Handling Unexpected Events in Production Activity Control Systems

Emrah Arica, Jan Strandhagen, Hans-Henrik Hvolby

Handling Unexpected Events in Production Activity Control Systems

Emrah Arica[1], Jan Ola Strandhagen[1], and Hans Henrik Hvolby[2]

[1]Norwegian University of Science and Technology, Trondheim, Norway
emrah.arica@ntnu.no, jan.strandhagen@sintef.no

[2]Aalborg University, Aalborg, Denmark
hhh@m-tech.aau.dk

Abstract. This paper highlights the important factors that influence the effectiveness of the event handling process in production control activity (PAC). Five key factors have been identified by the literature study. Production schedule generation and execution strategy under uncertainty, information and communication technology usage, coordination and feedback, human factor and interaction, and the performance measurement approach are the identified factors to be taken into account. Industrial interviews with three case companies, that are participating to the research program called The Norwegian Manufacturing Future (SFI NORMAN), have been carried out in order to gain practical insights as well as support and revise the findings by relevant empirical data.

Keywords: Production planning and control, Uncertainty, Event handling

1 Introduction

The production control activity takes place in the context of production planning and control (PPC) which aims for matching customer demand with supply of products and materials in terms of timing, volume, and quality in a manufacturing company [1]. When the orders are released to the shop floor, the production control activity takes place in order to ensure that the plans are indeed executed on track. If any deviation is monitored, some corrective actions (e.g. rescheduling) are taken for tuning the schedules [2]. In this study, the production activity control system encompasses the handling of unexpected events and rescheduling activities. A dynamic manufacturing environment creates many unexpected events (e.g. machine breakdowns, material problems, tool status, defects, etc.) that must be captured and responded effectively, namely timely and appropriately [2]. However, the difficulty of addressing the issue of uncertainty in dynamic manufacturing environments is well recognized by researchers and practitioners for many decades [3-5].

Hence, this study questions: What important factors have been identified in literature to handle the unexpected events effectively and what insights can we get from companies, regarding the event handling process and identified factors? The study attempts to answer these questions and raises the issues that should be considered for successful development and implementation of the production control systems in practice. Clearly there are alternative interpretations of the system effectiveness and practicality. This is one perspective based on the related literature study, without aiming for a comprehensive review of each of the factors.

2 Methodology

This conceptual paper is mainly based on a literature study, supported with an iterative process involving three case studies to refine the findings. The literature review established the theoretical basis of the study and led to a framework that categorizes the literature and highlights the factors for effective handling of the unexpected events. Research lacks in such a holistic approach since the majority of research focuses on discussing a single factor. Hence, the purpose of the paper is to highlight and discuss some of the most critical factors that lead to gap between the theory and practice. Given the main purpose of the study with a focus on the practicality issue, multiple case studies were performed to gain insights into the industrial practice. Data was mainly gathered through interviews and observations.

3 Production Control Structures

Production Activity Control (PAC) includes the principles, methods, and techniques that are needed to schedule, control, measure, and evaluate the effectiveness of production operations [6]. The production control process assesses the situation during the production execution; identify the disturbances related to schedules, and takes corrective actions (e.g. immediate re-sequencing, task reallocation, or rescheduling) if needed. In order to achieve this, it utilizes shop-floor control data to maintain and communicate shop order and resource status information by functions such as WIP tracking, capacity feedback, quality control, status monitoring, etc. play critical role [1]. In general, there are two fundamental PPC approaches adopted to design the organisation, structure the information flow and perform the decision making functions: centralized/hierarchical and decentralized/distributed production control [4, 7, 8].

