

Supporting shop floor intelligence

A CSCW approach to production planning and control in flexible manufacturing

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Abstract. Many manufacturing enterprises are now trying to introduce various forms of flexible work organizations on the shop floor. However, existing computer-based production planning and control systems pose severe obstacles for autonomous working groups and other kinds of shop floor control to become reality. The research reported in this paper is predicated on the belief that the CSCW approach could offer a strategy for dealing with this problem. The paper describes the field work and its constructive outcome: a system that assists shop-floor teams in dealing with the complexities of day-to-day production planning by supporting intelligent and responsible workers in their situated coordination activities on the shop floor.

1. INTRODUCTION

For most of the 20th century, manufacturing has epitomized a work organization characterized by radically centralized and very detailed and rigid regulation of work in which the individual's sphere of activity is reduced to a small repertoire of monotonous movements [3; 4].

For these reasons, the work organization of manufacturing has been subjected to fierce criticism from workers, labor representatives, sociologists, and ergonomists alike, as repressive and degrading and, indeed, as an assault on human dignity. However, the deeply problematic nature of this form of work organization became apparent also to managers and production engineers in the 1960's and 1970's, as workers took advantage of the high rate of employment and abandoned or avoided the most oppressive production environments. The result, of course, was a forbiddingly high rate of labor turnover. To deal with this problem, sociologists and ergonomists suggested radical changes to the work or-

ganization in the form of job enlargement and introduction of production groups on the shop floor that would have control over day-to-day task allocation and production planning and control. Over the following years, a number of 'socio-technical' experiments with work organizations based on higher degrees of local control were carried out, often successfully [14], but these principles were never implemented on a large scale. Fear of losing control generally kept managers from experimenting.

However, a series of fundamental changes in capitalist political economy over the last two decades have placed the issue of the work organization in manufacturing on the agenda again. Faced with turbulent markets, industrial enterprises are opting for strategies that involve shorter product life cycles and increasing product diversification, which in turn requires a reduction of inventories and buffer stocks, extremely short lead times, shrinking batch sizes, concurrent processing of multiple different products and orders, etc. [cf. 10]. To meet these requirements, industrial work organizations must be able to adapt rapidly and diligently to changing demands in a concerted and integrated way.

To cope with these demands, a large number of manufacturing enterprises are now trying to introduce various forms of flexible work organizations on the shop floor [6; 16; 26]. While the precise organizational forms vary, they are basically characterized by local control over job allocation and day-to-day production planning and control, often called 'autonomous working groups'.

It goes without saying that 'autonomy' here does not mean that stockholders and managers are relinquishing control. In fact, the 'empowerment' of shop floor workers often seems to be merely a fashionable word for giving workers the responsibility for getting things done without giving them any power over objectives, performance criteria, resource allocation, etc. [cf. 23]. However, in a large number of cases serious managers of manufacturing enterprises seem earnestly committed to introducing genuine shop floor control of day-to-day planning and control.

In these cases, when serious attempts at shop floor control are being made, it very soon becomes quite evident, however, that existing computer-based production planning and control systems pose severe obstacles for autonomous working groups and other kinds of shop floor control to become reality [15]. They were designed for an entirely different world.

In view of these experiences, the Central Organization of Danish Industrial Workers (CO-Industri) in 1996 initiated a research project — named FASIT¹ — with the objective of developing novel forms of production planning and control systems that would specifically address the requirements of autonomous working groups and other kinds of shop floor control.

1.1. Principles of production control

Manufacturing involves multitudes of discrete parts and processes that are interdependent in complex ways:

- each product consists of a many component parts, in some cases thousands of components;
- the production of each part may require that different processes be performed in a specific sequence, and the production of different parts thus requires different routings;
- different processes may require specialized tools and skills, and different parts thus compete for the same workstations;
- many products are being manufactured simultaneously, and at any given time a large number of products and their components coexist at different stages of completion;
- in flexible manufacturing, with a large number of different models and variants to be manufactured in small volumes at short notice, different product models and variants are being manufactured simultaneously.

Thus, in the words of Harrington [13], manufacturing can be conceived of as ‘an indivisible, monolithic activity, incredibly diverse and complex in its fine detail,’ the many parts of which ‘are inextricably interdependent and interconnected.’ Accordingly, for a manufacturing enterprise to be able to adapt to changing conditions, the entire enterprise must react ‘simultaneously and cooperatively’ [12].

In conventional manufacturing, the basic coordination mechanism consists of a set of interconnected models of the production processes that collectively are called MRP systems (Material Resource Planning). The crucial models are:

Bills of Materials: A bill of materials is a hierarchical list of every part that makes up the finished product, thus denoting all parts and their relationships.

