RESEARCH AGENDA:
SOLUTIONS FOR PROJECT-BASED MANUFACTURING
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ABSTRACT

Manufacturers that supply equipment for capital investment projects operate in the interface of two management paradigms. While their products are installed according to the practices of project management, the manufacturing operations are managed according to the methods of discrete manufacturing. The latter are mainly based on the MRPII logic, which is embedded in the production planning modules of conventional ERP systems. This article discusses how currently-used practices and information systems encumber the co-ordination between installation projects and manufacturing. The greatest challenges seem to be in managing changes and exceptions among interdependent end-products. Based on a literature review and preliminary results of an ongoing multiple-case study, the article presents five solutions to the identified challenges. They are: manual coordination, project MRP, ERP systems’ project modules, bolt-on software, and systems integration. Due to the prevalence of ERP systems and the importance of project-based industries, the solutions have diverse implications for both research and practice.

Keywords: enterprise resource planning, manufacturing management, project management, co-ordination, exception solving
I. INTRODUCTION

Large investment projects, such as building production facilities, are ultimately about integrating a number of smaller deliverables into a productive entity. The smaller deliverables, such as machine tools for a production line, are usually sourced from separate specialized manufacturers. These specialized manufacturers, their project-running customers, and their suppliers form project-based supply chains. One particular characteristic makes these supply chains especially interesting. That is the interface between the project-oriented and the repetitive production logics. For example, a contractor in charge of building a new production plant is running a project, whilst the manufacturer delivering the equipment for the production lines has most likely arranged its own processes according to the traditional repetitive logic. Earlier studies in supply chain management have shown that the co-existence of these two logics is troublesome due to their conflicting objectives and practices (Vrijhoef & Koskela, 2000; Akintoye et al., 2000; Collin, 2003; O’Brien, 1997). Therefore, it is both interesting and important to study how the interface between the two logics is currently managed and how it should be managed.

This paper describes an agenda of how manufacturing planning and control in project-based supply chains is studied at Helsinki University of Technology. First, a literature review about the concepts, challenges, and possible solutions is provided. Then, a research plan for evaluating the solutions is presented.

II. LITERATURE REVIEW

Five concepts are most important in understanding project-based manufacturing. They are: 1) the concept of project-based supply chains, 2) the practices of project management, 3) the practices of managing repetitive production, 4) the challenges of controlling the combined environment, and 5) the solutions for the coordination. Next, the relevant literature about these subjects is reviewed.

Environment: Project-based Supply Chains

Artto et al. (1998) have conceptualized the nature of project-based supply chains. They define the concept of a project delivery chain as a chain of several interlinked subprojects that together deliver a complete project product to the end customer who is the owner of the whole capital investment project (Artto et al., 1998; Kärkkäinen et al., 2003). The fundamental notion is that the interlinked subprojects vary greatly in scope. In the downstream of the chain, the deliverables are mostly unique, complex, and costly efforts that are wide in scope and long in duration. Such deliverables represent genuine project products according to many definitions (e.g. Turner, 1999). In the upstream of the chain, the scopes of single deliverables get narrower. Usually, the products in the upstream are no longer unique or engineered-to-order. Instead, they are made-to-order, assembled-to-order, or just combinations of standardized items and modules (Jahnukainen et al., 1995; Artto et al., 1998). These kinds of goods are usually produced and delivered according to the logic of repetitive manufacturing instead of the project-oriented production logic (APICS, 1998). An illustration of a typical project delivery chain, its stages, and the scopes of deliverables is presented in Figure 1.

For the sake of simplicity, Figure 1 presents only one representative from each stage. However, in reality the amount of participants increases as the scope of the deliverables reduces. Examples of participants on the different stages are:

1. Owner of an investment project: a company, which invests in a new production plant
2. Contractor: the main contractor who is in charge of the entire investment project
3. Subcontractors: other contractors that execute separate work packages. A possible work package could be the installation of an automated production line.
4. Equipment manufacturers: companies that deliver equipment to subcontractors. A possible deliverable could include the machine tools for the production line of the above work package.
5. Suppliers of the equipment manufacturers: the suppliers of the above machine tool manufacturer may include foundries, electronics manufacturers, and so forth
In the above example, the interface between the project-oriented logic and the logic of repetitive manufacturing is located in between the subcontractor and the equipment manufacturer. This means that the subcontractor is purchasing on the basis of project management practices, whilst the manufacturer is producing according to the conventional practices of manufacturing management. In order to understand the co-ordination challenges, let us take a brief look into both of these practices.

