

DESIGN OF INTEGRATED MANAGEMENT SYSTEMS FOR THE EXTENDED SHOP-FLOOR (Special Session – HOPS)

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Abstract

“HOPS-Special Session”: In the face of today’s globalized and dynamic business environment, proper production management systems (PMS) have become a critical success factor for manufacturing companies. In practice, however, designed PMS are often not satisfactory, especially for shop-floors that are part of larger supply chains. The paper postulates that this is fundamentally the result of using very technocratic models for the PMS design. A dual modeling framework is introduced in order to achieve a more integrated and holistic PMS design. A holistic design acknowledges that social and technical sub-systems can achieve through their interaction a better management performance than each of them individually. An integrated design does not artificially separate the PMS from the shop-floor it manages, but rather considers them as two intertwined and complementary parts of an organizational unit. Finally, a case study helps to illustrate the practical application of the framework.

Keywords:

Management systems, extended shop-floor, socio-technical design model, practical case study

1 INTRODUCTION

Activities along the supply chain are increasingly outsourced to different partners. This confronts manufacturing companies with a critical managerial challenge: finding the right balance between coordinating the entire supply chain, and locally optimizing the operation of the embedded shop-floors. To tackle this problem, many companies have resorted to technology (e.g. ERPs), often encouraged by key (external) partners in the supply chain. Many shop-floor managers, however, consider the results of this approach far from optimal [1]. One key problem is that the technological solutions implemented neglect the joint technical and social nature of shop-floors. The technologies adopted usually restrict the autonomy of shop-floors drastically, both in terms of decisions and execution; hence, they do not allow the full contribution and development of the shop-floor personnel [1] [2].

The more dynamic and global the business environment gets, the more acute these auto-imposed limitations become. As companies increasingly outsource operations to third countries where labor cost is low, supply chain coordination becomes more challenging. Furthermore, as low costs are no longer sufficient for achieving sustainable competitiveness in the longer term, flexibility and speed of response become crucial for differentiation.

As a matter of fact, in many companies this requirement has led to a profound change in the fundamentals of how planning and control is done, and in the way the nature of work within production management systems (PMS) is considered. Essentially, the change unfolding over the last decade, has been from a product/functional view focusing on certain states of production (e.g. utilization), to a more systemic view focusing on certain capabilities (e.g. agility) [3] [4].

Consequently, new PMS design strategies and concepts are needed. Traditional deterministic views, where the uncertainties arising from the complexity of production are considered a failure to be eliminated, are insufficient for coping with today’s production challenges. Instead these uncertainties should be accepted as the norm, or even as a requirement for organizational learning and development [5]. This realization specifically calls for abandoning pure

technocratic conceptions of PMS in favor of more holistic views, integrating human, technical and organizational aspects of production systems.

The conclusion is that to remain competitive, the design of PMS must become a main objective for manufacturing companies at least as important as product innovation [1]. But this design has to be based on a holistic and integrated understanding of production systems. Now the particular understanding of a given production system is ultimately determined by the model one has built of it (explicitly or implicitly). Therefore, in all the steps to be taken during the PMS design, a central role is played by the models on which the design is based. This article is designed to (1) analyze the role of these models, and (2) provide some guidelines and tools which can instruct the modeling of production systems for their PMS design.

The paper continues with a brief description of a practical case study of an industrial operation in Mexico (section 2). In this case, significant improvements were achieved through a re-design of both its manufacturing operations but also of its PMS. The case study shows the relevance of providing designers with an adequate production model. Only if the model enhances their systemic understanding of production systems they will be able to appropriately design the PMS. Consequently, potentials and general requirements of modeling production systems for the purpose of PMS design are analyzed in section 3. The gained insights are considered in section 4 for the development of a dual modeling framework for the PMS design. The description of the framework focuses specially on the underlying ontological groundings (i.e. the modeling constructs). The results achieved in the case study and final conclusions are drawn in sections 5 and 6.