Routings or Process Sheets: The process sheet specifies and lists, in sequence, each manufacturing operation a part or sub-assembly must go through to be manufactured and, for each operation, the average set-up and processing time.

Based on these models, coupled with the sales forecast, the MRP system decomposes the material requirements and computes the schedules for the production of each part, sub-assembly, and product. The outcome of these calculations is the *master production schedule*, a time-phased plan identifying the aggregate capacity requirements at a company level. The master production schedule is thus ‘the vital control center for the company’s manufacturing planning and

control system’ [9, p. 66]. The enormously complex production control problem is thereby, in theory, reduced to executing this plan. That is, in so far as the underlying models and forecasts are accurate and the production processes proceed as intended, coordination across functions and departments and operations can be mediated by this organizational construct. While occasional deviations can be coped with by simply running the MRP system again, this is computationally very heavy and is typically done at night. In an order-driven production, where exceptions are the norm, conventional MRP systems are out of proper element.

As indicated above, this approach is only feasible to the extent that the contingent nature of the whole operations can be held at bay, so to speak. As soon as firms launch on the course of flexible adaptation, however, entirely different production control strategies are required. In recent years, the so-called *kanban* system has entered into widespread use as a coordination mechanism for just-in-time production [cf., e.g., 1; 22]. As opposed to the MRP approach, which is inventory-driven, the kanban system is order-driven; it does not rely on accurate forecasts but on adaptation to changes in actual demand. For the kanban approach to work well, however, set-up times must be reduced to a minimum while batch sizes must be relatively high. Moreover, although the kanban system supports ‘horizontal coordination’ among workers on the shop floor [1], it does not in any way provide them with an overview of the — current or projected — state of affairs. They are, so to speak, immersed within an overwhelming and inscrutable algorithm that does not support shop floor intelligence [21]. The kanban approach is thus not appropriate as a production planning and control system for autonomous working groups.

1.2. A CSCW approach to production control

The problem now faced by flexible manufacturing has been a core problem of CSCW research over the years, albeit under different labels [cf., e.g., 7; 18-21; 24].

According to this approach, cooperative work is inexorably distributed in the sense that actors are acting, and have to act, on partial knowledge of the state of affairs [17]. There is thus, in principle, no all-knowing agent. Orderly coordination is accomplished through the local actions and interactions of actors who have only local control. The presumptions of MRP systems, that the planning department of the enterprise is able to predict and control, in essence, the manifold interdependent activities of a manufacturing enterprise, is illusory, and in flexible manufacturing the enormous systemic costs of maintaining this illusion have become evident.

However, cooperating ensembles do cope with the enormous complexity arising from the fact that their activities interdependent and yet distributed through organizational constructs such as plans, schedules, procedures etc. But such coordinative constructs do not in every detail or causally determine local action; they are rather ‘resources for situated action’ [24] in that they are normative constructs that, to competent members, specify the appropriate next step to be taken, unless the actors have reasons not to do so [19].

¹ FASIT is an acronym for ‘IT support for flexible work organizations in manufacturing’ in Danish.

Even when faced with turbulent environments, the models of independencies underlying coordinative constructs are far from useless. But they are used in a quite different manner than simple plan execution: they may indicate the desirable end result of the effort, they may be provide reasonably useful insight into the likely effects of an action, or they may be modified temporarily and then used for coordinative purposes even if the system otherwise would be beyond its bounds [2; 5; 8; 21].

Accordingly, the approach taken in the FASIT project is to develop a (prototype) system that assists shop-floor teams in dealing with the complexities of day-to-day production planning by supporting intelligent and responsible workers in their situated coordination activities on the shop floor. The underlying models of MRP systems are not obsolete but must be used — and made useful — in a very different way: constraints that are not essential must be removed or relaxed, so that workers can circumvent or overrule the recommendations of the system when that is deemed appropriate.

However, in order to understand how this general approach could and should be applied under the specific conditions prevailing in flexible manufacturing, in-depth field studies were undertaken to investigate the ways in which orderly production planning and coordination is accomplished in the course of the routine troubles of everyday work.

2. FIELD STUDY

Our study was conducted at one of Asea-Brown-Boveri's Danish factories, ABB Energy & Industry Inc. (hereafter called ABB) that manufactures electric power transformer stations and boxes. As one of the foremen phrased it: 'We produce anything required for handling electric power from when it leaves the power plant till it reaches the consumer's building.' The production is, as usual, divided into departments such as the production of semifinished parts from raw materials, finishing treatment of semifinished parts, and various stages of sub-assembly, assembly, etc.

