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PROJECT MANAGEMENT FOR SMALL- AND MIDSIZE-ENTERPRISES IN THE EMBEDDED SYSTEM INDUSTRY

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Abstract

Embedded systems development and production is an important domain for small- and mid-size enterprises (SME). The main reason is the adaptation of these systems to the specific use case – the product customization. Embedded systems are very often application specific standard products (ASSPs). They are based on a common (micro-controller) platform, which is tailored to the specific application. Such systems are produced in small or medium quantities and require close interaction with the development of the technical systems into which the embedded system will be integrated. They are customer specific and many customers are SMEs, too. Therefore, the lean development and production processes of an SME are better suited for this kind of business than the more complex and expensive processes of large enterprises. Nevertheless, the complexity of the embedded systems, of the respective applications and especially of the embedded software is rising fast. This is partly driven by the Internet-of-Things (IoT) trend. To stay competitive in term of technology, speed and quality, the SMEs in embedded systems have to move towards more sophisticated project management processes for their development and production projects. While doing this, they have to take process complexity into account to avoid overloading their projects with bureaucracy and losing the advantage of lean and fast processes. The solution we propose is a process framework derived from the standardized industrial processes of large technology enterprises. This process framework can be tailored to the specific needs of certain project types in SMEs. This takes a lot of complexity away while still guaranteeing state-of-the-art execution quality of projects. The concepts presented in this paper are derived from an industrial use case in an electronics manufacturing services (EMS) SME.

Keywords: *R&D processes, milestones, embedded systems development*
JEL code: *O33*

Introduction

Embedded systems are an important component for the emerging era of Cyber-Physical Systems and the Internet-of-Things (IoT) (CERP-IoT: Vision and Challenges for realizing the Internet of Things, European Union, 2010). They are the interface between the cyberspace and the physical world. The demand for such embedded systems is changing the industry of electronic manufacturing service (EMS) providers which consists of large players (e.g. Foxconn) but also of a huge number of small and midsize enterprises (SMEs). The customization of embedded systems to the ever changing applications and the development of more complex embedded systems with a higher amount of software (software intensive systems) leads to more research and development (R&D) effort and a higher complexity in R&D. Furthermore, EMS providers are facing more complex quality and process requirements (e.g. in automotive industry (Maurer, M.; Winner, H. Eds., 2013 and Hoermann, K.; Mueller, M.; Dittmann, L.; Zimmer, J. 2008) since their products become a more relevant part of new products (so called software defined products). Therefore, SMEs in the embedded systems industry have to convert from production-oriented EMS providers into R&D oriented electronics and software companies. This leads to a demand for well-defined processes,

standards and quality guidelines that achieve the quality level of large technology enterprises while keeping the bureaucratic overhead at a manageable level. This challenge can only be met by an intelligent design of the respective project management framework.

Development of Embedded Systems

The following contribution is mainly based on the experience with the case study of converting a former EMS provider into a R&D oriented electronics and software company. The change process was mainly conducted from 2011 to 2015. The company (CP contech electronic GmbH, Germany) was hit hard by the financial crisis and the subsequent economic crisis in Europe in 2009 to 2010. By that time, 50 employees were working mainly in production and production related service functions. The company was certified according to ISO9001, but had only a very limited development process. By 2015, the company still had 50 employees but with a most people in R&D and supply chain management while productivity in manufacturing increased by 2-3 times. Software-intensive products with IoT functionality are a major share of the overall products. To comply with the product complexity and the rising customer requirements, R&D processes are defined and rolled-out in both production and development.

For embedded systems development it is important to do a concurrent engineering of the product itself, the production process for this specific product and for the test and qualification process. Otherwise, the interdependencies between the three areas cannot be addressed sufficiently (Gausemeier, J.; Kahl, S., 2010). From a generic point of view, the process starts with a customer order. R&D develops prototypes (engineering samples) to support the in-house validation and verification of the product. Such samples focus on the functionality of the product and don't require the final production or testing process. While finalizing the product design, the customer is becoming involved. Based on prototypes which are much closer to the final product (customer samples) the customer does a validation and finally releases the product for production. This is a first acceptance test and therefore an important milestone of the R&D project. In this phase the production and testing process needs to be considered since product features are finalized which determine the production (Design-for-Manufacturability, DfM) and testing (Design-for-Test, DfT). While developing the production and test processes, the supply chain is set up and the purchasing and qualification of material and parts required for the product are done.

