Communication between design and manufacturing

A study of a Swedish startup company

Bachelor's thesis in Science in Engineering

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ABSTRACT

Communication between design and manufacturing is crucial for mutual understanding, yet mutual understanding between the two has been a challenge over the years. The aim of this thesis is to explore potential causes of a communication problem between design and manufacturing. A literature study related to communication and cooperation between design and manufacturing was conducted to create the theoretical framework. Data were collected through qualitative methods such as semi-structured interviews, immersion and observations. The data are presented in a timeline that is categorised into events, and analysed where further findings through immersion and observations were also established. The analysis of the results is discussed using the theoretical framework in order to identify the potential causes of the problem. The conclusion shows potential individual-, organisational- and interaction-related causes of the problem that have led to misunderstandings and subsequent manufacturing errors, and what could have been done differently. The study gives the case company not only identification of potential causes of the problem, but also some suggestions on what could have been done differently within their organisational, inter-organisational communication and the design-manufacturing interface. The findings of the thesis might be limited to other startup companies of similar characteristics.

Keywords: *communication, design, manufacturing, interface, outsourcing*

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GLOSSARY OF TERMS

The case company: The company that was studied and where the thesis was conducted.

Com: Used to label components when censoring when the word “Component” is too long.

EMP (External Manufacturing Partner): A third-party organisation hired by a company that produces goods or components on its behalf.

EOL (End of Line): a point where one or more previous steps has been completed. In this context it is used in relation with the tests performed during or after assembly of a product.

Interface: A point of interaction between, in this context different business units, teams, or between a company and its customers or partners.

1. INTRODUCTION

This section comprises the background, purpose, problem statement, and delimitation of the thesis.

1.1 Background

This thesis is carried out at a case company which designs a product related to the laundry industry. The case company is involved in complex coordination with an external manufacturing partner (EMP) which manufactures their products. Their recent product called Product 1 has cost the case company a fortune, approximately 80 000 SEK, due to a problem in communication between design and manufacturing. This presents the case company and the authors an opportunity to study the ways of communication both internally at the case company and externally with their EMP and what causes that played a role in some of the past product quality issues.

The case company has, over their short history, designed several iterations for a product used in the laundry industry. As of the date when this report is published, they are entering the production phase of their newest and improved Product 2.

This collaboration between the case company and the EMP underscores the importance of clear specifications and expectations to avoid the quality issues encountered in the previous iterations. This highlights the seamless transition from the challenges of miscommunication to the practical applications in product development and manufacturing processes.

The problem in communication between design and manufacturing has not only led to financial loss, but also loss of time, and customer goodwill. However, the problem has yet not been addressed sufficiently at the case company. A better understanding of this problem and its potential causes are crucial for the lessons learnt and the production of Product 2.

1.2 Purpose

To explore the potential causes of a communication problem between design and manufacturing and how to mitigate those.

1.3 Problem Statement

To fulfill the purpose of this thesis, two questions have been identified:

- What are the potential causes of problems in communication between design and manufacturing?
- What could have been done differently?

1.4 Boundaries

In examining communication related to the Product 1 between the case company and their EMP, several boundaries have been set due to specific challenges and limitations.

The quality of data available from the case company's single product history and past collaborations with production partners has been identified as low, which could restrict the scale of the analysis. The study will concentrate on the case company's existing data, excluding customer interviews, quantitative surveys and handling of raw datasets to effectively manage the scope and depth of data collection.

This thesis will only include studies of communication patterns between the case company and the main EMP. Thus, it leaves out other subcontractors in order to adhere to time and scope constraints. Furthermore, interviews will be limited to current employees and consultants hired directly by the case company, excluding individuals with only past associations and employees of the EMP, partly on the request of our case company. Analyses of communication logs will also be restricted to recorded forms of communication such as emails, meeting notes, and text messages, thus omitting non-recorded channels like phone calls, video meetings and in-person meetings that were not recorded.

The word *design* encompasses all forms of product development and any individual actively participating in such activities. In this context, the term is assumed to be synonymous with research and development (R&D).

2. THEORETICAL FRAMEWORK

In this section, information and theories found through the performed literature analysis, will be described. The contents are mainly related to the subject of communication and cooperation between design and manufacturing.

2.1 Transactional Communication Model

The word "communication" stems from early Latin and means to mutually share and it is used to share information by humans, among other things which is a basic need that contributes to development in social, psychological and cultural aspects (Nationalencyklopedin n.d.). Methods of communicating, such as pictorial and written communication, have evolved over time, and digitalization has further simplified global communication. Furthermore, not only words are important in communication, but body language also plays a big role, where bodily signals can reinforce or contradict the verbal message which someone is trying to convey.

Communication models aim to enhance the understanding of the communication process and show the basic factors of the real communication process as a visual representation (Jacobsen & Thorsvik, 2021). Understanding the components of the communication model and their interrelations gives opportunities to more effectively identify and address communication issues when they occur and how to prevent them.

Barnlund (1970) presented the transactional model that interprets communication as a transactional process. The transactional model is a more advanced way of understanding how people communicate and view communication as a fundamental element of our coexistence in society, see Figure 1.

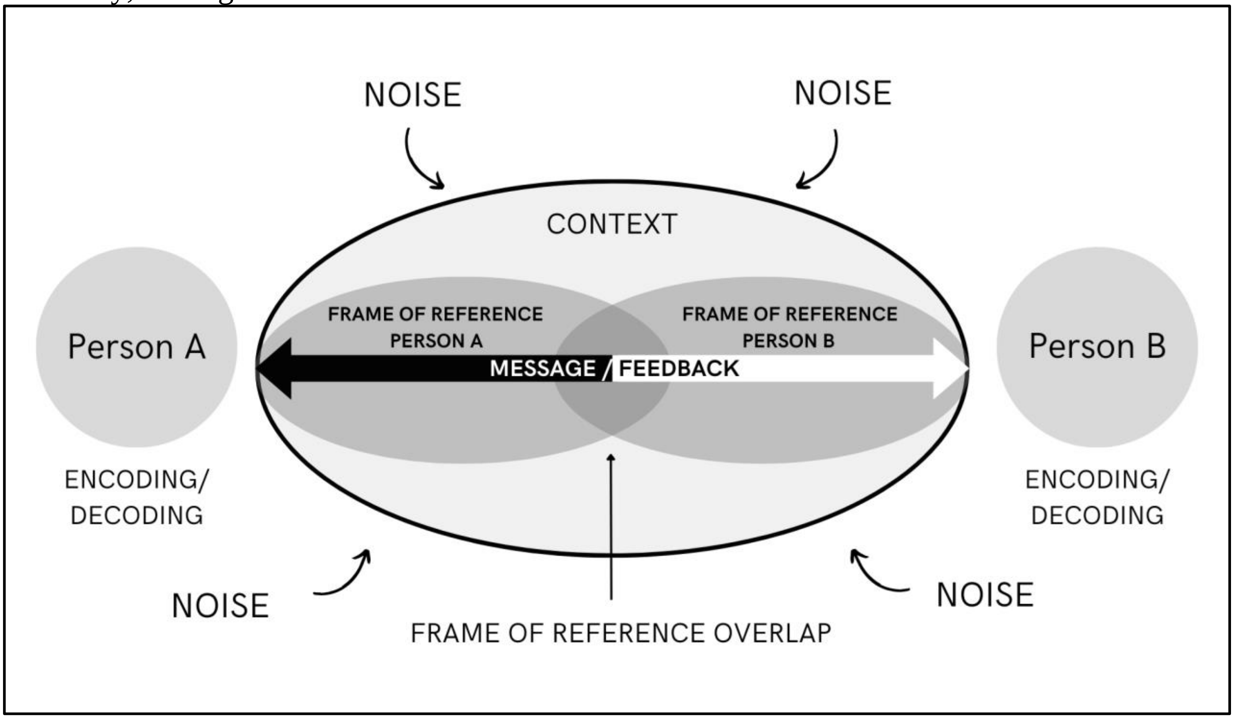


Figure 1: *The transactional model of communication.*

The transactional model is based on the belief that both individuals of a conversation play an equal role in creating the meaning of the conversation, unlike the belief that only the sender creates meaning. This means that we do not change roles between sender and receiver, because deciding to consciously stop communicating is not possible, for example, non-verbal communication such as body language and facial expressions. Therefore, communication exceeds merely sending and receiving. Everyone involved in the conversation plays the role of both a "talker" and a "listener" at the same time, this gives an understanding of how conversations can change and flow naturally. Viewing communication as something that shapes our reality, rather than just talking about it (Barnlund, 1970).

The transactional model also includes the *context* and the external environment of the conversation and how important it is to understand the conversation. Communication is not linear, but a complex and ongoing transaction where each individual is both a sender and receiver being influenced by and influencing the external environment and the other individuals involved (Barnlund, 1970).

The *frame of reference* is the individual person's perspectives, how they view the world. Each individual's frame of reference is unique, because people do not view the world in the same way. There are areas where the sender and receivers frame of reference overlaps, this includes what both communications have in common. Things we have in common give the starting point for communication, this is why the overlap is important (Hamilton et al, 2019). The process where the sender chooses the verbal and nonverbal symbols to use when communicating the message is referred to as *encoding*. *Decoding* is when the receiver attempts to interpret the message sent by the sender. Verbal and nonverbal messages used by communicators are called *code*. *Channel* is the medium used to communicate (Hamilton et al, 2019).

Communication postulates

Here are foundational principles that are essential to understanding how communication works. Each postulate reflects key characteristics of the communication process and shape Barnlund's transactional communication model (1970):

- Communication describes the evolution of meaning

In the start, the world does not have an inherent meaning, but through communication significance is created. The development of meanings is done through the process of communication and is based on interactions and experiences. Meaning is not something we receive passively but rather something we actively create or assign through our interpretation of cues around us.

