Proceedings of the 11th International Conference on Manufacturing Research (ICMR2013), Cranfield University, UK, 19th –20th September 2013, pp 39-44

CHALLENGES IN THE INDUSTRIALIZATION PROCESS OF LOW-VOLUME PRODUCTION SYSTEMS

Siavash Javadi
Jessica Bruch
Monica Bellgran
Department of Product Realization
School of Innovation, Design and Engineering
Mälardalen University
Drottninggatan 12,
Eskilstuna, Box 325, SE-631 05, SWEDEN
siavash.javadi@mdh.se, jessica.bruch@mdh.se,
monica.bellgran@mdh.se

Peder Hallemark
Atlas Copco Rock Drills AB
Klerkgatan 21,
Örebro, SE-70191, SWEDEN
peder.hallemark@se.atlascopco.com

ABSTRACT

A critical part of new product development projects is the industrialization process of new products which affects both time and the cost. The industrialization of new products or variants in low-volume production systems has some specific challenges which are caused by characteristics of low-volume products and production systems. Therefore, an exploratory case study is made within two Swedish manufacturing companies to understand these challenges and compare the industrialization process in high and low volume production systems. The results of the multiple case studies indicate four challenges including knowledge transfer from the projects into production, development of the work instructions, the need for a higher level of training of the operators and production system design and the obligatory tailoring of the new products to the existing production systems.

Keywords: Low-volume high-variety production, production system development, industrialization.

1 INTRODUCTION

Several factors such as globalization, faster evolvement of new technologies and shorter product life cycles force the manufacturing companies to introduce products more frequently to stay competitive in the global market (Bellgran and Säfsten 2010, Chryssolouris 2006). Introducing new products to the market and reaching the intended production volume in time allows the companies to avoid crucial consequences such as lost customers and revenue and early outdating of the products (Hendricks and Singhal 2008).

A critical part of new product development projects which affect the time to volume and product quality is the industrialization process. It is defined as the transition from product design to production and incorporate the activities which make the product producible and prepare it for production (Bellgran and Säfsten 2010, Johansen 2005). These activities are related to both product and production system development including adaptation and verification of them (Berglund, Harlin and Gullander 2012). An efficient industrialization process can lead to a shorter time to volume, a more functional and cost effective production system and higher quality of the product (Almgren 1999, Fjällström 2007, Säfsten and Aresu 2002). In this regard identifying and handling the challenges of the industrialization process is critical to retain competitiveness in the manufacturing industry.

In addition, companies with low-volume production face specific challenges during the industrialization process of new products. Characteristics like highly customized and relatively expensive products, low volumes and a "full make to order policy with guaranteed delivery dates" imposes extra challenges to these companies (Jina, Bhattacharya and Walton 1997).

Qudrat-Ullah, Seong and Mills (2012) point out some of these challenges such as shorter time for design and engineering, more variety in customer requirements and limited possibilities for major changes in the production system.

Although separate parts of the industrialization process have been studied in different research areas, more research about the industrialization process in low-volume production systems is necessary. Therefore, the purpose of this paper is to identify the challenges of this industrialization process. The purpose is accomplished through multiple case studies.

2 THEORETICAL FRAMEWORK

2.1 Industrialization process

Industrialization, also known as product introduction (Berglund, Harlin and Gullander 2012) or product and production preparation (Almgren 1999), is described by Fjällström (2007) and Berg (2007) as the "last phase of product and production development process" which consists of product and production system development, pre-production and production ramp-up.

Almgren (1999) presents a model for product development process which shows that the industrialization process includes activities related to development of both product and production system. Therefore, collaboration of different organizational functions and individuals in a cross functional project team with high degree of work complexity is necessary to accomplish the process(Berglund, Harlin and Gullander 2012). In this regard, project organization and leadership plays a critical role in an effective industrialization process. Clear definition of goals, responsibilities, resource allocation and developing a mutual understanding between product and production system developers are some examples of affected tasks by project leadership and organization (Bellgran and Säfsten 2010, Vandevelde and Van Dierdonck 2003).

