Dynamic Capabilities in Manufacturing Processes: A Knowledge-based Approach for the Development of Manufacturing Flexibilities

Philip Cordes and Michael Hülsmann

Abstract Manufacturing systems are subject to the risk of path dependencies and resulting lock- in situations. In order to avoid and cope with them, they need manufacturing flexibilities. A management approach that triggers strategic flexibilities is the concept of dynamic capabilities. Therefore, a knowledge-based conceptualization of dynamic capabilities—i.e. knowledge codification, transfer, abstraction and absorption—is taken and analyzed regarding its contributions and limitations to flexibilize manufacturing systems on the basic or component as well as the system and the aggregated level.

Keywords Dynamic capabilities · Knowledge management · Manufacturing flexibility · Path dependency

1 Introduction

As any other organization, manufacturing systems are confronted with the risk of lock-in situations due to path dependent developments [1, 2]. This risk is associated with the risk of being unable to alter elements on the component or basic level, on the system level and on the aggregated level of manufacturing systems, when it is required [3]. In other words, they need manufacturing flexibilities in order to avoid or leave such inefficient system states.

P. Cordes (✉) · M. Hülsmann
Jacobs University Bremen, Systems Management, Bremen, Germany
e-mail: p.cordes@jacobs-university.de

M. Hülsmann
e-mail: m.huelsmann@jacobs-university.de

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Arafa and Elmaraghy (2011) speak of such a manufacturing flexibility as dynamic capabilities. With respect to the notion that the most important resource of today's business organization is knowledge (e.g. [4, 5]), Burmann [6] developed a deeper conceptualization and operationalization of dynamic capabilities by defining two dimensions: Replication ability (codifying and transferring knowledge) and reconfiguration ability (abstracting and absorbing knowledge).

Adopting this approach, the following question arises: **How do knowledge codification, transfer, abstraction and absorption in manufacturing systems affect their flexibilities on the component or basic level, on the system level as well as on the aggregated level?**

Therefore, after an introduction in Sects. 1 and 2 aims to describe risks of path dependencies for the flexibility of manufacturing systems. Section 3 aims to depict and adapt the dynamic capabilities approach in order to make it applicable to manufacturing systems. Section 4 discusses the effects of knowledge-based dynamic capabilities—i.e. knowledge codification, transfer, abstraction and absorption—on the different levels of manufacturing flexibilities. In order to do so, associated contributions and limitations will be identified and opposed to each other. In Sect. 5 finally, further research requirements and managerial implications will be deduced.

2 Risks of Path Dependencies for Manufacturing Flexibilities

2.1 General Characteristics of Path Dependencies and Lock-In Situations

According to path dependency theory, today's decisions influence the scope of managerial decision alternatives and might reduce its amount over time (e.g. [7, 8]). The underlying principle is called **'history matters'** [9]. Accordingly, decisions can have formative character for subsequent decisions [7, 8]. Organizational processes are based on decisions of many kinds and hence have an essential historic character [7]. This implies that process developments or at least parts of them are irreversible [10]. Therefore, David [7] calls historical events that determine the future development in an undesired way 'historical accidents' that determine the circumstances and managerial options in the future. Van Driel and Dolfsma [2] point out that organizations are generally sensitive to initial conditions—i.e. a moment or event in the past that is to be seen as a starting point for a path dependent development.

Consequently, it cannot be assumed that economic actors have a free choice. Instead, their scope of available decision alternatives is restricted by decisions made in the past. This argument counts all the more, when '**increasing returns'** (also termed as self-reinforcing effects) occur—the second main characteristic of path dependent processes. They occur when an increase of a certain variable leads to a further increase of the same variable in the next time step [11].

The third main characteristic is finally the evolvement of a '**lock-in situation**', which is to be seen as the main critical result of path dependent developments. In its original meaning a lock-in situation describes a situation in which users adopt one particular technology although other technologies are superior. However, due to path dependent developments—i.e. historical events and increasing returns—the inferior becomes the quasi standard. Common examples are the QWERTY-type-writer keyboard [7] and the VHS format [12], which are respectively were both technology standards in their respective industry although superior alternatives exist. The main characteristic of suchlike technological lock-ins is that the users are not flexible enough to change the technologies they currently use although others might be superior [7].