- Communication is dynamic

Meaning is an event that takes place within the individual and is not a fixed entity. As we interact with the world, our interpretations and understandings are always in a state of change.

- Communication is continuous

Barnlund demonstrates how "*Communication with the physical world, or with other human beings, is not a thing, nor even a discrete act, but a continuing condition of life, a process that ebbs and flows with changes in the environment and fluctuations in our needs.*" (Barnlund 1970, s 48). The continuity of communication is more of a state rather than a series of acts.

- Communication is circular

As earlier mentioned above, communication is not a linear transaction where the communicator either takes the role as sender or receiver. Communication is circular where the roles of sender and receiver are fluid and constantly changing.

- Communication is unrepeatable

Each communication event cannot be reproduced exactly and is unique.
Individuals do not always behave differently every time and if they did, their behavior would be completely unpredictable. That would result in it being nearly impossible to understand human actions as a science, there is a certain level of consistency in how people behave. The external factors and conditions may seem the same, but the internal factors and the dynamic nature of communication guarantees that each event is distinct.

- Communication is irreversible

Communication moves forward and cannot be reversed, just like time. We cannot return to past stages of being, just like we cannot undo something that has been done or unsay something that has been communicated. The previous experiences gathered from previous communication events continuously contribute to the flow of understanding and experience, meaning that each communication instance builds upon the last.

- Communication is complex

Fully appreciating the complexity of communication is crucial to understand what it means to be human. Communication is complex in the way that it sometimes is conscious, pre-conscious or subconscious and communication can include both implicit and explicit meanings.

2.2 Noise

Anything that interferes and prevents the message from being sent and received successfully can be classified as a noise or a communication barrier (Hamilton et al, 2019). The two broad categories of noise are external noise and internal noise.

External noise
External noise includes environmental factors that can be represented as distracting movements or loud sounds, leading to difficulty of composing thoughts when speaking to others or decoding received messages. Defects in the medium are also included as an external noise where defects in devices used for communication and transmitting the message may fail or partially work, for example, if there are technical issues with the computer (Hamilton et al, 2019).

Internal Noise
Internal noise includes anything that interferes with the effective communication of receiving or sending. There are three subdivisions of internal noise: physiological noise, psychological noise, semantic and language noise (Hamilton et al, 2019).

- Physiological noise affects the physical condition and the effectiveness as a communicator, both as a sender and as a receiver (Hamilton et al, 2019). Examples of these internal physiological aspects are fatigue, pain, illness, and hunger.

- Psychological noise arises when factors tied to your feelings and thoughts obstruct the effective exchange of messages (Hamilton et al, 2019). This can, for example, be if someone is worried about a business presentation in the afternoon, the person might not be able to engage well in the meeting the person is attending in the morning.

- Semantic and language noise or barriers involve not being able to mutually understand the language used and is related to the individual understanding of words and their meaning. Sentences can take on different interpretations based on their vocal delivery, altering the emphasis on certain words may shift the meaning of the sentence significantly (Vandevelde & Van Dierdonck, 2003). During verbal interaction the speaker and sender can signify the meaning by stressing specific words. However, in written form the reader is in control but the receiver may read and place emphasis in another way leading to different understandings (Vandevelde & Van Dierdonck, 2003). The technical terms can also be an issue for effective communication, using specialised terms that are typically understood only within a specific group of professionals or those engaged in the same field. Such terminology is essential for their work and at the same time these terms often carry different meanings in common language, leading to confusion among those outside the profession (Vandevelde & Van Dierdonck, 2003). One of the most powerful tools of communication is in fact the language. Therefore, it is important to understand that the meaning of the words and language spoken can evoke different responses based on the receiving person's background, including aspects such as age, knowledge, culture, and past experiences (Jacobsen & Thorsvik, 2021).

2.3 Perception and Communication

"What causes two people, or several people, to see the same event yet describe what happened differently?" (Wakefield, 1976). Misunderstandings in communication often happen between individuals that have inaccurate or different perceptions. Explaining the nature of perception is said to be difficult, *"We are too close to it to be able to see it clearly*" (Wakefield, 1976). Perception is how an individual interprets the world and what the senses tell the person, including seeing, hearing, tasting, touching and smelling. Selective perception is the process when the person determines what to perceive, this can be done consciously or unconsciously. Two factors among others that determine selective perception are:

- Physical Point of View
  Something that influences the selection is the physical proximity to an object, event or person. If something is too close, far away or in an unbalanced location, this influences what is perceived.

- Past experiences
  These play a vital role in perception. The way individuals respond to situations is a result of previous experiences. A barrier when trying to accurately perceive others is the tendency of seeking perceptual constancy. This term refers to the desire for

constancy between past experiences and present interactions. This can for example be if your first impression of a person is that the person is honest, it is expected that the person will continue to be honest in all future interactions (Hamilton et al, 2019). Elements are often considered stable and unchanging after interpretations are formed. The following quote illustrates this: *"In a dark room, we perceive an apple to be red in color, when actually, it does not show up as red in the darkness"* (Wakefield, 1976).

Perceptions depend on backgrounds, interests and expectations. Mostly, what is seen and heard is dependent on what is expected to be seen or heard. By being able to speak or communicate accurately, misunderstandings can be avoided. To avoid misunderstandings the perceptions must be accurate (Wakefield, 1976). To enlarge the range of expectations there needs to be a decrease in stubborn and well-established attitudes.

When communicating, faulty explanations and information are often given due to the weakness in the individual's own perceptions. The presumably largest obstacle to clear perception is the individual's own inability to take the time to observe and reflect thoughtfully. A key factor is time, haste makes poor judgements and makes people miss important clues (Wakefield, 1976).

Wakefield says that differences in perception often create difficulty in communication (1976). There are several different methods of checking the accuracy of perception, among others:

- Being observant and attentive of what happens in the surroundings.
- Admitting errors that can occur in the individual's own perception.
- Checking with other people, presenting the information to someone else can verify one's perception.
- Check by repeating the observation. By repeating an observation, the individual has an opportunity to check their own perception.
- Check by recalling past experiences. If an individual gets a feeling in a situation, the person can recall past experiences when they were in the same situation.

2.4 Designer's Empathy

Vandevelde and Van Dierdonck (2003) focus on the challenges and strategies to enhance collaboration between design and manufacturing departments to ensure smooth production startups. They introduce the concepts of formalisation and empathy from the design towards manufacturing as essential elements for integrating these two functions effectively.

Empathy from design to manufacturing is emphasised as the designers' awareness and understanding of manufacturing, highlighting the significance of understanding manufacturing constraints to streamline the product development process. The study also deals with three relevant integration barriers that are based on organisational, physical and language differences. These are communicative obstacles that hinder effective interaction between departments with mainly design and manufacturing in mind. These barriers lead to inefficiencies and misunderstandings, underscoring the importance of overcoming them to facilitate a seamless transition from design to production. Structured management approaches, clear communication, and involving designers in production startups can eliminate or avoid these challenges, thereby enhancing overall project performance and success rates.

Vandevelde & Van Dierdonck (2003) provide insights into the necessity of empathetic understanding and breaking down communication barriers for successful design and manufacturing integration. They conclude by mentioning that senior management also has a key role in how successful the department integration will be. Through the setting of examples, they can create an open culture of communication and cross-function empathy that encourages collaboration through organisational structures and breaking down barriers. Managers can also support opportunities for interaction through recreational activities to create more informal relationships between business functions. Furthermore, management has the final say in strategic decisions and these tend to have a large impact on the development within the company. Such are geographical location and system design. These can promote better teamwork through the relocation of functions. While increasing focus on smooth production start-ups, it is crucial for managers to also nurture innovativeness as these tend to have a negative impact on each other.

2.4.1 Integration Barriers

The cooperation between design and manufacturing teams is critical to a project's success. However, this is often challenging because of several different types of integration barriers. Personality conflicts across departments may lead to misunderstandings. Stereotypes, regardless of their truth, can limit their ability to understand and work effectively with each other. Teams within an organisation may have different training and problem-solving methods, creating cultural differences. These differences can challenge the team's ability to collaborate and find common ground, especially if the organisation's reward system does not encourage collaborative work. Different priorities may also impact the design manufacturing interface, such different priorities.

Design teams often strive for innovation and transformation, whereas manufacturing strives for efficiency and process completion. These differences can cause self-contained societies and have the same overall corporate goals, but the way they interpret these goals in distinct ways. The differences in perceived status can stimulate a “we versus they” mentality and therefore contribute to creating a cultural barrier. The design function is often assigned a higher status compared to the manufacturing sector. When one team is seen as more important than another, the relationship differs from a scenario where the teams are seen as equals (Vandevelde & Van Dierdonck, 2003).

2.4.2 Organisational Barriers

Barriers that occur within a company that make it difficult for different parts of their business to work well together. Vandevelde & Van Dierdonck (2003) present several different organisational barriers among others:

- The high-speed culture or quick-fix approach from senior management. When upper management demands rapid results, it may result in the loss of critical processes as product testing may be overlooked, potentially leading to future issues.
- The lack of clarity in roles and goals may be a barrier, working without understanding the objectives or who is responsible for what.

- People and organisations' reluctance to change. For example, one department introduces a new technology, philosophy or operating rules that may evoke resistance from other departments that prefer the traditional way.
- A problem-solving paradox can be created when attempting to solve particular problems; the solution might end up creating new problems and challenges, highlighting the delicate balance of internal dynamics.

2.4.3 Physical Barriers

Physical barriers are the actual physical distances and layouts that affect effective communication and significantly impact the likelihood of interactions in the workplace (Vandevelde & Van Dierdonck, 2003). These barriers can take various forms, such as geographic separation, which makes informal face-to-face communication inconvenient over long distances. The design and layout of the workspace, including how furniture and offices are arranged, can either inhibit or promote collaboration and spontaneous communication. Poorly designed buildings can encourage the use of jargon and foster perceptions of personality differences (Vandevelde & Van Dierdonck, 2003).

