Article

Not peer-reviewed version

Tailoring Product Introduction Management Strategies to the Characteristics of Low-Volume Manufacturing: A Focus on Improving Information Content Quality

Siavash Javadi and Koteshwar Chirumalla *

Posted Date: 9 November 2023

doi: 10.20944/preprints202311.0549.v1

Keywords: Product industrialization; low-volume; high-mix, low-volume manufacturing; information management; information content quality; management mechanisms; production management, new product development, design-manufacturing interface

Article

Product Introduction Management Strategies and Information Content Quality: A Low-Volume Manufacturing Perspective

Siavash Javadi and Koteshwar Chirumalla *

Production Development Research Group, Innovation and Product Realisation Research Environment, Mälardalen University, Eskilstuna, Sweden

* Correspondence: koteshwar.chirumalla@mdu.se

Abstract: Product introductions play a pivotal role in the success and competitiveness of manufacturing, particularly in the context of new product development. Low-volume manufacturing companies exhibit distinct characteristics that significantly influence the product introduction process. Notably, the quality of information exchange between product design and production interfaces becomes paramount in this high-mix and low-volume industry. Consequently, there exists a pressing need to explore various methods for adapting and customizing management mechanisms and strategies to align with the unique requirements and characteristics of low-volume manufacturing and its associated product introduction processes. While the need for this knowledge is critical in the context of low-volume manufacturing, a majority of existing studies predominantly focus on the management aspects within high-volume manufacturing. Therefore, the primary aim of this study is to investigate the customization of product introduction management strategies to enhance the quality of information content within the realm of low-volume manufacturing. Drawing upon a longitudinal analysis of new product introductions within a low-volume manufacturing company, this study narratively elucidates how the examined company implemented product introduction management strategies to facilitate the enhancement of information content quality during the product introduction phase. The study presents its findings on management strategies across three key stages: pre-implementation, post-implementation, and subsequent modification and refinement of strategies following the initial round of implementation. By shedding light on these strategies, this study offers a comprehensive understanding of management approaches in the context of low-volume product introduction. As a result, it makes a valuable contribution to the discourse on information management and interface management in the high-mix, low-volume manufacturing literature.

Keywords: product industrialization; low-volume; high-mix; low-volume manufacturing; information management; information content quality; management mechanisms; production management; new product development; design-manufacturing interface

1. Introduction

The ever-increasing competition in the global market and the faster introduction of new technologies force manufacturing companies to develop and introduce new products more frequently and to reduce the time-to market and time to payback [1]. A well-functioning product introduction process, which in this paper refers to the process of transferring product concepts from engineering design to production [2], plays a key role for manufacturing companies' competitiveness by shortening the time to market, allowing low-cost production, and ensuring high quality products [3-5].

In this context, managing information with the right quality during the product introduction process becomes critical [6-11]. In particular, researchers acknowledge that content quality of the developed and shared information during product introduction, **i.e.,** the soundness and relevance of

 doi:10.20944/preprints202311.0549.v1

the information to its purpose [12-14], plays a key role in management and success of product introduction [9, 15, 16]. Information content quality shortcomings such as handing over incorrect, incomplete, outdated or unclear information to production is a common cause of disturbances during early stages of production of new products [9, 17, 18]. More specifically, lack of quality of information content about product and production processes can lead to disturbances such as production stops and delays in achieving product introduction targets such as planned product quality and production volume [9, 19].

Therefore, one of key aims of most of the product introduction management strategies is to improve content quality of developed and shared information during product introduction process. Examples of such management strategies are the early and active involvement of production in the product introduction activities [20, 21] and the formal coordination between design and production [22-24]. Using design for manufacturing methods, design reviews, joint design and development teams [22] and including a launch manager in the project organization [25] are some examples of such formal coordination between design and production.

Whereas low-volume manufacturing companies comprise a considerable part of manufacturing industries, product introduction and its management strategies in such companies have not been considered sufficiently studied [26-29]. Companies that produce low-volume highly customizable products comprise over 10% of all production in Europe's manufacturing industries and employ more than 4 million people [30].

The characteristics of low-volume manufacturing companies impose challenges and requirements on the product introduction process, which cannot be managed by solely relying on the management strategies that have been developed for high-volume manufacturing companies [31-33]. Low-volume manufacturing companies are usually characterized by the high variety and customizability of their products and have a make-to-order production policy [34]. Such characteristics form a product introduction process that differs from the common product introduction process in high-volume manufacturing industries. There are fewer opportunities for testing and refinement of products and production systems and adapting them together which means fewer opportunities for identifying and removing the information content quality shortcomings.

Therefore, it is important to develop product introduction management strategies that are customized for such characteristics and can meet the requirements of low-volume manufacturing industries. As information content quality is a focal point of many product introduction management strategies, one way to customize those strategies to the requirements of low-volume manufacturing companies is to study how the information content quality can be improved by different means that are more suitable to the characteristics of such industries.

Therefore, the aim of this paper is to investigate how to customize product introduction management strategies to improve information content quality within low-volume manufacturing.

This aim has been followed by a longitudinal study of new product introductions in three stages in a low-volume manufacturing company that implemented new product management strategies: before the implementation of new product introduction management strategies, after the pilot implementation, and after the modification and refinement of the implemented strategies based on the lessons learned from the pilot implementation.

The paper presents how implementation of product management strategies and customization of the strategies to the characteristics of low-volume manufacturing facilitate enhancement of content quality of information during product introduction in low-volume manufacturing.

2. Theoretical framework

2.1. Product introduction and management strategies

Product introduction management strategies have been investigated from different perspectives because of the critical role of successful product introduction in achieving time-to-market & quality targets [1, 2]. Product introduction covers iterative mutual adjustment of product and production system during production system design to transform a product design into volume production [3].

 doi:10.20944/preprints202311.0549.v1

Whereas it is defined with different scopes and activities [4, 5], it is generally recognized as the interface between product design & production design for collaboration and information sharing [6-9].

Different strategies have been suggested and investigated for managing product introduction to achieve high product quality and low disturbances in production during introduction of new products. Product introduction management strategies are primarily aimed to facilitate development and adaptation of product and production system together and identification the required changes in product and production system as early as possible to avoid disturbances and higher costs in later phases of product introduction [3, 6, 10, 11].

Many of such strategies can be categorized as strategies for formal coordination between design and production [12]. Such strategies are primarily aimed to establish more formalized and structured ways of collaboration between design and production to facilitate information sharing and assure that both sides receive information with high content quality about both product and production system [6, 13, 14]. A very well-known strategy in this category is having a formal approach to design reviews to go through the latest design changes together with production in every design cycle to understand their influences on production. Another formal coordination method is creating joint design and development teams with early involvement of production engineers and personnel from the start of the projects in the project through joint organizations [1, 6, 15] .

Other coordination strategies include formalizing production requirements as design goals by different methods such as DFM/DFA to assure that production requirements and limitations are considered and included in the design of new products [6, 13, 16].

Another category of the product introduction management strategies covers strategies for testing and verification of the production system. The primary focus of such strategies is creating opportunities to test the production processes to verify them and identify non-conformities between product and production processes and eliminate them by modification of product or production system [3, 17, 18]. Development of prototypes in earlier phases of product introduction is a common example of such strategies. Whereas in many cases prototypes are developed to test the functionality of the product [4, 5, 19], it also provides an opportunity for production to investigate manufacturability of the product and test and develop the production processes [4, 5, 19-21]. Another common way of production test and verification is production of pre-series in later phases of product introduction [2-4] when the product is mature enough so the production can finalize the production processes and refine the product and production processes to remove the remaining non-conformities [4, 10].

