

APPLICABILITY OF DIFFERENT CAPACITY PLANNING METHODS: PRACTICAL IMPLICATIONS FROM CONTINGENCY THEORY

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ABSTRACT

Most practitioners use considerably simpler production planning methods than what is recommended in the literature. The explanation for this observation is sought in a strong-inference study, where a universalistic hypothesis on the superiority of sophisticated planning methods is tested against a contingency hypothesis, which assumes that simpler methods may prevail in certain kinds of production processes. Multisource data from machinery manufacturing support the contingency hypothesis and show that simple methods often outperform the most sophisticated techniques. The findings are explained with task interdependence and bounded rationality. The results illustrate that classic organization-theoretical concepts may bring practically relevant insights to operations management research.

INTRODUCTION

The planning of manufacturing operations constitutes a major research area in operations management (Kouvelis et al., 2005). Yet, it has been repeatedly observed that most practitioners employ considerably less sophisticated planning methods than what is discussed in the literature (Melnyk et al., 1986; Wiers, 1997; McKay et al., 2002). Moreover, surveys indicate that those practitioners, who use advanced planning methods, are on often less satisfied with their plans than those, who use simpler and less accurate methods (Jonsson & Mattsson, 2003). This article seeks to explain the gap between the practice and the academic models of production planning.

The article employs the logic of *strong inference*, the *contingency theory* of organizations, and *empirical data* from machinery industry to explain the determinants of planning methods' effectiveness. The strong inference refers to a research design, where theory building is based on tests of competing hypotheses (Platt, 1964). The contingency-theoretical perspectives to process complexity (e.g., Thompson, 1967) are used to propose that sometimes the most sophisticated planning methods may be less effective than the simpler techniques. The contingency proposition is tested against a hypothesis on the universal superiority of the most advanced planning methods.

HYPOTHESES

Planning is an important coordination method in complex organizations (March & Simon, 1958). In simple organizations, where resources' specialization, action variety, and interdependence are low, coordination can be achieved with rules and heuristics (Cyert & March, 1963). In manufacturing management, the central concept in the planning-based approach is *material requirements planning* (MRP, Orlicky, 1975), while the *just-in-time* (JIT) methods represent an approach that emphasizes simplicity and rule-based execution (Ohno, 1988). Despite the important contributions of JIT, the time-phased planning methods have remained as a vital part of manufacturing management. That is because some amount of planning is necessary when customized goods are produced in make-to-order (MTO) processes (Karmarkar, 1989; Vollmann et al., 2005).

The contemporary methods of time-phased production planning are based on the *manufacturing resource planning* (MRPII) framework. It complements MRP with various ways of checking material plans' feasibility against capacity constraints (Landvater & Gray, 1989). While the material planning parts of MRPII always need to be done in certain ways, there is freedom of choice in the level of detail and the efforts that are put to the planning of capacity utilization (Vollmann et al., 2005). Consequently, it has been observed that the capacity planning parts of MRPII are far less utilized than what could be expected on the bases of the literature (Halsall et al., 1994; McKay & Wiers, 2004). The variance in the utilization of the capacity planning methods is interesting because it enables testing whether the complex organizations that do not emphasize planning suffer from the lack of coordination (e.g., March & Simon, 1958; Zwikael & Sadeh, 2007). Thus, the following hypothesis is presented as the underlying assumption of this study:

H1: Efforts in capacity planning are positively associated with performance

It is reasonable to assume that not only the efforts in planning but also the ways of planning matter. The MRPII framework of Vollmann et al. (2005) includes the following alternatives for capacity planning: *non-systematic capacity planning*, *rough-cut capacity planning* (RCCP), *capacity requirements planning* (CRP), *finite loading with capacity leveling*, and *finite loading with optimization*. The methods differ from one another by the level of detail and the amounts of master data that is needed for their maintenance. The above list is in the ascending order of sophistication. [The complete descriptions of the methods can be found in the original paper, which is available upon request from the author.] The framework of Vollmann et al. (2005) is used in this study because the production planning modules of dominant enterprise systems are structured in the same fashion (e.g., SAP, 2008a) and because most textbooks either refer to it directly or provide models that closely resemble it (e.g., Hill, 2005; Slack et al., 2007; Stevenson, 2004).

