

HUMAN FACTORS IN SHOPFLOOR PLANNING, SCHEDULING, AND CONTROL

Special session on "Human and Organisational Factors in Industrial Planning and Scheduling – HOPS"

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Abstract

Human Factors are widely neglected in research on shopfloor planning, scheduling and control (PSC). To tackle this problem the HOPS-network (Human and Organizational factors in Planning and Scheduling) of European researchers was founded in 2004. HOPS established two working groups investigating distributed/collaborative PSC and decision support systems in PSC. This paper presents results from a research project of the first group. PSC is considered a complex process being performed by a secondary work system, i.e. a network of people and PSC-technologies which is distributed throughout an organization. Within this network PSC-related information flows and PSC-related decision-making occurs. In a case study such a network is identified, described and evaluated. Based on the results consequences for the design of secondary work systems are discussed. It is suggested to refer to the complementary interplay of pro-active and re-active PSC activities when assigning PSC-tasks to planning and to shopfloor instances respectively. In general it is proposed to assign feed-forward PSC-control to the planners and feed-back PSC-control to the shopfloor.

Keywords:

Planning, scheduling and control, sociotechnical system design, information flow, decision making, human factor

1 INTRODUCTION

Planning, scheduling, and control (PSC) processes tend to become increasingly critical since customer and supplier markets gain in turbulence, competition is growing, and the complexity of production processes increases. In general, PSC matches dynamic market demands with potentially unstable production resources and co-ordinates order flows. An organisation's respective competencies determine its responsiveness and hence constitute an increasingly critical competitive (dis-) advantage.

Far most research in PSC follows a technology-oriented approach. Thereby many relevant factors are not taken into account appropriately. Most prominent among these factors are those concerning human behavior [1]. Many PSC-models omit the human entirely. Those incorporating humans consider them to behave in a deterministic and predictable fashion, to be independent of each other, to be 'stationary', to be emotionless, and to be perfectly observable. Furthermore also many non-human factors that contribute to the complexity of PSC are often disregarded (e.g. variations in machine behavior under different seasonal conditions). Whether or not technology-oriented research will ever reach a comprehensive quantitative description of this complexity is questionable. This has recently even been stated by the IBM Research Centre [2].

In order to better understand the human factor in PSC a cooperation of European researchers in the domain was established in 2004. This initiative, funded by COST (European COoperation in the field of Scientific and Technical research; cf. <http://cost.cordis.lu>), is called HOPS (Human and Organisational factors in Planning and Scheduling). HOPS is a network of researchers from currently twelve countries, who are organized in two thematic working groups:

- Distributed / collaborative PSC: This group investigates the collaboration of humans in PSC under the condition of distributed problem-solving. In business reality such collaboration is normally mediated by ICT.

- Decision-support systems in PSC: This group investigates the human decision-making process in PSC and how it can be supported by ICT.

Furthermore all HOPS researchers cooperate in a working group focusing on methodological aspects, aiming at advancing human factor oriented research methods in the domain of PSC.

In the following sections of this paper results from a research project are presented, which belongs to the thematic field of the first working group.

2 THE SOCIOTECHNICAL CHARACTER OF PSC

PSC deals with uncertainty. The purpose is to assure an efficient flow of orders through the organisation. Information processing and decision-making are the main activities performed in PSC. Aiming at a good balance of proactive and reactive PSC-activities makes PSC a complex process of information flow and decision making that is distributed throughout the whole organisation. In business reality the following key features characterise it [3]:

- Information to be processed is incomplete, ambiguous, dynamic and of stochastic nature.
- Information flow follows feed forward as well as feed back and formal as well as informal structures.
- Decisions to be taken are highly interrelated not only in content but also time wise.
- Goals to be followed are – even if set clearly – highly interrelated.
- Information processing and decision-making is distributed among many different (human and non-human) actors.
- Result oriented performance measurement and even more process-oriented evaluation of PSC practices are highly constrained.
- PSC duties are not clear, overlaps occur and organisational positions do not necessarily reflect duties, responsibility, and authority.