In addition to two above mentioned categories, other strategies have been mentioned for managing product introduction such as:

Adding a launch/product introduction manager and group to the project teams for planning and following-up product introduction goals and activities [6, 12].

Co-location of design and production to facilitate communication and information sharing [6]

Establishing within- and cross-project learning structures by documenting, sharing, and using the lessons learned from product introductions[22-25].

Considering the ever-increasing role of digitalization in different aspects of product introduction, use of digital tools has been considered as an integrated facilitating part of the above-mentioned product introduction management strategies.

For example, using CAD/CAM tools in design reviews [26], digital prototyping [20, 21], and simulation of production processes for test and verification [27]. Use of such digital tools in many cases enables faster, more cost-effective and more efficient implementation of the product introduction management strategies [26]. For example, using CAD/CAM for digital prototyping and testing different production scenarios helps to avoid the high cost of development of several physical prototypes and implementing physical test assemblies [20, 21]. Such benefits made digital tools an integrated part of the product introduction management strategies.

 doi:10.20944/preprints202311.0549.v1

2.2. Product introduction in low-volume manufacturing

In comparison to products with high production volumes, introduction of new products in low-volume manufacturing industries usually contain additional challenges which are caused by characteristics of such companies and their products [2, 28]. Products with high variety, high level of customizability and low production volumes have influences on the product introduction such as

- spreading resources of both production and design thinly among introduction of several products [28, 29].
- limited availability of common product and production system test, verification, and adaptation methods such as prototyping and production of pre-series products [28, 30].
- lack of opportunities for training production personnel and final verification of the production processes for production of new products due to infeasibility of conventional production ramp-up [2, 28].

Such challenges limit the possibility of using conventional product introduction management strategies which are generally based on practices in high-volume manufacturing companies. Different studies such as [2, 31] have clearly identified a need for products introduction management strategies that are tailored for the characteristics and requirements of low-volume manufacturing industries.

However, studies on the product introduction management strategies in low-volume manufacturing industries are limited [2, 32]. Qudrat-Ullah, Seong and Mills [29] suggests early and clear definition of both product and production systems requirements. Kumar and Wellbrock [33] emphasize on the front-end loading strategies and use of digital tools such as CAD/CAM technologies to manage the product introduction in low-volume manufacturing companies. Other studies investigated using product introduction management strategies on a general level without investigating the requirements and characteristics of low-volume manufacturing companies [1, 6, 7, 12, 22, 34-38].

2.3. Information content quality and its role in product introduction management strategies

In general, information quality is defined as fitness of information for a given use [39] and information content quality refers to soundness and relevance of the information for that given use [40]. Information content quality has been defined by different criteria by researchers such as English [41], Eppler [40] and Wang, Pierce [42]. Table 1 summarizes different information content quality criteria.

Table 1. information content quality criteria.

Criterion	Definition
Completeness	The required data values and facts are complete
Accuracy	Information conforms to reality
Clarity	Information is clear and understandable for its user
Applicability	The information is directly and practically usable for its purpose in a given context.
Conciseness	The information does not contain superfluous and unrelated elements.
Consistency	The equivalency of the information about the same object in different data collections
Correctness	The information does not contain errors
Currency	The information is not outdated by more recent information.

Product introduction as a knowledge-intensive process involves continuous cross-functional information development and sharing, including between design and production [3, 7, 43, 44]. The quality of the developed and shared information about both product and production system plays a key role in success of introduction of products [5, 38, 43, 44].

Incomplete, incorrect and inaccurate information about production processes and product specifications [5, 38, 44] and lack of clarity and applicability of the information shared by design about new products [5, 44-46] are common sources of disturbances during introduction of new products.

 doi:10.20944/preprints202311.0549.v1

Examples of such information content quality deficiencies are unclear or incomplete assembly instructions [5, 9] and incorrect, incomplete, inaccurate or inapplicable product details information [5, 9].

From this perspective, many product introduction management strategies are concentrated on improving the content quality of the developed and shared information during product introductions [6, 18, 34, 47]. For instance, using DFM methods and design reviews help to improve clarity, completeness and correctness of the information about manufacturability of the products [6, 12, 16]. Other management strategies such as test and verifications plans contribute to different content quality aspects of manufacturing processes information such as assembly instructions [4, 10, 45, 48, 49].

Studies such as Surbier [9] highlight the content quality shortcomings of the information that is developed and shared during product introduction in low-volume manufacturing industries. They mention disturbances caused by incomplete, incorrect, inaccurate, and unclear information about both product and production processes such as missing information about small connecting parts which are caused by the characteristics of product introduction in such industries.

3. Materials and Methods

3.1. Research approach

Given the multifaceted and context-specific nature of the product introduction challenges in low-volume manufacturing, a qualitative research approach [53], employing a longitudinal case study design [54, 55, 56] , is well-suited for this research endeavor. The inherent complexities and unique characteristics of low-volume manufacturing call for a research approach that delves deep into real-world contexts. A case study design offers several advantages in investigating and addressing the intricacies of this contemporary phenomenon.

First and foremost, the case study approach provides an avenue for an in-depth understanding, description, and exploration of the real-life issues, events, and phenomena [56] specific to low-volume manufacturing product introductions. This method is particularly apt for capturing the dynamic nature of the product introduction process, as it unfolds over time, within the unique context of low-volume manufacturing [56]. Furthermore, the case study methodology excels at facilitating exploratory research, which is vital for uncovering the nuances of the product introduction process within the low-volume manufacturing sector [57]. By allowing for an extended examination of a real-world situation, it encourages the generation of new insights, the discovery of innovative ideas, and the development of customized management strategies to improve information content quality [56, 58].

In addition, the case study method is instrumental in capturing the social and organizational contexts that surround the evolving phenomenon of product introduction in low-volume manufacturing [56]. It enables the collection of multiple observations, encompassing perspectives from both product designers and production interface personnel, thus shedding light on the intricate relational processes involved in managing information content [56, 57, 59]. Moreover, the case study approach is well-suited for understanding "how?" (e.g., how can management strategies be adapted to enhance information content quality?) inquiries that pertain to this contemporary phenomenon embedded within the real-world context of low-volume manufacturing [56]. It harmonizes seamlessly with the specific objectives of this study, which seeks to uncover and elucidate the management strategies that drive improvements in information content quality during the product introduction process within low-volume manufacturing companies.

In addition, the longitudinal examination chosen for this research allows for a comprehensive exploration of this crucial aspect of the manufacturing industry, fostering a deeper understanding of the strategies that drive success in this high-mix, low-volume sector Longitudinal research allows for the investigation of how product introduction management strategies evolve and adapt over time to meet the changing needs and challenges in low-volume manufacturing. This temporal perspective provides valuable insights into the long-term effectiveness of these strategies [54, 60]. By tracking the

 doi:10.20944/preprints202311.0549.v1

implementation, modification, and refinement of management strategies at multiple time points, a longitudinal approach can help establish causal relationships between strategy adjustments and improvements in information content quality, contributing to a stronger evidence base for effective strategies [60, 61]. Longitudinal studies provide opportunities to observe how organizations learn from their experiences and adapt their management strategies accordingly [60]. This is particularly relevant in the context of low-volume manufacturing, where continuous improvement is essential.

3.2. Research setting

The study was conducted at a Swedish manufacturer of mining and construction equipment. During the study, the company developed and produced products in five product families with several variants with high levels of customizability based on the requirements of different customers and markets all around the world. When the study started, the company had recently introduced new product introduction management mechanisms. After three years of implementation of the mechanisms, they were revised and modified based on the experiences and lessons learned during those three years. To capture the journey of the company through the three stages, i.e., before and after the pilot implementation and after modification of the implemented mechanisms, five product development projects as the context of product introduction has been studied during these stages which are presented briefly in Table 1.