**Practices 1: Project Management**

Project management involves planning and control of several conceptually different issues. They include at least: scope, schedule, cost, risk, quality, and organization (Turner, 1999). There are several well-established practices for managing these areas. For example, there are tools such as cost breakdown structure and earned value management for planning and controlling costs (APM, 2000; PMI, 2000). Similarly, there are generic tools for managing risk (e.g. PRAM in Chapman & Ward, 1997), quality (e.g. QFD in Kamara et al., 1999), and organizational resources (e.g. OBS in APM, 2000). However, from the perspective of the equipment suppliers, the most important issues lie in the management of scope and schedule because those practices define what is required and when.

Two documents are in the core of planning the scope of any project. They are: product breakdown structure (PBS) and work breakdown structure (WBS). The PBS document is a hierarchical presentation of deliverables required for completing the project. It is supplemented by the WBS document, which describes the required activities for completing the deliverables specified in PBS. (Turner, 1999; APM, 2000; PMI, 2000) Each pair of product specifications and task descriptions constitutes a work package, which can be assigned to a resource (Leach, 2005). Later, the output produced by that resource can be measured against the documented specifications and therefore controlled. Whenever work packages are assigned to external resources, the documents are used to specify the contents of contracts and purchase orders. (Fleming, 2003)

The management of project schedule is the other issue affecting the equipment suppliers. In creating the schedule, the first and most important input is the WBS document (APM, 2000; PMI, 2000). In the planning, techniques like precedence diagramming method (PDM) and critical path method (CPM) are used to translate the hierarchical structure of WBS into a time-phased one. The resulting schedule is illustrated with Gantt charts or network diagrams. (APM, 2000; PMI, 2000) The schedule and duration estimates are sheltered from uncertainty by allowing certain floats to each activity (Turner, 1999) or placing so-called feeding buffers in front of the nodes of the schedule diagram (Leach, 2005). Such floats or buffers...
are obviously useful, however, they affect purchasing because precise materials-required dates may not be known for sure at the time when the orders are placed. The frequent adjustments, which often result from this, may seriously hamper the efficiency of suppliers’ production and delivery processes (Howell & Ballard, 1997).

One trend in contemporary project management affects both the management of scope and the scheduling. It is the continuing pursuit to compress the lead times of projects. Its techniques are often known as concurrent engineering or fast-tracking (APM, 2000; PMI, 2000). These techniques relax the precedence constraints of conventional PDM and CPM and thus allow executing interrelated tasks simultaneously (Badiru, 1993). Likewise, the planning and execution phases of the project are allowed to overlap (Turner, 1999). Both the concurrency of activities and the concurrency of phases affect purchasing and supplier relationships. For example, it has been observed that ordering materials with approximate specifications necessitates placing change orders later, which is a problematic practice from the perspective of the suppliers (Koskela & Leikas, 1997). Similarly, compressing lead times in general puts pressure on the delivery times of the suppliers and thus incurs costs to suppliers in some or all of the following forms: increased finished goods inventories, inefficient transportation, and smaller-than-economic batch sizes in production (O’Brien, 1997).

**Practices 2: Manufacturing Planning and Control**

Unlike the contractors, the equipment manufacturers do not have the luxury of focusing on a single deliverable at a time. Instead, they are probably involved in several projects at the same time and deliver several end-products to each of them. In addition to that, they are likely involved in day-to-day business of selling spare parts for their earlier project customers (van Donselaar et al., 2001). Such production environments are generally managed with systems that are based on closed-loop material requirements planning (MRP), also known as manufacturing resource planning (MRPII) (Vollmann et al., 2005). This logic is an extension of the traditional material requirements planning (Orlicky, 1975; Miller & Sprague, 1975). Vollmann et al. (2005) have conceptualized its current form in their manufacturing planning and control (MPC) framework, which is illustrated in Figure 2.