The object of our study has been what is internally called 'the component factory', the first stage in the production chain. Raw materials — metal sheets and plates and copper bars — are received at one end, processed at a number of work centers, and then delivered to an intermediary inventory as semifinished parts. These processes involve about 60 shop floor workers and two foremen working in two shifts.

ABB is currently working on re-organizing the work in the component factory into autonomous working groups each responsible for monitoring, planning, and executing their own activities. From ABB's point of view our study was one of the inputs for this process.

2.1. The plate factory

The work in the component factory is basically separated into two major areas:

One area, called 'the excenter presses', is dedicated to the processing of bar materials as well as plates that need special processing. This is by means of a specialized work

center for cutting bar materials and number of more general-purpose work centers for machining, canting, polishing, deburring, threading, etc. of plates and bars.

The other area, called 'the plate factory', processes metal plates that are received in a variety of standard dimensions. The plates are then cut and/or punched at two dedicated cutting and punching centers. After this, the parts are processed following different process sequences, involving canting, welding, and chemical surface treatment.

Our study has mainly focused on the plate factory. The remainder of this paper will describe and analyze findings from the plate factory.

During our field work, a new computer-controlled punching work center and a matching buffer storage has replaced the cutting and punching work stations. Four of the workers were trained in programming the new work center.

At the same time, the work organization of the plate factory was being changed into that of an autonomous working group where workers are handling day-to-day planning and re-planning, quality assurance, and personnel administration. A set of corresponding roles was defined: Planner, QA-responsible, and Personnel Administrator. The roles rotate so that a worker will be responsible for each of these roles for a two month period. Then three new workers are assigned to the three roles.

The QA-responsible is in charge of ensuring that the members of the group pay attention to the quality of their products. The worker fulfilling the QA role is furthermore involved in establishing procedures and routines for improving and evaluating the quality.

The Personnel Administrator is responsible for maintaining plans for who is working when, for ensuring the required qualifications are at hand so that all work centers can be operating, and for establishing training and education plans for all members of the group. Regarding training and education, the group has decided to aim at a situation where all workers can operate at least two of the five different processes (punching, special canting, standard canting, welding, and surface treatment).

The Planner is responsible for planning the sequence in which the jobs are to be processed in collaboration with the operator of the punching center. Every morning at 9:00 the Planner meets with the planning specialist from the central planning department in charge of the component factory. The discussion taken on this meeting is primarily based upon three sources: (1) the list of production orders for the plate factory (the 'work schedule') which is produced by the central MRP-system each night; (2) the lists over problems and production delays produced by the central planning department, and (3) knowledge about the current state of affairs in the plate factory. On this basis, the jobs on the work schedule are prioritized and 'urgent semi-finished parts' identified. The meeting is also used for informing the central planning department of the status in the plate factory (e.g., machines or work centers that are not running well). Also problems with the routing schemes or the engineering drawings are discussed.

Work within the plate factory flows from the punching center to surface treatment as illustrated in figure 2-1. First the plates are cut or punched into parts of the different sizes

or forms. Most of the parts are then canted at one of the canting centers. If no canting marks must be left on the parts the specialized canting center must be used. Parts are then combined into sub-assemblies through welding at one of the four welding stations. Finally, about half of the parts are surface treated. About five percent of the parts produced in the plate factory are partially processed outside the plate factory when, e.g., threading or special welding is required. These parts are taken out of the process flow (i.e., placed in the 'outgoing' buffer storage) and transported to other parts of the factory or outside the factory. Upon return from these processes, they are put back into the flow in the plate factory.