Table 1. The studied product development projects.

Project	Product development goal	Study type	Related stage
A	New cabin for product A based on a customer demand	Retrospective	Before implementation of the management strategies
B	Upgrading the powertrain of product B based on changed market legislations	Retrospective	Before implementation of the management strategies
C	New cabin for product C based on a customer demand	Real-time	After the pilot implementation of the management strategies
D	Upgrading the powertrain of product D based on changed market legislations	Real-time	After the pilot implementation of the management strategies
E	Integrating a new technology in the powertrain of Product A	Real-time	After modification and refinement of the management strategies after the pilot implementation

3.3. Data collection

Data from the projects A-E were gathered using various methods, including semi-structured interviews, observations from project meetings and activities, and pertinent project documents. Table 2 provides a summary of the diverse data collection approaches employed in five distinct projects, labeled A to E. The data collected from these projects were utilized to conduct a comparative analysis of product introductions within the company across three different stages. The objective was to gain insight into the implementation of management mechanisms, their outcomes, and the essential components contributing to the establishment of a systematic product introduction management process.

Semi-structured interviews were the primary method of data collection [56] in this study. Semi-structured interviews offer a flexible and adaptive approach, well-suited for exploring the multifaceted and context-specific characteristics of low-volume manufacturing and the product introduction process. This approach allows for the formulation of open-ended questions and the use

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 November 2023 doi:10.20944/preprints202311.0549.v1

of follow-up probes, enabling researchers to delve deeply into the complexities of the subject matter [62]. Moreover, semi-structured interviews provide a platform for gathering rich, qualitative data by allowing participants to share their experiences, insights, and perspectives in their own words [63]. This method facilitates the acquisition of nuanced information, which is essential for gaining a deep understanding of the intricacies of product introduction management and information content quality within the low-volume manufacturing sector. In total, 46 interviews were conducted with relevant project stakeholders A-E, and all collected data were meticulously recorded and transcribed.

Observing project meetings and events allows researchers to gain real-time insights into the dynamics of product introduction management. This method provides an opportunity to understand how management mechanisms are put into practice within the dynamic context of project meetings, offering valuable contextual information that may not be fully captured through interviews alone [64]. Observational data can serve as a form of data validation and triangulation, helping to corroborate information obtained through interviews and document review [65]. By cross-referencing observations with other data sources, researchers can enhance the reliability and validity of their findings, contributing to a more robust analysis [65]. In total, 82 meetings and events are covered during the data collection process.

Examining complementary documents, such as historical project records and reports, can provide researchers with historical context and long-term trends related to product introduction management. This historical perspective can help researchers trace the evolution of management mechanisms and identify patterns that might not be evident through interviews or observations alone [56]. Complementary documents can offer supplementary information, details, and background knowledge that enrich the understanding of the subject matter. This additional information can provide a more comprehensive view of product introduction management and support the interpretation of findings from interviews and observations [66].

Table 2. Means and details of data collection.

Means of data collection	Project A	Project B	Project C	Project D	Project E	Details
Interviews: # of interviews (# of respondents)	Production engineers 1(1) - Project managers 1(1) - Production supervisors 1(1) - Production operators 1(1) - Prototype assembly operators 1(1)	Production engineers 1(1) - Project managers (1) - Production supervisors 1(1) - Production operators 1(1) - Prototype assembly operators 1(1)	- Product introduction managers 2(1) - Production planners for new products 1(1) - Production engineers 1(1) - Production operators 6(6) - Project managers 1 (1) - Prototype development managers 1(1) - Design managers 2(1)	- Product introduction managers 3(1) - Production planners for new products 1(1) - Production engineers 1(1) - Production operators 6(6) - Project managers 2(1) - Prototype development managers 1(1) - Design managers 2(1)	- Product introduction managers 1(1) - Project managers 2(1) - Design managers 1(1)	The interviews took between 30 to 90 minutes. The interviews were recorded and transcribed. Total # of conducted interviews: 46

 doi:10.20944/preprints202311.0549.v1

		- Prototype assembly operators 1(1)	- Prototype assembly operators 1(1)		
Observing project meetings and events: Meeting name (#)	-	- Weekly project meetings (22) - Design reviews (2) - Prototype development activities (1) - Production morning meetings (4)	- Weekly project meetings (29) - Design reviews (4) - Prototype development activities (3) - Production morning meetings (4)	- Weekly project meetings (11) - Design reviews (1) - Prototype development activities (1)	The meetings were attended as an observer. Notes were taken during the meeting and events. Total # of attended meeting and events: 82
Reviewing complementary documents	- Project logs, drawings, bill of materials, assembly instructions, minutes of meetings and emails - Records of a database that was used for the registration and follow-up of the disturbances during the production of new products			Project logs, drawings, bill of materials, assembly instructions, minutes of meetings and emails	

3.4. Data analysis

The data collected from diverse projects A-E and various sources, including semi-structured interviews, observations from project meetings, and a review of complementary documents, formed the cornerstone for conducting a comprehensive analysis of management strategies within the context of low-volume manufacturing product introductions. To unravel the intricacies of the qualitative data, a systematic approach was meticulously employed. Initially, the data underwent a rigorous process of transcription to ensure the accurate capture of all responses and observations for subsequent analysis. Subsequently, the analysis process entailed identifying recurring themes, patterns, and key elements within the data [67]. The categorization and pattern matching were executed through an Excel spreadsheet, which provided an organized platform for systematically sorting, coding, and categorizing the data. This approach streamlined the analysis process, improving the efficiency of pattern recognition and enabling the research team to extract meaningful insights from the extensive dataset.

This meticulous approach led to the mapping of how the case company adapted and implemented the primary management strategies across three defined stages encompassing the product introduction process. It illuminated how these implementations influenced information content quality. The analysis was characterized by an iterative process, commencing with an initial round of categorization and pattern identification, followed by a comprehensive exploration of the relationships and interdependencies among these categories. This iterative approach was indispensable for delving into the multifaceted and context-specific characteristics of management strategies within the low-volume manufacturing sector. Throughout the analysis, a strict and systematic approach was upheld to ensure the reliability and validity of the data [68]. The culmination of this analysis yielded valuable insights into the critical elements of successful management strategies and their impact on information content quality during product introductions in the low-volume manufacturing sector. These insights are further detailed and summarized in Table 4, allowing for in-depth explanations and the formulation of conclusive findings.

 doi:10.20944/preprints202311.0549.v1

4. Results

The results are presented in the following manner:

In Section 4.1, we provide an overview of the case company's low-volume product introduction process, highlighting its unique characteristics and key challenges. Moving on to Section 4.2, each of the four adapted management strategies is introduced individually, with in-depth details regarding their implementation and relevance. Section 4.3 offers a comprehensive account of how the case company addressed these management strategies during the pilot implementation phase and the subsequent modifications and refinements made after the pilot implementation. In Section 4.4, we present a thorough assessment of the impact of these strategies on information content quality throughout the product introduction process, providing a holistic understanding of their influence. Lastly, Section 4.5 outlines the path forward concerning the continued utilization of these management strategies by the case company.

4.1. Case company's low-volume PI, characteristics, key challenges

Before implementation of new product introduction management strategies, development and introduction of new products was done with a very limited consideration of production-related requirements and targets and with complete focus on products functionality and quality.

