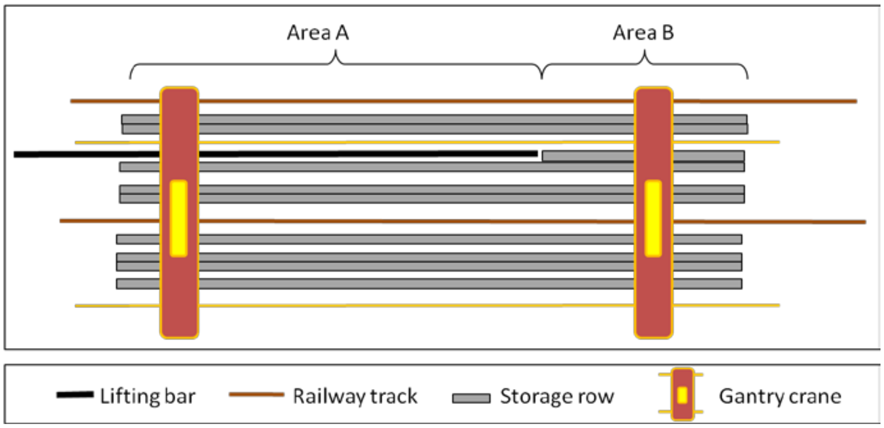

Figure 1: Layout of the coil inventory

To assess the performance of the stockyard, technical targets, such as throughput time of the coils, coil tardiness or crane utilization could be considered. However, the primary objective constitutes turnover, which is targeted to 2.4 Mill. tons per year. The secondary targets, minimizing throughput time and maximizing crane utilization, behave conflicting. In order to avoid a multi criteria decision situation, a monetary assessment needs to be employed. The turnover target could either be monetized in terms of revenues of the coils or it could be formulated as a restriction to the objective of cost minimization (compare chapter 2.2). We decided for the second option as the incorporation of revenues is not possible without caprice. With respect to a base scenario, four different configuration settings will be assessed. Table 2 states how the alternative configurations differ from the base scenario.

Table 2: Parameter settings that are subject to changes. Symbol (-) indicates no change of parameter setting with respect to the base scenario. Detailed explanations are presented in chapter 4.2.3.

Parameter setting	Base scenario	Measure A	Measure B	Measure C	Measure D
Storage capacity	100%	-	-	77%	82%
Storage area use	A & B active	-	-	A active	-
Stacking height	2.5	-	-	-	2
Crane use	6 crane shifts	5 crane shifts	-	-	-
Crane work balance	balanced	-	unbalanced	-	-

4.2.2 Model

For the assessment, a discrete-event simulation model including cost accounting based on Riebel's Generic Direct Costing is developed. The level of detail in the simulation model is high. Gantry crane movements are modeled in x- and y-axis using exact dimensions, the z-axis (lifting) is displayed via waiting times varying with the stacking height. Relevant costs include personnel, energy and inventory holding costs. Personnel costs occur from the crane operators. As Figure 3 illustrates, they depend upon the crane shifts. Inventory holding costs only include costs of capital that is bound in the coils (in the form of material value). Other inventory costs (maintenance, insurance) are not affected by the proposed measures and therefore not included. The energy consumption of the cranes, constituting one factor for energy costs, depend upon their operations. Here, the proposed concept of integrating consumption functions is applied. To gain knowledge about the consumption behavior of the cranes, an empirical study was conducted. Over a period of three days, energy consumption and the crane's movements were recorded and analyzed. As a result, consumption functions for specific crane activities can be plotted (cf. Figure 2 as an example). The technical parameter for the activities 'lifting' and 'dropping' is the coil weight; for the movement of the crane and the trolley, it is the moving distance. Without the study, energy costs could be assigned to the cranes at best. The consumption functions allow to insert a new reference object level 'activity', which is situated underneath the existing ones. As a consequence, new insights into the relationship between the cranes' work and their energy consumption can be gained. The prices for electricity represent the second important factor of the energy costs. At the energy spot market they vary strongly over the time of day. However, they are relevant, as energy savings first lead to a reduction in purchasable spot market energy.