Another challenging factor in the industrialization process is priority, timing and integration of the production system development in the product development project (Aresu 2001, Bellgran and Säfsten 2010, Säfsten and Aresu 2002). Prioritizing production system development after the product development can lead to critical risks like shortage of time and resources, implementation problems, production disturbances, frequent maintenance need and late changes during the early stages of the commercial production (Bellgran and Säfsten 2010). Therefore, more integrated development of the product and production system during the industrialization process is suggested (Aresu 2001, Bellgran and Säfsten 2010, Vandevelde and Van Dierdonck 2003).

Adler and Clark (1991) and Terwiesch and Bohn (2001) point out the role of the industrialization process in the learning process of the operators and improvement of the production process during the production ramp-up. They state that number of produced products during the ramp-up process have a direct relation to the learning and improvement of the production process. The ramp-up process is defined as "the period when the normal production process makes the transition from zero to full volume production" (Terwiesch, Bohn and Chea 2001).

Information management during the industrialization process has also been identified as critical for an efficient industrialization process. More formalized structure (Bruch 2012, Vandevelde and Van Dierdonck 2003, Bruch and Bellgran 2012) and applying the stage gate model (Berglund, Harlin and Gullander 2012, Bruch 2012) to both product and production system development can facilitate the information management in the industrialization process.

2.2 Low-volume production systems

Low-volume production systems have different characteristics and requirements from high-volume production systems which are usually the subject of study in product and production system development researches. Jina, Bhattacharya and Walton (1997) present some of the differences between low and high volume production systems in their work (see table 1.).

Qudrat-Ullah, Seong and Mills (2012) present some of the distinct challenges of industrialization in low-volume production systems such as shorter available time for prototyping and high cost of changes in production systems relative to the production volume. Late changes in design caused by misunderstanding of the customer requirements and non-conformity of the design and manufacturing are also identified as the sources of disturbances in low-volume production systems (Bellgran and

Aresu 2003). Resource bottlenecks caused by sharing resources between several projects are another challenging factor in low-volume production systems.

Table1: Comparison between high and low-volume production systems characteristics (Jina, Bhattacharya and Walton 1997)

Characteristic	**High-volume production**	**Low-volume production**
Typical annual volume	From 100,000 to 1,000,000+ units per year	From 20-500 and 5,000- 20,000 units per year
Product variety and complexity	Medium with no bespoke products, specialist products are separated into dedicated plants	Very high, some bespoke products are delivered also. All manufacturing in the same plant
Manufacturing planning system	Stabilized by a degree of make to stock with primarily assemble to order	Low-volume with full make to order
Order winning criteria	Variety, delivery speed, "All in" product features	Variety, bespoke products, "Extra features", delivery speed

To overcome these issues earlier and clearer definition of the customer requirements and clarity of the information flow are required (Qudrat-Ullah, Seong and Mills 2012, Srinivasan, Ebbing and Swearingen 2003). Using a functional engineering organization, designing the product within the abilities of the current production system and more collaboration of design engineers with manufacturing can facilitate the industrialization process in low-volume production systems (Qudrat-Ullah, Seong and Mills 2012). The mentioned differences between high and low-volume production systems and the need to find facilitating factors for challenges require more in-depth studies of the industrialization process in such systems.

3 METHODOLOGY

In this research, an exploratory multiple case study approach was selected due to the goal of this paper (Yin 2009) to identify challenges of the industrialization process in low-volume production systems. The empirical data of this paper is based on three case studies within two Swedish manufacturing companies. The industrialization process in product development projects in a low-volume production system were followed in the first two case studies while the third one was aimed to follow the same process in a high-volume production system. The case studies allowed observing the challenges of the industrialization process during the different stages of product development projects. The multiple case study method also allowed the comparison between industrialization process in low volume and high-volume production systems (Yin 2009).

Data has been gathered by means of active participation in meetings, daily activities of the industrialization process and study of the projects documents. In addition, semi-structured interviews were done with the key individuals who were involved in the projects. The gathered data allowed identifying the challenges which could degrade or hinder the industrialization process.

Case A and B were followed over a period of five months within a leading company in the off-road trucks and mining machinery industry. Five different product groups are produced at the company while each group includes different models with numerous options to meet the legislative and customers' requirements with a low yearly demand. Case C was carried out during an 8-month period at a service provider in the automotive industry, i.e. the company was responsible for the development, industrialization and assembly of the product. The company produces its products in high-volumes with limited variants.

