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ABSTRACT

In March 2015, the Chinesegovernment unveiled InternetPlus, an action plan expectedto push forward the Chineseeconomy. The plan aims to integratemobile Internet, cloud computing, big data, and the Internetof Things (IoT) with traditionalindustries to promote economicrestructuring, improve people'slivelihoods, and even transformgovernment and enterprises functions.
However for the enterprises, how to evaluate the capability is still an unsolved issue. In this study,considering capability maturity theory and model existed, we summarized the concepts of smart manufacturing and relative research field, combined with the development trend of smart manufacturing and characteristics of the enterprise's competition,a smart manufacturing capability maturity initial model with five levels and seven dimensions was defined. With this model, the connotation of smart manufacturing capability was unveiled andthe model also provides reference for enterprises to assess and improvesmart manufacturing capability.

Keywords: Smart Manufacturing, Capability Maturity Model（CMM）, Five Levels and Seven Dimensions

INTRODUCTION

With continuously generation and application of advanced manufacturing models, manufacturing technologies and manufacturing equipment, as well as the rapid development of business mode such as e-commerce in the internet age, the market environment and social environment faced by Chinese manufacturing enterprises have changed greatly. Product life cycles are getting shorter, the product variety is also increasing, and the user's expectations for products and services and the delivery cycle requirements are getting higher. Manufacturing enterprises have put forward higher requirements in improving product quality and reducing resource consumption, and improving production efficiency and reducing production costs. Production process visualization, intelligence and global optimization have become the manufacturing enterprises' focus[9].

The information technology revolution based on electronic computer and internet has a profound impact on the traditional manufacturing industry, which makes the resource allocation of manufacturing industry develops in the direction of information/knowledge-intensive. The production and applications of knowledge and information have become the main way to create wealth in today's society. As a manufacturing powerhouse, the Chinese national economy is in a crucial period of restructuring and changing of development mode. China urgently needs to make use of the high-tech including information technology to transform traditional manufacturing industries, which need to be upgraded comprehensively and scientifically to trend green manufacturing and smart manufacturing. Traditional manufacturing enterprises have a lot of resources which are difficult to directly apply to users, such as the design model, simulation data, and high-end equipment and various experience knowledge. The introduction of intelligence resources can effectively integrate these resources that can be able to be provided with a capability method, which means enterprises provide original resources and also complete solution and additional services for user at the same time; on the other hand, in order to meet the needs of users' personalization and professional services, service platform needs to provide multi type, multi granularity, and high quality and low cost services. Through the service technology of manufacturing capability, manufacturing capability can be smart and flexible combination and decomposition, so that it can make use of existing resources to form services of different functions, different types and different granularities and provide to the user according to uses' need to to meet the needs of users in the greatest extent.

This study summarizes the smart manufacturing, smart manufacturing capability and the capability mature research present situation both at home and abroad, combines with China manufacturing industry on the smart manufacturing capability of the actual demand and the trend of transition, gives the connotation and composition of smart manufacturing capability maturity. On the basis, a smart manufacturing capability maturity model with five levels and seven dimensions is constructed. The five levels include the initial level, repeatable level, defined level, managed level and optimizing level. The seven dimensions include smart manufacturing strategy, process, personnel, equipment, technology, knowledge and innovation. A description framework for this model is proposed.

THEORETICAL BACKGROUND

Smart Manufacturing

Smart manufacturing is a collaborative manufacturing mode of human-machine-object which is oriented service and based on knowledge, under the support of internet of service, internet of things, content/knowledge network, interpersonal network and advanced manufacturing technology, all kinds of manufacturing resources are connected together and form a unified resources pool, according to customer's individual needs and context perception, smart response are made under the decision of human-machine-object, in manufacturing life cycle process, smart manufacturing takes the customer as the center to provide customized, on demand, transparent and reliable human-oriented manufacturing services for customer [24] (see Figure 1), smart manufacturing mainly includes cloud manufacturing and smart union. Traditional manufacturing techniques combine with artificial intelligence and automation, which form smart advanced manufacturing technology. Driven by the market demand and

science and technology, advanced manufacturing technology has 10 kind of characteristics, which are precision, automation, information technology, flexible, graphical and smart, visualization, multimedia, integration and networking.