The MPC framework describes a hierarchical planning procedure. The first step, sales and operations planning (SOP), represents a cyclic decision-making activity, which states what end products should be produced, when they are required, and with what specifications. Inputs for that decision come from several sources including: strategic, marketing, resource, and financial plans as well as the demand management function. The output of SOP is used in generating the master production schedule (MPS or master schedule, in short). This activity considers also capacity constraints (this consideration is often referred to as rough-cut capacity planning) and is therefore not a statement of objectives but rather a realistic statement of when each required end product has to be finished. For the sake of stability, regenerating MPS records is a cyclic activity, which utilizes so-called time-fencing and freezing policies. (Vollmann et al., 2005)

The next phase, material requirements planning (MRP), refers to the logic of calculating demand for subassemblies and components from the demand for end products. To make the necessary connections, bills of materials (BOMs) are used. As the demand for subassemblies and components is derived from the demand for the end products, it is called dependent demand or dependent requirements. The end products’ demand, on the other hand, is given from the outside of the MRP logic and is thus called independent demand or independent requirements. For each requirement, the system generates and schedules an order that satisfies the demand in a timely manner. These orders are called either production orders or purchase orders depending on whether the ordered materials are internally or externally procured. Although the MRP logic takes into account the average lead times between production activities, the contemporary planning systems are also equipped with more sophisticated scheduling tools. The most com-

* At this point, lean management or just-in-time enthusiasts may point out that repetitive manufacturing might just as well be managed with rate-based planning and visual control systems. However, large equipment as well as other deliverables for investment projects have certain characteristics, which indicate that the time-phased planning, discussed in this paper, is a more likely solution. Such characteristics include make-to-order production, complicated manufacturing processes, and multitude of product variants (e.g. Karmarkar, 1989).
mon of them is the capacity requirements planning (CRP), which utilizes routing files in further scheduling the production orders. The routing files are records, which connect products, subassemblies, and components with the resources that are required in processing them. Iteration between MRP and CRP eventually schedules all production and purchase orders in a way that best satisfies the stated MPS. At this point the production planner releases the orders to be executed in the back end systems. (Vollmann et al., 2005)

![Diagram](image)

Figure 2. Manufacturing planning and control system (redrawn from Vollmann et al., 2005)

At the execution phase, the shop-floor control system ensures that production of each order is started and terminated in a timely manner. Meanwhile, the so-called vendor systems follow whether the purchased items are received on time. If not, the back end systems alert the production planner with exception codes. On the basis of these messages, the planner reschedules some parts of the detailed plans in order to satisfy the MPS in the new circumstances. If too many exceptions are generated during the execution, it might become impossible to fully satisfy the original MPS. In such cases, the MPC system reports the deviations from the plans. This closed-loop nature of the MPC system is illustrated in Figure 3. (Vollmann et al., 2005)

The MPC framework is not just any model among others. Instead, other textbooks of operations management either refer to it directly (e.g. Hill, 2005) or provide frameworks that very closely resemble it (e.g. Stevenson, 2004; Brown et al., 2005; Hopp & Spearman, 2000; Schroeder, 2000).

It is also noteworthy that the MPC framework is not an academic abstraction that only exists in textbooks. Instead, practitioner organizations such as APICS – The Association for Operations Management as well as Supply-Chain Council define manufacturing management in a similar manner. For example, definitions in the dictionary of APICS are equivalent to the definitions of the italicized terms in the above (APICS, 1998). Similarly, the generic processes of Supply-Chain Council’s supply chain operations reference (SCOR) model parallel the stages of the MPC framework. From the perspective of SCOR model, the process category: $P1 \text{ plan supply chain}$ can be viewed as the front end of the MPC system, the process categories: $P2 \text{ plan source}$ and $P3 \text{ plan make}$ as constituting the engine of the system, and the process types: source and make as covering the back end systems (see Supply-Chain Council, 2005).
Lastly and most importantly, the MPC system is not something that exists in conceptual frameworks only. Instead, its practical relevance is enforced by the fact that enterprise resource planning (ERP) systems work in the described manner (Vollmann et al., 2005). For example, mySAP ECC’s production planning (PP) and materials management (MM) modules include the following transaction packages: sales and operations planning (PP-SOP), master planning (PP-MP), material requirements planning (PP-MRP), capacity planning (PP-CRP), shop-floor control (PP-SFC), and purchasing (MM-PUR), which cover precisely the corresponding functions of the MPC system (see SAP, 2005). Let us yet notice that modern ERP systems feature also other valuable functions such as finite loading capabilities etc. However, the argument here is that the backbone of manufacturing management within enterprise systems is the rather conventional MRPII logic (e.g. Mabert et al., 2003; Klaus et al., 2000; Kumar et al., 2003). This seems to have a fundamental influence on the co-ordination of project management and manufacturing management practices.