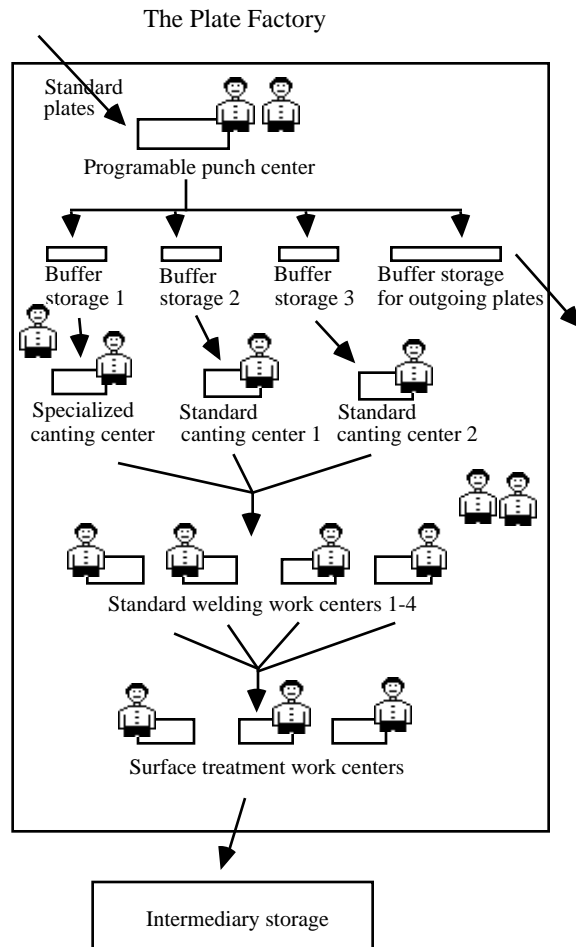


Figure 2-1: A typical layout and manning structure of the plate factory. Each work center is typically manned by one worker. A few of the workers are 'backup' that can support at the work centers when needed. The new punching center is manned by two workers who are also responsible for ensuring that the plates storage contains the plates required for the following day. Three of the workers have the roles of planner, QA-responsible and personnel administrator, respectively. Moving the plates from the punching center to one of the buffer storages is done by means of small crane, either by the worker at the specialized canting center or by the worker currently being planner. When a batch of parts is placed in one of the buffers it has to be processed by the related canting center, since it is very complicated to move materials from one buffer to another.

As mentioned, the detailed planning is done by the Planner. Until now, detailed planning has mainly been taken care of by each of the workers at the different work centers. Each worker consults the printed work schedule that is placed at a table central in the plate factory, which lists all the jobs to be done by the plate factory (the same part will appear many times on the list if it has to undergo several processes). He or she then chooses one of the 'pending jobs' on the list that is destined for his or her work center. Having identified which job to do next, the worker will find the batch of parts and the associated engineering drawing and routing scheme that will be attached to the parts. The drawing illustrates the part as it should look when delivered from the plate factory whereas the routing scheme describes the processes that the part should go through.

The parts are then processed by the worker at the work center. When the job is finished, the materials are placed in a buffer after the workcenter and the batch is marked as finished on the work schedule and on the routing scheme. Marking the routing scheme is done by means of a bar code reader connected to the central MRP system; thus, when a job is marked as finished it is also removed from the data stream on the basis of which the work schedule for the following day is generated.

2.2. Problems and requirements

For the purposes of this paper, i.e., for the purposes of delineating the requirements of a system to support the basic coordinative functions of an autonomous working group, it is most appropriate to organize the description of the findings from the field work on the basis of some - rather crudely categorized - problematic aspects: the requirements of alternative systems then become fairly evident.

Staff allocation: The manning of work centers is basically done by the Personnel Administrator through negotiation with his or her colleagues. The Personnel Administrator will check who is in. This is done by comparing the list of who were supposed to be at work with a list of people being ill or absent for other reasons. From the amended list and from his or her knowledge of personal preferences and skills of the individual workers, the Personnel Administrator works out an allocation plan. As it is now, the main problem in this is that the Personnel Administrator has no means for getting information on the consequences of these plans or of changes to them. For example, the number of welders and surface treatment workers that is required will depend on the types of jobs on the work schedule. Furthermore, the situation might change during the day, and there are then no means for getting an overview of these and of the consequences for manning.

A system for cooperative production planning and control (in the following CPC) should thus support workers in getting an overview of the manning situation and of the needs for manning at the various work centers, and should support workers in making detailed manning plans. The CPC system should support establishing an overall picture of available resources (personnel and machinery) and support workers in experimenting with different manning solutions. An essential requirement in this regard is that it should be possible to see the consequences of any manning

solution under consideration, in terms of its implications for the utilization of capacity. Furthermore, information on the work load on the individual workers should be available.

Detailed planning of the flow: Basically, detailed planning is done by the Planner at the morning meeting with the planning specialist from the planning department. The basis for decision making at these meetings are the flows suggested in the work schedule generated by the MRP system, as well as additional information on important and urgent new jobs and the Planner's knowledge of the actual state of affairs. This seems to be functioning quite well. After the meeting, the Planner has a fairly good understanding of the requirements for the production of the day. The problem is that detailed planning requires input from the central planning department. This means that the re-planning required during the day due to new orders, machine breakdowns, etc., is problematic. It is furthermore very difficult for the Planner to be aware of the consequences of different planning options, as this would require knowledge about which parts are going to be used in the same final product, which jobs concern parts for inventory only and which are directly related to a particular customer order, what are the consequences further downstream if a part is delayed in the plate factory, etc.