2 A PRACTICAL CASE STUDY AS STARTING POINT

Many practical case studies conducted by the authors corroborated the importance of an adequate modeling of production systems for the design of their PMS. One of the studies, led by a department colleague, should be presented in detail, as it is very representative for the addressed PMS design problem [6]. Additionally, the fact that the operation is located in Mexico, a traditional low cost

country, shows that the described concepts are not limited a priori to certain geographies.

The analyzed plant produces sterile disposable surgical gowns and sheets. It is located on the US-Mexican border close to El Paso (US), where its mirror plant is operating. Both manufacturing plants belong to a large industrial conglomerate from the US.

2.1 Existing production process and organization

The manufacturing process starts with the cutting of the fabric in the US plant. The fabrics are piled up in layers, and then the patterns are cut manually. Next, they are shipped in trucks to the Mexican plant. There, workers assemble the gowns in a series of basic sewing operations. At the end an exhaustive quality inspection guarantees meeting the required quality standards.

Originally, the Mexican plant was organized according to the classical "sea of equipment" model. That is, operators doing the same operations on their machines were physically grouped together in a workstation (e.g. sewing necks). As some process steps (e.g. fixing sleeves) take more time by their very own job nature, proportionally more operators were assigned to those steps. However, production times could vary depending on product types. The production was performed in batches of 28 gowns.

The capacity of the plant as a whole was balanced centrally in accordance with the planned production rates of the individual workstations. The ERP assigned incoming orders to a specific machine at each workstation. Once a day, depending on the accumulated work-in-progress, some operators were re-assigned to different workstations to compensate deviations from production plan.

However, since bonuses were based on the worker daily productivity, workers who had already some expertise in a particular task were reluctant to switch to different workstations, as their short-term productivity (and bonuses) would suffer.

Average labor turnover was high due to a high voluntary attrition, resulting from (1) work abundance in the region, and (2) higher productivity bonuses during first months in the job. Consequently many workers become plant nomads, migrating every few months from one company to the next. Most of the recruits immigrated from other parts of the country, and had reduced schooling.

2.2 The call for improvement

In the described system, average daily throughput per employee in the Mexican plant was 30 gowns per day. This was 33% below the industry average of 45. Several reasons for this low productivity could be easily identified.

For example, central planning was not able to balance properly over time the different workstations. This resulted in a work-in-process (WIP) much too high. On average, WIP occupied 50% of the available plant space, requiring around 10% of operators exclusively dedicated to move goods between workstations instead of performing productive tasks. The high operator turnover had also significant negative impact on the productivity in several different ways. First of all, new operators always needed several months to reach desired productivity levels. Secondly, experienced workforce showed high levels of absenteeism. Furthermore machine down-times were above industry standards, probably due to operators' low sense of accountability and responsibility for their equipment resulting from continuous re-assignment of workplaces. Finally, on average 6% of produced gowns had to be re-processed because of insufficient quality.

When a new general plant manager was appointed, the improvement potential of the plant operations was studied

in detail. The conclusion was that while some incremental improvements were surely possible, reaching industry productivity levels would require changing operations fundamentally, because of the inherent drawbacks of the "sea of equipment" model. These drawbacks exist both on the operators' side as well as on the planning and control side. To name only but a couple on both sides (c.f. [1] for more):

- Operators cannot develop any sense of product ownership. Most of them don't ever see finished goods leaving the plant.
- No sense of team spirit can be developed.
- The centralized planning detaches completely planning and operating entities. Operators are not involved at all in planning and control. Therefore their knowledge about specifics of a particular machine or tool is not used.
- No sense of accountability for the work-plans is developed by operators.

Summarizing, the plant analysis revealed two major problems. First, it became apparent that *the chosen production management approach was ignoring the socio-technical character of production systems*, or more precisely, human operators were not considered at all as enablers of dynamic production management. Paradoxically, the industrial group to which the firm belonged emphasized the importance of the social side of its organization as well as the caring about individuals in its mission statement. Other conducted case studies also confirmed that such technocratic designs generally lead to highly intricated PMS, which are not very agile. In industrial practice, this often reverts to an informal PMS with foremen keeping their own additional databases in order to be able to keep due dates despite numerous changes [7].