Hierarchical (Centralized) production control is the commonly applied approach in literature and practice. This paradigm decomposes the PPC problem into interdependent long term planning and short term scheduling levels to reduce the complexity and facilitate the solution [6]. The majority of the firms apply the Manufacturing Resource Planning (MRP II)/ Enterprise Resource Planning (ERP) system to create production schedules [9], with the core logic of Material Requirements Planning (MRP) to determine net material requirements. Output from the MRP run is a Planned Order Release (POR) schedule, which typically contains release dates and due dates of the orders. The production schedules further used to execute purchasing and manufacturing operations. Another alternative of scheduling the production orders on the shop floor is so called Advanced Planning System (APS), which outperforms the planning and control functionality of the ERP systems by simultaneously considering the finite capacity on the shop floor [10]. During the execution of schedules, any real time information can provide important input data for the production control. Over the last two decades, Manufacturing Execution Systems (MES) have been evolved to aid real-time production execution and control on the shop floor [11]

The hierarchical centralized approach coordinates the material flow and capacity for globally optimal outputs in the planning levels; however have drawbacks with handling unexpected events at the control level. One argument is that centralized systems are usually based on the aggregation logic in terms of time, material, location, and resources, which results in neglecting the level of detail in information flow and dynamics of decision making on the shop floor [2]. Another argument is that, in hierarchical control, the time and effort spent to react on changes by the right controller within the hierarchy (bottom-up), and then to make corrective decisions (top-down) generates ineffectiveness [8].

Heterarchical (Decentralized) production control is the other fundamental approach. Due to the complexity and difficulty of dealing with demand and capacity reconciliation, information processing, and unexpected events in a centralized system, distributing the decisional capabilities is receiving important attention recently [8]. There is therefore a rising trend of distributed MESs for real time production control [12]. Multi-agent scheduling systems are widely used to model the fully heterarchical systems [4]. These systems are composed of autonomous agents attached to physical and functional manufacturing entities, taking responsibility to carry out local scheduling and effectively responding local disturbances. They also try to achieve the required global performance by cooperating with each other. However, the difficulty of achieving a sufficient global performance is argued. This drawback led to the development of so called semi-heterarchical holonic production control systems, which enables localized decision making ensuring the global concerns of the factory [13]. However, there are many remaining issues (e.g. interoperability with existing information systems, complexity of interactions to understand and manage) that prevent the applicability of the distributed production control systems in industrial settings (see Trentesaux [8] for full review).

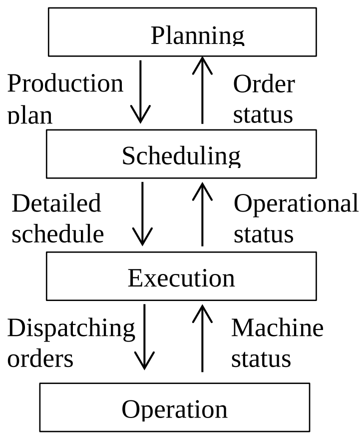

Fig 1. Hierarchical production control (Adopted from Leitão, [7])

In summary, the modern production control literature, both in centralized and decentralized approaches, have been dominated by the modelling and analytical studies to improve the expected outcomes [14]. A great number of research papers published with regards to this topic, however, very few of them influenced the industrial practice [15]. These studies formulate the scheduling and rescheduling as a combinatorial optimization problem, neglecting many important aspects of reality [9, 16]. However, the event handling and rescheduling process involve equally important factors to be considered for the practicality of the production control systems. Hence next chapter attempts to outline the event handling process and the underlying factors. Furthermore, conducted interviews contributed to observe these factors and revise the findings of the literature study in an iterative process.

4 Event Handling Process and Underlying Factors

In literature, several terms are interchangeably used for the unexpected events, such as uncertainties, disruptions, disturbances, and rescheduling factors [9]. There have also been some studies to characterize and categorize the uncertainty in manufacturing systems (see for example Koh et al. [17]). Based on our discussions in the industrial cases, we think that it is also important to append the complexity aspect of the events into these categorizations. There are simple events that basically cause a time delay on the schedule, whereas complex events trigger further actions to be identified and evaluated due to significance of their impacts and interdependencies with lateral schedules and higher level plans. As discussed earlier, the effectiveness of handling unexpected events require timely and appropriate responsiveness. The majority of the studies focus on the "timely" requirement of the production control system [18], considering a simple discrete event with an impact on a single schedule [15, 16]. However, the "appropriateness" requirement is equally important for the practicality issue and requires a holistic view of the event handling process and involved factors.