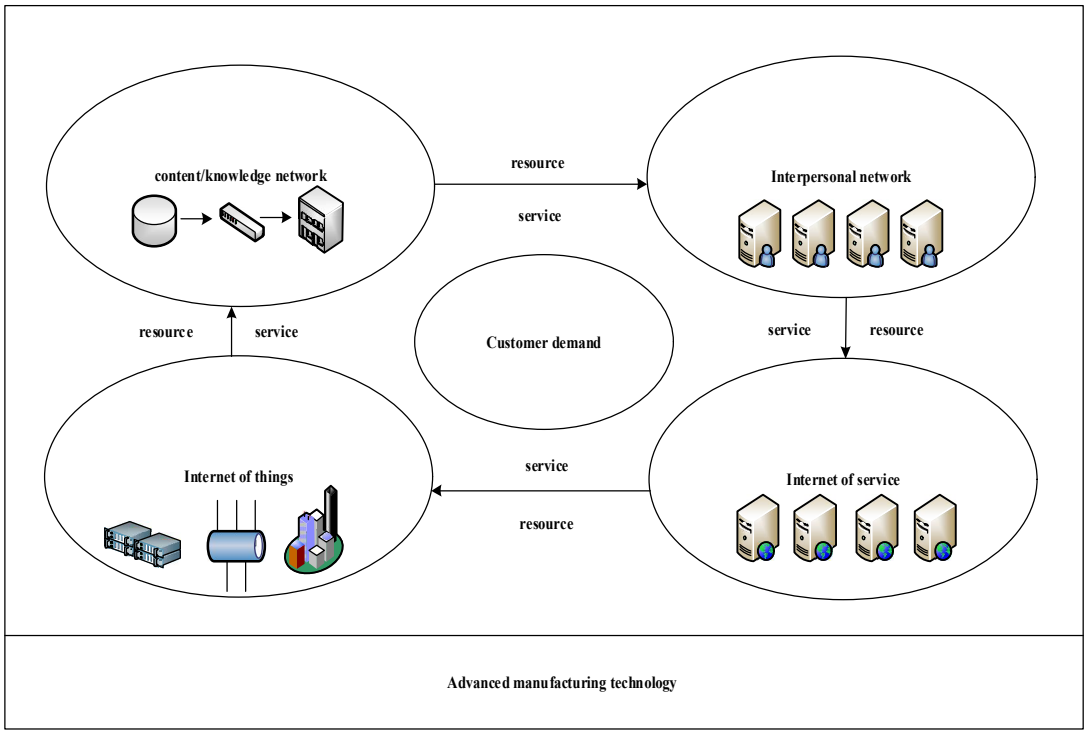

Figure 1：Four networks and smart manufacturing

Smart manufacturing is a new type of industrial form after the depth integration of information and industrialization, which emphasizes taking "smart" technology integration and optimization of manufacturing enterprise's design, production, management, services, and business to enhance comprehensive competitiveness of manufacturing enterprises. It reflects the development trend of the manufacturing technology from mechanization, automation, digital to intellectualization. The connotation of smart manufacturing mainly includes:

More thorough perception: Enterprises can quickly perceive various information related to the enterprise through sense networks. Sense networks have pooled together all kinds of information from enterprises, users, processes, devices, and systems of information. At the same time, sense networks service for different enterprises, which can expand and deepen the scope of sensory information of enterprises, also can greatly improve the completeness and accuracy of information search and comprehensively break the wasted of resources caused by the information asymmetry. When the smart terminal of the manufacturing enterprise is aware of the remaining resources in real time, the information of the residual manufacturing resources and the ability can be smartly passed through the virtual access technology and can be released to the application and the service support layer, and then through cloud service management of application and service support layer to make centralized manage the dispersed resources and then disperse use the pooling resources and achieve the optimal allocation of manufacturing resources and capability [25].