A second key error was to *neglect that the plant only supports a few manufacturing steps within an entire industrial operation*. Previous and following process steps should exert a more deliberate influence on the plant's PMS. As an example, the high WIP led to an average throughput time of over two days, compared to a pure manufacturing time of less than 15 minutes per gown. This was not only internally originated, but also a result from insufficient synchronization with the US operations.

These two problems seemed to be of basic nature and therefore to deserve a deeper investigation. A more careful analysis of the requisites for the development of a holistic and integrated model of production systems for the design of its PMS appears to be worth.

3 Some key axioms for the design of PMS

3.1 Modeling challenges and dilemmas

As firm face a more dynamic business environment, process-oriented views of production have gained significant interest in the PMS design, both in industrial practice and in academic publications. This has led to the development of a wide variety of modeling concepts using simulation for the design of PMS [1] [7].

However, new drawbacks arose. First of all, both the modeler and the adopted modeling technique precondition the set of variables to be represented in a model as well as their possible interactions. Obviously, when comparing different design solutions or scenarios (e.g. when using computer simulation), only those variables represented in the model are considered in design scenarios. As mentioned, most production models focus primarily on technical aspects of manufacturing, representing only "hard technical" (i.e. quantifiable) variables as throughput time or capacity. "Soft variables" such as skills or motivation, as well as the influences of a

given organization, are not considered at all. For instance, the developed model would neglect that the organizational context affects the appropriateness of alternative PMS design options [8], i.e. the model would be the same for the plant in Mexico as for one in Europe, regardless of their different social and organizational characteristics.

One of two basic modeling options can be chosen therefore. Either a numerically precise model is formulated, which will certainly miss some essential aspects of the production system behavior, or a certain kind of quantitative precision is given up, in order to include critical "soft variables".

Furthermore if one seeks to share and review the production model at a later stage, one is confronted with an additional dimension of this dilemma. One has to keep a balance between the required complexity of the production model needed for the proper understanding of the production system, and the required simplicity of the model to allow it to be shared by the different persons involved in the design to finally achieve a joint action.

The context of this dilemma even changes along the design process. In fact, to provide modeling support for the PMS design requires covering very different levels of mental abstraction at different stages of the design process. In the first phases, that is, the identification and clarification of the problem and the development of the conceptual frame for analyzing different solutions, designers have to deal with a high uncertainty with respect to the envisioned results. For the later phases of design, that is, the design of the favored solution in detail, a more concrete and specific model of the production system is required. In this later phase, detailed design decisions have to be taken (e.g. maximal workstation capacity or layouts).

3.2 First Axiom: distinguishing between regulatory and design models

Axiom: Models required for the design of PMS (i.e. design models) should be different from models required for the operational management of shop-floors (i.e. regulatory models).

A first answer to the posed dilemma of the adequate modeling complexity, is to distinguish between the models of production on which the PMS bases its operation (i.e. *the regulatory models*), and the models on which the designers base their design activities (i.e. *the design models*). This differentiation is based on two insights: (1) in industrial practice it is unlikely at all that the two can be identical, and (2) both model types pursue anyway fundamentally different purposes.

The production model on which the PMS design is based, never will be identical to the regulatory models coded in the brains of human operators because those regulatory models have been developed under particular influences of knowledge, experiences and interactions [9]. Even the models of different operators in the Mexican plant are likely to be different, depending for example on their background (studies) or experiences (other plants). Further, the models will be very different from the ones coded in the plant's ERP.

Regulatory models are required for performing the production management tasks. Design models instead should primarily focus on the adequate interaction between the different regulatory models, both within the shop-floor and with the rest of the supply chain [3]. A PMS design model must first define the particular action domains within the production management activities (i.e., what each sub-system should do – whether individuals, organizational units, or technology – and how the different sub-systems should communicate) [3] [8].

In fact, the quality of the designed PMS will depend on whether the used design models – and the semantics (terminology) it is built on - allow appropriate consideration of all relevant design variables (e.g. human operator's motivation) and representation of all the solution scenarios considered. The fundamental conclusion is that the primary purpose of a production model for the design of PMS is to improve their design, and not a regulatory purpose. Finally, since the two models pursue different purposes, one can decide what can be left out and what not based on these purposes.