The CPC system should support the construction of an overall picture of jobs to be done as well as currently available resources (work centers and parts). Facilities for experimenting with different sequences for doing the different jobs and with allocating jobs to different (relevant) work centers must be provided.

A particular operation can often be done in different ways, e.g., using different work centers. For instance, a scissor may in some cases be able to do the same as a punching center. Typically, the underlying MRP system, if properly maintained, will provide a satisfactory repertoire of alternative processes. However, the system's repertoire is never complete. The system must thus allow and support improvisation in this respect as well, and it should naturally record in its repertoire of alternatives.

In any event, an essential requirement is that it should be possible to see the consequences of the job sequence and allocation under consideration such as implications for capacity utilization and downstream scheduling. Finally, in order to improve capacity utilization, the CPC system should support the pooling of jobs according to familiarity, e.g., parts destined for the same final product or parts requiring the same work center set-up.

Overview of the schedule: The actual flow is to a large extent decided by the individual workers as they decide on what to do next on the basis of the work schedule. They are to some extent aware of which jobs they are supposed to take next. They know this mainly from the work schedule and to some extent also from the Planner. The piles of materials waiting in the buffer storages are also an indicator of which jobs are waiting.

The major problem here is that none of the workers has a sufficient overview of the actual situation, e.g., which jobs are important, or what are the consequences of changing the (already outdated) job sequence suggested in the work schedule. The problems here are due to the fact that changes

to the plans decided at the morning meeting are not reflected in the work schedule. Furthermore, a number of 'urgent jobs' are added every day, for instance due to new customer orders, previous delays, etc. The existence and urgency of these jobs are usually not known by most of the workers. That is, the status reflected in the work schedule is usually not representative of the actual situation.

A related problem is that the workers have very little support of understanding how jobs are interdependent. In most situations a job is only of high priority if it is ensured that a number of other jobs are considered high priority as well. If, for example, the production of one part for a final product is delayed, the other parts for this product may become less urgent. Hence, a CPC system should provide the workers with an overview of the production planned for the next days.

In the plate factory a planning horizon of 4-6 days would be required, but this should, of course, be flexible with respect to the individual needs in different situations. Users should generally be able to choose an appropriate planning horizon, in terms of scope (how far into the future) as well as granularity (hours, days...).

Both the production requirements and predictions of how the requirements affects the load on the different work centers and workers are important. Since many of the decisions taken in one autonomous working group can affect other groups of workers and their planning it is important that the overview provided by the systems extends the overview of the work of one autonomous working group.

Assessing the state of affairs: Apart from the surface treatment workers, workers in the plate factory can easily see each other and the batches of parts on the shop floor. They can thereby be aware of which work centers are manned and by whom, who seems to have problems (large piles of parts waiting), who is interacting with whom, etc.

However, such immediate awareness is far from sufficient in an operation this complex. The workers have little overview of what is supposed to be done the next hours or days. Apart from the Personnel Administrator's list of who is allocated to which work centers as well as the manning plan for the following periods, no artifact provides such an overview. The surface treatment workers, for example, have problems with being aware of how much work is in the line for them and when the parts will be ready for processing.

Hence, the CPC system should support the group in assessing the state of affairs within the domain of the group. Each worker should thus be supported in being aware of where the bottlenecks are right now, to which degree capacity is utilized, what are the prospects for the next days with respect to bottlenecks, capacity utilization, etc. When the individual workers are deciding which job to do next, the CPC system should instantly provide information of the consequences of the decision on the workload on the particular work center in question as well as other related work centers.

Also, even though the workers can see batches waiting on the floor, the shop floor is often a crowded place and different parts may look quite alike. The CPC system should provide a map-like facility that supports workers in simply locating the parts for the next job in the work schedule.

To assist workers in handling the myriads of contingencies in their everyday activities, the CPC system must support interaction and communication among the workers, especially in settings where the workers are separated in time and/or space. It is essential that messages and information on state of affairs (e.g., a defective machine, missing parts and materials, reasons for a planning decision) can be communicated from one worker to one or more of the others in a persistent and generally visible way. Our findings indicate that such a communication facility should be structured on the basis of the key categories of this particular social world: units of time, machines, parts, processes, jobs, etc. That is, for each object or object class in the system, a facility for notifying colleagues should be available.

Finally, the working groups in a factory like ABB are mutually interdependent in that they contribute parts and sub-assemblies to the same final products. The overview of consequences should thus also provide information on disturbances faced by working groups upstream and the consequences of local decisions for other working groups downstream.