These characteristics indicate that PSC is not a process that can be isolated and allocated to a clearly defined agent be it a human planner, an organisational unit or a sophisticated PSC-technology (e.g. an ERP-system). It must rather be considered a process that is performed by a complex interplay of people, technology, and organisational structures, i.e. by a sociotechnical system [4] [5].

However, a direct application of sociotechnical system design methods to PSC proves to be difficult [3]. In order to bridge this gap, thereby complementing the existing methods of sociotechnical system design, the concept of secondary work systems has been introduced [6].

A secondary work system is a human-computer network that overlaps the organisation. It consists of all people and technology that explicitly or implicitly participate in PSC. On the technical side these are planning and scheduling tools as well as plans, schedules and other relevant information sources (e.g. empty KANBAN boxes, large material buffers etc.). The social system consists of all people that provide or process information relevant to PSC. These might be planners and schedulers as well as shop floor supervisors and even operators who on site take *ad hoc* decisions on whether that job or another will be carried out next. Within that system, artificial and/or human agents take decisions. The system as a whole is a network of formal and informal information flow and decision-making.

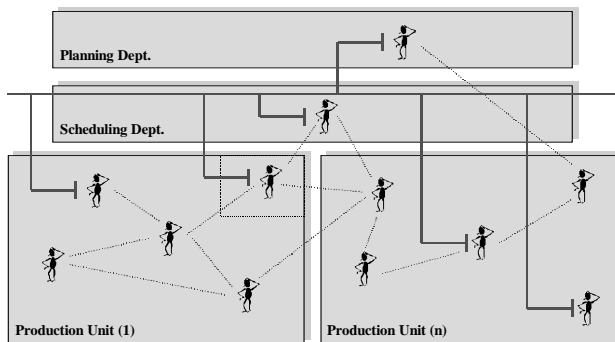


Figure 1: Secondary work system (explanations in the text).

Figure 1 schematically presents a secondary work system. It shows four organisational units (a planning department, a scheduling department, and two production units). These units are interrelated by a network of people who are members of one unit and at the same time are constituents of the overlapping network that forms the secondary work system. It is this network which actually performs the PSC process. Consequently the secondary work system consists of all humans and all technological devices that participate in PSC. Information flow and decision-making takes place in technical (full lines) as well as in social (dashed lines) networks, following formal as well as informal channels. The secondary work system overlaps and penetrates the whole organisation.

3 DESIGNING SECONDARY WORK SYSTEMS

Considering PSC a secondary work system implies that the total of PSC-related decisions and actions are taken within the secondary work system. The chance for a good overall PSC performance is certainly higher if these decisions and actions are tuned. Keeping them tuned could probably be achieved by centralizing decision-making competencies. However, such centralization controverts the principles of sociotechnical thinking, which follows a human oriented design philosophy. What is required instead, is an autonomy-oriented, non-hierarchical design that is supposed to increase a system's

PSC-capacity. The following indicators of non-hierarchical PSC-systems have been identified:

- Co-resident control [7] resp. simultaneous decision-making [8]: Frequent decision-making occurs on all levels of the planning hierarchy. Decision-making is not a linear process.
- Bi-directional constraining [7]: In the planning hierarchy, as well top-down as bottom-up constraining occurs. Decision-making is not a one-way process.
- Lateral coordination [8]: Coordination occurs also within levels. Decision-making regarding mutual coordination on one level does not necessarily require an intervention from a higher level.

The question remains how to systematically promote these three properties of non-hierarchical PSC-systems. In order to approach this design problem a case study has been carried out in an industrial SME (see below). The aim of this study was to identify and to describe the SME's actual PSC-related secondary work system. It is focused on the allocation of PSC-related decision-making competencies. For that purpose the actual PSC-related goals and activities of the different actors (planners, schedulers, and shopfloor workforce) are described in detail, as well as the flow of PSC-related information. From there design requirements with regard to an autonomy-oriented design of secondary work systems are derived.