More extensive interconnection and intercommunication: An enterprise can achieve interconnection and intercommunication of inside and outside the enterprise information through the internet, wireless networks and the internet of things. The user needs to be accurate and timely meet. The resources are fully utilized, the work efficiency is maximized, and all kinds of waste are controlled at the lowest level. In China, the researches of internet of things technologies and industry chain are still in the conceptual and exploratory stage, the overall technology architecture and industry pattern have not been formed. However, with the development and improvement of correlation technology of internet of things, unified architecture standard system and related agreements and data security, more extensive interconnection and intercommunication are realized.

More intelligent, Knowledge of massive data and information: The clarity of the value and relationship of massive knowledge; knowledge integration in different disciplines; human-machine cooperative organic; high efficiency of product innovation and process innovation; precision of business management and control precision; the flexibility of the strategy-process-resource path in the four network interactive environment.

Higher standards of talent demand and a wider range of employee participation: Personnel training of manufacturing is not only a basic need about the skills and management, but also a more advanced training as an operational need, innovation and quickly response to the market enterprises own competition capability, which is a key factor to improve the enterprises' economic

performance [5]. Manufacturing enterprises of different scale will reassignment the employee depending on the professional qualifications and technical level through the supply chain, advanced technology suppliers, innovation and start-up companies [18]; scientific talent evaluation and a broader employee involvement.

The smart manufacturing technology includes intelligent innovation network, manufacturing network and management network, people put forward the smart manufacturing based on the data, and information and knowledge as well, which is an inevitable result when manufacturing informatization and integrated develop to a certain extent.

This research focuses on smart manufacturing capability maturity to understand the enterprises' transformation demand and development trend of smart manufacturing capability and composition of smart manufacturing capability maturity model, promote enterprises' smart manufacturing capability evaluation and improvement.

Smart Manufacturing Capability

In recent years, smart manufacturing is hot in the academy and industrial. However, there is no consensus on the definition of smart manufacturing capability. Smart manufacturing capability is a smart upgrading of manufacturing capability. Compared with the traditional manufacturing capability, smart manufacturing capability owns higher requirements in the advancement and collaborative of human-machine-object and knowledge, which also increases to take into account of the innovation, service and environmental factors. Many scholars at home and abroad have studied the smart manufacturing capability from different perspectives. Through combing the relevant literature at home and abroad, Luo, Y.L. et al. (2012) summarized the manufacturing capability of cloud manufacturing mode from the view of macro strategy angle and micro resources angle. They believe that the manufacturing capability of cloud manufacturing mode is produced in the process of a specific activity, embodies as a kind of manufacturing resources allocation and integration capability, reflects a standard level of the manufacturing enterprise or manufacturing entity completed a task and the expected target, contains all kinds of capabilities in the manufacturing life cycle, such as design ability, and simulation ability and production and processing ability, etc.. The manufacturing resources refer to all kinds of software and hardware resources in the manufacturing process, which are the basis of the formation of manufacturing capability [13]. Li, X.B. and Yin C. (2016) summarized the characteristics and operation mode of cloud manufacturing, they believe that successful implementation of cloud manufacturing mode requires enterprises to have the ability of production process management based on cloud services, the high degree sharing ability of manufacturing resource and the ability to manufacturing information to interact in real-time based on large data [12]. Ngai, E.W.T. et al. (2012) researched on clothing manufacturing enterprises, determined the successful RFID use of the eight key factors. Although enterprises for the case study they selected are not smart manufacturing enterprises in the strict sense, RFID as one of the key technologies of smart manufacturing, the key success factors can be seen as a pioneer in the successful implementation of the smart manufacturing capability, which are worth for reference [16]. Choi, S. et al. (2015) believed that global is developing different smart manufacturing methods in constant, virtual factory has solved (improve) and manage (control) problems and the overall actual production tasks website, put forward the effective strategic planning and systematic design, achieves real application of virtual factory manufacturing enterprises, through the establishment of strategy and system design to take diagnosis and evaluation for virtual factory and implement intelligent manufacturing system better [3].

Through analysis and summary of the related literature, we define the smart manufacturing capability as the method and process of the integration and application resources in manufacturing process through using the advanced manufacturing technology as well as skills, technologies, knowledge and abilities that accumulated in the process in the "four networks" integration environment. Smart manufacturing capabilityis the integration and innovation abilities of enterprise integrate informatization and industrialization in depth, which is the main capability that can help enterprises to obtain sustainable competitive advantage in the manufacturing fields in the future.

