

Modelling of Digital Extended Enterprise

Antti J. Pulkkinen¹, Ville V. Vainio¹, Simo-Pekka Leino², Juha-Pekka Anttila²

¹Tampere University of Technology, Finland

²VTT Technical Research Centre of Finland

Abstract: The concept of Digital Extended Enterprise is presented as a form of highly competitive manufacturing network. The maturity model of digital extended enterprise is defined as a method for the management of the development of manufacturing networks. The research methods of this paper are literature studies in many topics as well as action research with five industrial companies. Our findings support the use of the digital maturity model in the qualitative assessment of development projects. The quantified business indicators can be used for evaluating the attained benefits, while the maturity model is used for assessing the development efforts and steps taken. A dependency matrix for studying the maturity model is defined. We address the oversimplification problem of maturity modelling and suggest the use of dependency matrix to alleviate the oversimplification problem, to improve the maturity model and to enhance the knowledge on the development of digital extended enterprise.

Keywords: Extended enterprise, Digitalization, Modelling, Maturity, Dependency

1 Introduction

In this article we briefly present how to assess the capabilities of a supply network by using digital extended enterprise concept and maturity models. In the use of the maturity model we realized that the model itself contains overlapping and interrelated areas. The further development of the maturity model requires improved understanding of these matters and the understanding of the maturity itself; the interrelations of different topics within the maturity model may present new knowledge for the development of supply networks.

The research project this article is a part of has taken place along with a concurrent industrial project for more than two years. In the project, an OEM supplier of mineral aggregates handling machinery and a selected few of its sub-suppliers have developed networked strategies, operations, digitalization, processes, business indicators, etc. The OEM supplier has selected these development activities based on its strategy as well as on the problems encountered in its supply network. The partners have developed the internal operations management and visualization, manufacturing and engineering processes, personnel capabilities, business indicators, IT-systems, etc. and the OEM supplier has collaborated with a hands-on attitude. The industrial development project has provided the material and the phenomena of developing an extended enterprise to the research.

1.1 Digital Extended Enterprise

During the last couple of decades, the organization of industrial activities has evolved towards manufacturing networks. It is an obvious path of evolution related to specialization and the focusing of core competence. For the outsourcing of operations and

the development of procurement, several methods have been introduced. Most notable of them is the Krajlic's matrix (Krajlic,1983), which defines four categories of items by relating profit against risk and consequently suggests respective characteristics of supply-procurement situation.

The definition of suppliers' characteristics is a challenge, which remains even after original equipment manufacturer (OEM) has defined the characteristics of items and classified the existing items according to the characterization. For example, Momme (2002) suggested a framework for outsourcing manufacturing and Gelderman and Semejin (2006) a methodology for procurement portfolio management for selecting the most suitable manufacturing suppliers.

However, it is not always an option to start selecting new suppliers due to reasons of economy, time, logistics or availability. Instead of supplier selection, the methods for the collaborative development of manufacturing networks and OEM-supplier relationship should be applied. In this situation, it is necessary to assess the existing suppliers and relations with them (Momme 2002).

The concept of Extended Enterprise (EE) integrates business strategies and operational modes, engineering and manufacturing processes. The objectives of EE are persistent and distinctive operational transformations that will lead to a set of benefits beyond the results of traditional technical or business process re-engineering cases. (Browne et al. 1995) Similar concepts are collaborative supply chain (Simatupang, & Sridharan, 2002) and collaborative networked organizations (Camarinha-Matos et al. 2009) as well as industrial platforms and ecosystems (Gawer,& Cusumano 2014).

The integration and communication aspects of an extended enterprise have been recognized for long time (Browne et al. 1995). The goal of an extended enterprise is the total optimization and competitiveness of the whole network. The role of digitalization is to enable the integration and transformation when an extended enterprise as a whole can utilize the traditional production development methodologies, such as Lean, within and over the organizations of a network (Xu 2015, Burton and Bodeur 2002). Thus, we consider the contemporary version of an optimal manufacturing network a digital extended enterprise (DEXTER).

1.2 Maturity Models

The word maturity is defined as “the state of being fully grown or developed” [Hornby, A. S., Wehmeier, S., McIntosh, C., Turnbull, J., & Ashby, M. (2005). *Oxford advanced learner's dictionary of current English* (7th ed.). Oxford University Press.]. In the context of a multistage model, maturity implies the evolution of a specific subject from an initial to a fully developed stage.

Capability Maturity Model® (CMM®) was developed by Carnegie Mellon with an original intention “...to characterize the capabilities of software-development organizations” (Humphrey 1988, p. 73). Later Software Engineering Institute has developed a set of Capability Maturity Model Integration (CMMI) reference models for a variety of purposes, such as acquisition, development and services (CMMI 2010).