3.3 Second axiom: Providing a dual modeling framework

Axiom: An integrated modeling support of the PMS design process should cover two basic design levels: an aggregated meta-level and a concrete object-level.

For initial design phases a more abstract system model would be most helpful, as it could make the desired functionality patterns of the design options more explicit, and consequently make the solution space more transparent. At this aggregated design level the modeling of the fundamental relations between the shop-floor elements as well as with its environment (e.g. supply chain), together with the reflection of design principles and criteria, are of primary interest [10]. The purpose of a meta-model for this phase is offering support for analyzing innovative solutions while reviewing the risk of detrimental decisions and failures. It should essentially provide a blueprint upon which to carry out the PMS design.

A more concrete object-model should support the detailed PMS design. For example, capacity profiles and scheduling procedures have to be tested. To describe the dynamic behavior of a system, ideally it should be possible to easily extend the object-model to a simulation model.

3.4 Third axiom: Complementing social and technical sub-systems

Axiom: Social and technical sub-systems can achieve through their interaction a higher production management performance than each sub-system individually, therefore a complementary PMS design is best.

Recognizing the importance of the interaction between the regulatory models means to realize that the PMS design depends decidedly on the interaction between the operators and the technical sub-system; or more precisely, between their corresponding regulatory models. Hence, the PMS design must also take into account that the coordination with the overall supply chain should not be dominated by technology (e.g. an ERP).

The degree of both centralization and automation of production management, and therefore the opportunities the human operators have to participate in this activity must be adaptable to match the qualification of the staff as well as the cultural environment. The goal is to empower human contributions by designing job positions that allow operators to develop production management capabilities. This is a precondition for an agile production management. Ultimately, operators should learn to leverage themselves with technologies in place while at the same time counter the proven weaknesses these technologies have [9] [11].

3.5 Fourth axiom: Integrating PMS and production

Axiom: For the PMS design one should not artificially separate the PMS from the shop-floor it manages.

The PMS and the shop-floor should be considered as two intertwined entities of an integrated organizational unit (e.g. a manufacturing shop-floor). Following the socio-technical system notion, a shop-floor (design) model is proposed where the manufacturing activities constitute the primary

work-system and the PMS the secondary system [11]. Such a structure weakens the boundaries between managing and managed entity. It also allows balancing local autonomy and overall supply chain coordination, as the later is only required to define the broader conditions for the shop-floor operation (e.g. performance goals) without intrusion into the details of the shop-floor planning and control activities [12]. The goal is to establish an organizational structure where PMS and production systems are intertwined along both technical and social sub-system. In consequence, re-designing only the PMS while leaving the production as it is has a low likelihood of being successful. For example, it would not make sense to distribute more planning and control in the Mexican plant without adjusting the “sea of equipment” manufacturing model it operates.

4 A DUAL MODELING FRAMEWORK FOR THE DESIGN OF MANAGEMENT SYSTEMS

4.1 Providing a common terminology for design

The first step of the development of the envisioned dual modeling framework is the specification of the key elements of a holistic and integrated production model that fulfills the four stated axioms. Semantics are therefore of crucial relevance in order to provide a precise terminology and mental conception for these elements. The difficulty of developing a terminologically precise modeling framework of production systems is that they comprise many, very different and interrelated constituents. In addition, they represent among themselves a variety of viewpoints of the system. Fortunately, significant work has been done already in this direction. Several production system models have been developed and validated in practice. A detailed description of the studied models, as well as the reasoning for which concepts were chosen to be build on (both in the meta- and object-model) can be found in [1].

The core of the developed socio-technical system view of production, are the *tasks* to be performed (e.g. sewing necks). *Functions* are then obtained by relating a task to a specific item to be transformed (e.g. gown fabrics). On the next level *activities* are generated by relating the functions to the resources which allow the transformation, and a management entity which manages the transformation. Finally, a *process* is made of an ordered sequence of connected activities which determines a transformation, i.e. activities are elementary processes. A process consists of a *source*, a *transformation* and a *sink* and takes place in an open, dynamic and socio-technical system. The relations with the environment (e.g. US plant) are modeled by the sources and sinks of the processes.

