Exploration of the impact of RFID and agent technology on operations management

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Abstract

The paper describes and details a design science approach for how to explore the impact of emergent technologies on the performance frontier in operations management. The process is illustrated through an in-depth case where the performance frontier was affected through finding RFID and agent applications that enable a move to simpler integrating mechanisms. The discovered solution designs simplified the information chain and reduced the need for management interventions in the organization and operation of customized delivery of products and services. The case example also illustrates how a successful solution design does not automatically translate to performance improvements but requires step-wise models for how to develop and introduce the solutions in practice. In the analysis the fundamental concept of a performance frontier in operations management remains intact, yet the conclusion of the study is that the performance frontier is not possible to determine until the applications of new and radical technologies have been explored.

Key words: Innovation, Technology Management, Operations Management, Design Science, Performance Frontier, Contingency Theory

1. Introduction

This paper is about structuring and solving problems that are not well-defined. It focuses specifically on the application of emergent technology in operations management, but can also be read as an example of searching for application opportunities for emergent technology in general.

When formulating operations strategy, a company has to choose between various dimensions of performance when its operations system's resources are in the best possible use. When this has been achieved we say that the company is on the performance frontier (Schmenner and Swink, 1998). However, operations management research is not only interested in optimizing resources, but also in ways to move the performance frontier (Hayes et al., 2005). When novel and useful applications for emergent technologies such as the Internet, RFID, and peer-to-peer computing can be found the performance frontier moves. It moves when success in finding new alternative ways to operate enable simultaneous efficiency and service improvements, which is an important factor in changing the competitive landscape of industry[1].

However, conducting and evaluating research that uses emergent technology to solve operations management (OM) problems involves many methodological challenges. The general challenges associated with such practical and technological

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[1] For example Dell's application of call-centre and internet technology to sell mass-customized PC:s has pushed back the performance frontier in the computer industry. The adoption of build-to-order manufacturing has led to a simultaneous improvement of service (customization) and efficiency (elimination of obsolescence) that has transformed the PC industry.

problem solving research are of such magnitude that a design science approach has been proposed alongside the branches of natural and social science (Simon, 1996; Dasgupta, 1992). Major challenges in developing methodology for this science of design are how to model, quantify and validate phenomena that are created by humans, do not yet exist, exist only as designs, or have only been implemented in a few instances. Too stringent requirements on representation, quantification and validation in the early phases of problem solving may inhibit the exploration of many good alternatives (Simon 1996, p 28). On the other hand, neither does it make sense to spend time and attention on each and every proposed solution and conjecture. In this situation, developing heuristic evaluation to assess the novelty, relevance and functionality of a proposed solution is a *satisficing* way forward. The methodological challenge can be further addressed by developing design theory to describe how the research is proceeding and how the problem discovery and solving has been performed. The rationale for describing and evaluating research procedurally as a design activity is supported by observations from general science studies. Pickering (1995) points out that successful scientists many times are as much active problem solvers and designers as they are observers and theorists.

Guidance on how to search for new alternatives for how to operate, and how to develop these further are most useful in a changing technological environment. Based on the above reasoning and short literature review the rest of the paper sets to study problem discovery, problem solving and solution implementation in operations management. First the epistemology of applying emergent technology to operations as a design science is described. The design science approach for exploring the performance frontier is then illustrated through a case. Finally, the implications of the study on the theory of a performance frontier and on explorative research in operations management are discussed.

2. Epistemology: Operations Management as a Design Science

Design science can be defined as the research in engineering, medicine, management and other areas of applied science that is focused on spotting and solving problems and on understanding this problem solving process. Operations management as a design science theory would attempt to describe the structure of problem discovery and problem solving in operations management.

For guiding the exploration of evolving solution alternatives satisficing (Simon, 1996) has been proposed for the design sciences. In the early stages of a design research process the aspiration is to design and test novel, relevant and functional solution alternatives, with less concern about optimality. This way satisficing can be seen as an epistemology that describes how the alternatives that are implicit in the concept of the performance frontier can be discovered.