The different planning methods are by no means mutually exclusive (Meal, 1984). However, a concept called *bottom-up re-planning* helps to define the main method of capacity planning (Fransoo & Wiers, forthcoming; Vollmann et al., 2005). It is the method that is used to ensure the feasibility of master production schedules. The variance in the sophistication of the main methods is interesting because the more advanced methods specifically aim to improve operational performance by reducing errors in planning. Some studies, which have focused on non-systematic methods, RCCP, and CRP, have provided preliminary evidence of the more advanced methods' benefits (Sheu & Wacker, 2001; Wacker & Sheu, 2006). Including the finite loading techniques in the comparisons is important because a lot of efforts have been put in their development during the last two decades (Kouvelis et al., 2005). The use of progressive methods would be well justified if there was evidence on the relationship between the accuracy of the planning methods and performance. Hence, the following hypothesis is formulated:

H2a: Sophistication of capacity planning methods is positively associated with performance

While the hypothesis on the universal superiority of the advanced planning methods is tempting in its simplicity, it can be challenged from a contingency-theoretical perspective. Such a perspective would assume the effectiveness of any method to be dependent on the context of its usage. Preliminary support for such an argument is provided by Jonsson and Mattsson (2002; 2003). Their surveys show that the managers of job shops are typically satisfied with RCCP, whereas the most satisfied users of CRP run batch processes, and the finite loading methods are most com-

mon in production lines. The influence of the process type can be explained with two classic contingency-theoretical constructs: the *repetitiveness* and the *complexity* of the tasks that constitute the processes (Perrow, 1967; Woodward, 1965):

- RCCP fits with the job shops because in low-volume and high-variety environments, the data records of the more detailed methods would be difficult to maintain. Moreover, they would not be necessary because the complexity of the system is limited by the general-purpose machinery and widely skilled workforce (Blackstone & Cox, 2005; Hill, 2007).
- CRP fits with the batch processes because the more repetitive operations make the maintenance of the data records worthwhile. Furthermore, information about the resource-specific workloads is necessary because the resources are more specialized and different products utilize them differently (Jonsson & Mattsson, 2003; Wortmann et al., 1996).
- Finite loading methods fit with batch processes, whose complexity is reduced with bottleneck control (Goldratt & Cox, 1984; Vollmann, 1986). Finite loading works in a batch process if a stationary bottleneck can be identified in it and all other resources are subordinated to its schedule. Otherwise, each finite loading of one resource can make another resource a new bottleneck, and the iteration of the plans may become endless.
- In the production lines, the complexity is low because all resources are subordinated to the flow of the line. Therefore, the capacity of the entire line can be planned as a single resource. Detailed planning is desirable because changeover costs are typically significant (Hayes & Wheelwright, 1979). The repetitiveness of the operations makes it easier to maintain the required parameters (Safizadeh & Ritzman, 1997; Stadtler & Kilger, 2005).

Also the literature on *task interdependence* implies a relationship between planning methods and process types. The alternative types of interdependence are pooled, sequential, and reciprocal (Thompson, 1967; Donaldson, 2001). The *pooled* and *sequential* tasks are the simplest to coordinate but they have different implications to planning (Barki & Pinsonneault, 2005). While the sequential tasks are easy to plan, the pooled tasks do not require much planning. A job shop is an archetype of pooled interdependence (Galbraith, 1973), while sequential relationships exist in production lines and around the bottlenecks of batch processes (Woodward, 1965). The *reciprocally* interdependent tasks are the most challenging to coordinate because each action by any resource may affect multiple other resources (Galbraith, 1973). Some sophistication in planning is necessary to prevent undesirable cascade effects but getting into the details is difficult because the possible interactions are numerous (Tushman & Nadler, 1978). Thus, an intermediately sophisticated planning method is most suitable for the reciprocal processes of batch shops (Reeves & Turner, 1972). In summary, the following hypothesis can be formulated:

H2b: Alignment between capacity planning methods and process types is positively associated with performance, that is: RCCP should be used in job shops, CRP in batch processes, and finite loading methods in bottleneck-controlled batch processes and production lines

METHODS AND DATA

The existence of two competing hypotheses calls for a research design that is known as *strong inference*. It is an inductive approach, where theory building is based on the tests of mutually excluding hypotheses (Platt, 1964). Strong-inference studies must be carefully designed to ensure

that none of the rival hypotheses is favored by the research setting (MacKenzie & House, 1978). In this study, it means that the sample had to be focused on such manufacturers, whose products are sufficiently complex to necessitate time-phased planning. Manufacturers of simple products can rely solely on rate-based *material* planning, and thus their presence in the sample would have biased the comparison of *capacity* planning methods. The screening of a sample is called *theoretical sampling* and it is typical to inductive research settings (Eisenhardt, 1989; Yin, 2003).