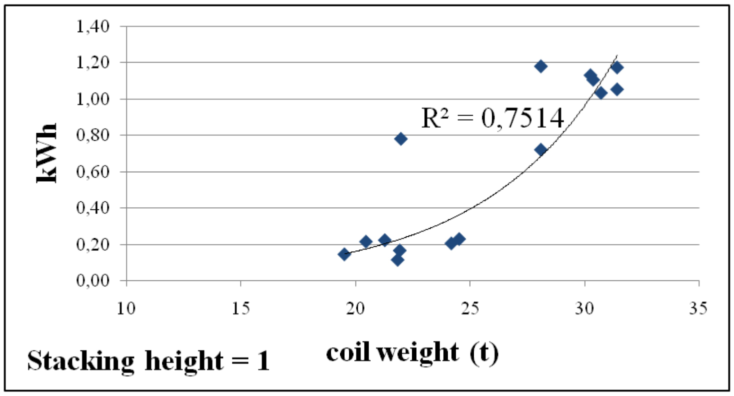

Figure 2: Consumption function for lifting coils from the ground (stacking height=1).

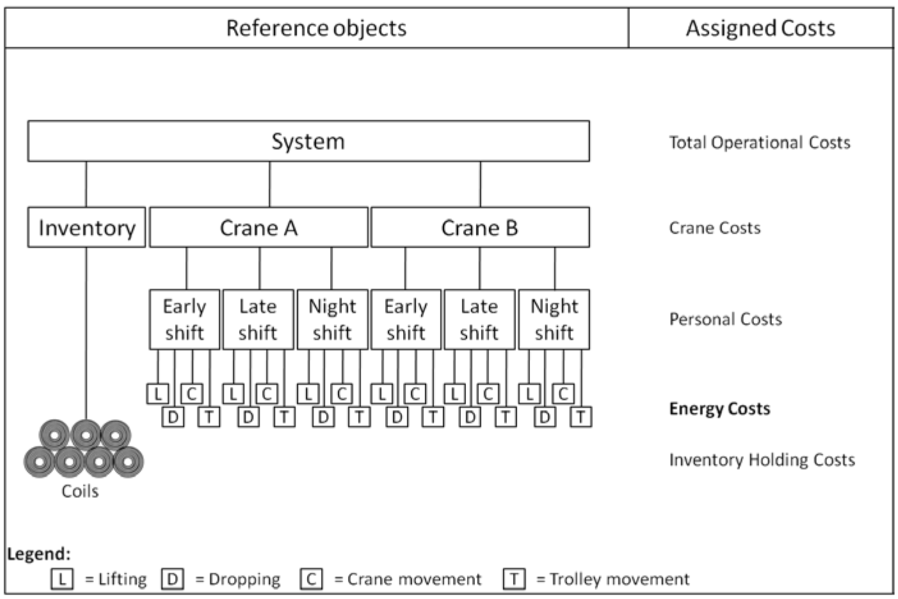

Figure 3: Reference object hierarchy

The model is developed in Plant Simulation™ 8.1. The experiments are conducted over a simulation time of 120 days. During this time, all relevant perturbations, such as maintenance intervals of the hot rolling mill, the pickling plant and the cranes take place several times. Furthermore, it is easy to extrapolate the simulation results up to a year. Each simulation experiment includes 5 simulation runs with differing random number samples. Total numbers, such as turnover or costs can be averaged over the runs; however, the 99% confidence interval of the total turnover is less than 1.3%, indicating, that the random factors level out over the simulation time quite well.

4.2.3 Results

Measure A treats the shutdown of a crane during the early shift. This could potentially reduce personnel and energy costs by $1/6^{th}$. It builds on the observation that the cranes are only moderately utilized. However, this setting violates the turnover restriction. In the early shift, the single crane is too busy stocking coils in, that it can hardly handle outbound coils. This leads to an increase in inventory, which cannot be completely removed during the other two shifts. The inventory runs full, blocking the hot rolling mill.

Measure B nourishes the observation of significantly reduced energy prices during the night. Therefore, in this setting, certain activities of the cranes are moved into the night shift. Coils, that are scheduled for departure during the next day can be relocated close to the rails. This way, the extensive reshuffling activities are laid into the low-price night hours. The measure is technically effective, as crane utilization shows significant fluctuations of 10% differences between day- and nighttime hours. However, this does not reflect in the cost structure. The amended crane operation leads to an additional crane activity per coil, when it is picked up from its night location onto the train. The additional energy required here over-compensates the energy price savings acquired during the night.

