Planning and control frameworks of the future

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Abstract: Since the 1970s, multiple planning and control frameworks have been introduced. The current digitalisation of the manufacturing industry, with all its Industry 4.0 related technologies, will have major implications on manufacturing logistics, and may change how manufacturing companies plan and control their production. In this paper, we discuss the effects of the developments in planning frameworks and technologies on different factors that constitute planning and control. These are the balance between human and automated planning, the influence on mid-term planning due to improved forecast accuracy, the influence of real-time information on short-term planning, horizontal and vertical integration and the impact on supply chain performance. The application of new technologies will lead to changes in all of these factors that cannot be fully captured by current planning and control frameworks. These factors need to be integrated into future frameworks in order to structure future research into planning and control.

Keywords: planning and control; planning frameworks; Industry 4.0; technology application.

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1 Introduction

The manufacturing industry always has a drive for improving their planning techniques to maximise service level while keeping up the cost efficiency level, often by meeting due-dates and avoiding overtime. According to Slack et al. (2013) planning is "a formalisation of what is intended to happen at some time in the future". It is intended because the resulting plans are not necessarily the same as the real-world outcome; and it is for this reason we need control in order to cope with the inevitable deviations between planned and actual outcome.

Since the 1970s, multiple hierarchical planning frameworks have been introduced, matching planning decisions to different hierarchical levels and underlining the exchange of information between these levels. These hierarchical levels distinguish decisions with different timing, going from long-term strategic planning decisions to short-term control decisions (Hax and Meal, 1973; Zijm, 2000; Vollmann et al., 2005).

Frameworks that are used today have three major components:

- the separate functions that need to be performed in manufacturing planning and control
- the horizontal interconnection between different functions, such as demand management, production planning and purchasing
- the vertical integration, going from long-term to short-term planning, also referred to as strategic, tactical and operational planning.

These hierarchical systems make sequential decisions, i.e. optimal planning decisions taken on a strategic level would give the constraints for sub-sequential levels. The two main reasons for segregating the different decisions have been the limitations of analytical tools and the involvement of management on each different level (Hax and Meal, 1973). Hans et al. (2007) point out that hierarchical planning has different objectives and levels of aggregation. They furthermore highlight Pareto-efficiencies, in which not only costs, but also the robustness of a solution is considered. Plan robustness helps to deal with variation in the actual operations to avoid reactive planning during operations.

The role of planning and control in manufacturing industries is changing. Existing frameworks are being questioned for their validity in the era of Industry 4.0. The emergence of artificial intelligence and machine learning, typically associated with Industry 4.0, will enable automation of tasks that previously have required human intervention (Pfohl et al., 2017). It is thus necessary to look at how these developments impact planning decisions, investigating which decisions that could be automated and which that still the human planner should undertake. This means that the balance between human and automated planning should be investigated in the light of today's planning and control frameworks.

Furthermore, increased computing power facilitates the possibilities for big data analytics as well as augmented and virtual reality, while progressively affordable hardware enables an increasing number of sensors and the Internet of Things (Lu, 2017). These Industry 4.0-related developments increase the availability of real-time information (Pfohl et al., 2017). Algorithms using real-time data can reduce supply and production uncertainties (Pfohl et al., 2017). Reducing uncertainty and the usage of big data analytics will improve the forecast accuracy. The influence on mid-term planning due to improved forecast accuracy should be further researched.

The increased number of data gathering points enables a near real-time control of the operations, which raises several questions regarding how it will influence planning and control. Real-time control of the operations enables feedback loops continuously monitoring the status of the operations. The influence of real-time information on short-term planning is another issue that is worth researching.

The integration of IT systems also facilitates horizontal and vertical integration (Strandhagen et al., 2017). The increased levels of horizontal and vertical integration will influence existing planning frameworks and is thus important to investigate.

Together, all the above-mentioned changes will influence planning as we know it today, and it is crucial to investigate the impact on plan robustness and cost effectiveness due to these developments.

As shown above, there are numerous issues regarding the transformation of planning and control processes in the Industry 4.0 era. This paper reflects on theory and cases, but does not contain empirical evidence. To summarise, this paper will investigate and discuss the following aspects:

- the balance between human and automated planning
- the influence on mid-term planning due to improved forecast accuracy
- the influence of real-time information on short-term planning
- horizontal and vertical integration
- impact on plan robustness and cost effectiveness.

By taking today's planning frameworks, the potential impact of new technologies can be discussed. By doing so, the paper gives insights in how we should discuss new Industry 4.0 development in the light of planning and control. Section 2 will first discuss the development of planning frameworks over time and new technologies that could be relevant for planning and control. Section 3 discusses the aforementioned factors and Section 4 paves the way forward and concludes the paper.