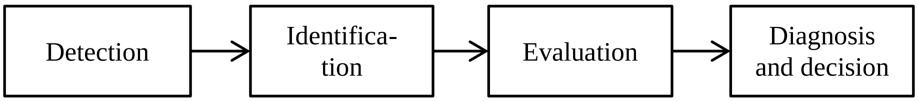

Fig. 2. Event handling process stages (Adapted from Cowling and Johansson, [3])

The event handling process typically consists of the following stages in practice: detection, identification, evaluation, diagnosis and decision making: When an unexpected event occurs it should be first detected by automated technologies or humans like operators [3]. The identification stage underlies the causes of the deviation, the context of the event for priority determination [15], and determines the relevant parties and information to handle the event. The evaluation stage identifies the required corrective actions based on the obtained information and evaluates the impacts of these actions on lateral schedules and plans. The final stage diagnoses if the required changes can be done with the current capacity and capabilities and leads to the decision making. The options are usually; to do nothing, repairing the schedule, or rescheduling [16]. On the basis of the literature study and industrial interviews, the following factors are identified to be important in the event handling process.

4.1 The strategy for production schedule generation and execution

There are three main strategies applied for handling uncertainty in PPC [4, 15, 16]: predictive, reactive, and predictive-reactive strategies. In the predictive planning strategy, uncertainties are considered when the plans and schedules are developed, predicting the changes to be happened. In the reactive approach, no global schedule is generated in advance to the planning horizon and scheduling decisions are made locally in real time, applying simple priority dispatching rules. However, this approach still considers the information from higher level production plans. In the predictive-reactive approach, firstly, a global production schedule is developed over a future time horizon, and then modified in response to unexpected disturbances during the execution [15]. Regarding the insights from industry, the investigated companies have a typical hierarchical planning and control structure. In order to reduce the impact of potential disturbances, they apply the predictive techniques (e.g. safety lead time and safety stock) as well as react on changes with some *firefighting* methods. Their main challenge is that handling the unexpected events are not so straightforward, requiring further evaluation of the context that the event occurred and corrective actions, and the impacts of these actions on the schedules of shared resources and personal. As stated earlier, these strategies allow considering only a small number of uncertainties discretely. Uncertainty is unpredictable by nature and can generate unexpected conditions beyond what these techniques can foresee. Hence, we suggest extending these strategies with the proactive approach on the control level, diagnosing the likely disturbing impacts of the events on a real time basis and taking continuous corrective actions based on these early warning signs. This approach is especially important for *complex events* which may generate *side effects* of disturbances in complex manufacturing environments.

4.2 Information and Communication Technology

Lack of attention to the production control level can also be seen on the information systems widely used in practice. When it comes to adopt the plans and execution phases, they hardly provide any guidelines or mechanisms [19]. For instance, Ivert [20] reports the negative consequences of APSs used to handle disturbances on the lower shop floor level as extracting information from these kinds of systems is too complicated. Effective incorporation of real time information about the events into the manufacturing planning and control systems is critical to handle unexpected events. MESs are emerged to provide this functionality. However, there is still need for MES modules that will detect production exceptions and provide production personnel with online information and decision support [11]. These drawbacks are also notable in the case studies. All three companies use a standard ERP system on the planning level and a tailor-made or standard MES system for shop floor control. When a disturbance occurs, it is hard to obtain the detailed information (location, resource and material status, etc.) required from the ERP system. Moreover, the primary functionality of the employed MES systems is data collection and visualization, however, they fail to provide real time analysis and decision making support for the operators on the shop floor. While these requirements are not met, the monitoring and control task becomes difficult to be performed effectively and therefore still largely relies on manual interventions.