McKelvey (2002) describes the epistemological relationship between theory, model, and phenomena as a semantic conception. The semantic conception views theory, model and phenomena as a chain of linked, but autonomous agents (ibid. p. 763). Combining this semantic conception with satisficing in an environment where technological change is an important factor means that the relationship between the semantic entities, or artefacts, needs to be described as an emergent relationship. This is necessary because we are dealing with artificial phenomena. First there may be nothing, then there is just an idea, and in the end there are a multitude of phenomena, models, and, sometimes explaining theory. An attempt to capture simultaneously the semantic conception and the emergent nature of design research is shown in figure 1. The idea of a new design or solution leads through implementation of the design to the creation of new artificial phenomena. These phenomena are both intended and unintended consequences of the design (Popper, 1963, p. 461). The intended consequences are fulfilled design goals while the unintended often are new problems that need to be resolved.

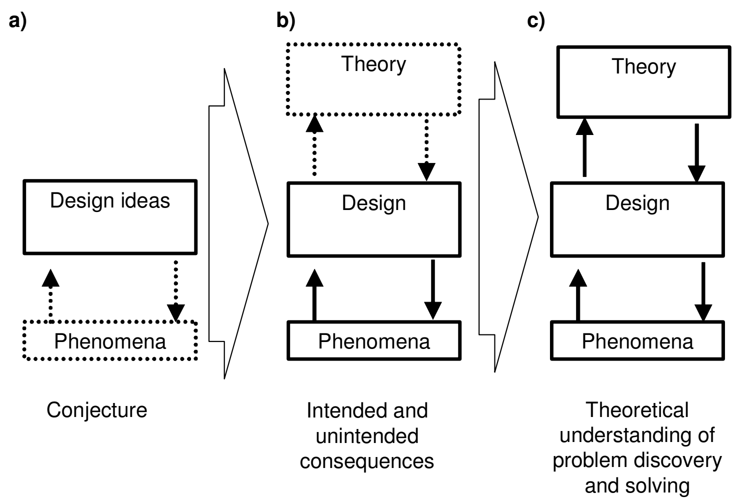

Figure 1: Emergent and semantic conception of design science

Theory development is separate of the design and phenomena in the emergent and semantic conception of design science. Though, progress in both solution design and theoretical explanation depends on ontological adequacy (McKelvey, 2002, p 765). Theory aims to understand and explain both the intended and unintended phenomena of the design, as well as the process of problem solving and explanation itself. A design science theory of operations management would describe the deep structures of problem discovery and problem solving. A design science theory could, for example, describe the design principles for creating complex systems that survive, independently of the technology that is used (Weber, 1987, p. 8). This aim of design science theory can be compared to the aim of a scientific paradigm (Kuhn, 1970), i.e. such principles would provide a coherent structure for problem solving, education, and research. Now such a coherent structure is lacking for problem solving in operations management.

The emergent and semantic conception of design science presented in Figure 1 needs to be formulated in more detail in order for using it to describe the exploration of the performance frontier of operations management. Figure 2 is an attempt to make the semantic and emergent conception of design science more concrete. It illustrates how a design conjecture may progress to a stage when there are already numerous implementations, and the structure of problem discovery and solution can be described. At this stage there are many more implementations than there are base cases and designs. There are also fewer evaluation procedures than there are solution designs and fewer formal models of the problem than evaluation procedures.