The product development projects included the following phases: the feasibility and concept study, the concept development and the detailed development of the product which included the development of a very limited number of prototypes to test and refine the products' functionality. After these phases, the products were officially handed over to production. In other words, there was no formal product introduction process that included the testing and refinement of the production system and adapting the product and production systems together. The projects were managed by a cross-functional team that included a project manager and representatives from design, marketing, after-market, and production. Production was represented by a production engineer from the related production line.

Such a lack of formal coordination was partially because of the low novelty of the products and production systems. The products were usually a new version or variant of an existing product (see Table 2), and the production systems were flexible enough to produce new products with minor changes. Therefore, it was assumed by design that there was already enough existing knowledge about the products in production, and therefore, formal design-production coordination strategies were not considered.

The company faced considerable challenges in the production of new products as an outcome of the above-mentioned lack of formal coordination strategies for product introduction. Such challenges occur in different forms such as production stoppages to quality problems and non-conformities in the products that were sent to customers.

The study of Project A and Project B showed that a considerable part of these challenges was related to content quality of the information that was handed over to production. Following aspects of information content quality have been identified as the main sources of the disturbances during production of new products:

Information completeness: The information about new parts or their assembly instructions was not created or was not complete.

Information correctness, clarity, and accuracy: Information such as part details and assembly instructions were incorrect or did not match the real product or were not understandable.

Information consistency and currency: information about parts such as part numbers and denominations did not match in different documents and information sources because similar parts or old information was used. Such issues were mainly caused by reuses of similar parts with small modifications in different products.

Such information content quality shortcomings were mainly related to the information about small connecting parts such as pipes and hoses, cables and mechanical joints which were not considered sufficiently during the design of new products because of increased focus on the product functionality and lack of consideration of product manufacturability.

 doi:10.20944/preprints202311.0549.v1

4.2. Product introduction management strategies

To improve the introduction of new products and reduce the disturbances, the case company adapted and implemented four main product introduction management strategies. The strategies were based on the knowledge and experiences from high-volume manufacturing because of the following: 1) The available literature about the product introduction process was based on studies from high-volume manufacturing companies, and 2) most of the members of the new product introduction department had backgrounds and experiences from high-volume manufacturing companies. The adapted strategies are described in the following.

4.2.1. Securing a production test and verification plan

To assure that the product and production system are compatible to each other and information content quality shortcomings about production of new products are captured before commercial production, new phases were added to the product development projects with a focus on including more opportunities for the testing and refinement of products and production systems and adapting them together. Such opportunities were based on the development of exact numbers of prototypes and pre-series based on the scope of the projects. Therefore, the projects were categorized into three categories, large, medium, and small, based on the level of newness of the products. For each category, an exact number of minimum required prototypes and pre-series products were assigned.

4.2.2. Revising the role of product introduction management

To have a more organized approach toward product introduction and assure that the activities and deliveries related to the product introduction are followed-up during the whole project, management of the product introduction was transferred from production to a new department that was called product introduction and new role of product introduction manager was added to project teams. The product introduction manager was responsible for planning and implementation of product introduction activities.

4.2.3. Formal design and production coordination plan

A few different methods of design-production coordination have been adapted to assure that production and design get correct, complete, clear, and up-to-date information about each other's progress and requirements. These methods were:

- Design reviews were for the coordination between design and production to allow them to discuss the new features of the products and their implications for production.
- Planned involvement of production personnel in the development of prototypes. Whereas prototypes were primarily assembled by prototype development operators, it was decided to plan the involvement of production operators and supervisors in the development of the prototypes to include their perspectives regarding the manufacturability aspects of the products.
- Collection of the production requirements early in the projects during the concept study of the products to analyze them and include them in the design goals.

4.2.4. Lessons learned management plan

A structured approach to gathering the lessons learned was established to collect them in each project with the main aim of understanding the effects of the new product introduction management strategies. However, it provided a basis for reusing the learnings in the future similar projects. The product introduction manager was responsible for collecting and documenting the lessons learned from the introduction of new products.

 doi:10.20944/preprints202311.0549.v1

4.3. Addressing four management strategies during the pilot implementation stage, and the subsequent modification and refinements made after the pilot implementation

4.3.1. Pilot implementation

4.3.1.1. Securing a test and verification plan

Planning a number of prototypes and pre-series in the project plans to secure test and verification of the production processes provided more opportunities to develop more accurate, correct, and complete information about production of new products for instance, the production engineers for new products had more opportunities to develop detailed assembly instructions. Furthermore, the pre-series production helped to capture the non-conformities or lack of the information about the products such as incorrect or redundant part numbers, incomplete, incorrect, or unclear information about small connecting parts or incompatibility of the product design with assembly methods.

4.3.1.2. Revising the role of PI management

Assigning a separate department and person to following up product introduction activities contributed directly and indirectly to the considerable improvement of different information content quality aspects. The product introduction managers helped to plan, follow-up and documenting the activities for introduction of new products and guide both design and production to focus on the critical information that should be exchanged to reduce the disturbances during the introduction of new products. More complete, clear, and correct information has been exchanged between design and production by planning and guiding activities such as design reviews and prototype and pre-series development with concentrating on manufacturability aspects of the products. The product introduction managers facilitated focusing on relevant questions to the goals of product introduction activities and understand the purpose of new PI management strategies and in this way increased the awareness also about the main information content quality shortcomings. One of the project managers stated the following:

"These activities are new to all of us, and it is great to have someone exclusively responsible for planning them and following them up. Otherwise, it will be really difficult to establish these new routines among activities that we are more used to and more comfortable to do".

4.3.1.3. Formal design and production coordination plan

Using different coordination methods between design & production improved different aspects of the information content quality already in the pilot period. Production received more up-to-date, complete, and correct information about the latest design changes as one of the production supervisors mentioned the following:

"It is easier to plan things as we get to know what is new, what is going to happen and what plan is going to be followed from the beginning."

Furthermore, the details provided both during the design reviews and prototype development to the involved production personnel helped them to receive and provide more correct, clear, and complete information, especially about manufacturability aspects of the new products and requirements and limitations of the production system. As one of the of the production operators commented on his involvement in the development of prototypes:

"They have a different set-up here (in prototype development workshops) so they can produce solutions for assembly that are impossible or difficult to follow in the production lines. When we are here, we can help them to understand what is doable and what is not … and we get a concrete idea about what is new in the products before they come to production."

 doi:10.20944/preprints202311.0549.v1

4.3.1.4. Lessons learned management plan

Whereas the lessons learned have been primarily collected for understanding the effects of the implemented product introduction strategies, they also provided a good basis for understanding the main types of information content quality deficiencies.

4.3.2. Modifications and Refinement of the strategies and the way forward

Despite the positive outcomes of the implemented product introduction management strategies, the company faced different challenges regarding both the implementation of the strategies and their outcomes. The collected lessons learned were analyzed to identify these challenges, their causes, and the required modifications of the strategies to overcome them. The lessons learned showed that the challenges and disturbances were very similar in different projects and, therefore, the learning outcomes from each project were usually highly applicable to other projects. The analysis revealed the following challenges.