3. IT-SUPPORT FOR PRODUCTION PLANNING

In accordance with the CSCW approach outlined above as well as the findings from the field study, the basic design principle of a CPC system is that there are no all-knowing agents in a flexible manufacturing enterprise.

The goal is thus to develop a set of general computer tools that assist shop floor production planners in their work by serving as a basis for decision making. The design goals for these computer tools are:

- To visualize production planning and control information in a clear and consistent manner to the production planner.
- To identify and indicate potential problems that the production planner needs to handle.
- To allow the production planner to manipulate directly the production planning and control information.
- To visualize the immediate consequences of the production planner's actions.

Thus, the production planner is in complete control of planning and control tasks. The computer tools merely aid in decision making. The chosen design philosophy has some implications for the development of the prototype. The computer tools should be based on a general underlying model of production planning and control that can capture many specific cases of shop floor control at different companies and different work groups. As a consequence of this, the computer tools should be able to function in heterogeneous environments (on many different computer platforms running different operating systems), and should allow for different personal preferences with respect to look (user interface) and feel (functionality) by different (groups of) production planners.

3.1. The CPC research prototype

The CPC research prototype is composed of two tools – one tool supporting production planning and control and one tool supporting human resources administration (see figure 3-1).

Both tools have their own data storage. When important changes are made in the human resources administration tool (i.e., when a worker is listed as sick), an event (a message) is sent from the human resource tool to the production planning and control tool. This causes the production planning and control tool to read in the latest data from the human resources data storage and calculate (and display) the consequences of the change.

Currently, the CPC research prototype is implemented in Java (using JDK 1.2) as a single monolithic program.² CPC is an application of the Construct framework, which is developed in collaboration with the Coconut project [11; 25]. Both tools consist of a model and a user interface part. The object-oriented models in the tools are based on general objects for production management. The specific data handled by these models are stored in files in the underlying file system. The user interfaces of the tools offer different views on the stored data. The language of the user interface is Danish – the natural language of the workers at ABB. (Important terms will be translated into English below.)

The *human resource administration tool* is comprised of two parts, an overview of the individual workers' skills and a plan for manning workstations in ABB's component factory.

Figure 3-1 is a screen dump of the training overview. The names of the workers are listed in the column to the left and the names of the workstations are listed in the top row. A cell in the matrix indicates the level of training by the particular worker on the particular workstation. We operate with three different levels: fully trained (marked with XX), under training (marked with X), and no training (empty space). For example, the worker named 'Jeanette A.' is fully educated for workstation 9242 and under training for workstation 9250. It is possible to drag a new training level from the list to the right and drop it into a cell in the matrix, when a worker has reached a higher level of training on a particular workstation.

Figure 3-2 is a screen dump of the manning overview. The window provides two different views on the planning data. The upper half is a plan for the individual workers starting from the current date. Each row in the matrix shows what workstation the particular worker is assigned to in what shift on what day. For example, the worker named 'Jens S.' is scheduled to operate workstation 9241 in the first shift on April 12. Workstation names can be dragged from one cell in the matrix and dropped into another cell as part of the planning process. Workstation names can also be dragged from the list of workstations to the right into cells of the matrix. The last item in the list ('syg' means 'sick') can be dragged from the list and dropped into a cell when a worker has called in sick. The lower half of the window is a

² For further information, visit <http://www.cs.aue.auc.dk/fasit>

plan for each workstation also starting from the current date. Each row in the matrix shows which worker is assigned to what shift on what day. As in the upper half, names of workers can be moved around between cells and copied from the list to the right into cells as part of the planning

process. The two views are kept consistent with each other. If, for example, the upper window is updated by placing a workstation name in a ‘worker’ cell, the corresponding ‘workstation’ cell in the lower half of the window is also updated with the name of the worker.

Uddannelsesoversigt												Fuldbefaren (XX) Under oplær. (X) Ikke prøvet ()
	9430	9450	7970	9250	9241	9242	9243	9244	9280	9290	7960	
Jens S.	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	
Henning S.		XX										
Birgit S.		XX										
Tonja S.		X										
Toke E.	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	
Uffe W.			XX								XX	
Peter C.			XX								XX	
Kjeld S.			XX								XX	
Steen A.				XX		XX						
Jeanette A.				X		XX						

Figure 3-1. Overview of the individual workers’ training levels.

Bemandingsplan

Figure 3-2. Overview of the manning plan for the workstations in the component factory.

The *production planning and control tool* operates with a main window and a set of secondary windows. A screen dump of the main window is shown in figure 3-3. The main window consists of two parts. The top half presents the list of jobs to be handled by the component factory. The bottom half shows the calculated workloads for the workstations in the component factory.

