Situation Awareness in production planning and scheduling

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Everyday production planning and scheduling is known to be highly complex work. Situation Awareness (SA) is a concept used to understand operator work in information compact and highly dynamic contexts. The objective of this case study is to explore how production schedulers in woodworking industry develop and maintain SA in everyday work activities. The study shows that SA is obtained and maintained by the schedulers constantly interacting with technology in terms of production systems and computerized control systems, intense interaction with other humans, and with the organization (including internal and external interests).

Practitioner Summary: This case study explores how production schedulers in woodworking industry develop and maintain their Situation Awareness (SA) in everyday work activities in order to make more effective schedules. The study shows that the schedulers obtain SA as a result of intense interaction with other humans, with existing technology and with the organization. Managerial implications are to acknowledge the need to support the schedulers not only with relevant computerized support systems but also with appropriate authority and social recognition.

Keywords: decision-making, uncertainty, complexity, woodworking industry

1. Introduction

Everyday production planning and scheduling, further referred to as scheduling, has been described as highly complex (Berglund, Guinery and Karltun, 2011), contextually based (Karltun and Berglund, 2010), information driven (McKay and Buzacott, 2000), and with a need to handle competing goals (Higgins, 1996). The concept of Situation Awareness (SA) was developed to understand operator work in information compact and highly dynamic contexts and was considered by Crawford and Wiers (2001) as a relevant approach to deepen the understanding of the difficulties schedulers meet in daily operations. There are different definitions and perspectives of SA; that it refers to merely human cognitive processes “knowing what is going on” (Endsley, 1988); that it is imbedded in technology and displays (Stanton et al, 2010); or that it can be understood by a sociotechnical systems perspective (Stanton et al, ibid). SA has been applied on various dynamic domains, such as aviation, traffic and process control, but less attention has been paid to industrial work (Wickens, 2008). The objective of this paper is therefore to explore how production schedulers develop and maintain their SA in everyday work activities. This research was based on four case studies in companies with different production characteristics in Swedish woodworking industry.

2. Theoretical background

2.1 Situation Awareness

The concept of SA is related to decision making in complex, information compact, and dynamic systems in which the operator’s accuracy and speed are crucial for performance (Endsley, 1995; Wickens, 2000; Durso et al, 1998). There are several definitions of SA; from “knowing what is going on” as stated above to “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, 1988). SA is a multi-dimensional construct. It can be modelled in terms of the processes of memory and attention. SA concerns the state of knowledge about the world, or the model of external reality that enables adaptive decisions to be made in
uncertainty. Endsley (1988, 1995) has described how information is treated on three levels: Level 1 concerns *perception* of independent elements that are relevant for the task to be performed; Level 2 concerns *comprehension* of the combined perceived elements to understand the full situation; and Level 3 constitutes the *prediction* of a near future state. This prediction is a based on the perception of elements as well as an interpretation of a combination of these elements. The treatment of information is influenced by several factors such as the system design (components, interfaces and level of automation), stress factors, workload, and individual abilities in terms of perception, attention, etc. (Endsley 1995).

Although less described in literature, SA has also reached attention in other disciplines such as engineering, where e.g. flight controllers and pilots describe how SA in practice is imbedded in artefacts and interfaces (Stanton et al, 2010) or Ergonomics/Human Factors where a systems perspective is adopted and SA occurs in the interaction between humans and artefacts (Stanton et al, ibid).