Authors like Sydow et al. [9] transferred the underlying mechanisms to the behavior of organizations and their selections of managerial options. Accordingly, self-reinforcing effects that emanate from the selection of a certain option or a type of option can result in a decrease of the amount of options that is generally available . Since combinations of such managerial options, which aim to create a certain industry position, are regarded as corporate strategies [13], it can be deduced that such path dependent developments can reduce the amount of strategies generally available. Consequently, companies that face such a reduction of potential strategic alternatives loose their ability to react flexible to environmental changes. Therefore, one main characteristic of organizational lock-in situations is strategic inflexibility. Hence, with recourse to the problem depicted in Sect. 1, the question arises, in how far manufacturing systems are subject to such risks of lock-ins and resulting inflexibilities.

2.2 Risks of Path Dependencies and Lock-In Situations in Manufacturing Systems

Whereas path dependency was mainly used for analyses on the level of entire organizations [9, 14], industries [15] or even nations [16], it was much less used on the micro levels of organizations, such as manufacturing systems [2]. Van Driel and Dolfsma [2] e.g. apply it to the evolvement of the Toyota production system and identify initial conditions and lock-in characteristics of the development of just-in-time production strategies. Morrey at al. [1] find in a case study on a construction company that the process of implementation of a lean culture exhibits fundamental path depende0nt characteristics . Dean and Snell [17] examine organizational inertia, which have strong similarities to lock-in situations, that arise from integrated manufacturing concepts. Hence, manufacturing systems are generally exposed to path dependent developments. Thereby, the risk of lock-in situations for manufacturing systems occurs on three levels:

First, on a technological level, the decision for a particular technology in manufacturing affects subsequent decisions through determining the scope of technologies that are compatible with the selected one. Hence, companies might choose subsequent technologies that are not the best on the market, to either ensure compatibility with the already existing one or to be able to use existing knowledge and capabilities of employees to handle the technology in order to avoid sunk-costs and additional costs for training of employees or technology upgrades. Hence, increasing returns occur: the selection of a certain technology increases the probability that a similar or at least a compatible technology is selected again in the next time step. Finally, a lock-in situation occurs if there is no possibility left to choose another technology than the current one in use although there are superior ones available on the market.

Second, on a managerial level, the decision for a certain manufacturing strategy [18] affects the subsequent decisions through determining the remaining scope of potential manufacturing strategies. E.g. a manufacturing strategy that aims to achieve economies of scale and low cost production through the creation of giant plants and docile work forces [19] cannot be reversed without any efforts into a strategy that focuses on flexible and individual customer-tailored production lines. Hence, in order to avoid related sunk costs (e.g. marketing efforts for positioning as a cost leader) and the loss of an already established market position, subsequent strategic decisions are self-reinforced by the previous ones. Therewith, the risk of an institutional lock-in situation occurs that would reduce the amount of decision alternatives on manufacturing strategies to a restricted field of options.

Third, there are strong interrelations between technological and managerial path dependencies. When the selected manufacturing strategy is based on the investment in a certain manufacturing technology that enables e.g. mass production but no customer-tailored production, the increasing returns on the technological level trigger also increasing returns on the management level. The other way round, if a certain strategy has been chosen that involves the use of a particular technology, increasing returns on the institutional level trigger also increasing returns on the management level.

Consequently, path dependent developments endanger the ability of manufacturing systems to react flexible on internal and external changes. Therefore, inflexibility can be regarded on the one hand as an outcome of lock-in situations. On the other hand, the key to avoid or to cope with path dependencies in manufacturing systems might be manufacturing flexibility.

2.3 Flexibility in Manufacturing Systems

From a general perspective Arafa and ElMaraghy (2011) define flexibility in manufacturing systems *“[…] as the ability of a system or facility to adjust to the changes in its internal or external environment with little penalty in time, effort, cost, or performance“*[20, p. 508]. However, this general perspective seems to need a concretization in order to be applied in particular contexts. Sethi And Sethi [3] propose a classification of flexibility types that distinguish between **component or basic flexibilities**, **system flexibilities** and **aggregate flexibilities** (other classifications have been developed e.g. by Gupta and Goyal [19] based on [21]).