In a design manufacturing context, physical barriers can be a major problem when creating new products as a team. Teams that do not collaborate well might fail to agree on important matters or listen to each other, fostering a “not invented here” attitude where teams only value their own ideas. This mindset can hinder the sharing of information and effective collaboration (Vandevelde & Van Dierdonck, 2003). Effectively facilitating and using information is crucial. If people cannot understand or rely on the information they receive, it may not be used. Physical barriers can significantly impact collaboration, the overall efficiency of operations, and the flow of information, leading to challenges in aligning teams toward common objectives (Vandevelde & Van Dierdonck, 2003).

2.4.4 Language Barriers

In design manufacturing, using functional slang within a team can enhance the efficiency of intradepartmental communication, but it can also create barriers to inter-functional information exchange. If information is misinterpreted or misunderstood, its value is diminished or even lost from the receiver's perspective. These subtle languages can significantly impact the perceived success of a project. Communicating ideas that are not fully formed, intangible, or non-standardised can be extremely difficult. Explaining new, undeveloped ideas can lead to misunderstandings and tension. The more abstract the information, the more challenging it is to exchange between individuals from different functions, interests, or backgrounds (Vandevelde & Van Dierdonck, 2003).

2.5 Supplier Involvement in Development

Flankegård et al. (2021) delve into the experiences of suppliers involved in the product development projects of their customers, identifying various challenges these suppliers encounter. They propose a framework that incorporates four dimensions: people, process, tools/technology, and interaction. This framework outlines 24 challenges across these dimensions (see Figure 2), paired with corresponding strategies for mitigation. The conclusions about effective strategies were drawn from literature studies and/or empirical evidence. Some of these challenges are similar to those identified through qualitative methods and the study of data sources. The research emphasises the importance of supplier awareness of these challenges to develop proper internal capabilities. Additionally, it argues that customers need to be mindful of these challenges to provide optimal conditions for suppliers, aiming for successful project outcomes. The study highlights the complexity and dynamics inherent in supplier involvement in product development and offers insights into improving supplier-customer relationships and project success from a supplier's perspective.

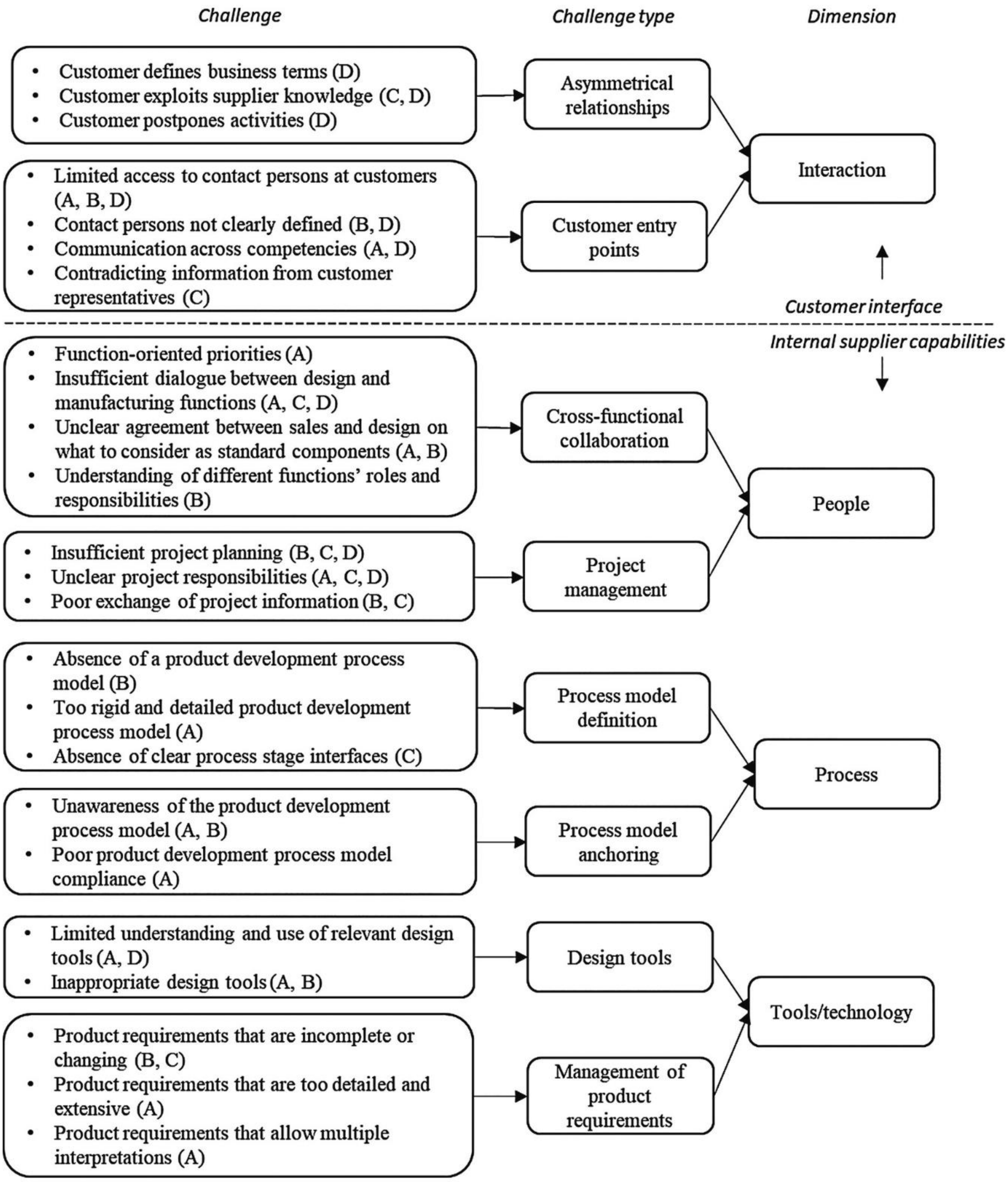


Figure 2: *Challenges experienced by suppliers when involved in customers' product development*. (Flankegård et al., 2021)

Flankegård's study contributes to the existing literature by offering a detailed examination of supplier experiences in product development and proposing a framework for mitigating challenges often encountered by suppliers. It underscores the significance of both supplier and customer roles in building effective collaboration and enhancing the quality of product development projects. While the article primarily serves the interests of manufacturing and design suppliers, it is important to note that its perspective contrasts with that of this thesis. As this thesis mainly focuses on the customer, and their decisions regarding internal and external communication. But these choices also likely have an effect on the operations of their suppliers. Flankegård et al. (2021) suggest that customers should be aware of the challenges faced by their suppliers to ensure successful partnership outcomes.

2.6 Low-Volume Manufacturing Communication

Javadi and Chirumalla (2024) focus on the challenges and strategies in managing product introductions in low-volume manufacturing. They identify that the quality of information exchange between design and manufacturing departments is critical in these settings due to the unique challenges of high-mix, low-volume production. By studying five Swedish manufacturing companies, they propose several strategies to improve the quality of information content in communications:

- Securing a production test and verification plan: To ensure that products and production infrastructure are compatible and address any issues with information quality before manufacturing, phases emphasising testing and refinement of both elements together are introduced. This strategy is designed to offer more opportunities for identifying and resolving potential problems early on rather than later.

- Developing a formal design and production coordination plan: This strategy incorporates several methods of coordination to verify that the information manufacturing receives is accurate, up-to-date, and easily interpretable. These methods include joint design reviews involving designers and manufacturers, prototype assembly by production managers and operators to gain valuable manufacturability insights, and including manufacturing requirements in the requirements specification for new products.

- Developing a lesson-learned management plan: Initially introduced for pilot evaluations, this strategy enhances cross-project learning by identifying past information quality issues and incorporating those lessons to improve future projects.

Javadi and Chirumalla (2024) explore how these strategies were implemented and evaluated, demonstrating their impact on improving information content quality. For the companies involved, these improvements helped reduce production disruptions, start-up delays, and non-conformities in produced products. The research provides new insights into adapting product introduction strategies to better meet the unique requirements of low-volume manufacturing, thereby enhancing information content quality when transitioning a product from the design phase to manufacturing.

2.7 Effects of Strategic Outsourcing

In the past, outsourcing was primarily used as a cost-cutting measure, but it has now spread into the competitive cores of companies (Hoecht & Trott, 2006). Outsourcing can refer to contract manufacturing as well as the hiring of consultants on short-term contracts, posing risks related to compromised innovativeness (Hoecht & Trott, 2006). Hoecht and Trott (2006) also suggest several strategies that managers can adopt to combat these risks and mitigate their effects. They highlight how this evolution in outsourcing practices introduces significant innovation-related risks, primarily through the increased potential for information leakage and the jeopardization of intellectual property rights. Additionally, they point out the growing dependence of companies on external expertise. This reliance, combined with short-term contracts, can dull a company's competitive edge, reducing it to an expected industry standard over time. They provide examples from the oil and gas drilling industry in the North Sea, where larger, more established firms benefited from outsourcing and network sharing, while smaller companies were more exposed to risks. They assert, *"Innovative ability cannot be simply bought and sold"* (Hoecht & Trott, 2006).

3. METHOD

In this section, the different methods used to reach the conclusions in this report will be described. These methods were employed to gather information and study the material in order to discuss and draw conclusions. This report primarily utilised three types of information sources, each of which could be further divided into subcategories.