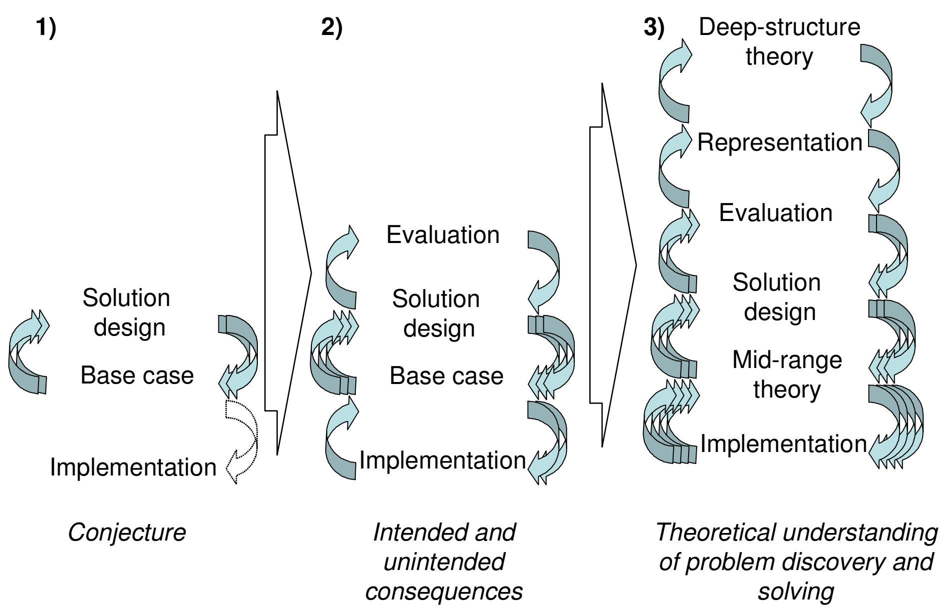

Figure 2: Operations management as problem solving and design research

Figure 2 explicitly tries to capture the emergent dimension of problem solving and design research in operations management. The terms in the figure are defined as follows. The base case is a description of the problem to be solved, including an outline of a possible solution and the expected result. The solution designs are the specifications of solutions that are detailed enough to be implemented in a test environment or in practice. The implementations are the implementations of the designs. Evaluation refers to the analysis of intended and unintended consequences of the implemented design. The middle-range theories are the refined base cases that take into account the results of the evaluations. The representations are descriptions of problems and solution designs that can be formally analyzed. The theories of deep-structures are theories explaining both intended and unintended consequences of the designs.

The emergent dimension of design is trial and error based on testing, prototyping and empirical observations. Implementation and test is necessary to arrive at functional designs and eliminate false assumptions (Simon, 1996). Implementation and testing gives the feedback from practice a pivotal role in the design process. Implementation and testing is needed for design science to be a self-correcting and realist method (McKelvey, 2002). It serves also as a key to make this conception of design science consistent with an evolutionary epistemology (Popper, 1972; Campbell, 1974; Dennett, 2003).

The first steps in problem solving are the most problematic to describe rigorously (Figure 2a). How to find a good base case for a new solution design that affects the performance frontier is difficult to describe methodologically and formally. Abductive reasoning is a logic (Dubois and Gadde, 2002, p. 559) and disciplined imagination a heuristic (Weick, 1989) that have been proposed. The original conjecture, or problem framework, is successively modified, partly as a result of unanticipated empirical observations, but also from theoretical insights. Reformulating an old problem so that a new technological tool becomes relevant is the critical step in putting together the necessary pieces for a useful and novel operations management solution proposal that affects the performance frontier. To do this is, however, the challenge. The difficulty in developing a logic or heuristic for discovery is that the problem situation needs to be represented before it is known what the problem is (Newell, 1982). Perhaps it can only be done in an environment that has deep structure?

After a relevant/novel base case has been formulated the focus of research can shift to solution design and implementation trials (Figure 2b). As the base case is validated, the solution is a design which is implemented, and its effect can then be evaluated, after which the base case may become middle range theory (Weick, 1989, p.525). In moving from base case to middle-range theory evaluation is the critical activity. This is because there is a difference between intended design and real-world implementation. As the evolutionary theorist Daniel Dennett (2003, p. 50) observes: It is necessary that the un-designed features that are introduced when implementing in practice can first be *identified* and later *co-opted* in the intended designs.

A fundamental epistemological challenge for developing the heuristics and describing a procedure that facilitate problem discovery and solution designs is how can conjectures and tentative solutions be represented and documented. One possibility for how to represent and document conjectures and tentative solutions is to put design propositions in the form of the technical norm (Niiniluoto, 1992), or the technological rule (Popper, 1963), or means-ends propositions (Simon, 1996). The common structure of these representations is a statement describing what should or should not be done in a situation to achieve some specific goal, e.g. "If you want A, and you believe that you are in a situation B, then try to do X.".

A proposition posited in the form of such technical norms is not a descriptive statement of the world, but a conjecture on what ought, or ought not to be done in a specific situation to achieve stated goals. This is the base case in Figure 2a. Thus, before implementation a technical norm does not yet have truth content, it only represents a solution conjecture that is more or less well-founded. This conjecture will either work or not, but to determine this testing is needed. As a structured representation of a design intention it can be tested and refuted in a transparent, i.e. objective, fashion through conceptual analysis, modelling, and experimentation (Niiniluoto, 1992). Simon (1996) views objectification in terms of means, goals and selection criteria as the foundation for creating a rule-based system for adaptive solution design.