4 CASE STUDY

The company is a Swiss SME that produces high-end plumbing articles for private households as well as for commercial use. Its products are sold worldwide. Independent traders buy directly from the company and resell to the plumbers. The company employs about 500 people. Around 300 of them work in the production unit (250 directly productive, 50 indirectly productive). The database of the company's IT-based PSC-system includes around 15,000 customer order positions and 4,000 articles that are purchased from about 250 suppliers. The scope of production is fairly wide (casting, pressing, milling, drilling, grinding, polishing, surface treating, varnishing, assembling). Additionally, purchased articles are mainly accessories and plastic parts. The production unit is divided into a manufacturing part (250 employees, 6 sub-units) and an assembling part (50 employees, 5 sub-units). An interim stock separates the manufacturing from the assembling. The sub-units of the manufacturing unit work sequentially, i.e. most workpieces pass through all sub-units. Order processing is planned and scheduled centrally by an MRPII like system based on forecasts. The assembling unit is organised in independent assembly lines; each assembles final products.

4.1 The company's PSC-related secondary work system

In order to identify the company's PSC-related secondary work system, as a first step a group interview was conducted with three people including the heads of the production unit, of the construction unit, and of the PSC-unit. The purpose of the interview was to map the company's PSC process with regard to information flow and decision-making (cf. figure 2). As can be seen from figure 2 the main task of the planners is to adjust the PSC-IT's parameters in order to reach certain goals (e.g. low stock, service level). The main information sources are the sales-people and the historical data. The PSC-IT makes job proposals to the schedulers, whose task it is to check the proposals' plausibility, to check the readiness to fulfil a proposed job (e.g. availability of material and production resources), to release the jobs (including make-or-buy decisions), and to control progress in job processing. The manufacturing units are controlled centrally by the

scheduler, in a top-down cascaded way via supervisors and foremen down to the workers. The assembly units get their jobs directly from the PSC-IT. Here the foremen do the scheduling for their work groups. However, assembling is highly standardised in a way that no critical decision-making is required from the foremen.

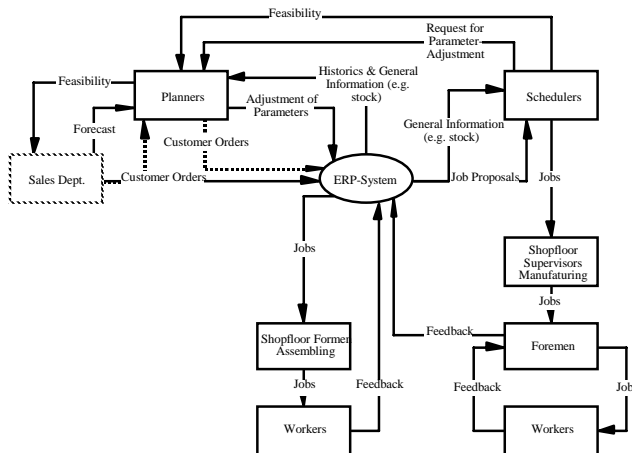


Figure 2: Scheme of the company's PSC-process

On the basis of the mapped PSC-process (cf. figure 2) the case study's unit of analysis was concretized; i.e. it was defined within and between which departments an in-depth analysis of information flows and decision-making is required in order to be able to describe the company's secondary work system. For that purpose a total of 16 semi-structured interviews and seven observations have been conducted. On this basis the company's PSC-related secondary work system can be described regarding three aspects: Allocation of PSC-tasks, characteristics of information flow, and goal structure. These three aspects are described in the following sections.

4.2 Allocation of PSC-tasks

Following the allocation of PSC-tasks within the secondary work system is described. Generally it can be distinguished between four different tasks that are allocated to (i) the planners, (ii) the schedulers, (iii) the foremen on the shopfloor level, and (iv) the foremen in interim stock and shipping.