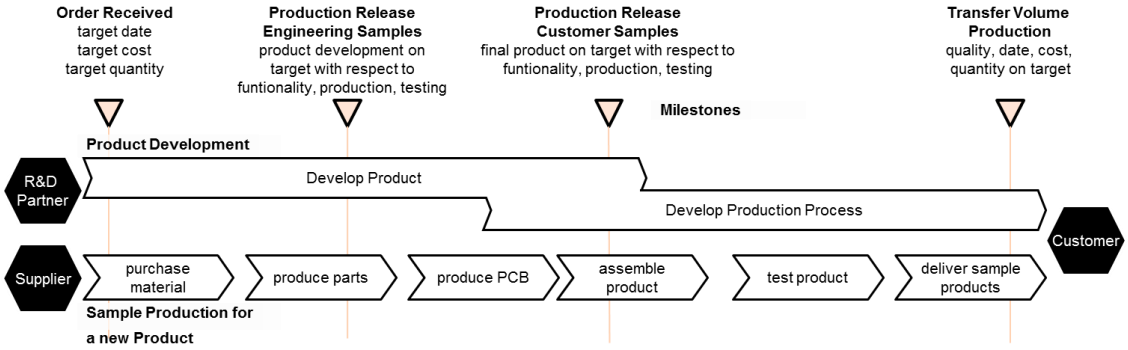

Fig. 1: **Stage-gated product development process with the concurrent production process development**
Source: *contech: www.contech.de, last accessed Feb 26, 2016*

During the final stages of the product development process, the ramp up of the production is done and the incoming supply chain is set up. Developing, adapting and tuning the product and the production process for mass production is called the industrialization process.

Milestone Process

Milestones are an important tool within a project management process (Kerzner, H, 2013). They are used for quality assurance (QA), for project controlling, for performance measurement (key performance indicators, KPI, e.g. cycle times) (Ha, W.; Sun, H.; Xie, M., 2012), for reporting, and for project communication in general (Kerzner, H, 2013). Milestones help to define a stage-gated project management process where certain tasks and deliverables need to be accomplished before moving on to the next phase. A milestone is accomplished after successfully conducting a milestone review. Such reviews are used to have a four eyes principle with at least another person (e.g. engineer from another project) together with a project team member (or the project manager) checking the results achieved by the project. Some milestones involve customers and lead to an acceptance of the accomplished results by the customer. At contech, reviews are used for both internal and external (customer) purposes. For an SME, it is important to have a simple but standardized milestone process (Kerzner, H, 2004). Standardization of milestones leads to better communication within the company and to a better understanding of the project status within the team and the whole organization (Guilin G., Chen Y., Sun Y., Zhou, X, 2007). Therefore, contech defines a set of 6 standard milestones and some optional intermediary milestones.

Table 1

Set of standard milestones for an embedded systems company

Phase	***Milestone***	***Name***
Initial Offer/Basic Concept	*M0.1*	Customer Request/Product Idea
	M0.2	Feasibility
System Concept	**M1**	**Project Release/Customer Order**
	M2	**Product Specification**
Develop Internal Prototypes (Engineering Samples)	**M3**	Prototype Phase Completed/ **Release for Pre-Series-Production**
Develop Final Prototypes (Customer Samples)	*M3.1*	Handover to Production for Pre-Series-Production
	M4	Pre-Series-Phase Completed (Customer Feedback)/**Design Freeze**
Pilot Phase	*M4.1*	Handover to Production for Pilot Production/Zero Production
	M5	**Volume Production Release**
Volume Production	*M5.1*	Ramp Up Completed
Ramp Down	**M6**	**Production Ramp Down**
	M6.1	Product Cancellation

Source: *contech: www.contech.de, last accessed Feb 26, 2016*

To ensure a proper definition of the required results to accomplish a milestone and to document the required checks during the milestone review, for each milestone a specific milestone checklist is provided.