2 Background

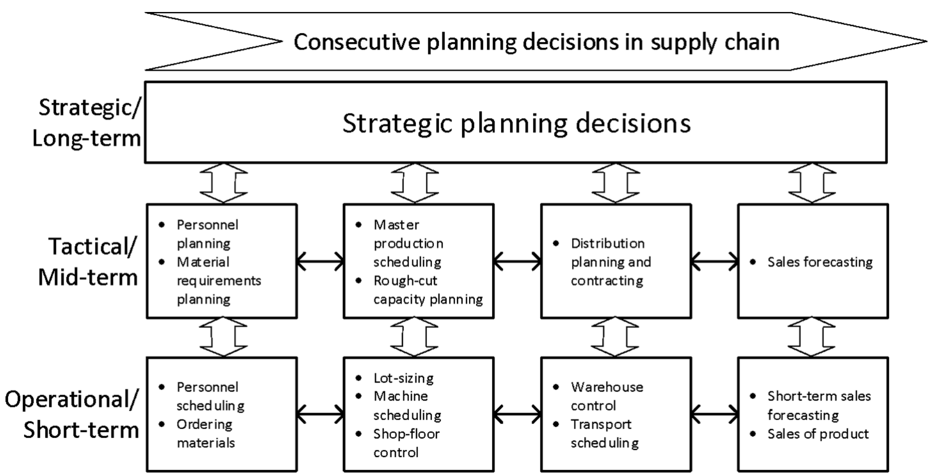
2.1 The history of planning frameworks

Planning frameworks come forward from developments in the 1970s, noticing that each planning decision has a time frame, constraints and a level of detail in planning decisions. The longer the time frame, the fewer the constraints and the lower the level of detail (Hax and Meal, 1973).

Frameworks can also connect several functions, such as demand management and resource management unified through sales and operations planning in order to create final production schedules (see for example the frameworks by Jacobs (2011) and Vollmann et al. (2005)).

The most used framework in practice is manufacture resource planning (MRPII), often connected to the architecture of the enterprise resource planning (ERP) system that is in use. MRPII is criticised for the fact that it does not plan against finite resource capacity, it merely gives a rough-cut schedule of how much capacity is required in order to fulfil demand based on the lead-times for each item in the material requirements planning (MRP). In order to cope with uncertainties in production systems, the control mechanisms in MRPII are lead-times and safety-stocks (Zijm, 2000). In addition, it is unclear how the different tasks in MRP need to be performed, leading to imprecise and inconsistent organisation around the planning functions (McKay and Wiers, 2003; Berglund and Karltun, 2007). Furthermore, MRP is criticised for neither integrating planning nor having a clear objective other than backwards scheduling all backlog (Fleischmann et al., 2015).

Figure 1 A typical planning and control framework, based on Rohde et al. (2000), Zijm (2000) and Vollmann et al. (2005)



Another development that has been taking place since the beginning of the 21st century is the development of advanced planning systems (APS). Three characteristics define APS systems (Fleischmann et al., 2015):

- integral planning, i.e., integration from at least supplier to customers within an enterprise
- true optimisation, i.e., clear objectives, constraints and alternative generation for planning problems
- hierarchical planning, i.e., the subsequent planning of different planning decisions in order to be able to optimise and integrate them.

It is argued that planning must be hierarchical: An overall planning system for all tasks would be not functional and it would be difficult to find optimal solutions for different problems in the supply chain (Fleischmann et al., 2015).

This has led to different hierarchical planning frameworks that integrate supply chain functions and at the same time distinguishes between them (see Figure 1). It is not necessary such that all functions need to be executed and can even lead to sub-optimal solutions (Buer et al., 2018).

Furthermore, it has been argued that planning and control is not only fulfilling the objective of cost efficiency, but also the objective of robustness, i.e., "recognising and exploring the uncertainty that is inherent in supply chains, and distilling from it the planning decisions that will yield more predictable and stable results". This implies that a higher cost will give a more stable result that copes with the uncertainty of the supply chain (Van Landeghem and Vanmaele, 2002).

2.2 Potential relevant technologies for planning and control

As described in the last section, the latest developments in planning and control are mainly in APS. APS are now provided as software modules to fulfil one or multiple functions as described in Figure 1. It is thus how new techniques either complement or interface with advanced planning techniques and thereby alter the setup of planning frameworks. Strandhagen et al. (2017) point out to digitalisation technologies that are relevant to manufacturing logistics. These techniques help with decision support and decision-making, identification and interconnectivity, seamless information flow, and automation. This can be translated to knowing what is where at real-time, being able to analyse this information and using this information in decision support. Using new technologies enables functionalities in planning that are not explicit in today's planning and control frameworks. They are sorted hierarchically by supply chain function, with no integration of functions or use of different technologies made explicit.