In the top half of the window, the production planner can move jobs around and assign jobs to workstations to optimize the production and to complete the jobs with the high-priority first. Each line represents a job and displays vital

information about the job such as due date, work process, estimated job time, relation to other jobs, assigned workstation, etc. The buttons to the right are used to move jobs up and down in the job control list. The buttons below the jobs are used to bring up detailed information about the selected job (technical drawings, etc.) in separate windows. The first three columns in the job control list indicate relationships between the selected job and the other jobs. ‘P’ indicates that the jobs have identical job processes, ‘T’ indicates that the jobs are due on the same day, and ‘S’ marks preceding and succeeding jobs of in the process of creating a particular

component. The numbers in the ‘S’ column indicate the ordering.

In the bottom half of the window, the production planner can see the consequences of her or his actions. The workloads are calculated based on data from the human resources administration tool and on knowledge about jobs and assigned workstations. If a worker is assigned to a workstation in both the first and the second shift of a day, then the total work time for that day is 16 hours (8 hours of work time per shift). If the production planner has assigned jobs to the same workstation that is estimated to take 20 hours, then the calculated workload is 125%. Workloads that are higher than 100% (plus a small margin) are marked in the window with a yellow ‘X’ (the color can be customized) to notify the production planner about a potential problem. A workload of 125% may be intentional (if overtime is planned for the workers) or it may constitute a problem that needs to be handled. If the production planner clicks on a particular workload (e.g., the workload for workstation 9242 for April 12 – which is listed as 69%), then the jobs that constitute this workload are marked in the job control list in light blue (again the color can be customized). This makes it much

faster to identify the direct relationship between jobs assigned to a workstation and the workload for the workstation.

The production planner can use the panel to the right to customize the workload view. One of three workstation views can be selected:

- Show workloads for all workstations.
- Show workloads only for the workstations that can handle the selected job in the job control list (i.e., workstations 9241, 9242, 9243 and 9244 can handle the same types of jobs).
- Show workloads only for workstations that handle jobs that are related to the selected job in the job control list (i.e., preceding or succeeding jobs of the same component).

The production planner can also decide on the preferred number of workdays to be displayed in the window (currently 20). In addition, several other preferences can be set such as the special colors in the main window to mark potential problems, selected jobs, etc.

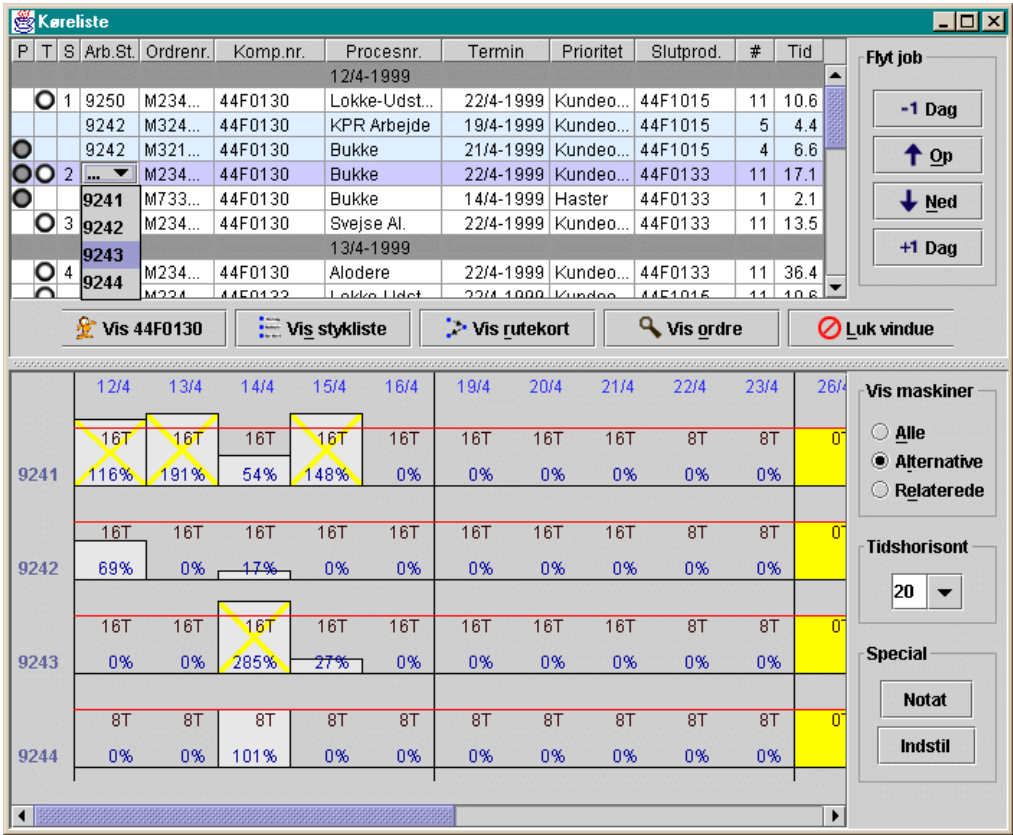


Figure 3-3. Main window of the production planning and control tool.