Component or basic flexibilities describe possibilities to change the machines, the material handling and the operations. Thereby, **machine flexibility** *"[…] refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another."*[3, p. 297]. **Material handling flexibility** describes the *"[…] ability to move different part types efficiently for proper positioning and processing through the manufacturing facility it serves"*[3, p. 300]. **Operation flexibility** refers to the ability of a part *"[…] to be produced in different ways"*[3, p. 301].

System flexibilities reflect possibilities to change the manufacturing system's processes, routings and volumes and to expand. Thereby, **process flexibility** *"[…] relates to the set of part types that the system can produce without major setups"*[3, p. 302]. **Routing flexibility** *"[…] of a manufacturing system is its ability to produce a part by alternate routes through the system"*[3, p. 305]. **Product flexibility** *"[…] is the ease with which new parts can be added or substituted for existing parts"*[3, p. 304]. **Volume flexibility** *"[…] of a manufacturing system is its ability to be operated profitably at different overall output levels"*[3, p. 307]. **Expansion flexibility** *"[…] is the ease with which its capacity and capability can be increased when needed"*[3, p. 309].

Aggregated flexibilities finally reflect possibilities to change elements on a higher level within an organization—i.e. the program, production and the market. **Program flexibility** is *"[…] the ability of the system to run virtually untended for a long enough period"*[3, p. 310]. **Production flexibility** *"[…] is the universe of part types that the manufacturing system can pro- duce without adding major capital equipment"*[3, p. 310]. **Market flexibility** *"[…] is the ease with which the manufacturing system can adapt to a changing market environment"*[3, p. 312].

Considering these different types of manufacturing flexibilities, the question arises, how they enable manufacturing systems to avoid or to cope with path dependencies and resulting lock-in situations?

2.4 Manufacturing Flexibilities as Enablers to Avoid and Cope with Lock-In Situations

On the level of the components or the manufacturing system's basics, the different types of flexibilities ensure or even increase the availability of certain amounts of different decision-alternatives regarding the operations machines can perform, the materials the system can handle and the ways in which parts of products are produced. Hence, the occurrence of initial events that determine the paths on which the manufacturing system develops can be prevented when a great amount of varying decision alternatives is ensured in the first place. Therewith, the risk of lock-ins decreases.

The same argument counts for the flexibilities on the entire system's level. Maintaining the availability of certain amounts of different decision-alternatives e.g. regarding the manufacturing system's processes or the volumes of produced parts or products avoids that initial events can reduce these alternatives to only one remaining one.

Finally, these flexibilities form on the aggregated level. When lock-ins can be avoided on the prior levels, the risk that they occur decreases also on the aggregated level. Furthermore, in order to ensure market flexibility e.g., it is necessary to maintain different decision-alternatives regarding the products that are produced in the manufacturing system.

Subsuming, lock-ins that are based on technological and managerial path dependencies can be avoided through ensuring and maintaining manufacturing flexibilities on the components and basic level as well as on the entire system's and the aggregated level. Therefore, the question arises, how these flexibilities can be developed and maintained. Arafa and ElMaraghy [20, p. 508] draw an interconnection to the general management approach of dynamic capabilities of organizations. Accordingly, *"from a manufacturing perspective the dynamic capability for enterprise organizations is known as manufacturing flexibility"*. Considering the above-mentioned contributions of manufacturing flexibilities to avoiding and coping with lock-ins, this notion conforms with O'Reilly and Tushman [22, p. 187] who state that overcoming *"[…] inertia and path dependencies is at the core of dynamic capabilities"*. Therefore, the following questions arise: *First*, what exactly can be understood of dynamic capabilities from the perspective of manufacturing systems? *Second*, how do such dynamic capabilities of manufacturing systems contribute or limit the development of flexibilities on the components or basic level, on the system's as well as on the aggregate level?

3 Dynamic Capabilities in Manufacturing Systems

3.1 A General Understanding of Knowledge-based Dynamic Capabilities

The dynamic capabilities approach picks up the main assumptions of the resource-based view (e.g. [23]). Accordingly, competitive advantages can be gained and sustained, if companies possess resources that fulfill the so-called VRIN-criteria—i.e. when they are valuable, rare, inimitable and not substitutable (e.g. [24]). However, Katkalo et al. [25, p. 1176] argue that *"[…] even the VRIN-est of resources can lead to little benefit, when managed by incompetent indivudals […]"*. Therefore, the dynamic capabilities approach also incorporates the underlying assumptions of the competence-based view that traces competitive advantages back to individual and organizational competences (e.g. [26]). However, since both fail to explain, why companies can perform substantially different from others, although they are equipped with the same resources and competences [27], Teece and Pisano [28] challenged the underlying core-notion by stating that the essential capability is to be able to alter organizational resources and competences over time and under consideration of environmental changes. However, the question arises: What are concrete dimensions of dynamic capabilities that can be applied in manufacturing systems?