Capability Maturity

Maturity is the concrete quantification of the development and perfection of things and it is a special ability to measure and assess the expected goal of an organization [22], which can be evaluated by the company itself or a third party to put forward an effective and continuous improvement programs [19]. Maturity thinking comes from the theory of the quality maturity grid proposed by Crosby, P.B. (1979) [4]. The capability maturity model (CMM) was proposed by Carnegie Mellon University [8] initially as a best practice tool to guide enterprises to improve the quality of the software process, because it presented an evolutionary and dynamic scale standard to drive software development organizations to constantly improve and perfect in practice and make software development management from chaos and immature to mature and standard, which is a great success in software business applications and gradually extended to other areas [14, 15, 20, 21]. De Bruin, T. et al. (2005) considered capacity maturity was a life cycle model, which was composed by range defined, design model, application, test, adjustment, improvement and other steps [6].

Smart manufacturing is a system engineering which is from exploration to science, from technology dependence to early warning management, from extensive decision to precise scheduling. Smart manufacturing is also an immature to mature process which is a gradually improving process of the comprehensive manufacturing capability. By using capability maturity theory to build a smart manufacturing capability maturity model (CMM), the purpose is to find and continue to improve low efficiency link through evaluating the maturity level of management process and integrating resource, to assess and analyze smart manufacturing capability, to provide decision support for managers and to improve and perfect the management process, which

also can provide guidance to improve enterprise performance, ensure enterprise production orderly, efficient and high quality, plan resources reasonably and reduce all kinds of waste and loss due to poor management and information asymmetry.

SMART MANUFACTURING CAPABILITY MATURITY MODEL

Related Work

We use a general method made by Lahrmann, G. et al. (2011) [11]for reference to establish a smart manufacturing capability maturity model (see Table 1).

Table 1: Method of capability maturity model

Procedures	**Methods**	
(1) Identify needs or new opportunities	➢ innovation methods ➢ focus groups ➢ case study ➢ literature review ➢ field survey	
(2) Define scope	➢ providing data	➢ making plans
(3) Design model	➢ design from top to bottom ✧ Delphi method ✧ case study ✧ literature review	➢ design from bottom to top ✧ algorithm analysis ✧ data provide ✧ theory suggests
(4) Assess design	➢ functional test ➢ structure test ➢ survey ➢ focus groups ➢ interview	
(5) Reflect improvement process	➢ field trips	➢ interview

We adopt the design method from top to bottom, the procedures are like these: first, after selecting the design object we get the main indicators and secondary indicators through consulting literature and expert interview method and according to the process from top to bottom to complete the initial model design; then we use a measurement software to measure the validity, reliability and applicability of the design model, after evaluating, we eliminate the indexes of the initial capability maturity model, which did not pass the test; finally, we obtain the final revised model.

SM-CMM Dimensions and Levels

We extracted dimensions first by taking the method of consulting literature review, we searched articles whose key words contain "smart manufacturing" and "capability maturity" in domestic and foreign data platform of CNKI, SCI&SSCI, ProQuest, Science Direct and Web of Science and the time set to 2005-2016, a total of more than 800 articles were searched. We sorted and eliminated these articles according to the number of citation, subject classification and relevance and a total of 52 papers were obtained. According to the research needs and the research integrity, eventually we screened out 23 articles these were the most authoritative and the latest. Then, through studying and analyzing these 23 articles, we determined the dimensions and levels of the smart manufacturing capability maturity model, summarized the key process areas contained in each dimension and on this basis modified the framework of the smart manufacturing capability maturity model through 3 rounds of interviews.

The first round, the participates including 5 Ph.D. and 1 masters came from mechanical manufacturing professional, whose length of 3 hours, mainly aimed at inducting and extractingdimensions sorted by literature analysis method; the second round, the participates were 16 executives and CEO of manufacturing enterprises from Daqing, Harbin and Foshan, the interview divided into 2 ways of interview and video and 4 times, 30 minutes to 1 hours each time, mainly for inducting and extracting the key processes contained by the dimensions determined by the first round interview, and determined level boundaries; the third round, the participates were 3 experts in the field of manufacturing, aiming at consulting experts advices respectively for the first two rounds of the extracted dimensions, key process areas and key practices.