Each shift has its own dedicated production planner. The production planners of different shifts must therefore coordinate and negotiate. In addition to meeting face-to-face in the short overlap between the first and second shift, this can be handled by placing notes and messages in the built-in bulletin board. The bulletin board can be used to place all kinds of notes and messages such as argumentation for current production plans, scheduled maintenance of worksta-

tions, sudden workstation breakdowns and repairs, sick workers, and new jobs with high priority. In the current version of the prototype, the bulletin board is organized around a calendar. It is possible to add and delete notes on individual dates. The bulletin board displays notes for the current date as default. When a note has been created on a particular date, the date is marked with green on the calendar. In a fu-

ture version, this facility should be made universally available for all object classes and objects.

3.2. A use scenario

The following use scenario is an example of how the two tools could be used in the component factory to assist the production planners. The scenario takes place in the beginning of the first shift of a normal workday when the dedicated production planner (Jan) starts working.

Jan's first action is to look for notes in the bulletin board. He finds a note that is important to his planning task. Tom, the production planner in the second shift, left one note saying that workstation 9242 broke down yesterday evening – and that it will take about one day to get the necessary parts and another day to fix the problem.

At the same time, Christian (the personnel administrator on this shift) reads the same note as Jan and another note on the bulletin board saying that Jens (one of the workers) called in sick this morning. Christian then opens the human resources administration tool and discovers that Jens was supposed to operate workstation 9243 while Brian was supposed to operate workstation 9242. To handle the two situations, Christian lists Jens as sick and move Brian from workstation 9242 to 9243. (Brian is also trained to operate workstation 9243.) The consequences of this are immediately made available to Jan.

The next step for Jan is to open the production planning and control tool and get a quick overview of the jobs in the job control list. (New jobs are transferred every night from another computer system in the factory and old completed jobs are removed.) Jan checks the priority and due dates of the jobs and moves jobs around in the job control list based on these data. To optimize the production, Jan moves jobs with identical job processes back to back on the same workstation to save workstation setup time.

Now it is time to take a look at the workstation workloads. Several workstations have loads much higher than 100% and some have little or no load at all. First, Jan splits up jobs that take more than a workday to complete (16 hours) into several days. Now the detailed planning really starts. In this phase, Jan reassigns jobs to alternative workstations and moves jobs back and forth in the job control list to reach a reasonable workload on as many workstations as possible. On this particular day, Jan specifically needs to move all jobs away from workstation 9242 to alternative workstations.

When Jan is satisfied with the workloads, he is done with the majority of the planning for that day. He may have to adjust a few things later in the day. While the rationale is still fresh in his memory, he writes a brief note in the bulletin board to Tom explaining how his planning influences the planning for the second shift of the workday.

4. DISCUSSION

The current version of CPC is only a partial implementation of the required functionality of a system for genuine shop floor control. It does not, for example, provide general facilities for annotating objects and object classes; it does not of-

fer flexible support for controlling the granularity of the planning horizon, nor does it provide any support for workers' maintenance of the underlying MRP model, e.g., by adding alternative processes or routes to the model. Furthermore, the interface to the underlying MRP system has not been implemented (it would probably require many person-years). For these reasons alone a full-blown field trial of CPC has not been feasible.

Anyway, to obtain some indication of the validity of the approach, the research prototype has been demonstrated to and discussed with managers, planning technicians, shop stewards, and workers at ABB, who all found the functionality and its presentation very useful for shop floor control. In the course of these discussions, a number of additional requirements were developed but none of these challenged the general design and architecture.

While CPC is an application of innovative CSCW technologies, it does not in itself represent a distinct technological innovation. That was not the aim of the project either.

The project does demonstrate, however, that the CSCW approach may help the manufacturing industry overcome the obstacles that existing production planning and control systems pose for the ongoing, very difficult transition towards flexible production. This may turn out to be crucial for the manufacturing industry, that is, for an industry of strategic economic importance. More than that, in a wider social perspective the FASIT project indicates that a CSCW approach may be of assistance in the development of shop floor control and thus in improving the quality-of-life of a large number of working people.

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