One concretization was developed by Burmann [6] who conceptualized dynamic capabilities as the ability to **replicate** and **reconfigure** organizational resources (including competences) through managerial and organizational processes. Furthermore, as a multitude of authors have stated, the most essential resource of an organization to gain and maintain competitive advantages is assumed to be **knowledge** (e.g. [4, 5]). According to Burmann [6], all resources that fulfill the VRIN-criteria are based on an advance in knowledge. Even the essential resource knowledge can only be acquired—i.e. organizations learn through knowledge accumulation—if there is knowledge that can be acquired and exchanged [29]. Daniels and Bryson [30, p. 977] observe a particular importance of knowledge for manufacturing systems since *"[…] there is an important shift away from production that is dependent upon material resources to production that utilizes knowledge as the key source of competitiveness and innovation"*. Consequently, a concretization of dynamic capabilities as replication and reconfiguration of organizational resources should focus on the resource knowledge.

3.2 Knowledge-based Dynamic Capabilities in Manufacturing Systems

Following Burmann [6] organizational flexibilities and hence dynamic capabilities through knowledge replication and reconfiguration occur if organizational knowledge…

- …can be identified and externalized through **knowledge codification**
- …can be made available to the entire organization without an unintended diffusion to competitors through internal **knowledge transfer**
- …can be devolved to new fields of appliances respectively markets through **knowledge abstraction**
- …can be combined with new organization-external knowledge through **knowledge absorption**.

Consequently, the four dimensions of dynamic capabilities in this knowledge-oriented perspective are knowledge codification, transfer, abstraction and absorption.

3.2.1 Knowledge Codification

Grant and Gregory [31] examine the transferability of manufacturing knowledge and state that *"[…] the transfer of know-how, some of which may be tacit and hard to transfer, is clearly critical for learning"*. This involves the notion that tacit knowledge on manufacturing processes has to be converted somehow into a form that allows to circulate and to exchange it [29]. Hence, manufacturing knowledge has to be codified so that *"[…] knowledge managers and users can categorize knowledge, describe it, map and model it, stimulate it, and embed it in rules and recipes"*[32, p. 80]. Consequently, knowledge codification in manufacturing systems refers to processes of transforming implicit knowledge on manufacturing processes into explicit knowledge through representations in symbolic forms.

3.2.2 Knowledge Transfer

The transfer of knowledge is an essential process within manufacturing companies in order to enable a strategic manufacturing alignment. Accordingly, manufacturing performance can be increased through process changes and knowledge creation, based on knowledge transfer [30]. Consequently, knowledge transfer in manufacturing systems refers to processes of devolving knowledge from one application place to another. Such a transfer can be made either within one manufacturing system or between a manufacturing system and other organizations that are in cooperation with each other (based on [6]).

3.2.3 Knowledge Abstraction

Knowledge abstraction latter refers to disengaging knowledge from its original context and making it applicable in other contexts [6]. Hence, it is necessary to reveal causal relations [33] that underlie a company's manufacturing processes. Not until then, knowledge on manufacturing processes can be devolved to new fields of appliances—i.e. to other manufacturing processes in different circumstances.

3.2.4 Knowledge Absorption

Cohen and Levinthal [34, p. 128] speak about a firm's absorptive capacity as *"[…] the ability of a firm to recognize the value of new external information, assimilate it, and apply it to commercial ends"*. For manufacturing systems it is therefore necessary to be able to identify knowledge about manufacturing processes from its environment, to evaluate its potential contribution when being applied and finally to apply it as appropriate in similar or totally different forms within the own manufacturing processes (based on [35]).

Having identified these four dimensions of a manufacturing system's dynamic capabilities, the question arises how they contribute or limit the component/basic flexibilities, the system's flexibilities as well as the aggregated flexibilities of manufacturing systems.