3.1 Literature Study

A literature study involves identifying relevant scientific papers, websites, and books. To find pertinent scientific papers, three databases were searched: Web of Science, Google Scholar, and Chalmers Library. Various search terms were used, including "design, manufacturing, interface, communication" and "development and manufacturing communication patterns." The resulting titles and abstracts were then further examined to determine each article's potential value to the work. All sources used were critically reviewed to ensure their credibility and continued relevance to our report. The literature study has been a continuous project throughout the entire writing process to constantly expand on existing knowledge (Bryman & Bell, 2015, p. 104).

Much of the information found in the literature study was later used to discuss and compare results from other methods as part of the triangulation process. It also provided the opportunity to identify processes and structures that have been proven to work in similar cases, which could be suggested for future improvements.

3.2 Qualitative Methods

This section outlines the qualitative methods employed in the research, including interviews, observations, and immersion techniques. These approaches allowed us to delve deeper into individual experiences and behaviours, offering detailed insights into the subjects under study. By engaging directly with participants and their environments, we aimed to uncover the underlying dynamics and meanings that shape their actions and perspectives.

3.2.1 Interviews

Throughout this project, multiple rounds of interviews were conducted with current employees or consultants directly hired by the case company. The interviewees were individuals who had been involved in the development and/or manufacturing of Product 1 and had interacted with employees of the main EMP on one or more occasions. All seven interviews took place on-site at the company's office in Gothenburg, Sweden, with each session lasting approximately 30 minutes. These interviews were conducted between the beginning of February and the beginning of April in the year 2024.

The interviews were semi-structured, with each participant in a round being asked the same set of yes/no and explanatory questions. Supplementary questions were personalised and asked when deemed relevant based on the interviewee's prior responses. To minimise the risk of misunderstanding, the questions followed the same order and formulation in each interview, with additional clarification provided if needed. Consistency in questioning was maintained to mitigate variations in interpretation that could affect the responses (Bryman & Bell, 2015, pp. 219-221).

Concurrently with the interview rounds, the literature study progressed to inform the development of relevant questions and improve the quality of each subsequent round. After each round, the identification of relevant interview subjects and prioritisation of topics were refined based on emerging insights.

The first round of interviews served as an immersion into the company, allowing for an understanding of departmental operations and challenges faced by individuals in their roles. Each interviewee was asked to identify potential interview subjects within the company who met the criteria for participation. Subsequent rounds, such as the second round, involved a reduced number of subjects and focused primarily on error identification and categorization. Errors were grouped to assess the impact of poor communication between the case company and their main EMP on production-related cases.

Table 1: *Pseudonyms and interview information.*

Interviewee	**Pseudonym**	**Role**	**Date of interview**
Person 1	Franklin	Production Manager	15/02/24 09/04/24
Person 2	Dwight	CDO (Chief Design Officer)	20/02/24 09/04/24
Person 3	John	Designer (R&D)	13/02/24
Person 4	Lyndon	Software	20/02/24
Person 5	Richard	Aftermarket	27/02/24
Person 6	Gerald	Project Manager	03/04/24
Person 7	Jimmy	COO	29/04/24
Person 8 (EMP)	Ronald	Lean Coordinator	N/A
Person 9 (EMP)	George	Product Development Manager	N/A

The table above shows the pseudonym names for the people referenced in the thesis, this to make it easier to read and understand. These are not the real names of the people interviewed.

3.3.2 Immersion

As previously mentioned, all interviews were conducted in person due to the short geographical distances that allowed for easy access. This approach also facilitated frequent visits to the company premises. During these visits, visual observations and informal conversations, which were not recorded, were conducted. These interactions were carried out with individuals within the defined boundaries outlined in Section 1.4 and were aimed at clarifying answers provided during the interviews. Additionally, this method allowed for engagement with individuals outside the group of formal interview subjects, providing further insights into the company that semi-structured interviews alone could not offer.

3.5 Data Triangulation

As part of this thesis, a case study will be conducted to serve as the basis for later discussions and conclusions. This case study aims to illustrate how employees of the company interact both internally and externally, providing insights that interviews alone may not highlight. Possible reasons for this include inadequate questioning, limitations to interviewees' memories, or reluctance to disclose their roles in events.

Data triangulation involves collecting past communication logs related to the cases discussed during rounds one and two of the interviews. During the second round, participants were asked to share any past recorded communications from the previously discussed cases. These communications included emails, text messages, meeting notes, and direct messages through other online platforms. The dates used to reference the time of events are written in the format DD/MM/YY. These records were utilised to verify the accuracy of the information provided by the interviewees regarding the case and to gain further insight into the sequence of events. The effectiveness of this method largely depended on the willingness of the interviewees to share their communications and their ability to recall the platforms on which the communications took place.

Given the set boundaries restricting the analysis to information collected from internal sources at the case company, a comprehensive strategy of method triangulation was used (Polit & Beck, 2008, p. 554). Method triangulation involves using multiple methods to collect information about the same phenomenon, in this case, to jointly contribute to interpreting past communicative patterns within an organisation.

3.6 Research Quality

The sources used in this thesis are from Web of Science, Google Scholar, and Chalmers Library, all of which contain peer-reviewed material, thereby enhancing the credibility and trustworthiness of literary material used. The Journal Impact Factor was also considered when selecting sources.

The aim of the interviews was to understand the case company's communication, processes, and challenges relevant to the case study. These interviews were conducted between February and April 2024, while the case study pertains to events from March 2023. Consequently, the interview data may reflect some changes over time. Combining interview data with data logs provides a more reliable foundation, reducing the dependency on the interviewees' recollection. Analysis of communication logs is limited to recorded forms of communication, such as emails, meeting notes, and text messages. This excludes non-recorded channels like phone calls, video meetings, and unrecorded in-person meetings, thereby enhancing the study's reliability and research quality.

Validity refers to the extent to which the study investigates what it intends to investigate, while reliability refers to the consistency of the methods used. High reliability can be achieved without high validity, but high validity cannot be obtained without high reliability (Patel & Davidson, 2019).

The thesis is written by two authors and could serve as a well-grounded base for further analysis and discussion on the subject. The thesis has during its writing continuously been reviewed and discussed by the supervisor at Chalmers University of Technology and staff at the case company. This increases the thesis' validity, quality and prevents errors by giving others the opportunity to identify potential inaccuracies. The study is only based on the case company's own perspective, with no external views or inputs, and does present a risk for potential one-sided results.

4. EMPIRICAL RESULTS

The following section includes the results from the qualitative research methods, those are the seven performed interviews and studies of communication log data.

4.1 The Case

The following is related to how the case was selected, its timeline and how the events can be interpreted.

4.1.1 Case Selection

Through interviews conducted at the case company with its current partners and employees, as well as the study of communication logs and meeting notes, product problems and their consequences were identified. These issues were discovered during in-house testing, EOL tests at the EMP, or through consumer use. On the same occasions as the interviewees were asked to reflect on the past product problems they had encountered during their work, they were also asked which of these were caused by both the design department at the case company and the EMP (manufacturing). By using the experience of the designers when categorising, the speculation could be kept to a minimum as most of the issues had previously been internally investigated by the company. The results revealed 16 issues of varying causes and magnitudes. Among these, only three could be attributed as having been influenced by both design and manufacturing. Upon examining the consequences listed for the three problems related to the design-manufacturing interface, one issue stood out: a flow sensor installed in the wrong direction, on multiple units, over a period of time.

There were however other issues caused solely by design or manufacturing. In these cases, assumptions can be made that an improved interface between the functions would not have resulted in a more favourable outcome. The problem chosen for the case study cannot be isolated to one function without intersection with others.

4.1.2 Description

The situation with the incorrectly installed flow sensors arose during the production process following a design change implemented by the case company. Specifically, the design change involved the addition of a third flow sensor. Previously, two similar components had been installed in each unit without any issue.

These sensors are utilised to measure the volume of water passing through their openings over time. Most models require specific mounting directions depending on the flow direction to be measured. Installing them incorrectly can result in inaccurate and misleading readings. As John stated during the interview on 13/02/24, *"The thing about the flow sensors we use is that they still give measurement values if they are mounted in the wrong direction, but these values do not necessarily reflect reality."* This was the case for the case company when implementing the third flow sensor, leading to a reduction in performance and ultimately failure for the affected units. The design change was implemented during the production phase under significant time pressure because the new flow sensor was critical for the product's functionality and needed to be implemented promptly (Dwight).

According to data from the company's records (the case company, 2023), the consequences of this mistake affected 84 units and incurred substantial direct costs totalling over 80,000 SEK. These costs included expenses for new components, salaries, and travel. Additionally, other consequences included a decreased return on investments (ROI) during downtime and potential loss of future contracts due to the company's tarnished reputation. As Franklin mentioned, *"Return on investments is greatly affected. The recycling rate of water is measured by flow sensors. If they show misleading values, it can lead to less satisfied customers, potentially impacting future sales."*

4.1.3 Chronological Events

Figure 3 shows a chronological timeline illustrating the development of the case involving the misinstalled flow sensors. The timeline aims to provide a comprehensive understanding of the events leading up to the detection and aftermath of the issue. It serves as a vital tool for tracking the sequence of events and as a foundation for later discussions and conclusions. The grey areas on the figures in this section are used to censor names and other sensitive information such as different types of components also labelled as “Com”.