For the modelling of manufacturing capability, Britton et al. (2007) used the breakdown structure of Production System Design. They modeled the part-of structure of functional requirements (FRs) with performance metrics (M) and plausible physical solutions (PSs)

and analyzed the model with mind maps and matrices (see Fig 2.). The purpose was to define relevant questions for manufacturing assessment.

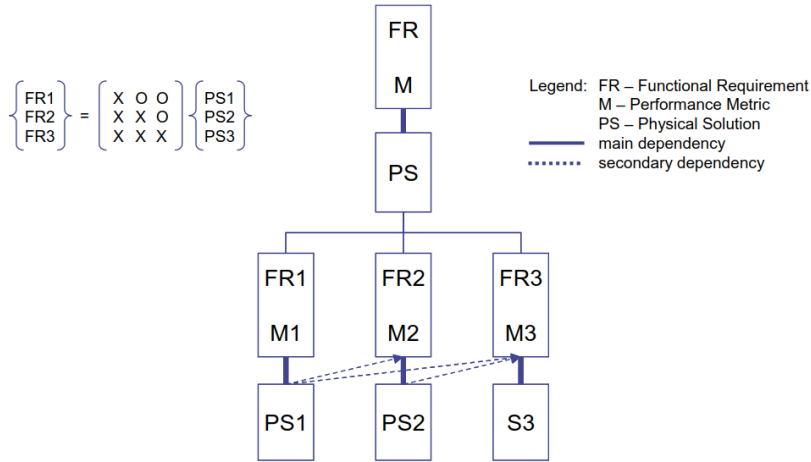


Figure 1. Illustrative decomposition of Production System Design (Britton et al. 2007, p. 3)

Eventually, Britton et al. (2007) structured the assessment questions in the form of maturity assessment statements or questions concerning the performance metrics and solutions of different level of decomposition. The order of maturity assessment followed the dependencies of the current solutions.

Maturity models for supply chain assessment and development has been the focus of many researchers and consultants. Lahti et. al (2009) studied six models that were published during the years 1999 and 2007. All the studied models were “based on years of supply chain benchmarking experience... tested, tried and proved ” (Lahti et al. 2009, p. 666). The models had common themes, but their sources and data collection varied. The models focused on the extended connectivity and integration, collaboration, evolution from dysfunctional to strategic partnership. Based on the models, Lahti et al. (2009) developed and tested their own supply chain maturity model that comprised of four maturity stages and key performance areas (KPA): plan, source, make, deliver and overall.

Done (2011) developed also another supply chain maturity model. He focused on the relation of performance and maturity and emphasized the downstream and upstream planning as the means of collaborative and integrative practices. Other KPAs in his model were sourcing, making, delivering, NPD as well as upstream and downstream return maturity. With the analysis of large sample respondents to an online survey Done claimed that the framework constitutes an appropriate model for the concept of supply chain maturity. He also found out that there is a “strong statistical support regarding the significant impact of supply chain maturity dimensions on multiple objective performance measures”. Done (2011, p. 24).

Leino et al. (2017a) have defined the model of digimaturity as an aid for understanding and structuring the concept of digitalization. An organization can assess its capabilities in six dimensions of the associated tool: strategy, business model, customer

interface, organization and processes, people and culture, and information technology. Leino and Anttila (2017b) suggested that a new version of the model could be defined for the assessment of manufacturing industry.

Common for all maturity models are the levels of maturity, which is a standardized way to measure the situation of different KPAs or topic areas of the model. Humphrey (1988) defined the five process maturity levels: initial, repeatable, defined, managed and optimizing. CMMI (2010) separates the concepts of capability and maturity and therefore defines the subtler levels from 0 to 5. In addition, Britton et al. (2007) used levels from 0 to 5. The studied supply chain maturity models (Lahti et al. 2009, Done 2011) had maturity levels ranging from 4 to 5.

“A Capability Maturity Model® is a simplified representation of the world” (CMMI 2010, p. 5). While evaluating the maturity level of a subject, there is a risk of oversimplifying reality and not having empirical basis. In addition, the common lack of a linear sequence of stages in organizational life must be acknowledged. (Poepplbuss et al. 2011)

1.3 Design Structure Matrix

Design or Dependency Structure Matrices (DSMs) have been used to model the relations and dependencies of objects, such as complex systems (e.g. electronic systems, buildings, aircraft and automobiles), business, manufacturing and engineering processes and organizations (Eppinger & Browning 2012, Browning 2016). The most known use of the method is to manage the structural complexity of a system experienced within product development and engineering (Eppinger 1994, Lindemann et al. 2009).

Eppinger and Salminen (2001), Browning (2001) and Bongulielmi et al. (2001) presented the concept of using matrices to represent the relations between the objects of different domains. Malmqvist (2002) considered the relations of the objects of one domain as intra-domain and the relations of the objects of two domains as inter-domain relations. Maurer (2007) coined the term Multi Domain Matrix (MDM).