4 Effects of Dynamic Capabilities on the Flexibility of Manufacturing Systems

4.1 Effects of Knowledge Codification on Manufacturing Flexibilities

Knowledge codification leads to both contributions as well as limitations of a manufacturing system's development of flexibilities on the component or basic level, the system level and the aggregated level.

One exemplary **contribution** arises from the fact that codifying knowledge requires forming a mental model of it [36]. Hence, manufacturing knowledge has to be brought to mind by the codifying employees, which facilitates generating new ideas on how to change existing routines and identifying strengths and weaknesses. Hence, knowledge codification does not only reduce the tacitness of manufacturing knowledge. It does also increase the deepness with which manufacturing knowledge is anchored within the employees, which in turn enlarges the scope of possibilities regarding the appliance of certain knowledge.

For the component or basic level of manufacturing systems, this means that knowledge e.g. on how to flexibilize machines, on how to enable them to handle material and on how to ensure an operational flexibility is enlarged and converted into symbolic forms. These forms, in turn, can be transferred and hence diffused within the entire manufacturing systems, so that other machines can learn from the machine, material handling and operation flexibilities of other machines. The same argument counts for the system flexibilities. For example, if knowledge on how to flexibilize the manufacturing volume of certain machines is deepened, then codified and hence made available to other members of the manufacturing system, this knowledge can be applied to other machines. In consequence, the volume flexibility of the entire manufacturing system can increase. Finally, Sethi and Sethi [3] show the interrelations between the system and the aggregated flexibilities. Accordingly, if knowledge codification increases the elements of the system flexibilities, it affects positively the flexibilities on the aggregated level. For example, increasing product flexibility enables a manufacturing system to offer a wider production range. Hence, new options are created that enlarge the scope of actions within manufacturing systems and hence, increases flexibilities on all three manufacturing system levels.

One exemplary **limitation** of knowledge codification results from the risk of a solidification of learned routines: In an empirical study García-Muiña et al.

[37, p. 144] showed that *"[…] an excessive presence of codified knowledge, strongly institutionalized in the heart of the company, can put a serious brake on the creativity, intuition and employees' radical improvisation skills that major innovative activity requires"*, (see also [38–41]). Consequently, the codification of manufacturing knowledge increases the risk that routines within a manufacturing system—e.g. how to program machines or how to design manufacturing processes—are solidified. The reason is that most of the existing codification tools create guidelines for the execution of tasks in the future or for other employees [36]. Such guidelines however, hinder employees to find new and innovative solutions for occurring problems or even to find any solutions for problems that are not covered in the respective guidelines. This problem occurs on all three levels of manufacturing flexibilities: Guidelines for machines—e.g. on how to handle certain material—hinder them to develop material handling flexibility. Guidelines for an entire manufacturing system e.g. on the volume that is intended to be produced hinders the system to deviate from this volume if necessary und hence to develop volume flexibilities. Finally, guidelines that determine e.g. the market for which products are manufactured hinder the manufacturing system on an aggregated level to change their target markets if appropriate.

Additionally, codification of manufacturing knowledge requires efforts that have to be undertaken (e.g. development of manuals or other process-specific tools [36]). Hence, investments in information technologies are necessary that enable a search for knowledge that is worth to be codified and knowledge management systems have to be maintained over time [42]. Furthermore, alternate costs occur since the respective personnel is not able to conduct their usual tasks while codifying their manufacturing knowledge [6, 32]. In sum, knowledge codification is expensive and requires time [32]. Consequently, financial resources are bounded to processes of codifying manufacturing knowledge that cannot be used to make investments that might increase manufacturing flexibilities. One example on the component or basic level is an investment in different machines in order to widen the amount of different markets for which products can be manufactured and thus to increase market flexibility on an aggregated level. Another example on the system level is an investment in an extension of the manufacturing capacities in order to ensure volume flexibility [43]. Hence, the costs that are associated with the codification of manufacturing knowledge can lead to the necessity to resign flexibility investments, which in turn might reduce manufacturing flexibilities on all three levels.

4.2 Effects of Knowledge Transfer on Manufacturing Flexibilities

Knowledge transfer does also lead to both contributions as well as limitations of manufacturing flexibilities on all three levels—the component or basic, the system and the aggregated level.