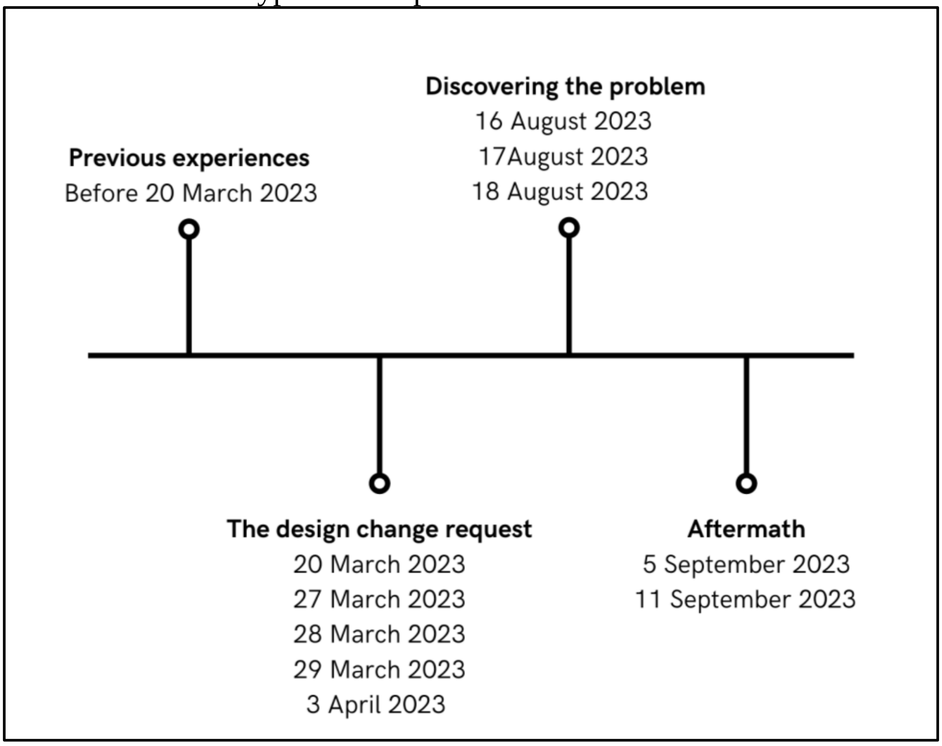


Figure 3: *Chronological events timeline.*

4.1.3.1 Previous Experiences

- Before 20/03/23

The third flow sensor was first mentioned to the EMP contact person on 20/03/23. Before this, there had only been two direction-sensitive components used in each unit and there are no earlier accounts of problems related to the installation of these. Proving that both the case company and their EMP were aware of the importance of correct installation. Figure 4 below is taken from blueprints used before 20/03/23 and shows a text box that informs the reader to pay attention to the flow direction of component 30 and two other units of components 14.

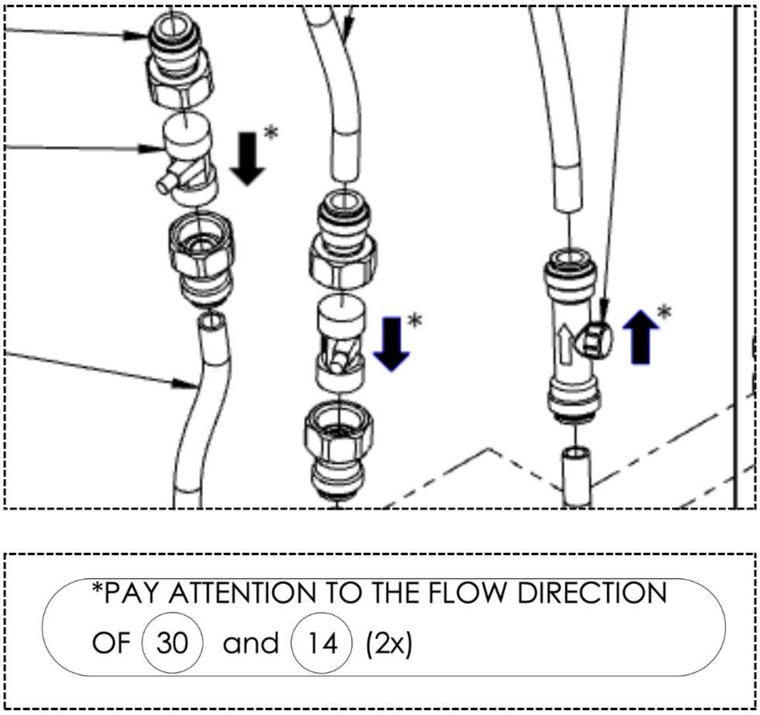


Figure 4: *Installation of other direction sensitive components with text box regarding direction of flow sensors, taken from blueprint (the case company).*

4.1.3.2 The Design Change Request

- 20/03/23 - Emails

The first recorded mention of the implementation of a third flow sensor was discussed between Dwight and a EMP-representative over email. A description of what points the sensor should be connected to and in what direction it should measure flow. The description, translated from Swedish reads as follows: *"Add a flow sensor on the hose from the pump to the valve box".*

An initial hand-drawn sketch was also provided by Dwight during an exchange on the same day (see Figure 5). It is supposed to illustrate how the component in question should be connected. In the same communication that included the sketch, a disclaimer was added that John would get back with a more detailed illustration at the end of the same week. The emails used and images used in the above summary from 20/03/23 are presented in appendix 4.

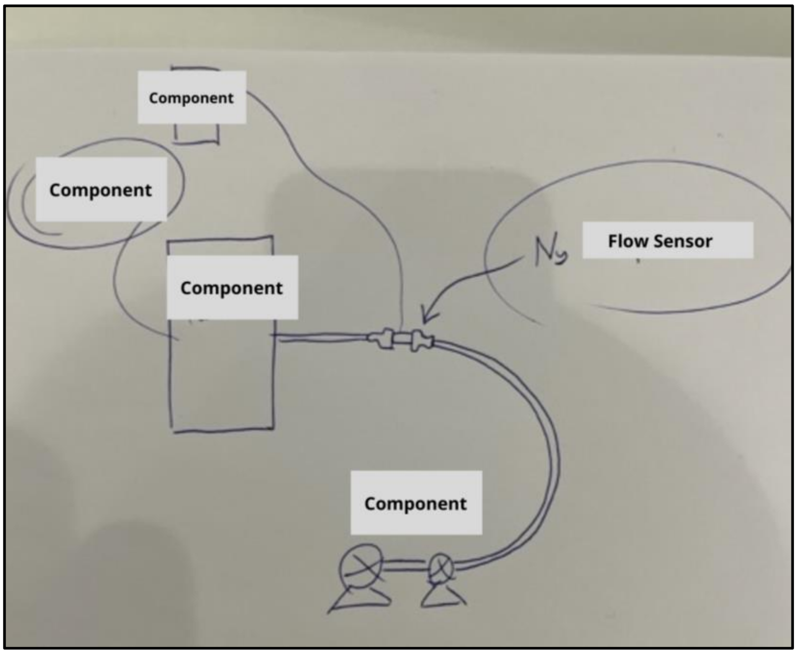
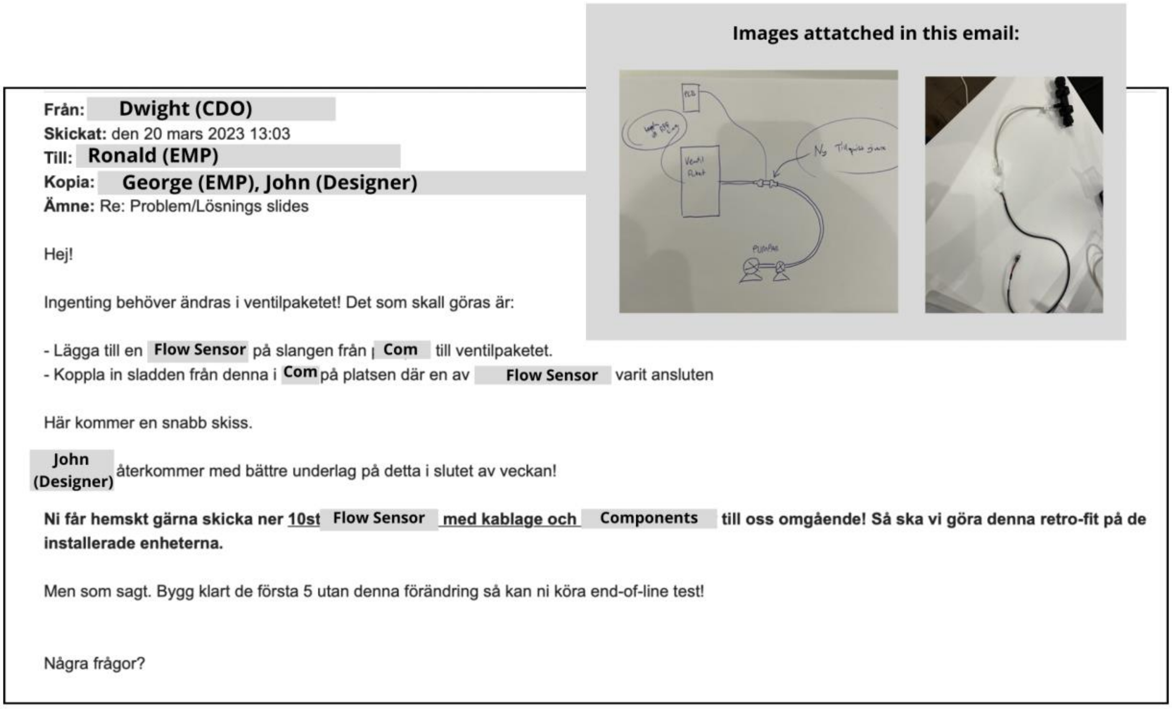


Figure 5: *Initial sketch of component connections (Dwight).*



Från: Dwight (CDO)
Skickat: den 20 mars 2023 13:03
Till: Ronald (EMP)
Kopia: George (EMP), John (Designer)
Ämne: Re: Problem/Lösnings slides

Hej!

Ingenting behöver ändras i ventilpaketet! Det som skall göras är:

- Lägga till en Flow Sensor på slangen från Com till ventilpaketet.
- Koppla in sladden från denna i Com på platsen där en av Flow Sensor varit ansluten

Här kommer en snabb skiss.

John (Designer) återkommer med bättre underlag på detta i slutet av veckan!