SPC is performed in close co-operation of planners and schedulers who are located in the same office. Whereas planners care more about long- and middle-term planning, schedulers concentrate on the scheduling. Short-term planning is performed jointly. Permanent communication and joint decision-making regarding short-term planning guarantee multidirectionality of information flow as well as mutual instead of top-down constraining. By checking the plausibility of automatically generated order proposals the schedulers implicitly check the usefulness of the system's parameters that are fixed by the planners. The opportunity to request alterations of parameters as well as the inclusion of the schedulers in feasibility-decisions regarding special orders allows for factual bottom-up constraining. The schedulers' rather broad scope of decision-making allows for simultaneous decision-making.

The interaction between the schedulers and the shopfloor personnel is quite different. The schedulers strongly constrain the manufacturing units. They try to optimise the schedules for those resources they consider to be the bottlenecks. For these resources only the jobs of the actual day are released with detailed prescriptions regarding sequencing. They do it in order to put themselves in the position of the actor in control. As a consequence, lateral co-ordination between the units does

not take place. On the one hand the schedulers criticise this situation. On the other hand the shopfloor supervisors complain that they have not the information base to actively co-ordinate with their colleagues.

The centralised decision-making leads clearly to the fact that everybody delegates responsibility to the schedulers. Bottom-up information flows as formally prescribed, i.e. the shopfloor (mostly) gives feedback on job completion through the ERP-system. This information does not nearly cover the information need of the schedulers. They are permanently gathering information by the means of walking through the factory and making intensive use of their telephone. Remaining up-dated is a rather hard job.

Top-down information flow from the schedulers to the shopfloor is restricted to the communication of decisions. Consequently, the shopfloor's comprehension of goals and working of the scheduling department is low.

The interaction between the schedulers and the assembling units is slightly different. The assembling units directly get the orders out of the ERP-system. They schedule their orders themselves. However, there is not really a need to schedule the orders. Almost no co-ordination with other units is needed. Set-up times are little and consequently do not make a co-ordination of jobs necessary. Components are available on site, controlled by a KANBAN-system. If there are any disturbances the assembling units' foremen delegate the problem to the schedulers or to the head of the interim stock, who himself chases for jobs in the manufacturing units or asks the schedulers for help.

In the relation between the scheduling departments and the shopfloor, autonomy is centralised, there is no lateral information flow (e.g. there is no direct mutual co-ordination between production and assembling units), constraining only goes top-down, and simultaneous decision-making has not been observed.

4.3 Information Flow

In order to describe the information flow within the company's secondary work system also a quantitative analysis has been carried out. To do so the protocols of the interviews and the observations were in a first step analyzed in order to identify evidence for bilateral information flow, i.e. an information flow with a defined source (e.g. the scheduler) and a defined addressee (e.g. a foreman). This excludes multilateral information flows, which have also a defined source but several addressees (e.g. a meeting of the scheduler with the foremen). Such multilateral information flows haven't been analyzed further, as the foremen indicated that the meetings provide them with information that is rather general (e.g. sales figures) and hence has no much relevance for PSC related decision-making. Within the unit of analysis a total of 100 different bilateral information flows has been identified (i.e. among planners, schedulers, foremen of manufacturing, assembling, interim stock, and shipping). In a second step the different information flows have been assessed regarding trigger, direction, and content. For the purpose of validation, the results were discussed on the occasion of a feedback-workshop with all persons that have been interviewed or observed.

The identified information flows were analyzed in a first step with regard to active versus passive triggering. For that purpose the information flows were differentiated as following:

- Input: Information that is received without effort of the recipient.
- Output: Information that is provided to the outside without effort of the outside.
- Intake: Information that is received only when actively demanded.

- **Outtake:** Information that is provided to the outside only on active request from the outside.