**Challenge: Co-ordination in Project-based Manufacturing**

Although the interface between the project management system and the MPC system is easy to locate, its effective management appears challenging. The connection between the systems lies in the front end of the MPC framework as illustrated in Figure 4. The figure shows that the manufacturers of project deliveries have, indeed, two sources of demand: the one originating from conventional, cyclic SOP and the one originating from project plans (van Donselaar et al., 2001). This fact has several minor consequences. They include, for example, that the demand for projects is likely to occur irrespective of the SOP cycles, which is a fact that impacts upon the master planning policies. The resulting challenges are, however, quite uninteresting because ERP systems with up-to-date production planning modules are equipped with other tools than freezing policies to enable regenerating master schedules without inducing unnecessary system nervousness (see e.g. net change planning, firm planned orders, and single-item planning in SAP, 2005).
The fundamental challenges of integrating project management with the MPC system arise from the interdependence between end products when their demand is derived from the project plans. Even in the most recent conceptualization of the MPC system, all items in MPS are by Orlicky’s (1975) original definition: unrelated to any of the other items (Vollmann et al., 2005). This assumption does not hold for those end products that together constitute a project deliverable. As described earlier, the precedence diagrams of project plans establish the sequence, in which the items are required. Similarly, WBS and PBS documents describe how the specifications of individual items relate to each other. Naturally, the sequence translates quite simply to the initial MPS. However, maintaining the original order during the production may be difficult because the feedback loops of the MPC system do not consider logical sequences. Let us consider a simple example:

A manufacturer of sawmill tools is supplying a project to expand the capacity of an existing timber mill. The required products include among others: a barking machine with an original materials-required date for May 1st and three automatic bench saws required originally: May 1st, May 8th, and May 15th. During the production, temporary problems arise with the barking machine and the MPC system advises the production planner to reschedule it to the first available slot on May 22nd. In the end, the system reports that 75 per cent of the deliveries were on time. However, if the original project plan required the barking machine to be in place before the bench saws could be installed, then the whole project ended up being four weeks late. From the perspective of the project manager, postponing all bench saws might have been more desirable option. That way, a proportion of the project could have been finished on time. The conventional MPC system is not equipped to deal with these kinds of dependencies.

Similar issues may arise from interdependent specifications as well. For example:

A manufacturer of process industry equipment is supplying a flow control system for a new production facility. The deliverable includes among others things: two valves and a piece of piping. During the project, the original specifications are changed and the diameter of the pipe has to be expanded. Now, someone at the plant must be aware of the possible dependencies of such changes. He or she must also be able to track down the two valves at the ends of the pipe and to make the corresponding changes to their specifications. The conventional MPC system is not equipped to assist in any of these tasks either.

For the purposes of conciseness, the above examples are overly simplified. A well-educated production planner would be able to detect and settle such issues. In reality, however, counting on human judgment may be infeasible as the dependencies are more complex, and moreover, the production volumes may be overwhelming for manual control. For example, one studied project-based manufacturer produced several thousand items monthly and was continuously involved in tens of projects (Tenhiälä & Eloranta, 2005). In addition, two type of uncertainty ensure the continuous need for changes in production orders, rescheduling, and resolving exceptions. The first type is caused by the project-running customers, who are keen to make changes to both: the schedules (Howell & Ballard, 1997) and the specifications
Koskela & Leikas, 1997). The second type consists of the general uncertainties that are common to all manufacturers. They include: late deliveries from suppliers, machine breakdowns, rework, labor shortages, and engineering design changes (Koh & Saad, 2002; Koh et al., 2000).