After the third round of interviews, we finally determined the dimensions of the initial theoretical model, key process areas and key practices. Seven dimensions are strategy, process, personnel, equipment, technology, knowledge and innovation (see Table 2).

Table : SM-CMM dimensions

Dimension	**Reference**
Strategy	Choi, S. et al. (2015); Ngai, E.W.T. et al. (2012); Jung, K. et al. (2015) [10]
Process	Choi, S. et al. (2015); Ngai, E.W.T. et al. (2012); Abrell, T. et al. (2016) [1]; Jung, K. et al. (2015); Xiao, Y. et al. (2013) [23]; Li, X.B. and Yin, C. (2016); Zhou, J.J. and Yao, X.F. (2015) [26]
Personnel	Ngai, E.W.T. et al. (2012); Davis, J. et al. (2012)

Equipment	Choi, S. et al. (2015); Ngai, E.W.T. et al. (2012); Jung, K. et al. (2015); Xiao, Y. et al. (2013); Li, X.B. and Yin, C. (2016)
Technology	Ngai, E.W.T. et al. (2012);Davis, J. et al. (2012); Abrell, T. et al. (2016); Baily, M.N. and Bosworth, B.P. (2014) [2]; Zhou, J.J. and Yao, X.F. (2015)
Knowledge	Abrell, T. et al. (2016); Li, X.B. and Yin, C. (2016); Zhou, J.J. and Yao, X.F. (2015)
Innovation	Abrell, T. et al. (2016); Baily, M.N. and Bosworth, B.P. (2014); Zhou, J.J. and Yao, X.F. (2015)

A dimension describes the different aspects of maturity assessment objectives, which is a division of the specific capacity area. The description of the dimension is detailed and distinguishable best. Each dimension of the maturity model can further explain a series of characteristics of each maturity level[7].

According to the characteristics of CMM research results and smart manufacturing, we set the initial theoretical model as fivelevels: the initial level, the repeatable level, the defined level, the managed level and the optimizing level (see Table 3).

Table 3:SM-CMM levels

Code	Level	Description
Ⅰ	Initial	Relying on technology, management disorder
Ⅱ	Repeatable	Following the benchmarking enterprise, productivity is the first pursuit
Ⅲ	Defined	Meeting industry standards, exploring the flexible management mode actively
Ⅳ	Managed	Getting the industry leading level, and constantly improve the level of smart service
Ⅴ	Optimizing	Keeping continuous innovation, and keeping the harmonious development of man, machine, material

Each level should have a series of characteristics that can be distinguished by empirical testing [17]. Each maturity level is impassable, which shows the process of smart manufacturing from chaos to mature. The upgrading of maturity represents the continuous improvement of the level of smart manufacturing.

Smart Manufacturing Capability Maturity Initial Model

The SM-CMM initial model is divided into seven dimensions. We explain and summarize the connotations of the seven dimensions, combine literature and expert opinions to deconstruct the dimensions into key process areas and key practices which are corresponded different levels by functions, then construct a complete smart manufacturing capability maturity models (see Table 4).

Table 4: SM-CMM initial model

Level / Dimension	Initial (Ⅰ)	Repeatable (Ⅱ)	Defined (Ⅲ)	Managed (Ⅳ)	Optimizing (Ⅴ)
Strategy	To improve productivity	Keeping up with industry benchmark	Suitable for enterprise's overall strategy	Long-term strategy	Collaborative strategy
Process	Information to support	Continuous improvement	To match the production task	Implementation of the flexibility	Service oriented and customer requirements
Personnel	High technical competencies	Inter-disciplinary talent demand gradually	Rising to the requirement of management	Focus on the professional training and scientific evaluation	Efficient talent can fuse with the machine and environment friendly
Equipment	High demand of smart performing , mainly to meet the production tasks	For intelligent diagnosis and self-optimization ability to ascend	Higher requirements under uncertain environment	Owning a standard to equipment maintenance function	Equipment has self-learning and share the ability to learn, and perfect match with people
Technology	Support the complete intelligent manufacturing process of the enterprise	Continuously improve technology, improve production efficiency	Meet the customized needs of customers, at the same time, control costs	Provide support for service-oriented manufacturing	To the perfect control and manufacturing resources integration
Knowledge	Knowledge acquisition, expression, storage,	Management of real-time updating and putted forward to	Recording all kinds of data information in the whole life	To provide decision support for user needs and services	Intelligent matching and dynamic combination