Table 1 shows the distribution of information flows, as distinguished regarding trigger and direction. In general the sender is rather active and the addressee is rather passive; both in a ratio of one to two. This may indicate that in general the person possessing an information actively provides it, while active search for information is less common. For the role of the sender this is especially true for representatives of 'planning/scheduling' and 'interim stock/shipping' whereas the representatives of the 'shopfloor' show no difference regarding 'active/passive'.

For the role of the addressee such differences are not obvious. All groups are rather passive than active. In general the planners and schedulers seem to be the holders and the active providers of information, whereas the representatives of the 'shopfloor' are rather passive receivers.

Table 1: Distribution of information flows, distinguished regarding trigger and direction (N=100).

	Sender		Adressee	
	Output (active)	Outtake (passive)	Intake (active)	Input (passive)
Planners & Schedulers	34%	8%	8%	18%
Shopfloor	23%	23%	17%	39%
Inter. Stock / Shipping	10%	2%	8%	10%
Total	67%	33%	33%	67%

Figure 3 shows the distribution of information flows, distinguished regarding direction and content. The following categories of content have been identified:

- **Decisions:** A decision is communicated
- **Re-assurance:** The accuracy of a decision is checked.
- **Clarification:** The preconditions for a decision's accomplishment are checked.
- **Disturbance (sender):** A disturbance is communicated; the sender determines measures.
- **Disturbance (addressee):** A disturbance is communicated; the addressee determines measures.
- **Completion:** The full accomplishment of a decision is communicated.
- **General update:** General information regarding the actual situation is communicated (not specified for a certain decision).
- **Goal:** General goals for decision making are communicated (not specified for a certain decision).
- **Miscellaneous:** Contents not covered by the previous categories.

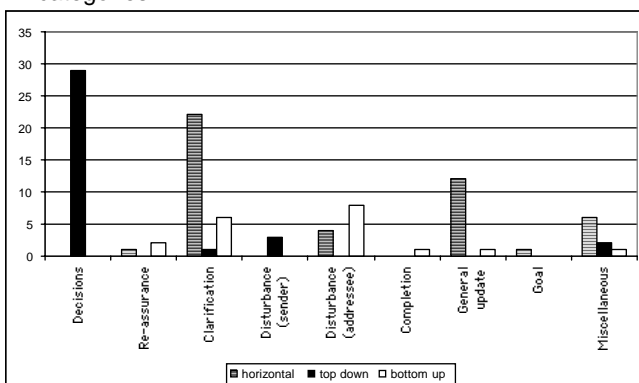


Figure 3: Distribution of information flows, distinguished regarding direction and content (N=100).

As can be seen in figure 3, decisions are primarily communicated top-down. Disturbances are communicated top-down when the sender determines measures and bottom-up when the addressee determines measures. Again it becomes clear, that decision-making competencies are allocated to the planners and schedulers. Compared with this, information referred to clarification and to providing a situational update mainly flow horizontally. This indicates that the communication on the shopfloor level aims at checking the preconditions for the realization of the planners'/schedulers' plans. However, if problems occur they are communicated to the top where decisions are taken.

4.4 Goal structure

In order to analyze the goal structure within the company's secondary work system each interviewed/observed person was asked to prioritize a set or pre-defined goals. Each person was provided with a set of 16 cards, representing logistic-goals (cf. Table 2). The cards had to be arrayed according to their priority. As table 2 shows 'product quality' has the highest priority. This is probably typical for Swiss SMEs, which often weight product quality more than productivity or service. On the other hand some directly PSC-related goals are prioritized quite low; particularly 'high loading of capacity', 'low in-transit inventory', 'high flexibility regarding use of technical resources', 'short throughput time of material', and 'high flexibility regarding deployment'.

However, more interesting are the differences between the groups (i.e. 'planners/schedulers', 'manufacturing/assembly' and 'interim stock/shipping'). Generally, there seems to be more dissent within the shopfloor level (i.e. between 'manufacturing/assembly' and 'interim stock/shipping') than between the planning levels (i.e. shopfloor and 'planning/scheduling'). Furthermore, there seems to be more consent regarding goals that rank in the first half of the list than regarding goals in the second half.