One exemplary **contribution** is that knowledge transfer enables the combination of existing knowledge with internally transferred and received knowledge—so-called combinative capabilities. On this basis, new knowledge is created [44]. On a component or basic level the combination of manufacturing knowledge (e.g. general knowledge on how to modify machines with special knowledge on particular machine functions) leads to additional decision alternatives and hence, to a wider scope of actions. Therewith, flexibilities on the component or basic level increase. The same argument counts for the system as well as the aggregated flexibility level: If knowledge on how to expand a manufacturing system's capacities is combined with knowledge on how to serve different markets, a chain of flexibility effects is triggered that results in a higher manufacturing flexibilities.

Furthermore, the transfer of manufacturing knowledge can also lead to a higher efficiency of manufacturing processes. The underlying assumption is that most of the knowledge that is transferred within a company is based on the transfer of best practices – hence, knowledge that has already proven to lead e.g. to higher efficiency [45]. An increasing efficiency instead leads to redundant potentials in the manufacturing systems that can be used elsewhere. One example is a machine that is working to full capacity anymore since knowledge has been transferred on how to run the machine more efficient. The redundant capacity can be used e.g. to ensure volume or expansion flexibility. The same argument counts for the component or basic as well as the aggregated flexibility level: E.g. redundant capacities might result in new options to handle material or to change the manufacturing system's program.

An exemplary **limitation** result from the transfer of 'locked-in' knowledge. Zollo and Winter [36] argue that codified and transferred knowledge consists mainly of the creation and diffusion of guidelines, that have already proven successful in the past. However, as it has been shown in Sect. 2, such knowledge or beliefs of what might work because it has been working in the past might be subject to path dependencies and hence, to lock-in situations. Hence, the risk occurs that lock-ins are created or even solidified due to a diffusion of best practices. On the basic or component level of manufacturing systems, this risk refers to a diffusion of knowledge on how to handle machines and conduct manufacturing operations, which is solidified as a result. Hence, machine, material handling and operation flexibilities are reduced. On a system level, knowledge on processes, routing, products or the volume and capacity expansion can be solidified that results in an inability of the manufacturing system to react to changing circumstances that require approaches that are different from the ones that were successful in the past. Finally, as Sethi and Sethi [3] show, there are strong interrelations between the levels, wherefore also the aggregated flexibilities can be negatively influenced.

Additionally, as for the codification of manufacturing knowledge, its transfer requires efforts that result in costs. Correspondingly to knowledge codification costs, costs for knowledge transfer might include a necessary employment of additional personnel, the implementation of additional tools and technological equipment that enable a transfer of manufacturing knowledge as well as alternate costs because the personnel cannot be utilized in order to conduct their usual tasks during the time required for the transfer of manufacturing knowledge. Consequently, financial resources are bounded that could otherwise be utilized in order to invest in manufacturing flexibilities on all three levels. Furthermore, Paliszkiewicz's [32] prefigure that a transfer of codified knowledge increases the risk that knowledge is transferred to the wrong participants—on purpose or involuntary. Such an unintended leak out of manufacturing knowledge might weaken the knowledge's fulfillment of the VRIN criteria, since it might enable competitors to imitate certain manufacturing abilities. Hence, this risk can result in a loss of competitive advantages, which in the end might lead to financial losses. These in turn would decrease the manufacturing system's ability to invest in flexibilities on the three observed levels of a manufacturing system.

4.3 Effects of Knowledge Abstraction on Manufacturing Flexibilities

The third dimension of knowledge-based dynamic capabilities—knowledge abstraction—does also contribute and limit manufacturing flexibilities on the component or basic, the system as well as the aggregated level.

One exemplary **contribution** results from an increased scope of application areas of existing manufacturing knowledge: According to Burmann [6], knowledge abstraction enables the organization members to identify new fields of appliances of the underlying causal relations of their knowledge. Consequently, abstraction of manufacturing knowledge on the basic or component level, the system level as well as the aggregated level leads to a wider scope of possibilities where this knowledge can be applied. For instance, process-related knowledge that is decontextualized from the particular manufacturing processes from which it origins can be used in order to flexibilize other manufacturing processes that do not have that much in common so that a simple knowledge transfer would enable an applicability. Such underlying process- related knowledge could also be applied on other levels such as the processes of the machines' material handlings or the processes of identifying new markets for which the manufacturing system can produce. Hence, decontextualizing manufacturing knowledge enables manufacturing systems to develop new flexibilities on all three levels.