The data of this study were collected from the supply chains of seven machinery manufacturers. The units of analysis were the production processes of different business units along the chains. The data consist of 40 plants from five countries. 98 different manufacturing processes were identified within the sample, and electronic questionnaires were sent to their production planners. The survey yielded 89 usable responses, which translates to a response rate of 91 percent. In addition to the survey, qualitative data were collected to better interpret the results of the statistical tests. Altogether 21 production planners were interviewed about the rationales of implementing specific planning methods. To further test the validity and reliability of the analyses, work observations were done in 16 plants, and reporting data were collected from 38 production processes.

The dependent variable was operationalized as a three-item scale of delivery performance because that dimension of operational performance is the only one to represent an equally important competitive priority for all process types (Safizadeh et al., 2000). The independent variables included a formative two-item continuous scale of planning efforts, five dichotomic items for the planning methods, and four dichotomic items for the process types. The fitness between the methods and the process types was operationalized with a dichotomic congruence term (Venkatraman, 1989). In addition, the effects of size and product complexity were controlled with appropriate measures, and dummy variables were included to control for the average performance of each supply chain. [The exact items and the reliability analyses of the measures can be found in the original paper, which is available upon request from the author.]

RESULTS

The hypotheses are tested with hierarchical regression analyses. The results are shown in Table 1. The control variables are entered in the first step. The explanatory power of the dummy variables is considerable. That is due to the research design: as the units of analysis belong to the same seven supply chains, many of them share same competitors and performance standards. Thus, controlling for that effect is crucial. The second step adds the planning effort into the equation. Its effect is significantly positive as predicted in *Hypothesis 1*. The methods are entered in the third step. Contrary to *Hypothesis 2a*, the sophistication of the method does not seem to matter because none of the effects is significantly different from zero. The last steps add the congruence terms: Step 4a shows the average negative effects of using the methods in wrong environments. Step 4b shows their positive effects in the fitting environments. The congruence term has a significant coefficient and it explains a considerable portion of variance in performance. Therefore the results give fairly strong support to *Hypothesis 2b*. As all methods' coefficients are significant or at least approach significance in Step 4b, the contingency proposition appears to hold for all of the methods. Meanwhile, *Hypothesis 2a* does not seem to hold even when the methods are used in the fitting contexts because the effects fall within the confidence intervals of each other. On the other hand, all methods seem to be equally bad if they are applied with wrong kinds of processes. That is because the methods' coefficients do not differ significantly from each other in Step 4a.

Table 1: Regression results

Variable	Step 1: Controls		Step 2: Planning effort		Step 3: Methods		Step 4a: Congruence		Step 4b: Congruence		Toler- ance
Constant	2.91*	(.48)	2.12*	(.51)	2.08*	(.56)	2.30*	(.39)	2.27*	(.39)	
(Dummy variables are omitted to save space)											
Size of organization	.06	(.07)	.05	(.07)	.05	(.07)	.01	(.05)	.02	(.05)	[.66]
Products' complexity	-.06	(.05)	-.04	(.05)	-.04	(.05)	.03	(.04)	.03	(.04)	[.73]
(Job shop is the baseline of process types)											
Batch process	-.40‡	(.20)	-.48†	(.19)	-.52†	(.20)	-.57*	(.14)	-.57*	(.14)	[.57]
Batch process & bottleneck ctrl	-.16	(.25)	-.26	(.24)	-.31	(.27)	-.12	(.19)	-.12	(.19)	[.57]
Production line	-.28	(.22)	-.13	(.21)	-.12	(.25)	-.30‡	(.18)	-.29	(.18)	[.33]
Planning effort			.28*	(.09)	.31†	(.13)	.17‡	(.09)	.17‡	(.09)	[.30]
(Non-systematic planning is the baseline of methods)											
Rough-cut capacity planning					-.13	(.28)	-.38‡	(.20)	.47†	(.21)	[.27]
Capacity requirements planning					.09	(.31)	-.32	(.23)	.53†	(.23)	[.23]
Finite loading: capacity leveling					.02	(.37)	-.38	(.27)	.48‡	(.27)	[.26]
Finite loading: optimization					-.18	(.37)	-.30	(.26)	.56‡	(.28)	[.26]
Fitting method & process							.86*	(.12)			
Unfitting method & process									-.86*	(.13)	[.63]
Adjusted R ²	.44		.52		.49		.74		.74		
F for ΔR ²	1.4		9.6*		.3		46.6*		46.6*		

Dependent variable is *delivery performance* ‡ p < .10; † p < .05; * p < .01
Regression coefficients are unstandardized. Standard errors are shown in the parentheses.