In detail it is noticeable that there is a very high consent concerning 'high flexibility regarding deployment', 'on time delivery', and 'quick flow of information'. On the other hand there is low consent regarding the directly PSC-related goals 'low in-transit inventory', and 'short throughput time of material', both ranking in the second half of the list. Regarding these two goals 'manufacturing/assembly' is in dissent with the other two groups. This might be due to the fact, that the aim of reducing stock and of shortening throughput time comes along with a reduction of lot sizes, which in return causes disturbances and more work on the shopfloor level. Consent is also low regarding the directly PSC-related goal 'high loading of capacity'. This goal ranks surprisingly low in the list. Here it is the representatives of 'interim stock/shipping' who are in dissent with the other two groups. Maybe this is due to the fact, that 'interim stock/shipping' has no influence on the attainment of this goal.

Generally the inter-group differences regarding many directly PSC-related goals suggest that the prioritizing reflects fields of influence and responsibility. This goes especially for those goals ranking in the second half of the list, regarding which no clear strategy exists. However, regarding these goals there is more consent between the planners/schedulers and the shopfloor representatives then there is among the shopfloor representatives. This hampers lateral cooperation on the shopfloor and consequently demands centralized coordination. Hence, the conclusion may be drawn that a distribution of decision-making competencies is unlikely when fields of responsibility are demarcated in a potentially incompatible way.

Table 2: Mean ranking of PSC-goals (column 2) and differences between the three groups 'planning/scheduling', 'manufacturing/assembling', and 'interim stock/shipping' (columns 3-5). The differences are calculated on the basis of each goal's absolute ranks within the groups.

Goal (descending order as per ranking)	Mean rank all groups (N=22)	Differences between groups		
		Planning/ scheduling vs. Shopfloor	Planning/ scheduling vs. Int. stock/ shipping	Shopfloor vs. Int. stock/ shipping
High quality products	3.1	3.0	1.0	4.0
On time delivery	3.8	0.0	0.5	0.5
High flexibility regarding customer demands	4.5	3.0	1.5	1.5
Short delivery lead-time	6.0	0.0	2.0	2.0
Quick flow of information	7.0	0.5	1.0	0.5
High quality of production processes	7.5	0.5	5.5	6.0
High flexibility regarding deployment	8.0	0.0	0.0	0.0
Short throughput time of material	9.1	3.5	0.5	3.0
High transparency of products	9.4	1.0	5.5	4.5
High flexibility regarding use of technical resources	9.7	0.5	2.0	2.5
Low in-transit inventory	9.9	8.0	3.0	11.0
Exact data base for calculation	10.9	7.0	0.5	6.5
High flexibility regarding cooperation with other enterprises	11.6	2.5	1.0	3.5
High loading of capacity	11.7	0.5	4.5	4.0
High transparency of production processes	11.7	5.0	6.5	1.5
Low costs for administration	12.2	3.0	1.0	2.0

5 DISCUSSION

The company's PSC-related secondary work system as presented above is far from being designed in an autonomy-oriented way. Decision-making is extensively centralized with the planners and the schedulers, information flow consists mainly of top-down constraining and bottom-up informing, and the goals are – especially on the shopfloor level – heterogeneous and represent potentially incompatible fields or responsibility. Typical properties of non-hierarchical PSC-systems like co-resident control and bi-directional constraining [7] or simultaneous decision-making and lateral coordination [8] have rarely been found. However, following ideal types of PSC-related roles are outlined for planning instances as well as for shopfloor instances in order to approach the problem of an autonomy oriented design. The proposed roles aim at tackling the two main optimization potentials as emphasized in the case study, i.e. the cooperation at the secondary systems boundary, and the lateral cooperation on the shopfloor level.