Figure 5 summarizes the activities in the coordinated management of project management and MPC systems (hereafter this is referred to as project-based MPC). The first step is to translate all sources of demand into detailed plans. Here, the difference to the conventional MPC is in the need to accommodate also the lumpy and sporadic demand from projects into the MPS. This, however, can be managed within the conventional system as described earlier. The second step is to release the detailed plans, i.e. production and purchase orders, to be executed in the manufacturing. This is a rather straightforward activity as well. The third step is triggered by unexpected events during the manufacturing. In this phase, the production planner is required to identify all deviations from the original plans as well as all other events that jeopardize satisfying the MPS. As regards to the delays and problems that arise from the general uncertainty of the manufacturing environment, the conventional MPC system is, in principle, capable of identifying them, alerting the production planner about them, and helping the planner to solve their causes (Vollmann et al., 2005). Nevertheless, these capabilities are criticized by many. Koh and Simpson (2005) and Klaus et al. (2000) claim that the MPC system is most effective in planning and releasing plans whilst the rescheduling and problem solving capabilities are less frequently utilized. In addition, some argue that the conventional system is inevitably late because exceptions are triggered when they have already caused disturbances (Otto, 2003). Considering these criticisms, it is unsurprising that the conventional system is of little help when the events come from the outside of the manufacturing environment, namely from the projects as described in the above examples.

Figure 5. Uncertainties and activities in project-based MPC
Since already identifying the exceptions is cumbersome, the fourth step, resolving them is naturally a challenge as well. Here the production planner should consider the dependencies between individual products so that he or she would minimize the overall harm to all projects while rescheduling or reprioritizing orders. The planner can use the pegging function of the MPC system to track down the respective customer orders for all dependent requirements (Vollmann et al., 2005; SAP, 2005). However, the ability to bundle production orders with certain projects does not yet reveal anything about the interdependencies between the orders. Thus, the planner is, in the end, left either unassisted or at best to the mercy of informal systems.

Finally on the fifth step, the project-based MPC should be able to generate reports that are meaningful for both: the management of repetitive manufacturing and the project management. The conventional MPC system offers a variety of options for the needs of the former. However, aggregated logistics performance metrics, which are widely used in repetitive manufacturing (Keebler et al., 1999), are quite uninformative for project managers. Instead, they would require information about issues like schedule adherence and buffer statuses (Leach, 2005). Trivial solutions, such as earmarking the products on the critical path, are futile as the criticality of paths tend to change during the projects (Leach, 2005; Turner, 1999).

**Solutions: Preliminary Categorization**

Large equipment manufacturers and other companies involved in project-based manufacturing face the above challenges daily. As these companies have remained in business, they have obviously found some solutions for the above described problems. Yet, these solutions are hardly ever addressed in the current academic literature. Even the works that title-wise discuss about project management in manufacturing environments seem to consider only low-volume-high-variety manufacturing, new product development, or implementing process changes (e.g. Badiru, 1996; Porter et al., 2000; Fricke & Shenhar, 2000). Although important, these issues can be managed without much considering the practices of repetitive manufacturing.

Despite the lack of published studies, something can be said about the nature of solutions for project-based MPC. Hints in the literature, observations in the industry, and discussions with practitioners imply that the solutions can be assigned to at least five categories. They are: manual coordination, project MRP, ERP systems’ project management modules, bolt-on software to ERP systems, and systems integration.

The first category, manual coordination, refers to an arrangement where both the organizations and the information systems for project management and manufacturing management are separated from one another. In such a setting, project engineers run projects within their specialized project management software and the production planners use ERP system’s production planning module. The coordination is handled informally through meetings, emails, spreadsheets, and at best with groupware solutions. Along the years, some published works have described arrangements that would clearly fall under this category (e.g. Hoevers, 1986; Jahnukainen et al., 1995; Tenhälä & Eloranta, 2005). Moreover, personal experiences and discussions with industry representatives suggest that this approach is relatively common.

The second category, project MRP, stands for the solution where project planning is done within the conventional MPC system. For example, Hamilton (2003) has described a method where conventional MRP logic and its master data: BOMs and routings are used for project management purposes. In his approach, end product is a project, for which PBS is a planning BOM, and the precedence diagrams are represented in routings. The approach is, indeed, quite reasonable, and it inspires some researchers to go even further. Vollmann (2005), for instance, argues that there is actually no mismatch between the project and the manufacturing systems because there is no need for the former at all. Thus, the solution for the project-based MPC would be to educate and motivate the project managers to plan and execute within the production planning module of their company’s enterprise system. These arguments have, however, faced a rather unsympathetic reception in the discussions with practitioners. For example, project planning is considered as such a creative, informal, and iterative activity that trying to merge it with the rigidities that are inherent to ERP systems is considered absurd by many.