Processes are only meaningful if they fulfill the tasks of the system. Two types of tasks can be the foundation of a process, primary or secondary tasks. The primary task (e.g. producing gowns) is given through the key purpose of the system and is the reason it (e.g. the Mexican plant) was created [11]. Secondary tasks are defined to preserve and control the system. Apart from production management, maintenance or calibration of the sewing machines would be other secondary tasks.

To completely understand the behavior of production systems, the concepts of *purposes* and *goals* are also crucial. The purpose refers to the “raison d'être” (e.g. gown production capacity) of the system related to its environment and consequently derives in the primary task. The goals (e.g. costs, time or quality) specify the intended characteristics and objectives of behavior and are measured by a set of key performance indicators (KPI's) and with regard to targeted *capabilities* [4]. For the realization of goals and purposes a performance potential

is needed. This must be provided by the resources of the production system (e.g. the machines and the operators).

The specific capabilities of a system are determined through its structure and processes. The structure of the production system is constituted by the amount, the arrangement and types of its internal and external relationships (e.g. within the plant and with its environment). It is necessary to distinguish between a static and a dynamic view of structure. The second is only given as processes take place. Together both views show the order in time and space characterizing the system behavior [4]. The structure is in a complementary relation to the process, i.e. structures enable processes but are also result of processes. For example the original “sea of equipment” layout results in particular manufacturing processes. At the same time those processes do generate WIP that changes the plant's working structure.

4.2 The meta-model for the design of PMS

The meta-model is primarily thought as a design aid which should guarantee a holistic and integrated perception of production systems in order to approach appropriately the PMS design. Based on the outlined conception and terminology a *meta-model for production systems* was defined (Fig. 1). It offers a design catalogue conceived as a set of key levers for tackling the PMS design.

The chosen set comprises seven highly interdependent dimensions: management, tasks, structures, processes, resources, KPI's and capabilities. The first five are independent variables of design; the last two are dependent variables. In the management dimension the framework for the specification of tasks is determined. Together with the tasks dimension this establishes the base for the design of processes, structures and resources.

The outlined meta-model is based on a recursive modeling concept which states that on all modeling levels the same seven design dimensions must be considered (e.g. for the entire plant, a section of it, or a men-machine system).

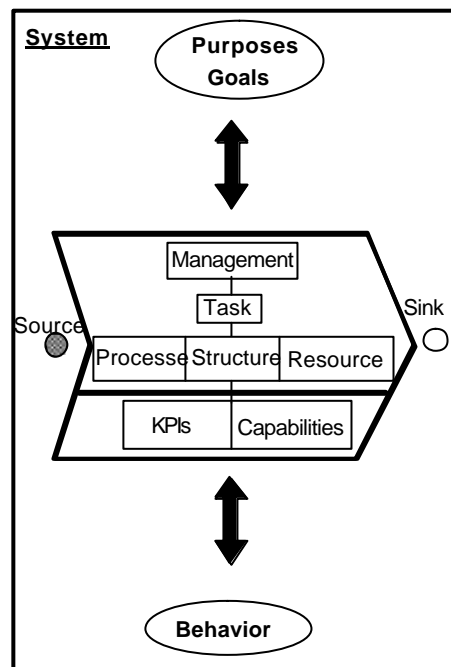


Figure 1: The meta-model

The seven dimensions are essentially descriptive. They provide a reference framework for the PMS design and are specified in more detail in Table 1.

However, an additional explanation is needed with respect to the management dimension. The inclusion of a normative level was considered necessary for the modeling as a holistic design requires a corresponding design policy for technology usage.