- Whereas the disturbances during the production of new products have been reduced considerably, many disturbances still occurred during the production of new products, which were primarily related to the content quality of information related to the manufacturability of the products.
- The involvement of the production personnel in the development of prototypes was not implemented completely because the required resources were not planned and allocated in the early phases of the product introduction process. The allocation of production resources in later phases was difficult because of the involvement of the production personnel in ongoing production activities and other ongoing projects.
- Whereas the information about production requirements were collected and shared with design early in the projects during the concept study phase, there were no clear guidelines to translate them to design goals and prioritize them among the design goals.
- The new product introduction manager's role was not clearly defined, and there were many ambiguities in the position's job description. Therefore, in some cases, they had difficulties collaborating with other departments because of the lack of clarity and recognition about this new role in the other departments.
- - The phases and activities in the new product introduction process could not be implemented completely. The development of the required number of prototypes and the pre-series production could not be implemented in the planned timeframe of the projects because there were not enough orders from customers for the products, and the products could not be produced without a customer because of the high prices of the products. Therefore, the products had to be handed over to production without the complete implementation of the planned activities for the testing and refinement of products and production systems. This was necessary to close the projects on time and mobilize the resources for other projects.

Based on these outcomes, the newness of the strategies and the lack of consideration of the characteristics of the company as a low-volume manufacturing company were identified as the main sources of remaining disturbances. Particularly, basing the improvement of the manufacturability information content quality of the products on high-volume-based solutions, such as the development of several prototypes and the production of pre-series and pilot production runs, was not successful because of neglecting such characteristics. The combination of high costs and the variety of products with low-production volumes made the complete implementation of such solutions impossible. Therefore, the product introduction management strategies have been revised and modified by focusing on the following points:

- Finding alternative methods for improving the manufacturability of the products with focus on content quality of the exchanged information, and
- Facilitating the maturation and clarification of the new strategies.
- The revision and modification of the strategies are presented in the following.

 doi:10.20944/preprints202311.0549.v1

4.3.2.1. Test and verification plan

Because of the limitations of the company in its development of a certain number of prototypes and pre-series, the planned opportunities for testing and verifications were revised from an activity-oriented to a goal-oriented strategy, i.e., the modified strategy provided more flexibility regarding the numbers of prototypes and pre-series included in the project to the project managers. However, the requirements regarding the expected outcomes of the developed prototypes and pre-series have been clarified and highlighted. In other words, whereas the project managers could select the numbers of developed prototypes and pre-series, they were required to assure that the information about the new product and its production was developed with sufficient quality. For example, the details of assembly instructions and small connecting parts should be controlled and completed during the development of the prototypes and pre-series.

4.3.2.2. Revisiting the role of PI management

As the role of product introduction manager matured during the previous projects, after the revision of the strategies, the work definitions and responsibilities were clarified and completed. In addition, more standardized work procedures were introduced for the activities that were led by product introduction managers.

4.3.2.3. Formal design and production coordination plan

To compensate for the lack of opportunities for developing information with high content quality about the manufacturability of the products, design reviews were modified to focus more on the manufacturability aspects of the products. In these manufacturing-focused design reviews, the manufacturability information of the products was discussed and completed. For instance, based on the experiences from previous projects, developing complete and correct information about the small connecting parts of the products became a main part of these design reviews to assure that the information about these parts was complete, accurate and correct. Furthermore, the implications of the new features of the products (for the variants that were not developed as prototypes and pre-series) were discussed with the production personnel in the design reviews to develop the required information with high content quality and make the required alterations in the production system for those variants.

- The involvement of the production personnel in product introduction activities was improved by modifying the resource allocation process. The allocation of the required resources from production was discussed and planned in the early phases of the projects by an agreement between project managers and production. It helped production to have an extended time to level its resources based on the requirements of the product introduction activities and allocate them more easily when they were needed.
- Based on the experiences from previous projects, the collected requirements of production were not used efficiently because there was no clear process to integrate them into the design goals and priorities. Therefore, this strategy was completed by additional discussions and interpretations of the production requirements with production managers and supervisors during the early phases of product introduction. This new activity facilitated the interpretation of the production requirements into design goals and included them in the product and production system design requirements. The revision of this mechanism especially helped in reducing design for manufacturing/assembly problems. For example, in the project that was studied after revision of the mechanism, considering design for assembly issues such as the easy accessibility of the assembly points of some components was among the requirements of the production that were discussed early in the project and followed in the design of the product. The product introduction manager for Project E responded to this modification as follows:

"It is always an issue that there are parts and components which cannot be assembled easily because the assembly points are difficult to reach; now at least production gets a chance to discuss such problems with designers. … Probably they could not follow what production needs for every single component because other

 doi:10.20944/preprints202311.0549.v1

aspects such as design for serviceability have higher priority for the type(s) of products we produce. But at least they are aware of this requirement and usually come to us when they think there are such problems, and we get to help them, and we can produce a reasonable solution most of the time."

4.3.2.4. Lessons learned management plan

Whereas the lessons learned collection plan was primarily established to study the product introduction management strategies in the pilot period, it proved to be a useful tool for also for cross-project learning. Due to the usual low novelty of products and production systems in the product development projects, lessons learned were deemed to be even more useful due to similarities of products and production system changes in different projects. such cross-project learning, and improvement process helped improving different information content quality aspects by identification of main types of information quality deficiencies and solutions to them.

4.4. Assessment of influences of the strategies refinement on the information content quality

Overall, the revision and modification of the product introduction management strategies facilitated different aspects of the product introduction process by improving the content quality of the exchanged information between design and production. The discussed characteristics of the low-volume manufacturing company, such as the increased focus on the functionality of the products, the infeasibility of relying on conventional opportunities of testing and refinement of the products and production systems and adapting them together, primarily undermined the quality of the information related to the manufacturability of the products and led to disturbances during the production of new products. Therefore, the refinement of the strategies to focus more on the manufacturability-related information helped balancing the consequences of the characteristics of low-volume manufacturing. In particular, it was not possible to rely on conventional strategies such as the development of prototypes and pre-series production for developing high-quality information about manufacturability aspects of the products and adapting the products and production system together. Therefore, modifying other strategies to concentrate more on these aspects, such as manufacturability-focused design reviews, was necessary for the low-volume manufacturing company.

More formal and goal-oriented design-production coordination plan facilitated the development of common goals and a more common language between design and production which in its turn, helped developing and exchanging more complete, accurate, timely and correct information. Greater involvement of the production personnel in the product introduction activities helped them to provide designs with more complete and accurate information about the common challenges and issues during the late phases of the product introduction process, which includes the production of new products. Furthermore, it helped design to include production's perspective in the design of new products and identify the information content quality shortcomings. On a more detailed level, it led to the development of more complete, correct, accurate and timely information about the manufacturability of the products. Improved completeness and correctness of the information about small connecting parts was an example of such an improvement. A production manager stated the following:

"It is a common and repeating issue that information about parts such as nuts and bolts, hydraulic hoses, cables, etc. is not there or is wrong in the bill of materials when the product came to production. Now we can probably avoid many of such issues when we go through them in the design reviews."

The project manager also mentioned the following: "these new tools (mechanism) helped us to have more interaction with production about the issues that concern them. We have developed new perspective about difficulties that production faces when they receive new products, and we can work them out together."

Table 4 summarizes the influences of the product management strategies on the information content quality during the pilot implementation and after refinement of the strategies.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 November 2023 doi:10.20944/preprints202311.0549.v1

Table 4. influences of the product introduction management strategies on the information content quality during pilot implementation and after refinement.