Table 2

Example entries of the milestone checklist for the milestone M1 "Project Release"

Milestone M1 Project Release								
ID	**Mile-stone**	**Check**	**Document**	**Version**	**Result**	**Resp.**	**Review**	**Tailoring**
1	M1	Project Manager (PJM) appointed			done	PGM		Required
2	M1	Project plan available (MS-Project)	Project Plan	V1.0	Open	PJM	PGM	Required
4	M1	Project Manual available (with team liet)	Project Manual	V1.0	done	PJM		Optional
5	M1	Risk assessment (FMEA) done and risk management initiated	FMEA	V1.0	done	PJM	PGM	Required

Source: *contech: www.contech.de, last accessed Feb 26, 2016*

The milestone checklist contains references to relevant standard documents. Since these documents are "living documents" which grow and change through the project cycle, a

standardized numbering and versioning scheme is used. The "FMEA V1.0" for example contains always the initial risk assessment at project start and can later be used as a reference about the risks communicated with the customer at the joint project release milestone. Furthermore, the checklist contains who is responsible for the check and who is doing the review (four eyes principle). The last column allows a tailoring of the checklist to the needs of the project. With this feature, optional checkpoints can be skipped if not needed. This offers the possibility to make the process "lighter" e.g. for smaller or less complex projects.

To make such a milestone process useful for technology driven SMEs, it is necessary to design it in a way that is:

- Expandable for new business models: since customer requirements change fast, the process must be customizable e.g. if a customer requires in addition to the embedded system the development of mechanical parts, if for example only software is needed without producing hardware or if a new technology (e.g. cloud based services) is introduced. SMEs need pragmatic means to adapt to such a situation.
- Using roles instead of resources: roles in SMEs are not defined by assigning specialists to each role but they are defined by giving a person (maybe the same for several roles) the responsibility for a certain topic. Since people can be required to cover several roles, it is specifically important to define the roles and responsibilities clearly and attach them to the product development process. IPMA ICB is an important basis for this (ICB – Individual Competence Baseline for Project, Programme and Portfolio Management, Version 4.0 (2015).
- Based on standard documents, forms and checklists: Standardization is important to simplify communication (everybody knows what is meant if the project is at M3) but also for maturity development of the company and quality assurance. This follows the trend for project management standardization (PMS) (Guilin G., Chen Y., Sun Y., Zhou, X , 2007) (Oktaba, H.; Piattini, M., 2008) which makes it much easier for new employees to familiarize with and integrate into the ongoing projects.
- Allowing the tailoring of the process to the needs of the respective projects both in methods and tools (Silva, M.; Jeronimo, C., 2013) and in development software (Wolff, C.; Krawczyk, L.; Hoettger, R.; Brink, C.; Lauschner, U.; Fruhner, D.; Kamsties, E.; Igel, B, 2015): This is required to reduce the bureaucratic burden for projects while ensuring the development quality of a "heavy-weight" process.

Tailoring towards different project types

The tailoring of the process is specifically important for the SME contech from our case study. This is due to the fact that contech offers a full scale development and production service to the customer but also offers subsets and parts of the full scale solution as independent services. This means that contech (contech: www.contech.de, last accessed Feb 26, 2016) offers:

- The development of new embedded systems with electronic hardware, software, mechanical assembly, inhouse production or production by manufacturing partners, testing etc. based on a customer specification
- The modification/iteration/customization of an existing product e.g. by adding a different electronic component or a new software feature (also re-engineering e.g. for cost saving or because an electronic component is no longer available)

- The development of test systems for an existing product (no matter if the product itself was developed by contech)
- The "industrialization" of new or existing products both with an inhouse production process or a production process at a manufacturing partner, production process improvements (e.g. to safe cost or time)
- Software development
- Prototype development as means for new product validation by customers or as marketing samples.