One exemplary flexibility-based **limitation** of abstracting knowledge is that it requires time and hence financial resources without a coercive flexibility-benefit. Although BURMANN [6] assumes that the abstraction costs are relatively small in comparison to codification and transfer costs, they are not negligible. Accordingly, the main share of costs that is associated with knowledge abstraction processes account for alternate costs of employees that are decontextualizing their knowledge. While doing so, they are usually not able to fulfill their usual tasks. However, according to Smith et al. [46], knowledge abstraction requires expertise regarding the knowledge that is abstracted . Expertise in turn, e.g. in the form of cognitive flexibility [47] to find new fields of appliances of manufacturing knowledge can be assumed to be costly. Higher educated people have stronger abilities to abstract manufacturing knowledge from their original context but demand also higher salaries [48]. Hence, again, financial resources are bounded to knowledge abstraction processes that cannot be utilized for investments in manufacturing flexibilities, such as an expansion of the manufacturing system's capacity.

4.4 Effects of Knowledge Absorption on Manufacturing Flexibilities

There are also both contributions and limitations of the fourth dimension of knowledge-based dynamic capabilities—knowledge absorption—to the development of manufacturing flexibilities on all three observed levels.

The main **contribution** can be assumed to be an increased innovativeness. Cohen and Levinthal [34] argue that a firm's absorptive capacity contributes largely to its innovative capabilities. Empirical validations of this assumption have been conducted e.g. by [49]. The reason is the acquisition of external information and its combination with internally existing knowledge. For a manufacturing system, this refers to the acquisition of external knowledge on machines, material handling or operations as well as processes, routines, products and possibilities to expand the manufacturing system's capacity. Additionally, knowledge on the aggregated level of manufacturing systems can be internalized through knowledge absorption. A combination with such knowledge with internally existing knowledge can lead to a widening of the scope of decision alternatives on all three levels, e.g. how to handle material, how to design manufacturing processes or knowledge on certain market characteristics for which products are manufactured. Hence, when manufacturing systems absorb external knowledge and combine it with internally existing knowledge, their manufacturing flexibilities can be increased on all three levels.

An associated **limitation** however is that an information overload can occur [50]. The underlying notion is that an internalization of a large amount of external knowledge that has not proven its contribution to the manufacturing system's flexibility yet might paralyze the manufacturing system. Hence, its abilities to change the elements on the basic or component, the system as well as the aggregated level of manufacturing systems are hindered through an overload with information on how they could be changed. If the amount of incoming information is too high, the manufacturing system cannot evaluate its benefits and might utilize the 'wrong' knowledge that can lead to contradicting results. Consequently, too much knowledge absorption might result in lower manufacturing flexibilities.

5 Conclusion

The research question of this paper is how knowledge-based dynamic capabilities—i.e. knowledge codification, transfer, abstraction and absorption—in manufacturing systems affect their flexibilities on the component or basic level, on the system level as well as on the aggregated level.

Thereby, both contributions as well as limitations of the dimensions of knowledge-based dynamic capabilities of manufacturing systems to the development of manufacturing flexibilities have to be considered. E.g. knowledge transfer enables on the one hand to combine existing with newly received knowledge and hence to create entirely new manufacturing knowledge that leads to manufacturing flexibilities on the component or basic as well as the system and the aggregated level of manufacturing systems. On the other hand, the risk occurs that knowledge is transferred and applied elsewhere that has proven successful in the past but is not appropriate anymore in new conditions. Hence, manufacturing flexibilities can be limited through an internal transfer of such 'locked-in' knowledge.

Nevertheless, there is a chance that the demonstrated contributions to manufacturing flexibilities predominate the associated limitations. Hence, while designing and managing manufacturing systems, the positive effects of knowledge codification, transfer, abstraction and absorption should be stimulated in order to benefit from their positive effects on manufacturing flexibilities on all three observed levels.

However, neither do the exemplary limitations and contributions provide a complete picture of positive and negative effects, nor are they weighted. Hence, a net-effect could not be identified, wherefore future research is necessary that aims to quantify the influences of knowledge-based dynamic capabilities on the different elements of manufacturing flexibilities.

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