	organization, and management in manufacturing process	case base	cycle of manufacturing and unified coding		support as needed
Innovation	Focus on technology innovation	Focus on production and design innovation	Focus on management mode innovation	Focus on personnel innovation ability	Focus on service innovation

Smart manufacturing strategy dimension: strategy affects all aspects of the smart manufacturing enterprise management decision-making, which decides the enterprise how to implement the smart manufacturing in the daily production activities. Strategy is the plan of the smart manufacturing goals, integrity, long-term and collaborative for managers, whose essence is through the influence enterprise resource efficient configuration to achieve the unique competitive advantage.
Smart manufacturing management process dimension: process reflects the procedure of smart manufacturing capability optimizes resource configuration, emphasizes on the basis of manufacturing resources and the description of the business process and all kinds of knowledge in the process, such as business process constraints, design scheme, the simulation model and empirical knowledge.

Smart manufacturing personnel dimension: personnel are the important factor of uncertainty in smart manufacturing. The workers' quality is significantly higher than generally labor-intensive industries, especially requesting for workers with innovation ability, being good at coordination, owning the basic thinking of science and technology literacy and ability and needing innovative management talents and skilled technical personnel.

Smart manufacturing equipment dimension: in the process of dependent testing, intelligent diagnosis, self-optimizingvirtualization/service technology, all kinds of open source tools that applied to every level of smart manufacturing,decision package, the knowledge base and database thatfunction, they should have a set of executive abilities needs to be smart. When equipment is performing smart of implementation, preparation and maintenance equipment processing behavior, remote intelligent monitoring for the integration and summarize and analyze the requirements of all sorts of perform smart functions of devices; when preparing processing tasks, equipment should have independent changes in uncertain environment planning process parameters, preparation of codes and determine the control logic and other best behavior strategy abilities; when doing equipment maintenance, equipment can make independent failure detection, intelligent maintenance and remote intelligent maintenance, at the same time they have the ability to learn and share, whose functions are interaction and mutual support.

Smart manufacturing technology dimension: all the relevant technology to realize smart manufacturing and improve the efficiency, such as the semantic Web, Internet of things and finally realizes the control of the manufacturing resources.

Smart manufacturing knowledge dimension: knowledge is the foundation and conditions of the smart, which includes the knowledge base, case base, rule base and model base to provide decision support for the enterprise. Knowledge basis mainly implemented in the process of smart manufacturing capabilities to describe all kinds of knowledge acquisition, expression, storage, organization and management; case base is mainly implemented the organization and management of the business case for smart manufacturing products, which puts all kinds of data information in the whole life cycle process of manufacturingto update to the case base to provide decision support for users ultimately; rule base and model base are to describe and produced in the process of trading rules and unified organization and management.

Smart manufacturing innovation dimension: innovation is the soul of smart manufacturing. As the service integrates into products, effectively designing the product-service combination becomes a new challenge for product design, the great services and services in the physical sexual differences lead to there must be new thoughts and methods for service innovation and the design of the product–service.

CONCLUSIONS

In this study, we combined relative researches of smart manufacturing and capability maturity.Smart manufacturing(SM) and smart manufacturing capability (SMC) were clearly defined.A smart manufacturing capability maturity model with five levels and seven dimensions was constructed to help enterprises to evaluate their own smart manufacturing capability in the processing of transformation. This research results could be applied in the fields of innovation, strategy, organizational behavior, process reengineering, human resourcesand IT technologyetc. Thesmart manufacturing capability maturity model could be optimized and improved according to the theory developingin the future and more benefits will be added to the enterprises.

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