**ERP systems’ own project management modules** constitute the third solution category. Although rarely implemented (Mabert et al., 2000; Olhager & Selldin, 2003), some system vendors have offered such modules for a while already (O’Leary, 2000). Ideally, one would think that integrated project manage-
ment capabilities would solve the whole problem with project-based MPC. However, a closer look to the offered modules reveal that often they are rather aimed at the cost accounting functions than production planning. This notion has been made in the literature (Mandal & Gunasekaran, 2003) and it is strongly supported by personal experiences from the systems. Nevertheless, it must be admitted that some of the latest features seem to approach the project-based MPC as well. These features include for example the “requirements grouping by WBS elements” function of mySAP ECC’s Project System module (SAP, 2005).

The fourth solution category is the bolt-on software offered to the conventional ERP systems. The term stands for supplementary applications that are integrated to enterprise systems through standard interfaces (Gupta, 2000). It seems that some software developers have awakened to the deficiencies of ERP systems’ own project modules. For example, a German company Wassermann offers a solution, which seems to tackle project-based MPC. The company states that: “[conventional enterprise systems’ planning modules] presents only specific parts of the process, without demonstrating the important dependencies and synchronization issues between them as a whole or in detail” (Wassermann, 2005). A solution for this would be imperative for project-based manufacturers. Nevertheless, the awareness or experiences from such applications seem non-existent on the field.

The last solution category, systems integration, refers to an approach where separate systems are used by the project management personnel and the production planners but they are integrated through middleware software. The difference between this category and the previous one is that, in this approach, the project management software is not originally developed for supplementary purposes only. Instead, it is designed to be a separate standalone system. This difference has several implications for issues such as: infrastructure, usability, and maintainability. Therefore this division is considered in the enterprise application integration (EAI) literature. (Linthicum, 1999) The evidence about such solutions is mixed. On one hand, it is known that, in the past, various software applications for design, planning, and engineering purposes have been integrated to MRPII systems under the concept of computer integrated manufacturing (CIM) (Klaus et al, 2000). On the other hand, EAI applications are often considered risky or ill-fitting with ERP systems due to some of the fundamental characteristics of the latter (e.g. Al-Mashari et al., 2003). Thus far, discussions with practitioners have not disclosed a case of EAI-based solution to project-based MPC despite that the existence of such solutions has been considered very likely.

III. RESEARCH PLAN

With regard to the project-based manufacturing, the main shortcoming of the current body of knowledge in operations management is that it does not recognize the mismatch between the conventional MPC system and the project management system. As a logical consequence, the solutions are not discussed either, let alone analyzed or compared in an empirical enquiry. To address this gap in the literature, a study has been initiated at Helsinki University of Technology. The objectives of the study are:

- To describe the challenge of project-based MPC
- To identify, describe, and give examples of the different solutions for project-based MPC
- To describe each solution’s advantages and disadvantages on the basis of strong empirical evidence and diligent comparative analyses

The practical utility of such a study comes from three sources. Firstly, the project-based manufacturers that participate to the study learn to appreciate that they are actually facing a conceptual, rather than a purely practical, challenge. Secondly, they also get an opportunity to benchmark their solution to others, possibly more innovative ones. Thirdly, others than participating companies get to know about the results through publications in academic and practitioner-oriented journals.

So far, four Finnish-based global companies have participated in this study. They are manufacturers of industrial cranes, process industry equipment, elevators, and commercial refrigeration devices. Participation of other industrial partners is currently under negotiation.

The results of this study will be published in 2007 and 2008. The preliminary categorization that was presented in the end of the previous section provides some guidelines about the issues that will be dis-
cussed in the articles. Next, I will briefly describe the principles and methods that will be followed in studying those issues.

**Research Design**

At least three elemental factors affect the design and method of research. They are: the cognitive interest of conducting research (Habermas, 1972), the stage of existing theory (Handfield & Melnyk, 1998), and the nature of the studied phenomena (Miles & Huberman, 1994).

Firstly, the cognitive interest of an applied science like operations management is to create such knowledge that both explains and gives advice about practically relevant phenomena (Niiniluoto, 1992). In the context of this subject, such approach means first explaining the relationships between the solutions and outcomes, and then, translating that understanding into so-called technical norms about what should be pursued with certain solutions and what not (see von Wright, 1963).