The premise is that more data and better analysis of this data will lead to better information and therefore better decision taking. In the case of planning frameworks, however, it is not yet clear which functions will be altered and how that affects the overall performance of several planning functions that are working together. The next subsections present some of the technologies relevant for planning and control.

2.2.1 Sensors

Highly sophisticated sensors give the opportunity of rapid detection and notification of anomalies, which again enables more rapid replanning when events occur on shop floor. A factory and production system equipped with sensors will enable data acquisition from machines, equipment etc. providing real-time information on specific changes of the product, humans or processes in a facility (Zheng et al., 2018). This creates self-aware and self-configuring manufacturing systems (Lee et al., 2015). From a planning perspective, it could lead to a more event-driven, reactive way of planning.

2.2.2 Internet of things

The Internet of Things concerns the identification and networking of objects in a factory or supply chain (Slack et al., 2013). Objects with built-in electronics, software, sensors, actuators and network connectivity makes it possible for these objects to collect and exchange data with each other and with IT systems. Together with available tracking technologies, such as RFID, this may provide overview of the location of a product or component at any time, thus it enables real-time planning with a faster and safer flow of information.

2.2.3 Big data analytics

Data is generated from numerous sources in a supply chain, and the information it can give will be of great importance for planning and controlling production. This because the data now is available faster, in higher volumes, and in more types than before. Moreover, technological development now provides the ability to analyse and utilise these huge amounts of data. This will enable managers to make planning decisions based on evidence rather than intuition, resulting in more well-informed decisions (McAfee et al., 2012). A summary of possible big data analytics techniques can be found in Tsai et al. (2015).

2.2.4 Artificial intelligence

Artificial intelligence (AI) refers to the development of computer programs that can learn and reason in a manner similar to humans. Application of such technology in manufacturing will enables more automated and autonomous decision-making, where today human interaction is required. AI technology is unique in the way that it has the potential to supplement, substitute and amplify practically all tasks currently performed by humans (Makridakis, 2017).

2.2.5 Machine learning

The technological area Machine learning concerns the development of mathematical models and algorithms that analyse information and use this for self-optimisation. Machine learning will enable the recognition of patterns in datasets, and makes better decisions. Thus, the applications of this technology will be highly relevant for continuously optimisation of production plans, capacity utilisation, inventory levels and other elements of planning and control. Machine learning is applicable on both long-, mid-, and short-term planning levels (Knoll et al., 2016).

3 The effects on planning and control through changes in planning frameworks

This section describes the effects of the developments in planning frameworks and technologies on different factors that constitute planning and control.

3.1 Interaction between human and automated planning decisions

Berglund and Karltun (2007) point to the importance of the relationship between human, technology and organisation. In this study, it is pointed out that human planners and schedulers mainly are working with outcomes that are not captured by the planning and scheduling system. In the relation between human and technology, it is therefore important that the technology used provides support or solutions that are in accordance with the understanding of the human planner (Berglund and Karltun, 2007). Wiers and Van Der Schaaf (1997) indicate that humans mainly should focus on exceptions in planning, where the problem is ill defined and information is incomplete. This is because humans possess skills such as flexibility, adaptability, learning, communication and learning. McKay and Wiers (2006) therefore conclude that "it is very hard to think of a situation where the mathematical algorithms and planning logic are self-installing, self-setting, self-tuning, and self-adapting to the situational context of business realities". The developments in artificial intelligence are not such (yet) that it can do this.

Humans will most likely keep their role in the age of digital planning, especially in planning situations where the problem is ill defined. This results mainly to long-term planning problems and industries where products are engineered-to-order. We do foresee that decision support for humans will get better. As forecasts on market trends are likely to improve with better quality data, and forecasting and planning techniques develop over time, the decision taker must be enabled to take better informed decisions.

On the mid-term and short-term, humans will get less involved with algorithm-controlled planning and control decisions. There are, however, certain conditions that need to be met in order to do so:

- the objectives for the planning level need to be set in accordance with the strategic objectives or long-term planning decisions
- the objectives are achieved by the systems that are in use
- there is either trust in the black-box solutions that are provided, or the solutions are visualised and can be inspected by managers.

Acceptance of black-box solutions remains a crucial factor in digitalising planning, and while the advancements of technologies are apparent, the MRPII framework and spreadsheet decision support are still dominating within industry. Therefore, the role of humans in digitalising planning needs further research (de Man and Strandhagen, 2018).

3.2 The change in forecast accuracy and the influence on mid-term planning

Mid-term planning is best suited to cope with uncertainty, having more information than the long-term planning and not being as constrained in flexibility as the short-term planning horizon. This could result in robust planning, where the resulting plan either minimises the need for re-planning or allows for feasible production schedules (Van Landeghem and Vanmaele, 2002).