The suggested distinction of roles refers to the complementarity of pro-active and re-active PSC activities. In general it is proposed to assign the former to planning instances and the latter to instances on the shopfloor level. Such the planning instances are made responsible for feed-forward control whereas the shopfloor is responsible for feed-back control. The aim of this is to increase the shopfloor's capabilities for opportunistic planning [9] and situated acting [10]. The main argument therefor is, that it is the shopfloor instances that have the concrete possibilities to attain goals by influencing the actual situation, whereas planning instances can 'only' set goals and define rules for goal attainment thereby acting in an abstract-referential situation [11] [12]. Thus, the shopfloor instances need to be provided with opportunities for flexible reaction. This incorporates in particular the possibility of short, autonomous feedback loops on the

shopfloor level, which is especially required under the condition of high uncertainty [13].

Accordingly, the proposed inter-level assignment of PSC-roles aims at an empowered shopfloor. As a consequence, empowering is the main role of the planners and schedulers. Hence, their role changes away from producing plans that stipulate actions on the shopfloor level. Their 'new' role is similar to the sociotechnical concept of *boundary regulation* [14] and hence consists in negotiating with external instances in order to create the prerequisites that allow the shopfloor to act autonomously and in a situated manner. Such prerequisites incorporate stabilization at the system's boundary and the provision of an adequate information basis for decision-making. Assigning such a role of boundary regulation to the planning instances does not only differ from the usual role of planners/schedulers in practices but also from the role implicitly assigned to them by PSC-IT packages.

Regarding the intra-level assignment of PSC-roles on the shopfloor level it can be referred to the sociotechnical concept of *core tasks* [15] [16]. The original purpose of a core task is to promote cooperation within a team. It is argued that collective self-regulation and responsibility in a work team emerges only, when the team's whole task is not a set of individual tasks only, but incorporates also a core task for which the team as a whole is responsible. The right design of the core task is supposed to be crucial for successful implementation of self-managed work teams. Regarding PSC it is proposed to apply the concept of the core task within an organizational unit as well as between organizational units. The former corresponds with the original aim of the concept, i.e. to integrate several individual tasks into one collective task. The latter goes further. It aims at creating fields of shared responsibility between organizational units in order to bridge organizational boundaries. In correspondence with sociotechnical system design principles it is supposed that

the assignment of a boundary spanning core task creates task coherences that transcend organizational boundaries and as a consequence promote lateral cooperation. The perception of such coherences is considered a crucial prerequisite of cooperation. Against this background it is clear that the measures the company took in order to promote lateral cooperation of the foremen (i.e. weekly meetings; merging of foremen's offices) will not show the expected result. Such measures do only create *possibilities* for cooperation, but they do not provide a *reason* to cooperate. As long as no reason to cooperate is perceived, the foremen will continue to attribute responsibility for boundary spanning coordination to the planners and schedulers. However, assigning the minimization of throughput time or the reduction of a buffer stock in joint responsibility to two foremen are examples for boundary spanning core tasks.

The realization of the outlined assignment of pro-active and re-active roles requires an appropriate design of the secondary work system. This refers in particular to the provision of adequate control opportunities, including opportunities to understand, predict, and influence the situation according to the requirements of the role [11]. For both, the planning instances as well as the shopfloor instances, this includes:

- transparency of goals with own or shared responsibility,
- transparency of the actual performances regarding these goals,
- transparency of the actual PSC-situation, and
- transparency of the working of the PSC-process.

Furthermore it includes foresight regarding the development of the PSC-situation as well as regarding consequences of PSC-related decisions. Finally, it includes an adequate scope of decision-making as well as corresponding qualification and support.

6 CONCLUSION

The presented case study showed that the concept of secondary work systems is suitable for describing and evaluating PSC from a sociotechnical perspective. Furthermore, it allows for discussing design principles on a very general level. Much more work is required in order to elaborate concrete design requirements. However, the implementation as well as the validation of a corresponding system design is a task to be tackled in the future. Thereby it must especially be examined whether a non-hierarchical design really increases a system's overall PSC-capacity, or whether it rather causes additional PSC-costs due to frictional loss.

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