Product introduction management strategy	Pilot period	Influences on the information content quality	After refinement	Influences on the information content quality
Securing a production test and verification plan	Opportunities for testing and refinement were primarily planned similar to common high-volume product introduction processes including the development of prototypes, pre-series production and production run-up. However, the implementation faced different challenges because of the newness of the process and the limitations of LV manufacturing.	- Increased completeness, correctness, accuracy, and timeliness of information related to the production processes and manufacturability of the products.	The plans were refined by focusing more on the goals of the development of prototypes and pre-series production. A mature product was handed over with sufficient information and the implemented changes in the production system instead of focusing on the development of specific numbers of prototypes and pre-series.	- Increased focus on the manufacturability-related information and handing over the products to production with more complete, correct, accurate and timely information. - Increased product information consistency, e.g., early detection of duplicate part domination.
Revising the role of PI management	A product introduction manager role was added to the project teams. This person was exclusively responsible for the planning and implementation of the product introduction activities. This new role helped increase the priority of these activities in the projects and resulted in a better implementation of them. However, since the role was new, the	P- Facilitating information sharing between design and production with high content quality. - Identifying main information content quality shortcomings on both design and production sides	The function of this new role was improved by defining clearer procedures and work definitions.	- Facilitating information sharing between design and production with high content quality - Identifying main information content quality shortcomings on both design and production sides

 doi:10.20944/preprints202311.0549.v1

		responsibilities and work definitions were not clear enough.			
Formal design and production coordination plan	Involvement of production in prototype development	The involvement of production personnel in the development of the prototypes was planned in the projects to facilitate sharing information about the new products and include their perspectives in the development of prototypes and production information such as assembly instructions. However, the implementation of this involvement faces some challenges because of resource allocation problems.	- Exchanging clearer, complete, and correct information both about product and production system. - developing more complete and correct information about production processes such as assembly instructions	The involvement of the production personnel was implemented according to the plans using the early allocation of required resources.	- Early identification of information content quality deficiencies regarding the manufacturability aspects of the products. - Increased product information consistency, e.g., early detection of duplicate part domination.
	design reviews	Design reviews were used in the projects as one of the main coordination mechanisms to discuss the new features of the products and their implications for production.	- Providing more complete, accurate, correct, and timely product information to production	The design reviews' focus was shifted more towards the manufacturability aspects of the products. The experiences from previous projects showed that many details such as small connecting parts and the influences of new product features on assembly processes were usually neglected. Therefore, these aspects were incorporated into	- Improving completeness, correctness, and accuracy of the manufacturability-related information, e.g., information about small connecting parts

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 November 2023 doi:10.20944/preprints202311.0549.v1

				the focus of design reviews.	
	Early collection and consideration of production requirements	The production requirements and limitations were collected, categorized, and shared with design early in the projects by the product introduction manager. However, the process of prioritizing and including them in the design was not clear.	- Improved accuracy, correctness, and completeness of the information about production system among designers	The requirements and limitations of production were discussed by design and production to prioritize them and formulate them as design goals.	More information accuracy and consistency about production system requirement and limitation and processes.
Lessons learned management plan		The lessons learned for the introduction of new products were collected by the product introduction managers from the projects for further analysis and modification of the implemented strategies.	- General understanding of information content quality shortcomings in the projects	The collected lessons that were learned were used both as a cross project learning method and to modify the strategies.	- Overall improvement of different information content quality aspect by cross-project application of the lessons learned - Supporting constant improvement of product introduction strategies

4.5. The way froward

The implemented product introduction strategies and their later refinements based on the low-volume manufacturing characteristics improved the information content quality considerably and led to much smoother introduction of products with less disturbances in production. However, there was a consensus among the project members that there was a considerable potential for further improvements by using digitalization tools in combination with the implemented strategies. Whereas CAD tools have been used extensively for design of the products, there has been very limited use of them in DFM/DFA aspects and other aspects of production such as investigating safety and ergonomic aspects of production. Using digital tools to do digital test assemblies, design reviews and simulating safety and ergonomic aspects of production are some examples of such improvements which can facilitate developing and sharing information about product and production systems with higher content quality and faster. For example, all assembly of all product variants can be tested in a digital environment with a much lower cost and shorter time in comparison with physical prototype and pre-series productions. However, based on the feedback of different project stakeholders, extending the use of digitalization tools to the above-mentioned applications have been limited by factors such as

- Required investment and its rate of return considering the production volumes and prices and expected improvements in production and quality.

 doi:10.20944/preprints202311.0549.v1

- Availability of human resources and required competence considering the thin-spread design resources among several ongoing projects.

5. Discussion

5.1. Theoretical implications

First, this paper shows how the product introduction management strategies can be customized to the characteristics of low-volume manufacturing companies to meet their requirements and to enhance the content quality of the information that is developed and shared during product introduction process. In this regard, this paper contributes to the knowledge gap about product introduction management strategies in low-volume manufacturing stated by Surbier, Alpan and Blanco [2]. Whereas the product introduction management strategies have been discussed mostly on general level or in the context of high-volume manufacturing [2, 32], this paper addresses specifically how the characteristics of low-volume manufacturing should be considered in development and implementation of the management strategies.

Secondly, it is noteworthy that, in contrast to earlier studies that offer a relatively broad and generalized outlook on the management of information in the product introduction process [5, 50-52], this paper represents a shift towards a more detailed and structured perspective by the utilization of an information content quality framework for analysis. The adoption of an information content quality perspective is instrumental in affording a considerably more intricate and granular view of the role that information plays within the product introduction process, as well as a more precise comprehension of the disturbances brought about by information content quality shortcomings.

In this context, it's essential to underscore that this paper not only builds upon but significantly extends the foundational work of scholars such as Terwiesch, Loch and Meyer [44] and Fjällström, Säfsten [5]. These previous studies primarily concentrated on investigating the consequences of developing and sharing preliminary information during the product introduction process, as well as the strategies devised to manage the associated challenges. By introducing a framework centered on information content quality, this research takes their valuable insights to the next level, thus contributing to a more profound understanding of the multifaceted dynamics inherent in information management during product introductions.

Finally, it is worth highlighting that this research makes a pioneering effort in investigating the intricate interplay between information content quality and product introduction management strategies which has remained largely unexplored within the extant literature. Previous studies on managing product introductions, such as those by Adler [6], Chirumalla [1] and Vandevelde and Van Dierdonck [12] have undoubtedly contributed to the understanding of various aspects of product introduction management. However, they have not delved into the crucial linkage between information content quality and these strategies. This research, therefore, fills a significant void in the existing body of knowledge, emphasizing the indispensable role of information content quality in shaping the outcomes of product introduction management strategies. The empirical findings of this study offer valuable insights into the different dimensions of information content quality and its impact on the success of product introduction management strategies. By shedding light on how distinct dimensions of information quality influence the success of these strategies, the research not only advances our comprehension of the dynamics at play but also paves the way for a deeper understanding of how management strategies can be fine-tuned to navigate the challenges associated with each of these dimensions.

5.2. Practical implications

This paper offers invaluable insights for practitioners operating in low-volume manufacturing industries, shedding light on the challenges associated with managing product introductions in that sector. By presenting a real-world case study from a low-volume manufacturing company, this paper presents a tangible demonstration of how to effectively product introduction management strategies and customize them considering the characteristics and demands of low-volume manufacturing.

 doi:10.20944/preprints202311.0549.v1

This paper significantly contributes to the knowledge and expertise of practitioners in low-volume manufacturing industries by emphasizing the pivotal role of information content quality in the success of product introduction management strategies. It highlights the need for practitioners to view information as a fundamental component of the product introduction process as the quality of information profoundly influences the success of strategies. In essence, it empowers them to support their product introduction processes by aligning the product introduction management strategies with information content quality.

More specifically, this study shows how concentrating on content quality of the developed and shared information during the product introduction can help low-volume manufacturing companies to identify the improvement possibilities in product introduction management strategies and customize such strategies to meet the requirements and characteristics of product introduction in low-volume manufacturing companies.