Table 1. Descriptive dimensions of the modeling concept

The **management** dimension deals with the capability of the system to guarantee its viability, and consists of three levels:

- normative: specification of principles and values as well as determination of goals and purposes of the system
- strategic: specification of the relations with the environment and the system's development approaches
- operative: adding value, coordination of sub-systems and stabilization of perturbances

The **tasks** dimension consists of two main task types:

- the primary task is given through a determined purpose and is the reason that the system was created
- secondary tasks are defined to preserve, plan and control the system

Processes consist of sources, transformations and sinks:

- sources describe the entities to be transformed by the process and the relation with the previous processes
- sinks describe the transformed entities and the demand-patterns of the following processes
- transformations describe the transformation of entities from an initial state at time t to an end state at $t + ?$

Structures describe the relations between the elements of the system. Two views must be distinguished:

- the static view describes the hierarchical organization of the system and its sub-systems
- the dynamic view describes the procedural organization which is constituted during a process

Resources describe elements of the system that can be allocated and contain information about their availability and their behavior. There are five main aspects of resources to be considered:

- functionality, flexibility, autonomy, degree of interdependence and degree of virtualization (i.e. independence of time and space)

Capabilities describe the core capabilities of the system to reach determined goals and purposes as well as to survive in a given environment (c.f. management level). There are nine main capabilities to be considered:

- competitive advantages, communication, structural and dynamic reaction, synergism, realization, learning, efficiency and effectiveness

KPIs describe quantifiable system characteristics. There are six main KPIs to be considered:

- throughput, WIP, utilization, lateness, throughput time and costs

This policy should guarantee complementarities between social and technological sub-systems. The criteria chosen are both descriptive and normative, concern all five system design variables of table 1, and are documented in detail in [9] and [11]. The normative aspect provides designers with indications of how to meet psychologically founded demands for complementary system design.

Summing up, the meta-model is primarily thought as a design aid which should guarantee a holistic and integrated perception of production systems in order to approach appropriately the PMS design.

4.3 The object-model for the design of PMS

According to the purpose of supporting also more detailed design phases, the concept of the *object-model* was developed in a second step (cf. figure 2). It follows an object-oriented modeling approach leveraging the close relation between this approach and the general system theory.

In addition, this modeling approach facilitates the use of object-oriented simulation platforms for the PMS design. Simulation is probably the best methodical tool to gain insight into the dynamic complexity of production systems (e.g. feedback loops in the gown manufacturing) [1] [3].

To ensure modeling coherence and consistency, the five design dimensions of the meta-model were transformed into the object-model. This was possible through the specification of four recursive modeling levels derived from the system terminology of section 4.1.

Starting from the object-independent description of sub-tasks, functions are described by relating a sub-task to specific object-class entities (e.g. the processed items-gowns-), the instances of which have certain attributes that are transformed by the sub-task. On the next level, activities are described by relating functions to the object-class resources which allow the transformation, and the object-class agents, the instances of which control the transformation.

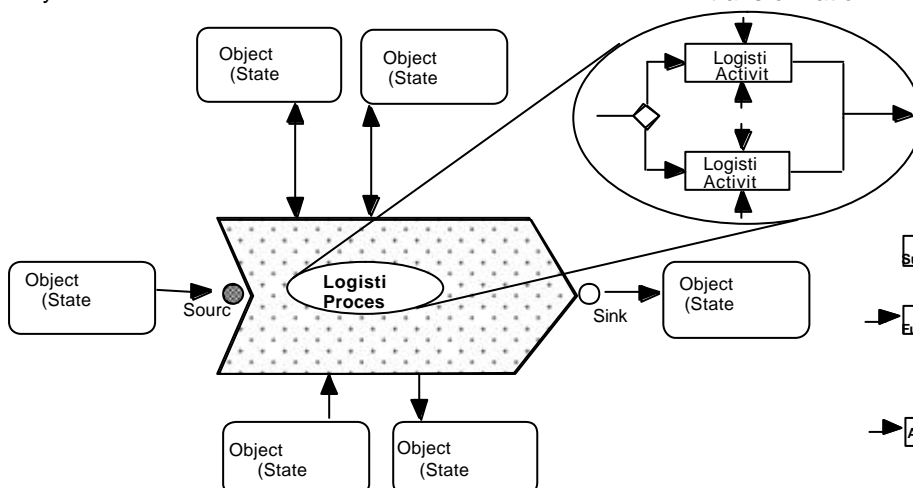


Figure 2: The object-model

Using these object-classes, a specific activity (i.e. an elementary process) is described completely by some instances of these classes.