Bongulielmi et al. (2001) and (Nummela) 2006 presented the variants of MDM and DSM to represent knowledge on the dependencies of product family for product configuration. Even the relations of functional requirements and physical solutions can be represented with an MDM as can be seen in the top left corner of Fig 1.

Despite the large variety of applications, DSMs rarely cover dynamic dependencies or system maturities. For example, Eppinger & Browning (2012) report only two case examples where change in time was incorporated in DSM or MDM representation. For example, duration, information maturity and probability of change are “additional attributes... that are not usually shown explicitly in a DSM” (Eppinger & Browning 2012, p. 140). In addition, Bongulielmi et al. (2001) stated that conditional dependencies cannot be represented in K- & V-matrix method.

2 Modelling digital extended enterprise

We developed a model of Digital Extended Enterprise (DEXTER), which comprises of sub-models: Dexter definitions, Dexter concept model and Dexter maturity model. We derived the concept model topics from the definitions from literature (see 1.1). The definitions

included following domains: extended enterprise strategy, organizations, processes, supply network structure, business indicators, change management, products and services, IT as an enabler, information flows and interfaces.

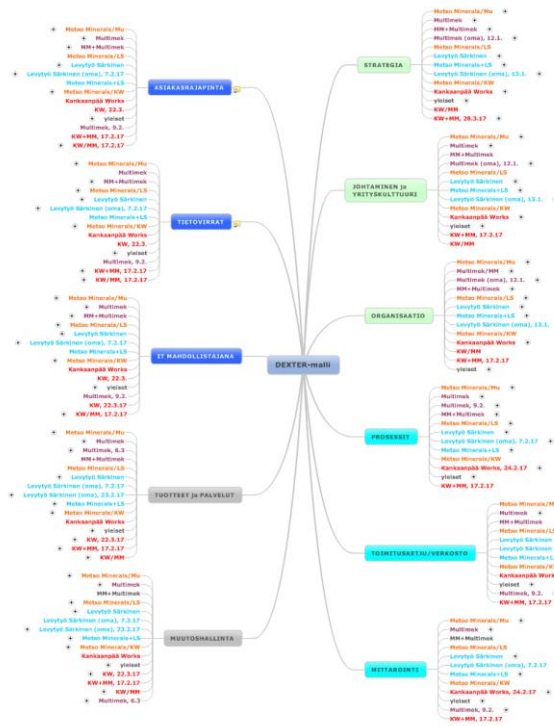


Figure 2. Dexter concept model (partial)

The concept model is a mind map diagram composed of all the topics, which the case companies found to be important in relation to the effectiveness of an Extended Enterprise network. We tested and further developed the model in co-operation with five manufacturing industry companies. As the figure above indicates, we documented implications of practical aspects in each domain from each interview in the concept model. This served the development of the extended enterprise: we recognized the relevant domains in practice and we defined pilot projects based on the concept model.

However, conducting interviews, documenting and assessing was tedious and time consuming. Moreover, the assessment was based on collecting similar opinions of the current state. Therefore, it became evident that collaboration within an extended enterprise needs a faster and more structured approach to discover the statuses and development targets within organizations.

2.1 DEXTER Maturity Model

For improved understanding of the state of an extended enterprise, it is necessary to have a structured method for assessing the state of the topics in the domains characterizing the

EE. Moreover, in an extended enterprise one must conduct the assessment with uniform measures and methods to collect equivalent information and to make valid comparisons of the states of topics in time and in the different organizations.

In the beginning of this research project, we did not aim to model maturity and did not seek any ready-to-use maturity models for our purposes, which led us to develop a suitable one. For example, we did not refer to such a structure and a method as Production System Development method like Britton et al. (2007) did in their maturity model. Rather, we focused on the literature on digital extended enterprise and the basis of the maturity model was the Dexter concept model. We further developed the maturity model with iterations between researchers and practitioners, mainly the procurement development team of OEM in the project. We analyzed the topics of the concept model, findings from the interviews and formed categorized sets of questions, which resulted in a maturity level questionnaire.

For the current version of the questionnaire, we chose the following six main domains: A) Strategy, B) Business Model, C) Processes, D) Performance indicators, E) Interfaces and F) Information flow. For the convenience of the respondents, we divided the categories into three forms: A+B, C and D+E+F. Answering each form took from twenty minutes to one hour. In total, there were 76 questions to be answered, of which 69 were multiple choice questions with five options. Generally, these five answers represent the maturity level on a scale of zero to four, four being the most developed or mature state. An example of a part of the questionnaire is in Figure 3.

14

Capabilities (digitalization and operations). *

Management, organizations and culture.