Due to the iterative and more agile development process for software-intensive systems (Liggesmeyer, P.; Trapp, M., 2009 and Oktaba, H.; Piattini, M, 2008) these offers need to be iterated and combined according the requirements of the customer. E.g. a customer could request to get 2 versions of customer samples (B-samples) because he wants to introduce changes after validating the first samples (B0) and still validate the resulting second samples (B1). Fig. 2 shows how the product development processes for a "Redesign or Standard Product" and for "Concepts/Prototypes" can be derived from the full scale R&D process for "New Products" by skipping process phases and milestones (M1-M6). E.g. a redesign of an existing product usually does not require a basic concept before doing a system concept and it does not require the production of engineering samples. On the other hand, the development of a concept or a prototype without the intention to bring it into mass production (e.g. because it is just needed as a technology demonstrator) does not require the later phases of the process.

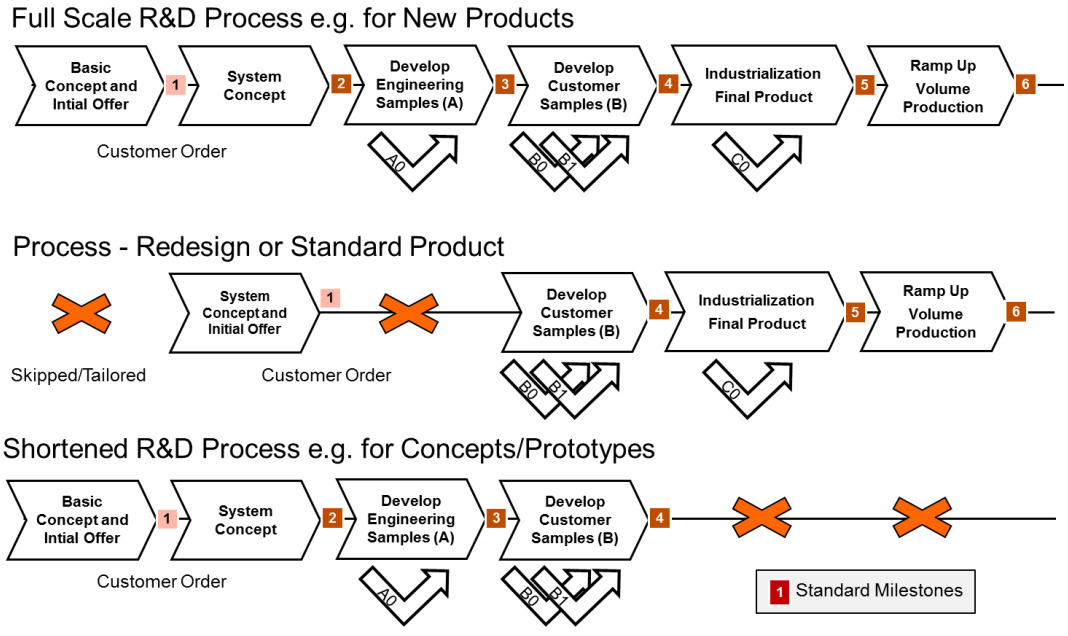

Fig. 2: **Tailoring of the full scale R&D process for embedded systems to different project types and sub processes**
Source: *contech: www.contech.de, last accessed Feb 26, 2016*

Results and Conclusion

Based on the experience with the development of a milestone and project management process for the embedded systems SME contech it can be concluded that a SME can operate R&D processes with similar quality levels as large enterprises while still managing the bureaucratic overhead. Project management standardization (PMS – based on standards like PMI or IPMA) and the development of a set of standardized milestones are powerful tools to introduce high quality processes in SMEs while still providing agility and flexibility. A defined way for tailoring leads the way to the generation of different service offers to customers out of a basic set of sub-processes while still keeping the process complexity in a manageable range. Finally, such processes give employees a framework to cooperate and communicate while allowing new colleagues an easy and fast integration into the projects.

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