Presenting solution designs explicitly in terms of goals, situation analysis, and proposed actions supports the further development, testing and replication of a design construct under different circumstances and with increasing availability of empirical data. The three-part definition of technical norm is systematically used in defining solution patterns in architecture and software systems design. The advantage has been significant in terms of documenting, communicating, and collaboratively improving effective solutions (Alexander, 1977; Lea, 1993; Gamma et al., 1995). This way the technical norm links three types of decisions: know-how, know-when, and know-why (Mahoney and Sanchez, 2004, p. 41) needed for building new middle-range management theory. In Figure 2 the base case of step ‘a’ becomes middle-range theory in steps ‘b’ and ‘c’.

In the last step (2c) the problem discovery, the problem solving, and the solutions need to be structured and understood theoretically. When viewed as a chain of autonomous agents the law of diminishing information (Kåhre, 2002) holds between implementation, design, and theory. There is a loss of detail in every transformation. However, the design and phenomena become more understandable for a rationally bounded mind if the right representations and models can be found for the design and problem resolution (Simon, 1996). A requirement for finding such representations is that there really are deep structures and regularity, and that these can be captured by representations (Weber, 1987).

Understanding the deep structure of problem discovery and the problem solving process is important both for the researcher and manager because the solution of an operations management problem depends on finding the right problem representation, and on knowing when the problem representation needs to be changed. For this a theory on the discovery and solution of problems needs to include also goals and evaluation models. Newell (1982) refers to this level of problem solving as the “knowledge level”.

For satisficing a stop rule or design goal is critical (Simon, 1996). This is needed for decision making for each type of problem solving activity outlined in figure 3. It is needed to decide when to stop searching for a base case, when to stop changing the design, and when to stop searching for better evaluation procedures, i.e. it serves as a design goal. It is also relevant for modelling and theory building. To indicate the different design goals in a satisficing exploration of alternatives, figure 3 links the artefacts of the different types of design research activity to their primary design goal, i.e. the stop rule. The functionality, relevance, novelty, and utility are pragmatic goals for different facets involved in finding and developing an operational design. For representations the pragmatic goal is validity and reliability, and for theory building the goal is finding deep structures that offer possible explanations.

Then, how do we know exactly when it makes sense to stop the search for alternatives to move the performance frontier? Is there a way to foresee the outcome of the exploration activity while it is in progress and optimize the effort? The answer is that unfortunately there is not, because of unintended consequences and bounded rationality. Until the alternatives are clearly established the performance frontier is really the exploration frontier. Also the representation of the performance frontier is in flux until alternatives are known. In exploration there is no alternative to satisficing as Simon (1996) observed.

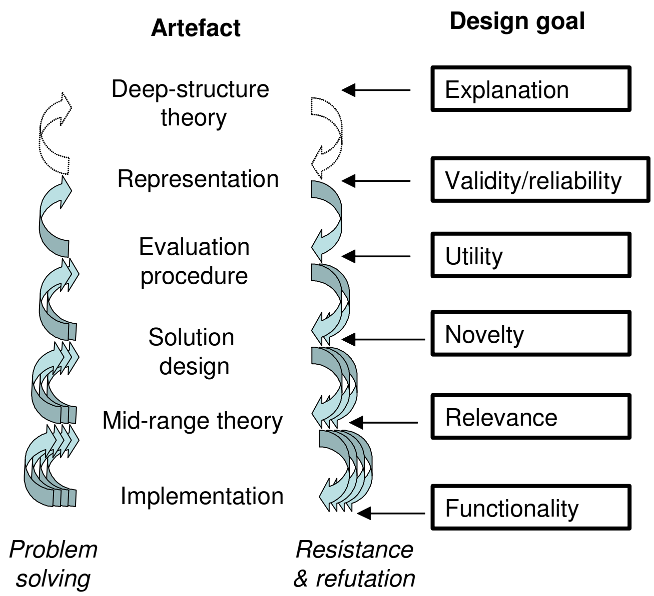

Figure 3: Artifacts of explorative research and their corresponding stop rules.

The satisficing process of discovery is iterative because the representations that make the task understandable are difficult to know before the solutions have been found. This is a fundamental challenge for formally describing discovery. However, attempts have to be made because without a description of problem solving and discovery it is not possible to learn from experience and improve how design science research and exploration is conducted.