6. Conclusions, limitations, and future work

This study has illuminated the process of tailoring product introduction management strategies to align with the unique characteristics of high-mix, low-volume manufacturing companies. In doing so, our research extends beyond the scope of existing studies, which typically offer a more generalized discussion of management strategies or focus on high-volume manufacturing. Our approach hones in on the specific characteristics of low-volume manufacturing, emphasizing the need for a context-specific approach when formulating and implementing management strategies. The study identified four main product introduction management strategies well-suited for the case company and other low-volume manufacturing companies. These strategies include:

1. Securing a Production Test and Verification Plan
2. Revising the Role of Product Introduction Management
3. Formal Design and Production Coordination Plan
4. Lessons Learned Implementation Plan

These strategies were introduced and integrated into the case company's low-volume product introduction projects as part of a pilot run. Subsequently, following the pilot implementation phase, these management strategies underwent modifications and refinements for application in future low-volume product introduction projects. The comparative analysis encompassing the periods before implementation, during the pilot implementation, and after the pilot implementation reveals that these adapted management strategies have a significant and positive impact on the quality of information exchanged between product design and production interface during the low-volume product introduction process and projects. This demonstrates their effectiveness in enhancing the information content quality in this specialized context.

This study introduces a nuanced and structured perspective by adopting an information content lens to analyze the low-volume product introduction process and improve the interface between product design and production. In contrast to previous studies that provided a broad overview of information management during product introductions, our research delves deep into the intricate details of information content quality. This approach allows for a more precise understanding of the role that information plays within the product introduction process and the potential disruptions that may arise when information content quality is compromised. While earlier studies have explored various facets of product introduction management, they often failed to establish a direct link between these management strategies and information content quality. This research addresses this gap and underscores the critical importance of information content quality in influencing the outcomes of product introduction management strategies. It emphasizes how the quality of information exchanged significantly shapes the success of these strategies, offering a more comprehensive view of this multifaceted relationship.

While this study provides valuable insights, it is not without limitations. Firstly, the findings are drawn from a single case study, and as such, generalizability to other low-volume manufacturing contexts may be limited. Future research could benefit from a larger sample size to enhance the generalizability of the results. Secondly, the qualitative nature of the data collection may introduce

potential bias in the analysis. Though rigorous procedures were followed to ensure reliability and validity, it's important to acknowledge the subjectivity inherent in qualitative research.

Future research in this area could consider the following avenues: Expanding the study to encompass multiple low-volume manufacturing companies would provide a more comprehensive understanding of the customization of management strategies and information content quality. Comparative studies can help identify commonalities and differences among companies. Combining qualitative insights with quantitative data can further enhance the research. Conducting surveys or analyzing quantitative data related to information content quality and its impact on product introduction management could offer a more robust perspective. Investigating the long-term effects of customized management strategies and information content quality in low-volume manufacturing would provide insights into the sustainability and adaptability of these approaches over time. Future research can explore the integration of new advanced digital technologies or Industry 4.0, in optimizing information content quality and product introduction management in low-volume manufacturing. By addressing these limitations and exploring these future research directions, the field of product introduction management in low-volume manufacturing can continue to evolve and provide valuable insights for both academia and industry practitioners.

References

1. Chirumalla, K., *Managing product introduction projects in operations key challenges in heavy-duty vehicle industry.* Journal of Modern Project Management, 2018. **5**(3): p. 108-118.
2. Surbier, L., G. Alpan, and E. Blanco, *A comparative study on production ramp-up: State-of-the-art and new challenges.* Production Planning and Control, 2014. **25**(15): p. 1264-1286.
3. Johansen, K., *Collaborative Product Introduction within Extended Enterprises*, in *Department of Management and Engineering, Assembly technology*. 2005, Linköping University, Sweden: Linköping.
4. Berg, M., et al. *Production ramp-up in the manufacturing industry: findings from a case study*. in *The 3rd international conference on reconfigurable manufacturing, Ann Arbor, MI, US*. 2005.
5. Fjällström, S., et al., *Information enabling production ramp-up.* Journal of Manufacturing Technology Management, 2009. **20**(2): p. 178-196.
6. Adler, P.S., *Interdepartmental interdependence and coordination: The case of the design/manufacturing interface.* Organization Science, 1995. **6**(2): p. 147-167.
7. Dekkers, R., C. Chang, and J. Kreutzfeldt, *The interface between "product design and engineering" and manufacturing: A review of the literature and empirical evidence.* International Journal of Production Economics, 2013. **144**(1): p. 316-333.
8. Wlazlak, P., D. Hussmo, and K. Säfsten. *Integration across knowledge boundaries during new product introduction*. in *Advances in Transdisciplinary Engineering*. 2021.
9. Surbier, L., *Problem and interface characterization during ramp-up in the low volume industry*. 2010, Institut National Polytechnique de Grenoble-INPG: Granoble.
10. Almgren, H., *Pilot production and manufacturing start-up: the case of Volvo S80.* International Journal of Production Research, 2000. **38**(17): p. 4577-4588.
11. Mamaghani, E.J. and K. Medini. *Resilience, agility and risk management in production ramp-up*. in *Procedia CIRP*. 2021.
12. Vandevelde, A. and R. Van Dierdonck, *Managing the design-manufacturing interface.* International Journal of Operations & Production Management, 2003. **23**(11): p. 1326-1348.
13. Souri, M.E., et al., *A structured approach to defect data management for improving DFM implementation in aerospace manufacturing.* International Journal of Product Lifecycle Management, 2017. **10**(4): p. 282-300.
14. Classen, A. and L. Lopez. *New product introduction between two geographically dispersed entities*. in *Engineering and Technology Management, 1998. Pioneering New Technologies: Management Issues and Challenges in the Third Millennium. IEMC'98 Proceedings. International Conference on*. 1998. IEEE.
15. Dreher, S. and M.J. Oesterle. *Ramp-up of New Products in International Manufacturing Networks: Exploring Coordination Challenges Based on a Multiple Case Study*. in *Procedia CIRP*. 2022.
16. Vallhagen, J., et al., *An approach for producibility and DFM-methodology in aerospace engine component development.* Procedia CIRP, 2013. **11**: p. 151-156.