Ni får hemskt gärna skicka ner 10st Flow Sensor med kablage och Components till oss omgående! Så ska vi göra denna retro-fit på de installerade enheterna.

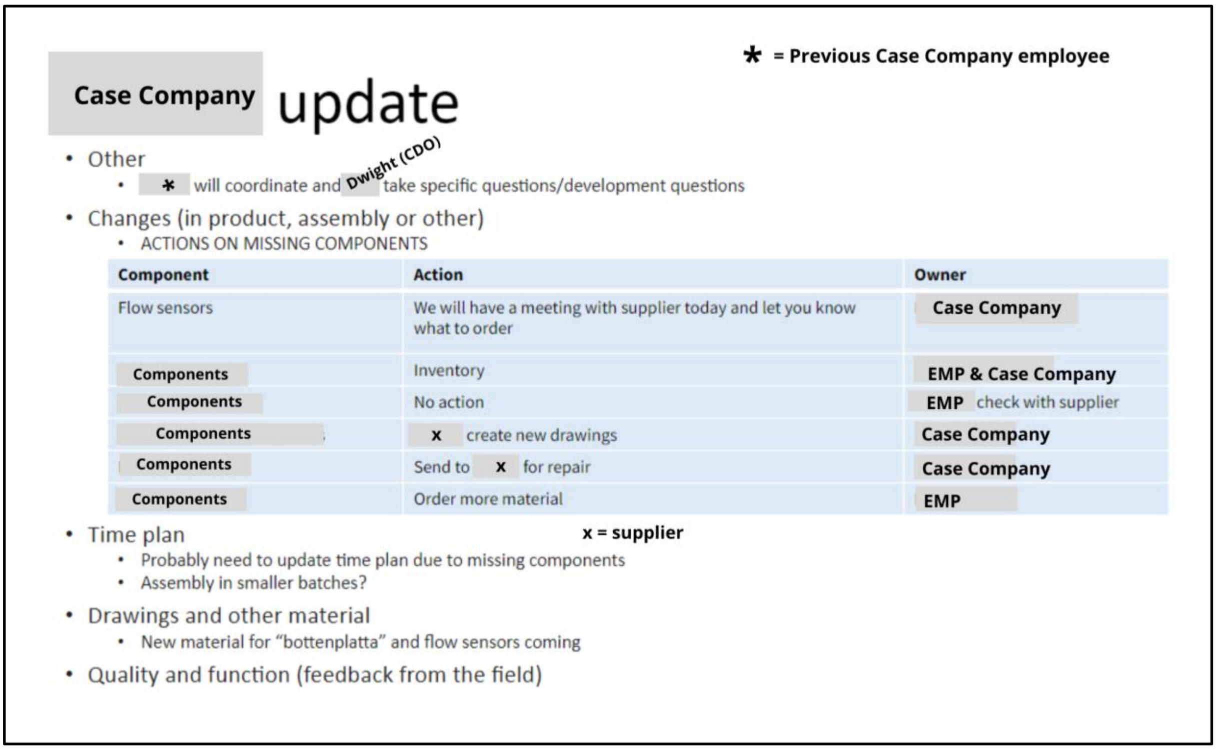
Men som sagt. Bygg klart de första 5 utan denna förändring så kan ni köra end-of-line test!

Några frågor?

Figure 6: Email from Dwight to Ronald (EMP) with a carbon copy to George (EMP) and John.

- 20/03/23 - Weekly status meeting
  Attendees: Not noted, according to Dwight the attendees were: Dwight, John, a previous case company employee, Richard, Ronald (EMP) and George (EMP).

A meeting with the EMP and the case company was held 20/03/23 09:00, where the new flow sensors were discussed, see the first row of the table in Figure 10 (Dwight).
In Appendix 4, Figure D there is a calculation, “*Before the third flow sensor was implemented, there were 2 flow sensors in Product 1. This is a calculation for how many Product 1s can be built with 3 flow sensors in it by taking flow sensors from previous Product 1. It is not possible to build as many units because it required more sensors, it went from 2 to 3 per unit.”* (Dwight). The meeting notes in Figure D also mentions the amount of flow sensors in stock and how these need to be allocated and retro-fitted into already assembled units



Case Company update

***** = Previous Case Company employee

- Other
  - * will coordinate and Dwight (CDO) take specific questions/development questions
- Changes (in product, assembly or other)
  - ACTIONS ON MISSING COMPONENTS

Component	Action	Owner
Flow sensors	We will have a meeting with supplier today and let you know what to order	Case Company
Components	Inventory	EMP & Case Company
Components	No action	EMP check with supplier
Components	x create new drawings	Case Company
Components	Send to x for repair	Case Company
Components	Order more material	EMP

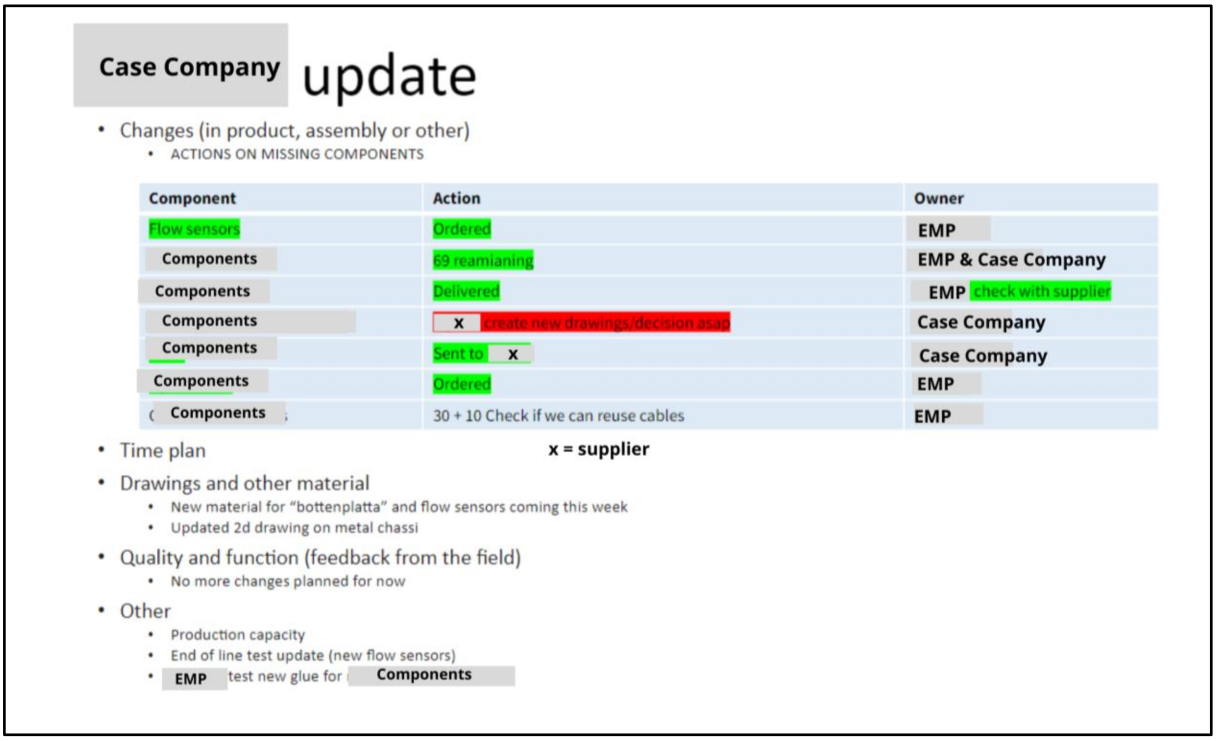
x = supplier

- Time plan
  - Probably need to update time plan due to missing components
  - Assembly in smaller batches?
- Drawings and other material
  - New material for “bottenplatta” and flow sensors coming
- Quality and function (feedback from the field)

Figure 7: *Weekly status meeting 20/3-23*

- 27/03/23 - Weekly status meeting
  Attendees: Not noted

The green and red color-coded markings in Figure I, Appendix 4 serve to highlight the status of matters. Red markings mean that the matter requires attention, green meaning that something has been dealt with and is not in need of action. *“Since the flow sensors is marked green, we probably did not talk about it”* (Dwight).



Case Company update

- Changes (in product, assembly or other)
  - ACTIONS ON MISSING COMPONENTS

Component	Action	Owner
Flow sensors	Ordered	EMP
Components	69 reamianing	EMP & Case Company
Components	Delivered	EMP check with supplier
Components	x create new drawings/decision asap	Case Company
Components	Sent to x	Case Company
Components	Ordered	EMP
(Components ;	30 + 10 Check if we can reuse cables	EMP

- Time plan

x = supplier

- Drawings and other material
  - New material for "bottenplatta" and flow sensors coming this week
  - Updated 2d drawing on metal chassi
- Quality and function (feedback from the field)
  - No more changes planned for now
- Other
  - Production capacity
  - End of line test update (new flow sensors)
  - EMP test new glue for Components

Figure 8: *Weekly status meeting 27/3-23, page 2*

- 28/03/23

Further exchanges were held between Dwight and Ronald and other staff at the case company. In relation to this case, these concerned unaltered EOL-test procedures after the implementation and the electrical wiring for the component. See those emails in Appendix 4.

- 29/03/23

John notified staff at the case company and George and Ronald at the EMP, that he had shared the updated blueprints. These were shared through Microsoft Teams in a group consisting of designers at the case company and representatives of the EMP. See Figure H in Appendix 4 that shows the original email from John that includes a screenshot of the file uploaded in Microsoft Teams. Those who had access to the Teams-group were Dwight, John, Lyndon and three consultants that no longer work with the case company. The EMP also has access, but who specifically is unknown *"Me, John, Lyndon and them from the Consulting Company, Name 1, Name 2, Name 3 I think. And the EMP, don't know which ones though"* (Dwight, personal communication, 10/05/24). Franklin was not a part of this Microsoft Teams-group (Franklin).