If demand forecasts become more accurate, the deviations between actual and forecasted demand become smaller. Forecast accuracy, however, will never become 100% and the three forecast laws will hold:

- "Forecasts are always wrong.
- Detailed forecasts are worse than aggregate forecasts.
- The further into the future, the less reliable the forecast will be" (Hopp and Spearman, 2008).

Higher forecast accuracy does mean that planning and scheduling becomes more robust without increasing the cost of the resources employed, because fewer possible outcomes are likely to happen. This implies that mid-term planning becomes more valuable by creating stability in the short-term planning without planning more buffers to cope with uncertainty.

3.3 The move towards real-time information and the influence on short-term planning

For the remainder of uncertainty that cannot be captured by advanced forecasting models, reactive planning and scheduling is necessary. Rescheduling is done in order to cope with changes that where not foreseen and cannot be covered for in the initial plan or schedule.

There is a concern with rescheduling, since planning and scheduling nervousness becomes greater when schedules are changed due to uncertainties. The question is whether each change in a supply chain should result in a reconsideration by the planning system to alter plans and schedules, because it results in nervousness that can propagate throughout a system or supply chain, with the most well-known effect being the bullwhip effect (Kaipia et al., 2006).

It could be that scheduling nervousness becomes a non-factor if planning and scheduling becomes a largely automated process, and maybe even a real-time process, where the system is constantly looking for the best solution based on its objectives. This implies that the application of technologies is such that:

- factories become flexible and setup costs and times become almost zero
- barriers attributed to information sharing across the supply chain can be mitigated (Kiil et al., 2015).

3.4 Horizontal and vertical integration of planning frameworks

The horizontal dimension of planning and control concerns the different activities/functions required for different stages of the value creation process. These stages are procurement, production, distribution and sales, which all include different planning activities, as described in for example (Rohde et al., 2000, cited in Fleischmann et al., 2015). Kagermann et al. (2013) describes horizontal integration as one of the main features of Industry 4.0 and argues that such an integration will include both an integration of intra-company business processes such as inbound logistics, production, outbound logistics and marketing, as well as being an inter-company integration. Future planning and control will thus be characterised by such a horizontal integration that will affect the planning functions we have today, making them more integrated, e.g., production planning would be integrated with outbound logistics planning, making use of the same planning system and input data.

The vertical dimension of planning frameworks concerns the different time frames of the planning activities, i.e., long-term, mid-term and short-term planning. Vertical integration is another main feature of Industry 4.0 as described in Kagermann et al. (2013), and refers to the integration of the physical and informational systems at the different hierarchical planning levels. That is for example the shop floor system, the manufacturing execution system (MES) and the ERP system in a manufacturing company. The vertical integration of systems will thus affect planning functions across the different planning levels in today's planning systems and frameworks, and is an enabler of more real-time planning (Arica and Powell, 2014), e.g., strategic planning would incorporate detailed operational planning to test different scenarios.

3.5 Improvements in robustness and cost effectiveness

From the perspective of the planning frameworks, planning and control is mainly concerned with the performance of the supply chain. The optimisation of the supply chain is dependent on how performance in the supply chain is measured. Beamon (1999) translates this into three key elements: the resources, output and flexibility of the supply chain, which can be translated into the costs, profitability and robustness of the supply chain.

With available planning tools, we try to achieve a balance between cost and achieving a certain supply-chain performance. For example, if the marketplace asks for a 90% service level for on-time delivery, planning needs to be able to cope with 90% of all potential outcomes in the supply chain. The introduction of technologies could lead to either an improvement in robustness, i.e., the ability to withstand uncertainty in the supply chain, or an improvement in cost efficiency. This means either delivering at the same service level for a lower cost or improving the service level at the same cost level. This also gives the possibility to offer a wider range of products at the same cost and service level, by increasing the flexibility of the supply chain through planning and control.

4 Conclusion and future work

In this paper, we demonstrated how different technologies influence different aspects of planning and control as structured in planning and control frameworks. Through the application of technology, we foresee changes in the relation between human planner and technology employed. We furthermore discussed the implications on mid-term (pro-active) and short-term (reactive) planning. We also discussed how vertical and horizontal integration could lead to fewer systems that control more than one planning function. This leads to a future in which planning and control functions change, become integrated and have a different relationship to its users.

The application of new technologies will lead to changes that cannot be fully captured by current planning and control frameworks. This can have limitations for firms that structure their planning and control around a framework. We propose future research into and the development of new planning and control frameworks that account for the use of technology, function integration and the relation between human planner and used technology. This will help to structure research into developing planning and control further, and will help practitioners develop a digitalised planning and control process. In order to do so, frameworks need to be redefined based on cases exploiting the technologies.

The limitation of this paper is twofold: The relation between cost and opportunity has not been discussed in this paper, making it possible that the return on investment is negative due to the investment and maintenance cost of technology. This relates to that some of the mentioned technologies have not matured and might never reach their full potential.

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