17. Surbier, L., G. Alpan, and E. Blanco, *Identification of problem types during production ramp-up*, in *International Conference on Industrial Engineering and System Management-IESM'2009*. 2009: Montreal, Canada. p. CD-ROM.
18. Säfsten, K., et al., *Proactive and reactive ways of managing product introduction*, in *The Swedish Production Sympoisum*. 2008: Stockholm, Sweden.
19. Winkler, H., M. Heins, and P. Nyhuis, *A controlling system based on cause–effect relationships for the ramp-up of production systems.* Production Engineering, 2007. **1**(1): p. 103-111.
20. Erichsen, J.A.B., et al. *Using prototypes to leverage knowledge in product development: Examples from the automotive industry*. in *10th Annual International Systems Conference, SysCon 2016 - Proceedings*. 2016.
21. Gibson, I., Z. Gao, and I. Campbell, *A comparative study of virtual prototyping and physical prototyping.* International Journal of Manufacturing Technology and Management, 2004. **6**(6): p. 503-522.
22. Chirumalla, K., et al. *Exploring feedback loops in the industrialization process: A case study*. in *Procedia Manufacturing*. 2018.
23. Wellsandt, S., K.D. Thoben, and P. Klein. *Information feedback in product development: Analysing practical cases*. in *Proceedings of International Design Conference, DESIGN*. 2018.
24. Letmathe, P. and M. Rößler, *Tacit knowledge transfer and spillover learning in ramp-ups.* International Journal of Operations and Production Management, 2019. **39**(9-10): p. 1099-1121.
25. Scrimieri, D., R.F. Oates, and S.M. Ratchev, *Learning and reuse of engineering ramp-up strategies for modular assembly systems.* Journal of Intelligent Manufacturing, 2013. **26**(6): p. 1063-1076.
26. Berg, L.P. and J.M. Vance, *Industry use of virtual reality in product design and manufacturing: a survey.* Virtual Reality, 2017. **21**(1): p. 1-17.
27. Soori, M., B. Arezoo, and R. Dastres, *Advanced virtual manufacturing systems: A review.* Journal of Advanced Manufacturing Science and Technology, 2023.
28. Andersen, A.L., et al. *Investigating the Impact of Product Volume and Variety on Production Ramp-Up*. in *Springer Proceedings in Business and Economics*. 2017.
29. Qudrat-Ullah, B.S. Seong, and B.L. Mills, *Improving high variable-low volume operations: an exploration into the lean product development.* International Journal of Technology Management, 2012. **57**(1): p. 49-70.
30. Javadi, S., J. Bruch, and M. Bellgran, *Characteristics of product introduction process in low-volume manufacturing industries: A case study.* Journal of Manufacturing Technology Management, 2016. **27**(4): p. 535-559.
31. Sigurjónsson, V., J. Bruch, and A. Granlund. *Exploring Challenges in a Low-Volume Product Industrialization Process–A Railway Case Study*. in *IFIP International Conference on Advances in Production Management Systems*. 2023. Springer.
32. Gan, Z.L., S.N. Musa, and H.J. Yap, *A Review of the High-Mix, Low-Volume Manufacturing Industry.* Applied Sciences (Switzerland), 2023. **13**(3).
33. Kumar, S. and J. Wellbrock, *Improved new product development through enhanced design architecture for engineer-to-order companies.* International Journal of Production Research, 2009. **47**(15): p. 4235-4254.
34. Lakemond, N., et al., *Assessing Interface Challenges in Product Development Projects.* Research-Technology Management, 2015. **56**(1): p. 40-48.
35. Lekhawichit, N., et al., *THE IMPACT OF INFORMATION QUALITY AND INFORMATION TECHNOLOGY ON THE BUSINESS MANAGEMENT IN THAILAND: MODERATING ROLE OF ORGANIZATIONAL SUPPORT.* International Journal of eBusiness and eGovernment Studies, 2022. **14**(1): p. 1-17.
36. Parvez Alam, M. and B. Toppur, *Hybrid agile project management model for new product development in aerospace.* International Journal of Operations and Quantitative Management, 2019. **25**(1): p. 59-73.
37. Dombrowski, U., J. Wullbrandt, and P. Krenkel. *Industrie 4.0 in production ramp-up management*. in *Procedia Manufacturing*. 2018.
38. Bruch, J. and M. Bellgran, *Characteristics affecting management of design information in the production system design process.* International Journal of Production Research, 2013. **51**(11): p. 3241-3251.
39. Fisher, C., E. Lauria, and S. Chengalur-Smith, *Introduction to Information Quality*. 2012, Bloomington, IN: AuthorHouse.
40. Eppler, M.J. *A generic framework for information quality in knowledge-intensive processes*. in *Proceedings of the Sixth International Conference on Information Quality*. 2001. Cambridge, MA, USA: Massachusetts Institute of Technology.
41. English, L.P., *Improving data warehouse and business information quality: methods for reducing costs and increasing profits*. 1999, New York, NY: John Wiley & Sons, Inc.
42. Wang, R.Y., et al., *Information Quality*. 2014, Armonk, NY: M.E. Sharp.

43. Frishammar, J., H. Florén, and J. Wincent, *Beyond managing uncertainty: Insights from studying equivocality in the fuzzy front end of product and process innovation projects.* IEEE Transactions on Engineering Management, 2011. **58**(3): p. 551-563.
44. Terwiesch, C., C.H. Loch, and A.D. Meyer, *Exchanging preliminary information in concurrent engineering: Alternative coordination strategies.* Organization Science, 2002. **13**(4): p. 402-419.
45. Surbier, L., G. Alpan, and E. Blanco, *Identification of problem types during production ramp-up.* Identification of problem types during production ramp-up, 2009.
46. English, L.P., *Information quality applied: Best practices for improving business information, processes and systems*. 2009, Indianapolis, Indiana: Wiley Publishing.
47. Twigg, D., *Managing the design/manufacturing interface across firms.* Integrated Manufacturing Systems, 2002. **13**(4): p. 212-221.
48. Van der Merwe, E., *A conceptual framework for ramp-up manufacturing.* Manufacturing and Management Division, Engineering Department. Cambridge, University of Cambridge. PhD, 2004.
49. Terwiesch, C. and R. Bohn, *Learning and process improvement during production ramp-up.* International journal of production economics, 2001. **70**(1): p. 1-19.
50. Kanan, M., *Investigating the relationship between information quality, system quality, service quality, and supply chain performance in the manufacturing sector of Saudi Arabia: An empirical study.* Uncertain Supply Chain Management, 2023. **11**(4): p. 1589-1598.
51. Bruch, J. and M. Bellgran, *Creating a competitive edge when designing production systems: Facilitating the sharing of design information.* International Journal of Services Sciences, 2012. **4**(3/4): p. 257-276.
52. Frishammar, J. and H. Ylinenpää, *Managing information in new product development: A conceptual review, research propositions and tentative model.* International Journal of Innovation Management, 2007. **11**(04): p. 441-467.
53. Vessela, W.; Robin, B. The Role of Context in Qualitative Case Study Research: Understanding Service Innovation; SAGE Research Methods: London, UK, 2022.
54. Leonard-Barton. D. A dual methodology for case studies: Synergistic use of a longitudinal single site with replicated multiple sites. Organization Science, 1 (3) (1990), pp. 248-266
55. Aaboen, L., Dubois, A., Lind, F. Capturing processes in longitudinal multiple case studies. Industrial Marketing Management, Volume 41, Issue 2, 2012, Pp. 235-246.
56. Yin, R.K. Case Study Research: Design and Methods, 5th ed.; Sage Publications: London, UK, 2013.
57. Robson, C. Real World Research: A Resource for Social Scientists and Practitioner-Researchers, 2nd ed.; Blackwell Publisher Ltd.: Hoboken, NJ, USA, 2002.
58. Crowe, S.; Cresswell, K.; Robertson, A.; Huby, G.; Avery, A.; Sheikh, A. The case study approach. BMC Med. Res. Methodol. 2011, 11, 100.
59. Eisenhardt, K.M.; Graebner, M.E. Theory building from cases: Opportunities and challenges. Acad. Manag. J. 2007, 50, 25–32
60. Rogosa, D. (1995). Myths about longitudinal research. Sage Publications.
61. Hannan, M. T., & Freeman, J. (1977). The population ecology of organizations. American journal of sociology, 82(5), 929-964
62. Smith, J. A., Flowers, P., & Larkin, M. (2009). Interpretative Phenomenological Analysis: Theory, Method and Research. Sage Publications
63. Rubin, H. J., & Rubin, I. S. (2011). Qualitative interviewing: The art of hearing data. Sage
64. Eisenhardt, K. M. (1989). Building theories from case study research. Academy of Management Review, 14(4), 532-550.
65. Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. Sage Publications.
66. Denzin, N. K., & Lincoln, Y. S. (2018). The Sage handbook of qualitative research. Sage Publications.
67. Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qual. Res. Psychol. 3, 77–101.
68. Creswell, J. W., & Poth, C. N. (2017). Qualitative inquiry and research design: Choosing among five approaches. Sage Publications