3. The case example: Product tracking with RFID and software agents

The case concerns the use of RFID and agent technology in logistics. The case is described by using a structure based on the literature survey. Based on the above literature review the case is presented by using three main-levels of analysis, with their respective sub-levels, these are:

- Performance frontier (i.e. phenomena-level in figure 1)
    - Introduce the case as an example of a moving performance frontier of OM with new technological solutions
    - Describe case background, environment and outcome
- Problem discovery and solution design (i.e. design-level in figure 1)
    - How the search for base case was carried out and
    - Describe the solution design and respective trials of implementation
    - Describe base case evolving towards middle-range theory
- Evaluation and theoretical research (i.e. theory-level in figure 1)
    - Present possible models of problem discovery and solution that describe also unintended consequences of the design
    - Describe possible contributions to a theory of design in operations management

The case was chosen because it illustrates how solution designs that reduce the complexity and need for higher-level integration devices in logistics were discovered when radio frequency identification (RFID) and agent technology became available.

The case example is an innovation action research study (Kaplan, 1998) that was launched to explore the applications and potential impact of RFID in logistics operations, but later expanded in focus to agent technology. Due to the variety of backgrounds in the research team approaches and solution concepts from supply chain management and software engineering were combined. The research team included in addition to logistics and supply chain management researchers, also researchers with expertise in artificial intelligence, object oriented programming, and enterprise resource systems. Companies from different industries, ranging from retailing to project delivery participated in funding, evaluating and testing results of the exploration and solution trials.

3.1. Moving performance frontier in logistics management

RFID, or radio frequency identification, is a technology that makes it possible to identify physical objects by radio signal. There are two basic types of RFID tags, depending on how the tags transmit the identification information. In passive RFID a reading device activates by induction a radio circuit on the tag that is attached to the object. The activated tag then sends out a signal containing information about the object. In active RFID a transmitter that is attached to the object sends out the identification signal. The advantage with passive RFID is that the tag does not need to have an internal source of energy.

The identification of individual shipments and products is the major challenge that the application of RFID addresses in logistics. Any manual work involved in the identification and customized handling of shipments and individual products leads to a direct trade-off between efficiency and flexibility. In these situations reducing the manual work involved with identification and handling of individual products and parcels directly influences the performance frontier. In the parcel delivery industry companies such as UPS, DHL, and FedEx invest heavily in systems to identify and track parcels. Improvements in identification can be translated into improved handling efficiency and faster and better service. Partially due to better tracking and integrated information systems various expert couriers are able to deliver parcels within 24 hours in any place of the civilized world.

A software agent is an autonomous application in a distributed software architecture. Individual agent applications interact directly without centralized co-ordination. Such applications for logistics management have become feasible in practice with the arrival of the Internet. In logistics management software agents organized in peer-to-peer networks can potentially be used to establish secure, flexible and efficient communication of handling instructions and tracking information over the Internet.

Distributing handling and control information across a network of logistics service providers is the major challenge that agent technology addresses. In complex operational situations, such as production and project management, improvements in identification and peer-to-peer technology make it possible to develop innovative agent applications that reduce the need for management intervention. The performance frontier is directly affected when these applications distribute control information more efficiently, reduce the need for manual integration, and make it easier to customize products and shipments.

To sum up, identification and agent technology potentially improves the efficiency of handling and customization. There are also opportunities to move to simpler co-ordination mechanisms that require less management intervention and looser organizational integration. Because it improves both aspects simultaneously the introduction of these new technologies has the potential to move the performance frontier of logistics management. In the new situation the trade-offs that companies are familiar with are perhaps not valid, and new business models may be feasible.

However, also investments that previously were a source of competitive advantage may have become obsolete.

3.2. Problem discovery and solution design

When starting the research the focus was on the application of RFID. Agent technology was not yet in the scope of interest. A focused review of industrial trials using RFID found that the potential impact on supply chain management, in addition to more efficient handling, and better integration of customization processes, is that it provides a new mechanism for information sharing and communication (Kärkkäinen and Holmström, 2002). This last point developed into a novel idea that would guide further research efforts by the research team. Product identification in combination with order information linked to the physical product was conceptualized as a tool for communicating important logistics and supply chain management information between companies. The term adopted to describe the idea was product centric supply chain management.

Product centric integration is an integration mechanism where the value adding activities of a network are guided by instructions linked to the individual product or individual assembly that is to be delivered. The concept was first illustrated by using a simple e-grocery example. The customer order is attached to the delivery tote that navigates between picking stations. By referring to the attached order the right products are added to the shopping basket at each picking station, and sent on to the proper next destination, and eventually to the customer.

Whether the order is on paper or programmed to a RFID only affects the amount of manual work. The essential point in the concept is that control is exercised by item or assembly specific instructions accessed by reference to the individual item or assembly. The benefit of this integration mechanism is that the value adding process does not have to be predefined. Value adding work can in principle be done by anyone referring to instructions attached to the physical item. The envisioned benefit of the concept was more efficient handling, customization and distribution of control information in changing networks of participants.