4.3 Coordination and feedback

Handling an unexpected event in a production control system involves a substantial amount of coordination and feedback efforts between relevant parties. However, the majority of research studies consider uncertainties independently [17], which is not the case in reality. This factor has been recognized by some recent empirical studies (see for example de Snoo et al. [9]), showing the interdependencies, communication, and feedback process between planning and control levels during event handling process using an in-depth single case study. This factor especially grows in importance for the identification and evaluation stages in the event handling process described earlier. In these stages the environmental context of the event outlined and the actors to be involved are identified. Results of these stages significantly affect what actions to take and when. This issue has been recognised as a critical factor in the case studies. The context of an unexpected event (e.g. the exact time that the event occurred, the remaining time of the job in the plan, the status of the next operation) and joint evaluation meeting leads to different corrective actions with different urgencies, rather than mathematically better approvable solutions.

4.4 Performance measurement

A great deal of performance measures guides the production control systems in scheduling and rescheduling actions. The majority of the manufacturing systems mainly focus on the classical measurement categories (cost and efficiency), however, especially in the dynamic and stochastic environments, stability, robustness, and instability (nervousness) are important measures to be defined and tracked [5]. Due to this fact, many research studies obtain conflicting results, regarding the benefits of frequent event driven rescheduling activity (see Hozak and Hill, [21]). The industrial practice is far from considering such advanced measures in the event handling and rescheduling process. The major concern of the investigated companies, which is quite understandable in the competitive market conditions, is the delivery due date adherence. It is even hard to notice any operational performance management practices for the PPC process. However through analysis and representation of the realistic instability and stability measures in the models can improve the rescheduling decision on specific work centres with relatively simple characteristics (e.g. stable process, continuous flow, and few machines).

4.5 Human factors

Human interaction with the production control system is often underestimated, however, also plays an important role in practicality of the production control system [22]. Real life manufacturing planning and control systems to varying extents involve human judgment and decision making. Especially, production scheduling and rescheduling tasks, in many cases, are left to the supervisors or operators in practice. In order to support the cognitive strengths of humans in decision making process, visualization plays a significant role in practice. In the observed case companies, detailed dispatching decisions and the task of reacting on changes are often left to the shop floor personal, based on their experience and knowledge. The system-user interfaces are considered to be highly complicated, limiting the understanding of the plans for the personal. Furthermore, the usage of many ICT systems and tools create confusions. The interviewed employees expressed a clear need for an intuitive and easy-to-understand decision support tool that exploits and visualizes the required information, and guides them in the event handling process, taking human cognitive skills into consideration.

5 Implications and Future Research

The intent of this paper was to investigate and outline the requirements from a practical production control system in order to respond the unexpected events effectively. In summary, following maturity levels are proposed for each underlying factor.

Table 1. Proposed maturity level of each factor for effective event handling process

Strategy: Proactive control strategy besides the widely applied predictive-reactive strategy to handle the events
ICT: A semi-heterarchical information flow and decision making structure is needed to provide quick responsiveness to unexpected events in cooperation with the overall planning performance. Full interface with information systems and real time access to internal and external required data. MES module for real time decision support to handle unexpected events
Coordination and feedback: Events are sorted and categorized for each strategy at each planning and control level. Structured event handling process with clear roles and responsibilities for interdependent levels
Performance measurement: Adopted realistic stability and instability measures when making event-driven rescheduling decisions as well as diagnostic early warning measures for classified events for proactive control
Human factor: Responsible person adopts an event driven proactive approach. The system is developed with respect to the roles of human and computer component interactively, facilitating the diagnosis of disturbances. The system should be user-friendly, easy to interpret, and intuitive, reducing the cognitive workload

Further work will be related to the generalizability of the findings of this study, specifically for the proposed maturity level of each factor. In order to achieve this goal, a questionnaire survey will be sent to a sufficient number of companies from a range of manufacturing environments and the results will be analysed.