Secondly, as the current body of knowledge identifies the coexistence of project management and manufacturing management systems but does not explain their relationships, the stage of theory about those relationships is in the mapping and relationship building phase (using the terms of Handfield and Melnyk, 1998). In this context, being in such a phase means that the study should identify the aspects that differentiate the solutions from each other. In addition, it necessitates suggesting how those aspects affect the outcomes from the solutions.

Thirdly, the studied relationships are complex and multifaceted by their nature, which speaks in favor of the inductive approach where abstractions are derived from observations (e.g. Glaser & Strauss, 1967). The complexity, in this context, means that the relationships are simultaneously affected by at least human, technical, and environmental factors.

This brief analysis on the subject at hand results in the appropriate design and method for studying it. That is the use of empirical evidence (Habermas, 1972), multiple-case study design (Handfield and Melnyk, 1998), and mostly qualitative data collection (Miles & Huberman, 1994).

**Methodology and Data Collection**

Numerous instructions exist on how to conduct empirical and qualitative multiple-case studies. The most well-known of them are written by Glaser and Strauss (1967), Yin (1984), and Eisenhardt (1989). The former call their approach the constant comparative method of analysis, whilst the latter two discuss about case study methodology. Synthesizing the contributions of these authors, the relevant methodology can be considered as consisting at least the following focal elements:

- **A priori constructs**
- **Unified method of data collection, documentation, and analysis**
- **Literal replication and its saturation**
- **Theoretical replication and its saturation**
- **Making theoretical propositions**

The *a priori constructs* stand for what the researcher assumes to be found within the studied subject. Their almost paradoxical function is to help focusing on relevant issues and yet not bias or limit the resulting findings (e.g. Eisenhardt, 1989). In this study, the a priori constructs are project management practices, manufacturing management practices, and the five solution categories for project-based MPC.

The *unified methods* mean that in order to provide reliable comparisons, similar sources of data, as well as methods for documenting and analyzing it, are required for all cases. In this study, the issue is taken into account by firstly, interviewing people in similar positions within their organizations. Secondly, structured interviews will be conducted and processes will be documented with a formal flow chart technique (as described in Aguilar-Savén, 2002). Thirdly, uniformity in data reduction and analysis will be enforced through the utilization of unified matrices as suggested by Miles and Huberman (1994).

The selection of cases can be divided in two parts: literal replication and theoretical replication. The former is more analogous to the sampling logic of hypothesis-testing research. Its purpose is to establish the
base-case scenario by describing the normal, the most common, or the simplest approach for the studied problem. This is achieved by adding cases until nothing particularly new arises from them and thus the similarities between the cases can be identified and the resulting propositions established. At this point, the evidence about the base cases is considered saturated. (Yin, 1984) The literal replication in this study is done by studying the manual coordination solutions at three project-based manufacturers from different industry sectors.

Yin’s (1984) other form of case selection, the theoretical replication, means studying cases that are known to be different from the base cases. In this study, it means going after the four less frequent solutions and analyzing them against the base cases. The saturation in theoretical replication is problematic because one can never know whether there still are more solutions that differ fundamentally from the already studied ones. This issue is tackled in this study by disseminating the results to both: academic and practice-oriented audiences. If feedback from academic reviewers or practitioners implies that other solutions exist too, then they will be included into the analysis.

The last phase in this kind of an inductive process is providing theoretical propositions. At this point, the relevant constructs have been identified and their relationships have been understood to such extent that operationalizable and testable propositions can be formulated (Miles & Huberman, 1994; Glaser & Strauss, 1967). In this study, it means that certain solutions for project-based MPC are predicted to result in certain benefits as well as certain disadvantages. To enhance the practical utility of such results, the propositions are probably formulated also in the form of a decision-making framework.

Further Research

Naturally, the lifespan of research in project-based MPC does not end into generating propositions. The theory-building process continues from propositions into the theory validation phase (e.g. Handfield & Melnyk, 1998). There, the theoretical propositions are operationalized in order to be tested with larger samples and more concise data collection methods such as surveys. In this study, such a step could be taken by, for example, collecting large sample data on project-based manufacturers’ environmental factors, their solutions for project-based MPC and their performance. Such a study could possibly result in contingency theoretical contributions. However, that step can not be taken before the inductive phase described above has been completed.

IV. REFERENCES


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