- 03/04/23 - Weekly status meeting

  Attendees: Not noted

A weekly meeting was held a few days after the final blueprints had been shared. No questions or notes related to the installation of the newly introduced flow sensor could be found. Warehouse levels and production quotas related to current batches and future updated units were instead discussed.

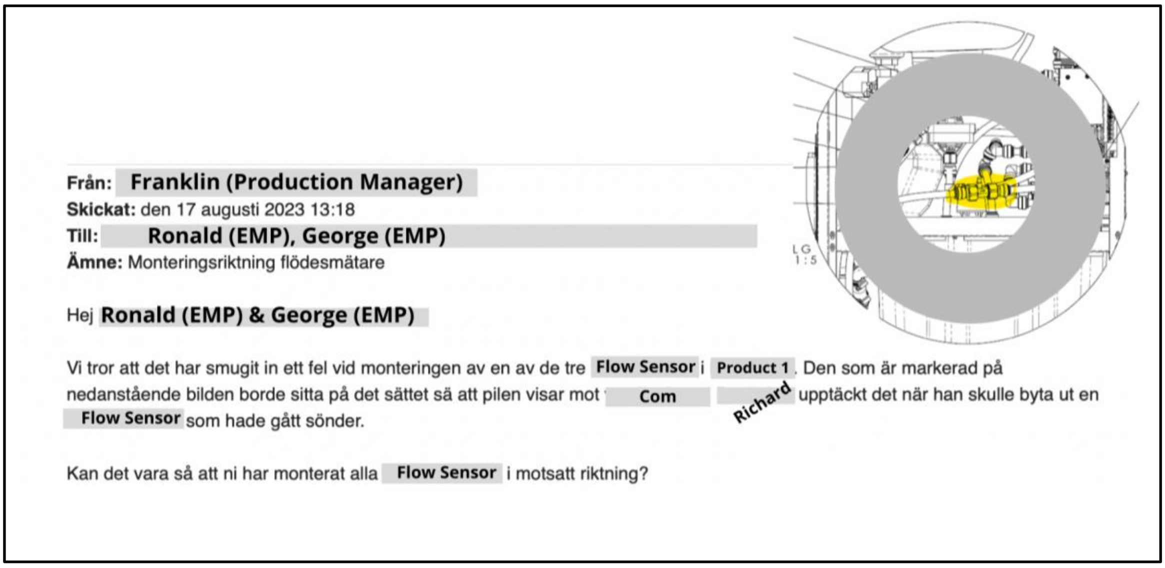
4.1.3.4 Discovering the Problem

- 16/08/23

In an interaction with Franklin, Dwight confirmed the instructions he had given the EMP's contact person regarding the flow sensor installation. He also pointed out how they were meant to be interpreted (see Figure J in Appendix 4). This was done shortly after some delivered units had been found with misinstalled flow sensors during service operations. *"It [misinstalled flow sensor] was something that I discovered during a service of a unit."* (Richard). Judging from the relative lack of context in this email, Dwight and Franklin had likely shortly before had an in-person conversation regarding the discoveries. Dwight only got back to relay the instructions that he initially provided the EMP with.

- 17/08/23

This was the first time the EMP was notified of the case when Franklin emailed Ronald and George. Franklin also asked if there was a possibility that all of those flow sensors, up until that point, could have been installed the wrong way, see Figure 10.



Från: Franklin (Production Manager)
Skickat: den 17 augusti 2023 13:18
Till: Ronald (EMP), George (EMP)
Ämne: Monteringsriktning flödesmätare

Hej Ronald (EMP) & George (EMP)

Vi tror att det har smugit in ett fel vid monteringen av en av de tre Flow Sensor i Product 1. Den som är markerad på nedanstående bilden borde sitta på det sättet så att pilen visar mot Com Richard upptäckt det när han skulle byta ut en Flow Sensor som hade gått sönder.

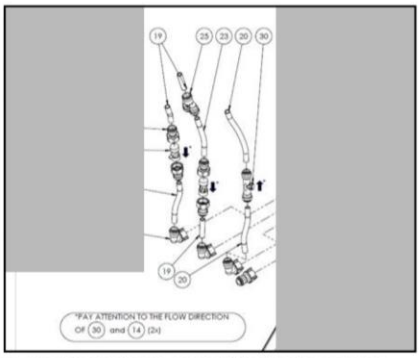
Kan det vara så att ni har monterat alla Flow Sensor i motsatt riktning?

Figure 10: *Email from Franklin to Ronald (EMP) and George (EMP).*

- 18/08/23

George at the EMP confirmed Franklin's suspicions previously presented on 17/08/23. After having checked with their operators, the EMP said that the flow sensors most likely had been installed incorrectly. They suggested that lack of information and feedback from the case company led to the components being installed incorrectly and that there were no signs of error when performing the EOL-tests. Also that the blueprint was not as clear for the current section as they were for other parts, where the flow direction is made more apparent, see the email in Figure 11 which also includes a smaller version of Figure 4.

Från: George (EMP)
Ämne: Sv: Monteringsriktning flödesmätare
Datum: 18 augusti 2023 16:35:38 CEST
Till: Franklin (Production Manager), Ronald (EMP)



Hej Franklin

Enligt överenskommelse så har vi checkat med operatörerna och tyvärr verkar det som man med största sannolikhet har monterat Flow Sensor fel.

Misstänker att pga. bristande information och återkoppling monterats fel initialt och sedan har man fortsatt i gamla fotspår samt att man inte upptäcker det i EOL-Testet. Tyvärr är just den monteringsanvisningen inte lika tydlig som den för ryggen, där det klart framgår riktning av givarna, se nedan.

Olyckligt ☹

Figure 11: *Email from George to Franklin and Ronald (EMP).*

4.1.3.5 Aftermath

- 05/09/23 & 06/09/23

Franklin emails George at the EMP, a Microsoft Excel file containing cost estimates for the price of repairing all the defective units. Franklin suggests that the case company and the EMP can split the costs for hotels and transport as they intend to perform other, unrelated service operations on the same occasions. An agreement seems to already have been made that the EMP should cover the costs related to the misinstalled flow sensors. It is likely that this had been agreed upon during an earlier interaction. Appropriate times for another digital meeting were also discussed in the same series of emails.

The email logs from this event are not included as a majority of the contains sensitive information that can not be censored without it affecting its contents. The remaining parts of the communications are also of low relevance to the studied case.

- 11/09/23 - Weekly status meeting
  Attendees: Not noted

The final agreement was presented during a weekly meeting between the case company and the EMP. The results were 84 affected units and 84 new flow sensors that the EMP would pay for and the two companies would split the costs incurred through transport and overnight stays. On the same occasion, the agreed upon time spent per unit for rework, hourly wage rates, costs for overnight stays and transport costs were also presented. See Figure 12 for further information.

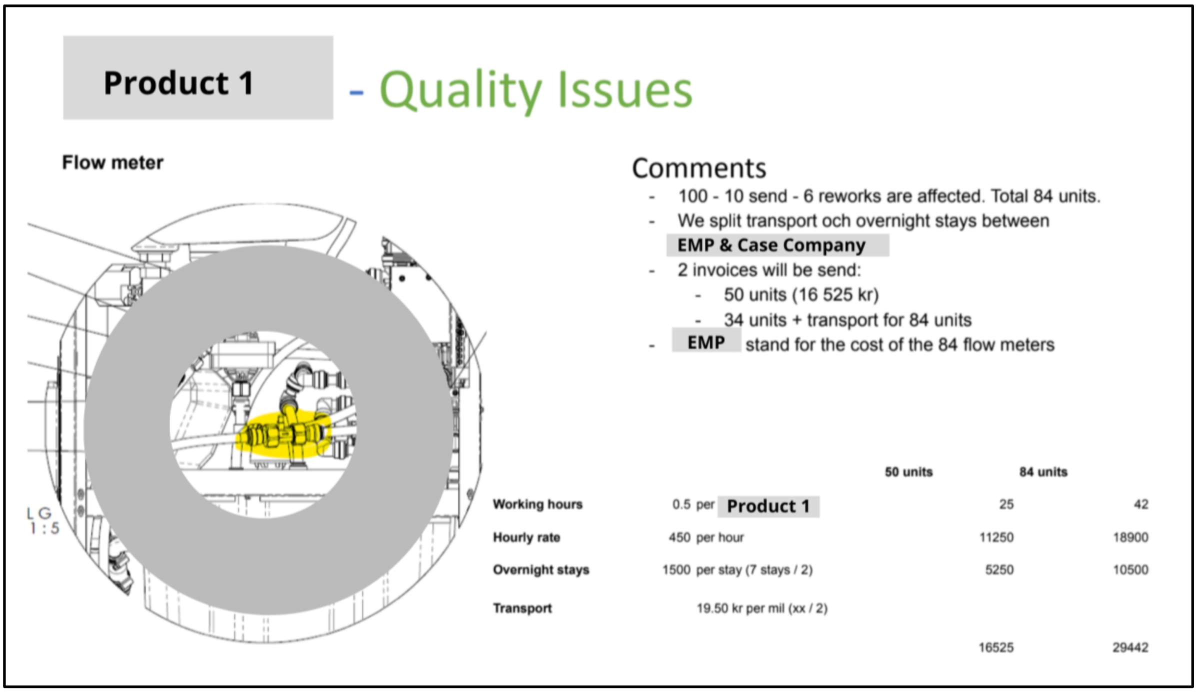


Figure 12: *Weekly status meeting 11/9-23, page 3*

4.1.4 Events Analysis

As the timeline in Section 4.1.3 illustrates, the installation details of the third flow sensor were never thoroughly clarified. While some discussions between the case company and the EMP focused on the electrical connections of the sensor, the direction of flow was never given sufficient attention. After the sensor's implementation was first mentioned and the updated blueprints were shared over Microsoft Teams, the flow direction was not further discussed. There were no reported issues related to the wiring of the sensor, indicating that the case company staff were capable of explaining and clarifying ambiguous details when necessary. From this, it can be assumed that both parties believed the instructions were clear and shared the same understanding.