This conceptualization of product centric integration was on its own not a sufficient base case for starting work with industry. To find industrial partners interested to develop the concept a more specific and more relevant base case was needed. The e-grocery example failed to raise interest among industry. This meant that a good base case required a more realistic problem domain. An interesting problem domain where product individuals already were controlled and monitored manually was found in the delivery of expensive equipment to project sites, for example the construction of new industrial plants. Changing the problem situation in the base case to an industry where the integrated control of product individuals is actually required, and currently done manually, resulted in a relevant base case for the product centric integration concepts.

In formulating the new base case the need to track the product individuals across many organisations surfaced and this prompted the researchers' interest in software agents and peer-to-peer systems. Identification and attaching instructions to the product individual was not sufficient in a project delivery environment. The location and movements of the product also needed to be recorded and monitored by project managers. To address this requirement the idea of linking a software agent to the individual product was introduced. It was proposed that the network of actors involved in the product delivery should access and update tracking and control information by referring to the product specific agent. This way a project manager, or other interested party, could follow the progress of a shipment at anytime over the Internet.

In the delivery of a project the project can be represented as an assembly of different services needed by a product individual. This product centric view of project delivery became the basis for formulating a concise base case in the form of a technical norm. Instead of looking at project delivery as a supply chain management problem, the goal for solution design was: “How can automated product identification and product specific software agents be used to improve the handling, customisation and other services needed by product individuals?” The answer is a technical norm (Niiniluoto, 1992) describing how a distributed information system (solution X) can be used to provide the logistics information management services (goal A) needed in project delivery and similar temporary supply networks (situation B).

A paper describing the base case (Kärkkäinen et al., 2003) was completed at the same time as a consortium of industrial companies in the project delivery business was searching for ways to implement material visibility and control in project networks. The product centric concept was this way introduced to the research plan of the industrial consortium. A simple product centric track and trace system was implemented and field tested for large project deliveries. After the first test was finished an open source community was established for the further development of the solution, and to facilitate the adoption of the approach in other application areas (http://dialog.hut.fi).

The approach was then tested in a company managing a large number of projects. The challenge for the second pilot company was managing expensive inventory in a large number of temporary storage locations. The original simple tracking and tracing functionality was enhanced in the pilot application with better data collection and monitoring features. The researchers could in the pilot see first-hand how product centric tracking could provide inventory monitoring functionality and creating inventory visibility in a changing network of companies.

The base case for product centric integration in project delivery was simplified and generalised based on the pilots and a number of feasibility studies with other industrial partners. The result was a mid-range theory on how to achieve inventory and material visibility in changing logistics networks. The mid-range theory describes a material and inventory visibility solution that focuses on the product individual or shipment. The advantage of this solution is that it is forwarder, or handler independent. This Forwarder Independent Tracking (FIT) approach and descriptions of feasibility analyses and successful pilots in short-term multi-company networks are described in Kärkkäinen et al. (2004).

The solution design was next in turn to be developed. The base case concept of product centric integration together with implementation insights on how tracking is easily enhanced to provide more advanced functionality turned the attention of the research group to design patterns. Design patterns are proven designs in object oriented programming (Gamma et al., 1995). They are documented in the form of technical norms describing the problem situation, solution design and consequences of the design. In these schemes, the participating objects and a description of the communication between these objects represent the operation. The goals of many popular designs are related to reducing redesign and improving adaptability in changing circumstances.

By building on tested design patterns from object oriented programming (OOP) a scheme for developing loosely coupled product centric services was formulated. The basis for a successful adaptation is the conceptual similarity of product individuals tracked by a product centric application, and software objects in OOP. Främling et al. (in press) elaborates the analogy and discusses the developed pattern based designs in detail. Operations design patterns have been described for solving four problems of managerial importance in the virtual manufacturing enterprise (Holmström and Främling, 2005): (1) track and trace of shipments; (2) track and trace of composite products; (3) dynamic order structures; and (4) planning and scheduling of customized products in a changing network of partners.

3.3. Evaluation and theoretical research

The primary mechanism for managing complex logistics operations is today through creating a vertically integrated supply chain or distribution channel. Product centric integration is an opportunity to create novel and simpler integrating mechanisms. It is in effect a move towards virtual integration and this offers significant opportunities for improving the operational performance in changing environments (Gunasekaran and Ngai, 2004).