References

1. Slack, N., S. Chambers, and R. Johnston: Operations Management. 5th ed., Harlow: FT Prentice Hall (2007)

2. Meyer, G.G., J. Wortmann, and N.B. Szirbik: Production monitoring and control with intelligent products. International Journal of Production Research. 49(5), 1303-1317 (2011)
3. Cowling, P. and M. Johansson: Using real time information for effective dynamic scheduling. European Journal of Operational Research. 139(2), 230-244 (2002)
4. Ouelhadj, D. and S. Petrovic: A survey of dynamic scheduling in manufacturing systems. Journal of Scheduling. 12(4), 417-431 (2009)
5. Sabuncuoglu, I. and S. Goren: Hedging production schedules against uncertainty in manufacturing environment with a review of robustness and stability research. International Journal of Computer Integrated Manufacturing. 22(2), 138-157 (2009)
6. Jacobs, F.R., et al.: Manufacturing Planning and Control for Supply Chain Management: APICS/CPM Certification Edition. McGraw-Hill. USA (2011)
7. Leitão, P.: Agent-based distributed manufacturing control: A state-of-the-art survey. Engineering Applications of Artificial Intelligence. 22(7), 979-991 (2009)
8. Trentesaux, D.: Distributed control of production systems. Engineering Applications of Artificial Intelligence. 22(7), 971-978 (2009)
9. de Snoo, C., et al.: Coordination activities of human planners during rescheduling: Case analysis and event handling procedure. International Journal of Production Research. 49(7), 2101-2122 (2011)
10. Steger-Jensen, K., et al.: Advanced planning and scheduling technology. Production Planning & Control. 22(8), 800-808 (2011)
11. De Ugarte, B.S., A. Artiba, and R. Pellerin: Manufacturing execution system–a literature review. Production Planning and Control. 20(6), 525-539 (2009)
12. Rolón, M. and E. Martínez: Agent-based modeling and simulation of an autonomic manufacturing execution system. Computers in Industry. 63, 53-78 (2011)
13. McFarlane, D.C. and S. Bussmann: Developments in holonic production planning and control. Production Planning & Control. 11(6), 522-536 (2000)
14. McKay, K.: Historical survey of manufacturing control practices from a production research perspective. International journal of production research. 41(3), 411-426 (2003)
15. Aytug, H., et al.: Executing production schedules in the face of uncertainties: A review and some future directions. European Journal of Operational Research. 161(1), 86-110 (2005)
16. Vieira, G.E., J.W. Herrmann, and E. Lin: Rescheduling manufacturing systems: a framework of strategies, policies, and methods. Journal of Scheduling. 6(1), 39-62 (2003)
17. Koh, S., S. Saad, and M. Jones: Uncertainty under MRP-planned manufacture: review and categorization. International Journal of Production Research. 40(10), 2399-2421 (2002)
18. McKay, K.N. and V.C.S. Wiers: Practical production control: a survival guide for planners and schedulers: J. Ross Publishing (2004)
19. Kreipl, S. and M. Pinedo: Planning and Scheduling in Supply Chains: An Overview of Issues in Practice. Production and Operations Management. 13, No. 1, 77-92 (2004)
20. Ivert, L.K.: Use of Advanced Planning and Scheduling (APS) systems to support manufacturing planning and control processes. Doctoral Thesis. Chalmers University of Technology (2012)
21. Hozak, K. and J.A. Hill: Issues and opportunities regarding replanning and rescheduling frequencies. International Journal of Production Research. 47(18), 4955-4970 (2009)
22. McKay, K.N. and V.C.S. Wiers: The human factor in planning and scheduling. Handbook of production scheduling. 23-57 (2006)