### 2.2 Production planning and scheduling

Production planning and scheduling are tasks performed in different types of operations in order to make efficient use of resources available for satisfying the needs of customers or clients (Crawford, 2001). In this paper, we choose to specifically look at the scheduling of the daily operations since this is probably the part of the planning and scheduling continuum that provides the largest difficulties in terms of understanding what is happening and that requires more of SA than other parts of planning and scheduling. While planning often refers to tasks performed before things happen in reality and thus ends up in plans, scheduling is performed in real time, trying to handle the complexities, uncertainties and resource and goal conflicts. The result is supposed to end up in work orders, daily deliveries and fulfils (McKay and Wiers, 2004). To summarize, the decisions concern who, when, what, where, how many, and what quality. This indicates that the problems the scheduler handles are not related to the technical matters but also to people both inside the company as well as the customers. Scheduling has also been found to be the interface between sales and production, thereby being involved in the different logics and conflicting goals that are present between these different parts of an organisation (Karltun and Berglund, 2001). The context of scheduling is therefore of organisational character where the complexity of the organisation as well as the production system and the products have to be considered. Moreover Scherer (1998) described the relation between the produced schedule and the shop floor reality as the relation between a route on the map and what you encounter when trying to follow it in terms of traffic, hindrances, people, etc. In every step the practical behaviour has to be adjusted in terms of e.g. directions and time and new decisions has to be taken to complete the journey. A scheduler thus cannot trust that the decisions will be followed and fulfilled but that there will be a significant difference between what is achieved and what was scheduled and the decisions taken must be followed up (de Snoo and van Wezel, 2011). McKay and Wiers (2004) developed a model for the seven general subtasks of a scheduler which is displayed in Figure 1.

![Diagram showing the seven general subtasks of a scheduler](image)
The daily routine starts with assessing the situation trying to determine what is where. As a second step the crisis identification is to deal with what needs immediate attention. Based on this, the production schedule is re-sequenced and tasks are allocated after which the scenario is updated by remapping the future. In the updated scenario future problems are identified and these are discounted. Thereafter the scheduling of the supposed stabilized system is done using the analytical tools available (McKay and Wiers, 2004).

2.3 Model for analysis

The seven subtasks involve differing needs for SA for the scheduler and particularly step one, two and four, five respectively involves perception, comprehension and projection of system state. Each of these steps can be analysed in terms of affordances regarding the SA as well as the different subjects to consider. The analysis performed here is limited to availability of material and information, the results of previous schedule, significant uncertainties in the system scheduled and customer expectations. Availability of people was in the studied companies the responsibility of the supervisors.

3. Research approach

3.1 Selection and overview of case companies

Scheduling work was studied in four companies selected according to two criteria. Each company should have at least one employee the company regarded as a full time scheduler. Furthermore, the companies should have different types of production characteristics, i.e. the conditions for determining differences in the scheduling work set by the scheduled system should be favorable. An overview of characteristics of the companies and scheduling context is presented in Table 1.

<table>
<thead>
<tr>
<th>Companies</th>
<th>Production</th>
<th>No of employ.</th>
<th>Scheduling organization</th>
<th>Scheduling scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawmill</td>
<td>110 000 m²/year sawn wood</td>
<td>42</td>
<td>One sawmill scheduler, one forestry scheduler, one precision planing and cutting scheduler (not the same companies but same owner and close collaboration)</td>
<td>Optimization of value of yield.</td>
</tr>
<tr>
<td>Parquet manufacturer</td>
<td>100,000 m²/week parquet</td>
<td>1,400</td>
<td>Two employees involved in daily production and two worked with the computerized scheduling system and development projects</td>
<td>Co-ordination of production in the main plant with that of the other plants. Satisfying different markets good enough.</td>
</tr>
<tr>
<td>Furniture manufacturer</td>
<td>1.3 million bookshelves (97% of the production)</td>
<td>220</td>
<td>One planner/scheduler, additional resource scheduling done at supervisor level</td>
<td>Capacity verification to weekly prognosis and customer satisfaction</td>
</tr>
<tr>
<td>House manufacturer</td>
<td>Wooden houses</td>
<td>370</td>
<td>One planner/scheduler, additional resource scheduling made by supervisors</td>
<td>Capacity utilization and deliveries on time</td>
</tr>
</tbody>
</table>

3.2 Data collection

One scheduler’s work was studied in each company. The methodological approach chosen for the overall project was activity analysis (Guérin et al, 1997). Data collection was carried out through interviews, studies
of company documents, and observations of real work activities. Before the observations, the schedulers, management and other employees the scheduler identified as crucial for his work were interviewed. These collected data served as the authors’ pre-understanding of scheduling work.