Product centric integration across a changing network of participants has so far only been implemented in pilots. Despite the ability to more efficiently collect and distribute logistics management information finding interested industrial partners has been difficult. Even though the basic advantage is becoming clear, i.e. material visibility and improved integration of operations in changing environments, which together provide a basis for innovative and performance enhancing supply chain practices, companies have found it difficult to introduce product centric integration in their operations.

The pilot implementations imply that existing systems and the existing architecture of enterprise systems limit the adoption of product centric integration. The problem is that product centric integration, instead of linking locations and focusing on accountability and transactions between locations, focuses integration efforts on value added operations that individual products in the value-adding network require. Figure 4 is an attempt to illustrate the difference between a conventional transaction driven chain and a product centric supply chain. A conventional chain is based on a a systems design that is focused on location specific material accounts and transactions between locations. This design underpins the familiar supply chain representation that emphasizes the integration of locations and the integrated control of transaction processes. A solution design that tracks and controls individual products independently of the location and the ownership of the product individual underpins product centric integration. This fundamental difference in how the systems are designed and how integration is represented makes it challenging to combine product centric systems with current enterprise systems.

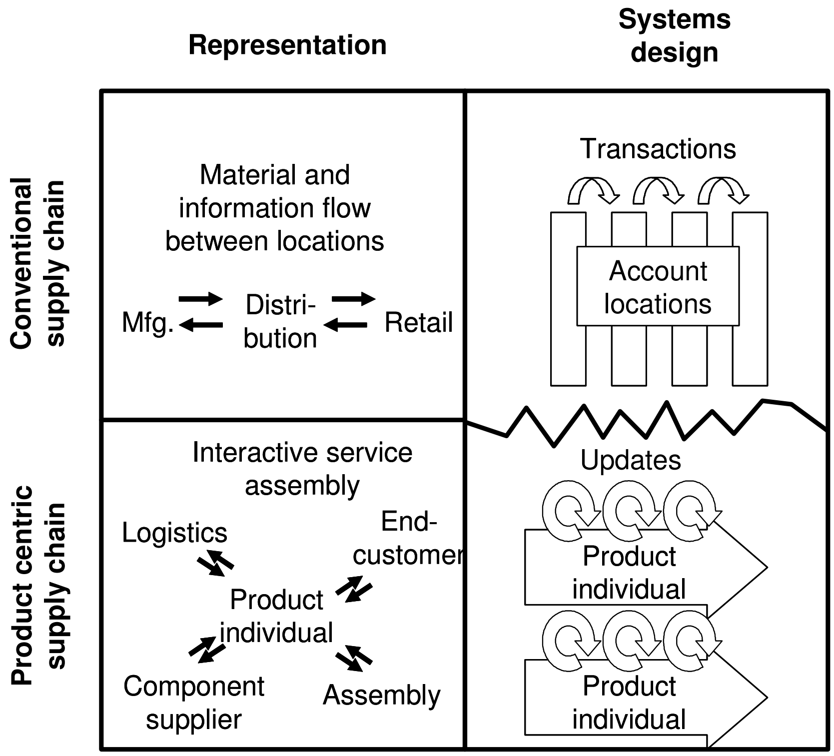

Figure 4: Product centric and conventional supply chain management are underpinned by fundamentally different systems designs

The difference between material account and product individual focus requires further elaboration. The conventional supply chain is effective when well-defined standard goods are produced and can be delivered based on simple order and delivery transactions. For ordering and delivering more complex products advanced integrating mechanisms such as projects are needed. However, shifting to product centric integration makes explicit the role of the product as the co-ordinating entity in the delivery of customized products and many value added services. In a network of actors the recognition of the product as an integrating mechanism opens up opportunities to reduce the need for project management and a priori agreed handling and processing rules. In a product centric operation the service provider can refer to definitions linked to the product individual in many situations that before would have required human intervention and prior agreement. This way it is possible to move towards simpler integrating mechanisms and ad hoc integration.

Thus, the problem discovery and solution design described in the case can be understood as a finding a novel "virtual integration" mechanism and taking steps that potentially move the performance frontier for logistics operations in a changing environment.