The product development project was selected as the unit of analysis. The data was analysed in three steps. In the first step, data from each case was analysed separately to identify the unique challenges of each case. Secondly, a cross-case analysis was done to compare the identified characteristics between the cases to specify the distinct challenges of the industrialization process. Finally the empirical findings were compared to the identified results of the literature study.

4 EMPIRICAL FINDINGS

4.1 The case studies of industrialization in a low-volume production system

Case A and B are still on-going and they basically followed a same process based on a conventional stage gate model. The projects were led by a cross-functional team consisting of a project leader and sub-project leaders from R&D, prototyping, purchase and aftermarket functions. In addition, an industrialization sub-project leader was responsible for following the production-related aspects of the project. Sub-project leaders were also involved in other projects and their daily work activities. Regular and informal meetings were the main way of information sharing. The industrialization and prototype development sub-project leaders contributed actively from the beginning of the projects to manage the product and production development systems mutual requirements.

In addition to those common characteristics, each case had specific characteristics. Case A was a minor product modification which aims to upgrade one of the product modules of a specific product and the total project timeframe is 14 months. The project did not include any pre-series production and had a shorter industrializations process. Therefore, the project is considered as a small product development project. This research presents the results obtained from the first three phases of the project which are feasibility and concept study, design and prototyping and functional and field test.

Case B was a general modification in a product group which consists of five different products. The total time estimation for the project was 30 months with a longer industrialization process including pre-series production. As a result, it was defined as a large project. The results from the first two phases of the project are presented in this paper.

4.2 The case study of industrialization in a high volume production system: case C

Case C targets for the industrialization were mainly related to cost, volume and quality. Since both the product and the production system was new, the industrialization can be described as complex.
The project followed a stage-gate process and was led by two project managers; one project manager was responsible for the product development and one responsible for the industrialization. The industrialization project team included members from production engineering, quality, and logistics. The project members were supposed to carry out the work activities related to the industrialization in addition to their daily work activities.

To coordinate and control the work between the two project groups and within the industrialization project groups regular project meetings were carried out and an engineering change order was implemented. The engineering change order described a process required to release or to change the product design. Information was mainly shared in regular and informal meetings and by means of documents.

4.3 Cross-case comparison

In addition to the above mentioned characteristics, other specifications of the cases are presented and compared to each other in Table 2.

5 ANALYSIS

The findings of the case studies show that an effective information management, project organization, resource allocation and early involvement of production in the project are critical factors for an effective industrialization process of both low-volume and high-volume productions systems. However, the results indicate some specific challenges in the industrialization process of the low-volume production systems.

The first identified challenge is fewer opportunities for training the operators and knowledge transfer from the projects into operation. This challenge is caused by low-volume highly-customized products and full make-to-order policy which do not allow high number of pre-series production and a gradual production ramp-up as the final stages of the industrialization process. Lack of resources which does not allow involving all the production operators in the industrialization process is another reason of this challenge.

Table 2: comparison of the characteristics of the case studies

Criteria	**Low volume**		**High Volume**
Case name	Case A	Case B	Case C
Product characteristics			
Yearly Volume	<20	<30	Up to 250 000
Product complexity	High	High	low
Variety (excluding options)	5 variants	7 Variants	3 variants
Production system characteristics			
Cycle time	96 hours	128 hours	55 sec
Number of stations	6	4	10
Flexibility	Different products are produced at the same production line	Different products are produced at the same production line	The production system produces one product
Automation level	Low, mainly manual	Low, mainly manual	High
Job rotation	No	No	Yes
Level of required skills for operators	High	High	Low
Industrialization process characteristics			
Targets for production system development	Applying the minimum changes to the current production system to maintain its flexibility	Applying the minimum changes to the current production system to maintain its flexibility	New production system designed aiming at optimizing for serial production
Prototype development	1 prototype of the modified module	Few prototypes of the whole product	Many prototypes of the whole product
Competence development	One expert line operator participates in the prototype development	Two expert line operators participate in the prototype development	Future team leader & operators are involved in the work but still work in current production
Pre- series production	No pre-series, new modules are assembled on products in the normal production flow	1 product, it can be increased up to 4 based on the customers' orders	1000 products
Work instruction development	Drafted during the prototyping, finalized during the production	Drafted during the prototyping, finalized during the pre-series	Developed during the prototyping
Production ramp-up	No gradual production ramp-up is possible	No gradual production ramp-up is possible	Gradual production ramp-up

The second challenge is developing and finalizing the work instructions. This challenge is also caused by the limited number of prototypes and the pre-series production and absence of a gradual production ramp-up process. This can lead to disturbances during the commercial production.