Each scheduler’s work was thereafter observed during five entire working days. Observations took place each day of the week (a Monday, a Tuesday etc.) to allow for regular variations in work to be observed. During the observations, all notable work activities were recorded in terms of descriptions of tasks, time, people involved, use of aids, initiatives to activities taken, communication pattern, physical placement, etc.

After the observations, the scheduling function and role expectations on the schedulers were investigated by interviews with the schedulers and those who during the observations were identified as having close contact with the scheduler. In total, 68 people were interviewed.

3.3 Analysis of data
Observation protocols, interview transcripts and company case descriptions, all produced in the first step of analysis, served as data sources for the second analysis. In this, cues for SA characteristics were sought for, both in terms of physical conditions like office location, movements during the day as well as regarding software use and social networking both inside and outside the studied schedulers’ organizations.

4. Findings and analysis
Four woodworking companies of different character were studied. For each company, some basic characteristics are described and how each scheduler dealt with tasks related to SA.

4.1 The sawmill
The sawmill had a serial process in which the latter stages were directly coupled to the previous. The process was divergent, meaning that when the wanted goods were produced, byproducts of other qualities like edge boards and chips were also received. There was high variation in output since it could not be fully predicted from input. Long-term contract agreements, usually prolonged for a three-month period at a time, were prioritized and necessary for the high-quality production. The planner worked with two different incompatible computer systems for sawmills and Excel for own simulations.

4.1.1 Situation assessment and crisis identification – Sawmill
Directly when arriving at work, the scheduler checked the sawmill software for sawing patterns and production results in the saw. He took a walk in the premises to the critical parts (technical bottleneck, most sensitive operations), talked to operators about results and situation, and collected production documentation for the Enterprise Resource Planning (ERP) system. Back at the office, he entered data from production documentation into the ERP software. Thereafter, he overlooked the situation in the ERP system, talked to different operators and supervisors, took another walk to find lost volumes in the enormous outdoor stock area. The scheduler also had his office directly situated with a view of all transports in and out as well as the infeed to sawing production.

4.1.2 Scenario update and future problem identification – Sawmill
The scheduler met with the planing scheduler, they optimized the schedule together, discussed problems and scenarios. Back he continued to check the computer, checked reality on the sawmill yard, discussed with the planing scheduler, the forestry scheduler and other operators, fork lift truck drivers and repeated this during the day. A typical day, he made eight visits to different parts of sawmill yard and had at least ten discussions with the other schedulers for capacities and timber availability as well as a multitude of other contacts (market officers, customers, site manager, etc.). In between the scheduler checked the ERP system, checked the sawmill software, simulated in Excel, made stage reports for the other involved and finally set the new schedule for three days in advance.
4.2 The parquet manufacturer

The parquet manufacturer produced multiple combinations of parquet floor at several plants, most of which situated in Sweden. The study was carried out in the main plant. The production scheduling function belonged organizationally to production and it consisted of four people, two of whom were involved with daily production and two worked with the computerized scheduling system and development projects. Scheduling involved co-ordination of production in the main plant with that of the other plants.

4.2.1 Situation assessment and crisis identification – The parquet manufacturer

The scheduler started every morning by reading e-mails and checking the computerized scheduling system in order to update himself about any changes and output of earlier scheduling. He then took a morning tour to control the status of finished parquet of different types. While walking in the premises he also spoke to the supervisors to learn about any disturbances and the forklift truck drivers as the latter had the latest information about transportation of batches before this information had been entered into the computerized system. The scheduler made visits to the production premises several times a day and also had tight contact with sales representatives to match incoming orders with production. Throughout the day he was also contacted by several employees and managers who wanted information of all kinds of matters, and he participated weekly in overall planning and production meeting with management. The scheduler described that he kept a large number of pieces of information in his head, but he also used own developed Excel sheets to obtain the overview he needed.