An interesting further theoretical direction regarding the specific example is to explore the relation of product centric integration to the economy of qualities (Callon et al., 2002). This is a theory developed within the sociology of innovation and technology studies. The basis of this theory is a distinction between product and economic good. The definition of a product in the theory is intriguingly close to the concept of product centric integration: "The product describes the different networks co-ordinating the actors involved in its design, production, distribution, and consumption" (Callon et al., 2002, p. 198).

4. Discussion

The case example was selected to illustrate the exploration of simplifying and potentially performance enhancing operations management solutions after a new information technology becomes available. In the case example the introduction of new technology led to the exploration of simpler types of integrating mechanisms that open up opportunities for companies to operate faster, more customized and more reliably with less management intervention and less organizational complexity.

Figure 5 summarizes the research example using the terms introduced in figure 2. The research resulted in a "stack" of related artefacts. The evaluation and representation schemes and the incipient theoretical explanation of how emergent technology affects operations management are based on the pilot implementations, mid-range theory, and solution designs.

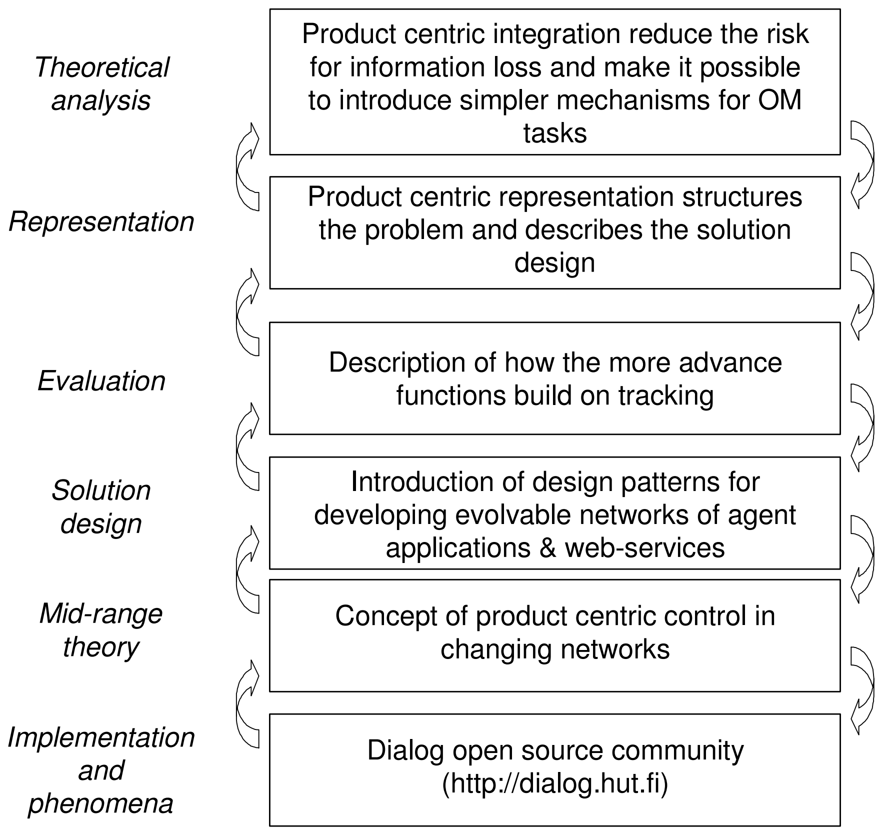

Figure 5: The outcomes of the explorative design research example

The study has been conducted over a period of 5 years. The slow exploration in the example, if typical, indicates that an important impact of emergent technology on operations management is that there are more alternative ways to solve an operations management problem than can be explored or evaluated by any one individual, research group, or company. This means that both operations management practitioners and researchers are rational in a bounded manner regarding the application and utility of new technologies for long periods of time while alternative practices are discovered and explored.

The underlying fundamental concept of a performance frontier in operations management remain intact in this analysis, yet the model of optimal choice and best practice that is implicit in the concept and its implications is challenged. The task of moving the performance frontier using new technology is best approached with a satisficing aspiration to discover novel, relevant, and functional solutions. As pointed out also by Hayes et al. (2005), in the absence of knowledge on deep structures and reliable representations based on this knowledge then the primary mode of both exploration and exploitation is learning by doing.

The proposed approach has in this paper been discussed in the context of introducing emergent technology to solve operations management problems. The problem domain is ill-structured and difficult to deal with because the problems and phenomena that were studied are in the process of being created. The applicability of the approach to other problem domains and disciplines that deal with designed phenomena has not been considered. This is left as an issue for further research.

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