The object-model concept describes a specific production system (e.g. the Mexican plant) by generating instances of the key object-classes, and specifying their behavior and their relationships. To describe the dynamic behavior of the system, an object-model can easily be extended to a simulation model.

For the specification of the object-class agents and its instances (e.g. an operator in

the plant) for simulation, two issues must be taken into account. From an external viewpoint, agents must be characterized by their purpose, their responsibilities, the services they perform, the information they require and maintain, and their external interactions. From an internal point of view, one has to impose structures upon the informational and motivational states of the agents and control structures which determine their behavior.

As the object-model facilitates the use of simulation for the PMS design, the tool of production operating curves was incorporated in the modeling framework. These curves are an aggregated representation of the operational behavior a production system intrinsically has and are described in [7]. The development of the curves allows modeling the interrelation between the KPIs.

On the one hand, designers can discuss in which operating state on the characteristic production operating curve the system should be driven (e.g. work-load). If for example, the Mexican plant's PMS does not take into account the high absenteeism, the elaborated schedules will always be unrealistic. On the other hand, designers are able to predict the influences of changes in the production system (e.g. increasing sewing speed) through the simulation of new derived curve structures.

The analysis of conflicting KPIs is absolutely relevant for the PMS design, because the design practice confronts paradoxes all the time. Perceived contradictions are often the result of different meanings a design issue may have depending on the viewpoint. For example, lowering WIP often brings to light problems as unstable processes, unbalanced capacities, little flexibility or long reaction-times (cf. capabilities). These problems are often considered in an isolated manner by the different actors.

To conclude, the dual modeling approach provides through its meta-model a general system model as reference for PMS design. Selected design options can be then modeled in detail at the object-level and even simulated easily.

5 RESULTS

After a failed attempt at the original location, decision was made to build a new plant in a different location in Mexico not "contaminated" in terms of working environment. After the usual startup phase, a throughput of 65 gowns per employee and day was achieved in the new plant. This significantly exceeded the initial productivity target of 45 (i.e. industry average). Hand in hand with this progression were other improvements as better product quality or reduced throughput time.

Essentially, the new production model adopted was a cellular manufacturing. Each cell consisted of a group of operators which produced a gown from start to end. The teams of operators had now production management functions and responsibilities, as production management was significantly less automated, and more decentralized into the distributed production cells. Moreover, each team chooses one of its members to act as a coordinator towards the cell environment.

New hires were explicitly trained in the newly envisioned team culture. Operators were now called associates. An absolute majority of recruits had secondary level education, was below 30 and were women.

The teams received both technical and human support. The first stemmed primarily from departments as R&D or maintenance in the form of preventive maintenance programs during lunch-time, for example. This did reduce drastically machine down-times. Human support went far above updating incentive schemes. Extensive training and induction programs were established, but also social collaboration outside the plant was targeted (e.g. community work).

Summing up, a model plant was developed both in terms of manufacturing performance as well as working culture. It served as a reference beyond the conglomerate it belongs to. The meta-model helped to confirm the adequacy of the production model to be implemented, which then subsequently could be analyzed in more detail with the object-model in some specific aspects.

6 CONCLUSIONS

First of all, the referred case-study has emphasized the necessity of a holistic and integrated design of PMS. Such a design aims to complement technical and social subsystem in the PMS and at the same time considers this PMS as an integral part of the shop-floor. Secondly, it has also shown the benefits of the presented dual modeling framework to support such an integrated and holistic design.

However, the modeling approach should not be understood in the sense of leading to one straight forward design solution. It aims at supporting the analysis of the design space and the reflection of decisions. In order to make the developed modeling framework more user-friendly to practitioners, the aim of further research is to integrate the framework operationally into a design methodology (i.e. like a toolbox). To do so, it will be examined in further case studies, among other aspects, the methodological principles to be made explicit in instructions for facilitating its use. These further practical validations, should also allow identifying opportunities for improving further the modeling framework.

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