	Non existent	Individuals	Teams	Company	Extend enterprise
Do you have capabilities, roles and /or positions related to digitalization in your organization?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Who possesses capabilities and / or will to change and develop your operations to match changing needs? (e.g. implement new technologies)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 3. An example of Dexter maturity question (domain: Business model)

Every company answered each form of the questionnaire twice. Once considering the state of spring 2018 and once as to what the state was in the first quarter of the year 2016, i.e. in the beginning of the research and development project. The level of maturity was not always explicit in a question (see Figure 3), but each option was coded to match a

certain level of maturity in the analysis of answers. For example, the answer “*Nonexistent*” to the statement “*Do you have capabilities, roles, and/or positions related to digitalization in your organization*” would correspond to level 0 in the topic 14a of the domain business model.

2.2 DEXTER Maturity Model Dependencies

There is no theory to put the different domains of DEXTER maturity model nor the questions of the model in order. We cannot predict a situation within a manufacturing network prior to a study. However, our study suggests that a digital extended enterprise is a combination of different domains, which are interrelated in practice. Therefore, adopting a matrix representation of the current version of the maturity model appeared potential for the development of the model itself further and we defined an MDM based on the maturity model.

We marked the domains and the questions of the domain in first rows and columns of a Dexter Maturity Dependency Matrix (DM²) and adhered to the structure of the maturity model in the DM². The DM² cells represented the relations of maturity levels within the topics of domains and between the topics of different domains. For example, we marked that level 3, i.e. “*Company*” of question / statement 14a **requires** level 2 of question / statement 14b, i.e. “*Teams*” (see Figure 3). On the other hand, we may indicate that the *Teams* with the *capabilities, roles, and/or positions related to digitalization* **enable** some other level in the domain *information flow*, with an inter-domain relationship in the DM².

Figure 4. Partial DM²

Furthermore, it is possible to indicate the level of maturity required in the cells representing relations between different topics of maturity with numbers. Instead, we may mark different kind of relation dependencies, such as “precedes X”, “enables X”, “enhances X”, “removes X”, “removes the need of X” or “depends on X”, with different numbers.

3 Findings & Conclusions

We compared the findings of our maturity assessment to the business indicators that the OEM procurement development team provided to us. The quantified indicators, such as

the improved quality and reliability of deliveries, and decreased losses due to obsolete items, presented the success of suppliers' development projects.

We studied the capabilities and results both before and after the development actions to find qualified results of the actions. As expected, persons with different expertise and experience levels answered the questions with different attitude. However, it was easy to recognize the trends, even though some respondents regarded the *status quo ante* less satisfactory as well as the steps of maturity more moderate than other respondents. In a couple of domains, such as business indicators, we could calculate from the responses a relatively high rise of maturity throughout the extended enterprise. The highest topic specific rise of maturity was 2.4, levels, highest domain specific rise was 1.3 levels and in general, the development average was 0.8 levels. Thus, we were able to recognize the actions in a variety of levels and the effects at a high level.

The current version of DM² is only a draft, because it is incomplete and only two researchers have developed the rationale behind the relations of the DM². Nevertheless, the existence of relations appears to be rather self-evident, but the number of relations is high. This requires a systematic approach to model the DM² and we are currently contemplating it.

Typically, the mind-set of maturity modelling is to move systematically from the one level of maturity to the next one. In the many cases of intra-domain relations this appears to be the case as the level 2 requires the level 1 and enables the level 3. One might assume that the development of digital extended enterprise is straightforward.

However, even with an incomplete model it is possible to start to recognize that the reason of oversimplification of maturity models may be the lack of dependencies between the aspects of maturity. In the model, this means that the dependencies are often inter-domain relations, which indicate the need to traverse from one aspect of development to another to attain the next level of maturity, which validates the finding by Poepelbuss et al. (2011).

The more rudiment weakness of maturity models is the presumption of independence. Often the maturity models are targeted to wicked problems, such as enterprise networks that "... are ill-formulated, where the information is confusing, where there are many clients and decision makers with conflicting values..." C. West Churchman (1967, p. B-141).

Based on the abovementioned findings it is evident that the DEXTER Maturity model is a viable option for the management and assessment of the progress of development in an extended enterprise. The DM² modelling indicates the use of Multi Domain Matrix can provide insight and documentation on the knowledge of the management of extended enterprise development. Furthermore, it may address the dilemma of the oversimplification of wicked problems with maturity model. In addition, the DM² will be used for the development of the DEXTER Maturity model.

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Part IV: Using Data

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Contact: A. J. Pulkkinen, Tampere University of Technology, Department of Technical Sciences, Korkeakoulunkatu 6, PO Box 589, 33101 Tampere, Finland, Phone: +358503289404, e-mail: antti.pulkkinen@tut.fi, URL: <http://fi.linkedin.com/in/pulkkinen>