4.2.2 Scenario update and future problem identification – The parquet manufacturer

The scheduler had numerous daily contacts by mail, telephone and personal meetings with representatives for production as well as the sales department. In parallel with these meetings he treated various future orders to ensure that there would not be any problems. He also recurrently updated his Excel sheets to be able to identify possible problems. During weekends and holidays he also checked the production status to ensure that everything ran as planned, which would prepare him for handling potential issues in the forthcoming planned production.

4.3 The furniture manufacturer

The furniture manufacturer produced high-volume bookshelves in long series for an international furniture retailer. A large investment in an automated production line had recently been made, which was expected to strongly increase productivity and production volume. There was one production scheduler who was responsible for master scheduling as well as for the MPC-system used. The large customer ordered products via three different systems using different time scales and delivery demands.

4.3.1 Situation assessment and crisis identification – The furniture manufacturer

Every morning the scheduler updated his Excel sheets with available stock, current orders (backlog) and sold volumes to keep track of the current production and order situation. During this work, the scheduler also tried to find unreasonable figures in the data. Based on this, the scheduler revised his plan. The scheduler started working one and a half hour earlier than everybody else to be able to do the analysis before the morning shift and all disturbances started. He also sat in the same office as the production manager and could thus hear any important information regarding the daily production.

4.3.2 Scenario update and future problem identification – The furniture manufacturer
The scheduler did not do this on a daily basis but more on a weekly. He did forecasts on the deviation of the customer’s forecasts and he spent a lot of time talking to the customer’s purchasing and scheduling officers, both by phone and by full day visits. He thereby not only tried to find out any background information to changes in figures but he also tried to influence them to accept deliveries according to the production status. These tasks were the dominant regarding future updates.

4.4 The house manufacturer

The house manufacturer produced wooden houses. Scheduling involved managing two different processes: single family houses to private customers and larger houses or groups of houses to external building contractors. The scheduler’s tasks included making a master and a detailed schedule for each house produced, controlling the drafting procedures with respect to necessary scheduling steps, synchronizing three production units, making financial overviews of the house projects, and ordering and planning flows of material to the production units and building sites.

4.4.1 Situation assessment and crisis identification – The house manufacturer

Information needed to get an overview was largely related to the different steps in the drafting procedure. The scheduler checked the status of each house project in the computer system daily, and updated his own Excel sheets, and the information system, after receiving additional information via mail and telephone. A further source of information was through weekly meetings where current statuses of the house projects were discussed by different organizational functions.

4.4.2 Scenario update and future problem identification – The house manufacturer

To gain an overview of different scenarios and identity future problems he regularly scanned the house projects, checked their future status by contacting other departments in the company, held recurrent contact with the building site to gain information about weather conditions and other possible influencing factors.

4.5 Summary

The study showed that it was crucial for the schedulers to have updated information of company operations from different sources in order to develop an overview and be able to predict outcomes depending on planning decisions, all of which constitute SA. An overview of features to gain SA in terms of perception, comprehension and prediction for the schedulers in the studied companies is shown in Table 2.
Table 2. Characteristic features that influence/contribute to SA.