One important finding from the survey is the wide utilization of non-systematic and contextually unfit planning methods (22 and 35 percent, respectively). The question of how organizations have ended up with their planning methods was addressed in the interviews of this study. The interviewees' opinions had considerable similarities: the planners, who used non-systematic methods or RCCP in unfit contexts, shared a feeling that more detailed techniques would be overwhelmingly complicated. Meanwhile, the planners who used RCCP in fitting contexts told that they had not explored 'fancier' techniques because they were satisfied with their current practices.

In both the fitting and unfitting contexts, the rationale for using CRP was that it was part of the companies' ERP systems. In the cases, where CRP should not have been used, the planners generally blamed the unreliability of their plans on the poor usability of their ERP systems. However, even those planners, who used CRP in the right contexts, told that capacity planning was a particularly challenging part of their work. That is aligned with the theoretical discussion about the batch shop being the most complex process type when it comes to capacity planning.

The most often referred reason to adopt finite loading methods was that someone in the organization had come across with a convincing software tool. In the situations where the method was too detailed for the process, the users admitted the existence of problems but attributed them to the incorrect use of the software. In the fitting contexts, the users of finite loading techniques appeared to be particularly grateful to the ease of use of their planning tools.

DISCUSSION AND CONCLUSIONS

The results show that there is time and place for such ‘imprecise’ planning methods as RCCP and CRP whose widespread utilization has been wondered in the academia (Halsall et al., 1994; Jons-son & Mattsson, 2003). It seems that if the finite loading techniques are used in job shops, they encourage making tight schedules for processes that are not sufficiently stable for them. In the terminology of contingency theory, the resources of job shops are said to be *pooled* (Thompson, 1967). If the resources are *aggregated* by definition, it is not surprising that the users of *detailed* techniques complain that their plans are not robust enough, as observed by Wiers (1997).

In batch processes, the problem is the ‘shifting bottlenecks’. The finite loading techniques do not seem to work despite that algorithms have been developed to tackle the problem (e.g., Kouvelis et al., 2005; SAP, 2008b). A contingency-theoretical explanation is that in the reciprocal processes of batch shops, the planning itself is less effective coordination mechanism (Tushman & Nadler, 1978; Barki & Pinsonneault, 2005). Thus, intermediately detailed planning is sufficient, and instead of pursuing precise *planning*, the managers of batch shops would be better off by focusing on solving exceptions in the *execution* of the plans (Perrow, 1967; Reeves & Turner, 1972).

While the finite loading techniques appear to be ineffective in regular batch shops, they seem to work in bottleneck-controlled batch shops and production lines. That is because the complexity of those processes is critically reduced by the fact that the tasks to be planned are *sequentially* interdependent (Thompson, 1967). The iteration of plans is simple because changes in the schedule of one resource only influence the resources in the downstream of the process. Consequently, production lines can be considered as single resources, and in the bottleneck-controlled batch processes, only the utilization of the bottleneck needs to be planned in detail.

In addition to contingency theory, the limited applicability of the most sophisticated planning methods is also aligned with the concept of *bounded rationality* (March & Simon, 1958). It holds that in the complex reality of organizations, it is usually sufficient to satisfy some level of performance, and only in special occasions, it is possible to try optimizing the outcomes (Simon, 1978). In capacity planning, the special occasions take place when scheduling problems can be narrowed down to relatively static formulae, status information from the processes is complete, and the processes can be isolated from external uncertainties. Unfortunately, such conditions hold very badly in typical job shops and batch processes (Reeves & Turner, 1972).

In summary, organization theory gives several reasons to suspect the universal applicability, let alone superiority, of the most sophisticated capacity planning methods. Yet, practitioners seem to be uninformed about the importance of matching planning methods with process types. The issue is not discussed explicitly in the literature either. Hence, this study elaborates the benefits of taking theoretical perspectives to issues that are traditionally viewed from a problem-solving perspective in operations management research (see, Schroeder, 2008). While some researchers have called for more pragmatic research designs (Guide & Van Wassenhove, 2007; Hopp et al., 2007), the results of this study show that practical insights can also be derived from organization theory, which may not be an immediately obvious source for all operations management researchers.

REFERENCES

A complete list of references is available upon request from the author.