The third identified challenge is a need for a higher level of training of the production operators. Longer production cycle times and more complex products comparing to the high-volume ones and mainly manual production system require more skilled operators. High commitment and involvement of production operators in prototype development is a possibility to overcome this challenge.

The last identified challenge is relatively costly and time-consuming development of a new production system for new products considering the low volumes of the products and short time for development. Tailoring the product to the current production capabilities is one way to overcome this challenge which can also reduce the need for new trainings for production operators.

6 CONCLUSION

The case studies in this research provide an insight to the challenges of the industrialization process of low-volume production systems. The presented results show that the low-volume production systems have different characteristics which distinguish their industrialization process from the same process in high-volume production systems. Such differences lead to specific challenges in the industrialization process of low-volume production systems as presented.

Overcoming such challenges require developing tailored solutions. Identification of different aspects of these challenges and developing appropriate solutions for them requires more in-depth studies which will be the subject of the future studies.

REFERENCES

Adler, P. S. & K. B. Clark 1991. Behind the learning curve: A sketch of the learning process. *Management Science,* 37**,** 267-281.

Almgren, H. 1999. *Pilot Production and Manufacturing Start-up in the Automotive Industry. Principles for Improved Performance.* Chalmers University of Technology.

Aresu, E. 2001. *Design process management for successful assembly systems,* Production Systems, Department of Mechanical Engineering, Linköpings universitet.

Bellgran, M. & E. Aresu 2003. Handling disturbances in small volume production. *Robotics and Computer-Integrated Manufacturing,* 19**,** 123-134.

Bellgran, M. & K. Säfsten 2010. *Production Development: Design and Operation of Production Systems*, Springer London.

Berg, M. 2007. *Factors affecting production ramp-up performance.* Jönköping University.

Berglund, M., U. Harlin & P. Gullander. Challenges in a product introduction in a cross-cultural work system - a case study involving a Swedish and a Chinese company. The 5th international Swedish production symposium, 2012 Linköping, Sweden.

Bruch, J. 2012. *Management of design information in the production system design process.* Jönköping University.

Bruch, J. & M. Bellgran 2012. Creating a competitive edge when designing production systems: facilitating the sharing of design information. *International Journal of Services Sciences,* 4**,** 257-276.

Chryssolouris, G. 2006. *Manufacturing Systems: Theory and Practice*, Springer Science+Business Media, Incorporated.

Fjällström, S. 2007. *The role of information in production ramp-up situations*, Chalmers University of Technology.

Hendricks, K. B. & V. R. Singhal 2008. The effect of product introduction delays on operating performance. *Management Science,* 54**,** 878-892.

Jina, J., A. K. Bhattacharya & A. D. Walton 1997. Applying lean principles for high product variety and low volumes: some issues and propositions. *Logistics Information Management,* 10**,** 5-13.

Johansen, K. 2005. *Collaborative Product Introduction within Extended Enterprises.* Linköping.

Qudrat-Ullah, H., B. S. Seong & B. L. Mills 2012. Improving high variable-low volume operations: an exploration into the lean product development. *International Journal of Technology Management,* 57**,** 49-70.

Srinivasan, M. M., S. J. Ebbing & A. T. Swearingen 2003. Woodward Aircraft Engine Systems sets work-in-process levels for high-variety, low-volume products. *Interfaces,* 33**,** 61-69.

Säfsten, K. & E. Aresu 2002. Assembly System Design and Evaluation of 15 Manufacturing Companies in Sweden. *Manufactoring Systems,* 31.

Terwiesch, C. & R. Bohn 2001. Learning and process improvement during production ramp-up. *International journal of production economics,* 70**,** 1-19.

Terwiesch, C., R. Bohn & K. Chea 2001. International product transfer and production ramp-up: a case study from the data storage industry. *R&D Management,* 31**,** 435-451.

Vandevelde, A. & R. Van Dierdonck 2003. Managing the design-manufacturing interface. *International Journal of Operations & Production Management,* 23**,** 1326-1348.

Yin, R. K. 2009. *Case study research: Design and methods*, Sage Publications, Incorporated.