Measure C treats a reduction in inventory space, as inventory utilization is moderate in the base scenario as well. By shutting-down inventory (23%) at the eastern end of the stockyard, movements particularly of crane B can be reduced. However, this measure even leads to a small increase in energy costs. Stocking of the coils becomes tighter which means that more coils need to be stored in the third layer. As a consequence, more reshuffling activities become necessary, resulting in additional energy consumption that over-compensate savings acquired through shorter travel distances in the x-axis.

At last, measure D builds upon the observations from measure C. Here, inventory space is reduced by limiting the maximum stacking height to two, instead of 2.5 in the base scenario (2.5 indicates that every second row the coils are stacked three layers high). This measure reduces the number of reshuffling activities and leads to an energy cost benefit of 17%. Interestingly, the cost savings for crane B are considerably smaller than for crane A, which can be explained by a stronger increase in the crane's travel distances. Total operating costs of the inventory can be reduced by 3%. All results are summoned in Table 3.

Table 3: Comparison of measures (mean values). Inventory utilization figures are based on the number of bin locations in the specific scenario.

Target (mean values)	Base scenario	Measure A	Measure B	Measure C	Measure D
Inventory utilization	52%	$\rightarrow$ 100%	52%	68%	63%
Crane utilization (crane A/B)	51%/58%	$\rightarrow$ 100%	Day:52%/60% Night: 63%/70%	51%/58%	46%/58%
Coil throughput time	100%	-	101%	102%	99%
Turnover > 2.4 Mill. t	Achieved	Not achieved	Achieved	Achieved	Achieved
Total costs	100%	-	102%	101%	97%
Energy costs (crane A/B)	100%/100%	-	109%/109%	103%/105%	78%/87%
Personnel costs	100%	-	100%	100%	100%
Inventory holding costs	100%	-	101%	101%	100%
Recommendation	-	No	No	No	**Yes**

An analysis solely based on technical targets has to remain unsuccessful. As the data in Table 3 indicates, the technical figures 'crane utilization' and 'coil throughput time' behave either conflicting or they show little, statistically insignificant, changes. The use of different figures, such as 'number of reshuffling activities' and 'total distance travelled' show conflicting behavior as well. Furthermore, an assessment of the monetary benefit, which is the primary target for a final management decision, would have remained undone.

In a study applying Cost Simulation or Simulation Based Costing, cost data would be included, but energy consumption would remain an external factor; this would likely result in an energy cost rate per hour based upon historical data, restricting analysis to time- and quantity-oriented measures. The effects of different crane or inventory controls on the energy consumption and cost structure could not be identified. Furthermore, following the principles of absorption costing, crane depreciation, maintenance and indirect inventory costs would be allocated to the units (coils) as well (for instance, by applying transportation time per coil and throughput time per coil as cost drivers), unnecessarily distending the cost basis. The knowledge of unit costs is of no use for the assessment of different configuration settings here.

5 SUMMARY

Base to this work was simulation-based decision support for the configuration of logistics systems in production. Due to the financial impact of the proposed measures, decision-making is usually based on monetary management figures. A selection of alternatives solely based on technical targets can lead to wrong decisions. For simulation-based planning, this shortcoming has been addressed by concepts like Cost Simulation and Simulation-Based Costing. However, the majority of the presented approaches unites a lacking understanding of the decision situation and the appropriate accounting technique. As mainly constituting nonstandard, project-related planning detached from the day-to-day routines, configuration requires decision-oriented accounting principles. ABC does not constitute a decision-oriented accounting with respect to this planning task. As a consequence, the presented approaches inherit conceptual inconsistencies. Furthermore, they do not exploit the potential that an integration of accounting and DES really offers. To this end, a new approach labeled as Value-oriented Simulation has been presented. Apart from issues concerning coordination, which were not treated here, the approach proposes a different accounting system and the application of detailed input-output-relationships. These can be incorporated using consumption functions or EPFs. The objective is to increase the explanatory power of the model to improve tactical decision support. A case study at a German steel mill was presented to illustrate the potentials of the approach.

In this contribution, we focused on short- to medium-term problems which are accessible to an intra-periodical accounting. However, once structural questions concerning plant design are analyzed, dynamic investment accounting methods are to be preferred. As stated above, we refrain from considering Riebel's Generic Direct Cost Accounting as a universal accounting technique for all kinds of decision problems. Yet, for simulation-based configuration planning, we consider it as the most appropriate accounting technique, combining high flexibility with a strong conceptual foundation.

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