<table>
<thead>
<tr>
<th>Companies</th>
<th>Perception</th>
<th>Comprehension</th>
<th>Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawmill</td>
<td>• Updated software systems</td>
<td>• Frequent discussions with people in production</td>
<td>• Simulations in Excel</td>
</tr>
<tr>
<td></td>
<td>• Updated Excel-sheets</td>
<td>• Frequent discussions with other schedulers and officers</td>
<td>• Frequent discussions with other schedulers and officers</td>
</tr>
<tr>
<td></td>
<td>• Frequent visits to production and stock yard</td>
<td>• Frequent visits to production and stock yard</td>
<td>• 35 years’ experience from that sawmill, different positions</td>
</tr>
<tr>
<td>Parquet</td>
<td>• Updated software systems and own Excel-sheets</td>
<td>• Discussions with sales department</td>
<td>• Simulations in Excel</td>
</tr>
<tr>
<td>manufacturer</td>
<td>• Tight contact with sales department</td>
<td>• Discussions with production representatives</td>
<td>• Tight contacts with forklift truck drivers, supervisors and sales department</td>
</tr>
<tr>
<td></td>
<td>• Visits to production and finished inventory</td>
<td>• Visits to finished inventory</td>
<td>• 11 years’ experience from the company</td>
</tr>
<tr>
<td>Furniture</td>
<td>• Updated ERP-system</td>
<td>• Working early hours</td>
<td>• Forecasts on customer forecasts</td>
</tr>
<tr>
<td>manufacturer</td>
<td>• Updated Excel-sheets</td>
<td>• Frequent and extensive communication / negotiation with customer</td>
<td>• Simulations in Excel</td>
</tr>
<tr>
<td></td>
<td>• Same office as production manager</td>
<td>• Simulations in Excel</td>
<td>• More than 10 years’ experience from production, different positions</td>
</tr>
<tr>
<td>House</td>
<td>• Updated software systems and Excel-sheets regarding status for different houses</td>
<td>• Contacts with external suppliers (e.g. windows, kitchen equipment)</td>
<td>• Simulations in Excel</td>
</tr>
<tr>
<td>manufacturer</td>
<td>• Recurrent contacts with building site</td>
<td>• Simulations in Excel</td>
<td>• Frequent contacts with building contractors, sales department, production supervisors</td>
</tr>
<tr>
<td></td>
<td>• Visits to production</td>
<td>• Contacts with sales department</td>
<td>• 29 years’ experience from different positions in the company</td>
</tr>
</tbody>
</table>

5. Discussion

The results showed that the schedulers had thorough knowledge of what information was relevant and needed and had different strategies to collect information from various sources and to integrate it into a coherent picture. The systematic recurrent search for information and overview of the situation was not only carried out through the use of computerized support systems, but by own developed spreadsheets and by walking around in the production premises and warehouses. Moreover, the schedulers developed tight contacts with different employees in crucial positions e.g. operators in specific divisions, forklift truck drivers and sales representatives to receive the latest updates, long before these were possible to be observed in the computerized systems. These networks of contacts had been built during many years and could not be maintained without understanding the difficulties, conflicting goals and priorities of other employees and departments. All studied schedulers were appreciated as high-value information nodes, they were frequently contacted and they also relied on long experience from previously working in the companies in other positions like truck drivers, supervisors, quality control officers, maintenance technicians etc. However, the influence of the experience is not further elaborated here.

The information search activities described formed the platform for handling simultaneous tasks and making decisions under levels of uncertainty. Decision making was characterized by complexity like layers of time constraints and trade-offs, technical systems’ shortcomings and taking into consideration conflicting expectations from operators, officer colleagues as well as managers and customers. To reach an acceptable
level of acceptance and enforcement the social skills and authority (formal and informal) of the scheduler were critical as well as their tight cooperation with a large number of people.

6. Conclusions

It is clear that SA as a concept may be used as a theoretical framework for studying scheduling work in industrial production. The concept of SA adds further understanding of how schedulers gain overview of the situation, make decisions and exert control over production. The study further shows that SA is not obtained and maintained in production scheduling by the scheduler alone performing his task, but in a sociotechnical system constantly interacting with individuals as unique information sources, collaborators as well as organizational representatives. Moreover, interacting with technology, both in terms of production systems and in terms of computerized control systems, was extremely important to schedule and obtain control. We therefore consider that the schedulers obtain SA as a result of intense interaction with other humans, with existing technology and with the organization involved (comprised of internal and external interests). Managerial improvement implications of the study are to acknowledge the need to support the schedulers not only with relevant computerized support systems but also with appropriate authority and social recognition. Moreover, further development of suitable decision support tools and decision making models for effective communication between organizational layers and functions will benefit.

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