This assumption, however, proved incorrect. For the sensor to function optimally, it needed to be installed in the flow direction intended by the case company. The EMP, however, consistently installed the sensor in the opposite direction on every unit produced until the error was noticed. The fact that the sensor was consistently installed incorrectly suggests that the EMP was aware of a correct and incorrect installation direction but mistakenly believed the flow travelled in the opposite direction. This indicates a flawed understanding of the product's basic functions on the part of the EMP, which they mistakenly thought was correct. Moreover, the case company took few steps to correct any flawed understanding of the product's functions.

The flow sensor's direction was mentioned or indicated on two occasions: 20/03/23, and 20/03/23. On 20/03/23, the installation was briefly mentioned by Dwight as *"Add a flow sensor on the hose from the pump to the valve box."* This communication was minimal, and the interpretation of the message relied heavily on how the receiver understood the prepositions used. On 20/03/23, the direction of the flow sensor was indicated in the updated blueprints used by operators during final assembly. In this case, the arrow indicating the direction on the component was barely visible unless zoomed in. Additionally, unlike previous blueprints, no text box alerted the operator to the correct flow direction.

Another error discovered in the same blueprints shared on 29/03/23 (see Section 4.2.2), might have contributed to confusion during assembly. However, since the connecting hoses to the flow sensor are of different lengths, and the instructions conveyed this, it is unlikely to be the sole cause. Nonetheless, it likely added to existing confusion or misconceptions.

The conclusions drawn from these events are that the operators at the EMP likely had a flawed understanding of the product's functions and systems. The updated blueprints did not adhere to the same standards as previous ones, lacking text boxes and bold arrows. The updated blueprint was not subject to the same level of scrutiny as expected, with issues such as the absence of text boxes, bold arrows, and inconsistent component numbering going unnoticed.

4.1.5 Artefacts

This section introduces a summary of findings derived from examining the content and attachments that were included or referenced on Section 4.1.3. These details could pertain to various aspects such as the nature of the information shared, trends in communication, or compliance-level with industry standards. It serves to set the stage for presenting detailed insights gained from reviewing the materials circulated via email communications.

4.1.5.1 Pay Attention to the Flow Direction

In the updated blueprints shared by John on Microsoft Teams on 29/03/23, blueprints were provided along with several irregularities. Figure 13 and 24 show instances where the third flow sensor appears in the assembly instructions. Notably, the direction of the arrow in Figure 14 is barely distinguishable to the naked eye unless zoomed in. Items labelled "*E*" require extra attention from the operator, as they need to be finger tightened with an additional ¼ turn. In previous instances of flow sensor installation, a prominently placed bold arrow was included, accompanied by a text box to highlight the direction of flow (see Figure 4).

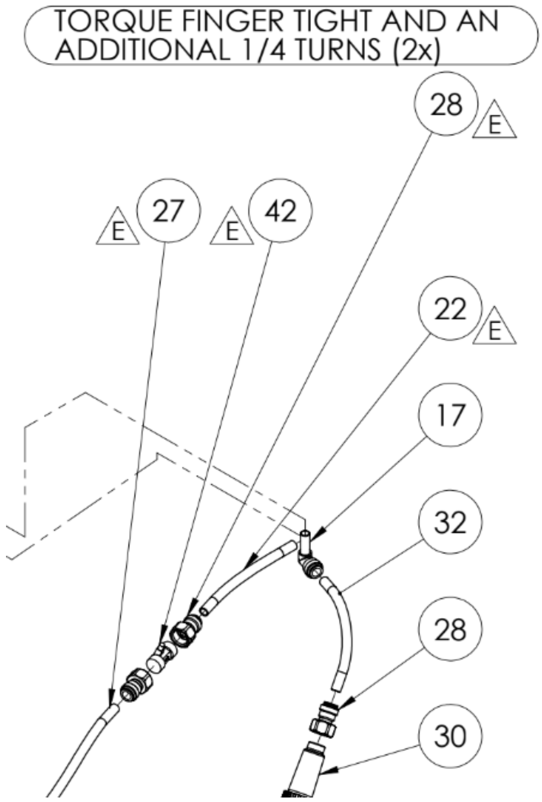


Figure 13: *Installation procedures of flow sensor (42) and other components (the case company).*

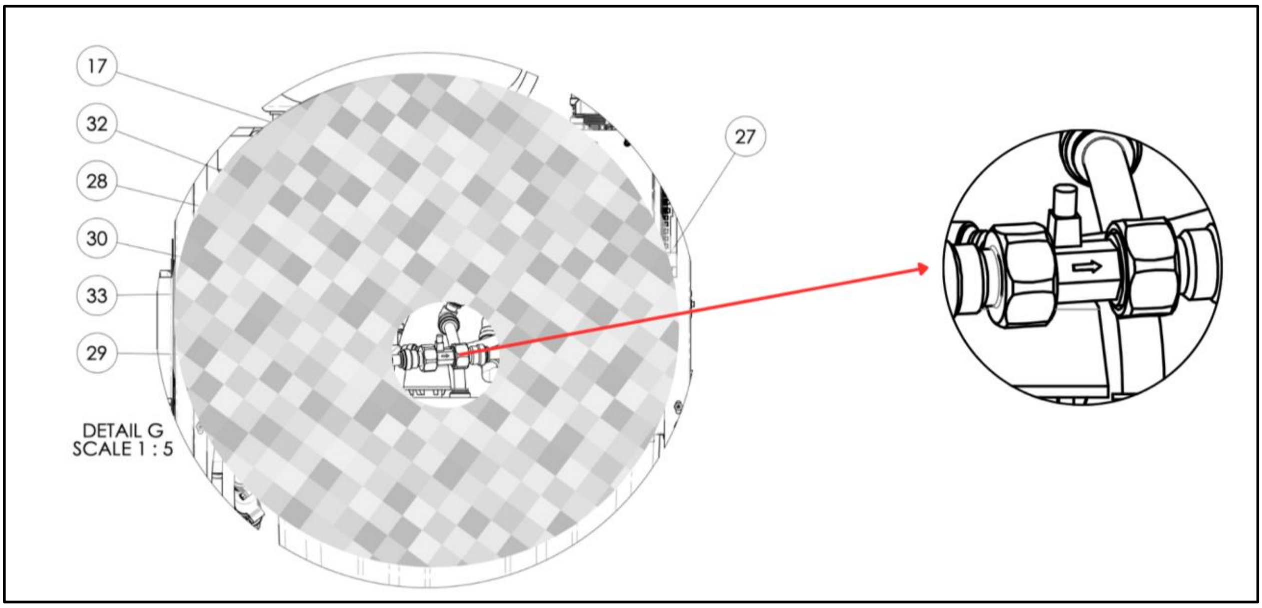


Figure 14: *Third flow sensor installed (the case company). This figure has been edited to enlarge the view of the component.*

4.1.5.2 Component Numbering

Through immersion and data collection, an error in the blueprints was noted. This blueprint, sent to the EMP on 29/03/23, was to be used for installing the new third flow sensor. The bill of materials, provided at the beginning of each blueprint, lists the materials used and their assigned numbers for referencing parts later in the instructions. Consistency in these references is crucial to avoid confusion during assembly (Arena Solutions, n.d.). However, in this case, consistency was lacking. The irregularity discovered involves the numbering of component 22 in Figure 13, which is later referred to as component 27 in Figure 14. In Figure 13, component 27 shows the flow sensor's other connector, opposite to component 22. This typographical error in the bill of materials had gone unmentioned in the interviews and was assumed to be unidentified by the case company. Normally, such an error should have been discovered during the blueprint review process before approval. The blueprint was created by John and approved by Dwight.

4.1.5.3 Assembly instructions

"Ronald makes assembly instructions that the operators use. Ronald bases the assembly instructions on the blueprints that we at the case company provide. He has very good knowledge of how Product 1 works" (Franklin).

The designer Dwight has not seen the assembly instructions for the design change and the case company did not check or look at them, and do not do so in their processes. The assembly instructions are a part of their organisation between Ronald and the operators and how their factory is laid out. The case company sends information in the form of blueprints and pictures that they believe is enough for Ronald to understand the product (Dwight).

4.2 Interview and Immerion results

Below, the results from the immersion and interviews performed at the company will be presented. These include information obtained from visual observations, unrecorded conversations and relevant information disclosed in interviews without a direct connection to the case studied.

4.2.1 Discovering the problem

Lyndon describes in her interview how the problem was discovered in the field and why the EOL-test did not pick up this issue: *"After we installed 50 Product 1's, we saw that all of them had this filter clogged error. Richard would go out and check the filter and it looked fine, but after a while we noticed that a flow sensor was assembled in the wrong direction. Flow sensors have a direction, if assembled in the wrong direction it stops working over time. It is not made to spin in that direction, and it is brand new. But the EOL-tests cannot detect this, because it still shows a flow. That was a design change we made after the start of production."* (Lyndon).

When asked why the flow sensors were assembled in the wrong direction Lyndon says *"Unclear, because as far as I understood there was a drawing with an arrow from us [case company] to them [EMP] how it should be implemented. So I think it is just a lack of care from the EMP's side."* (Lyndon). The image with the arrow that Lyndon mentioned can be seen in Figure 14.

Franklin also mentioned in the first interview how *"We sent an update on the blueprint when there was a design change with the flow sensor. But it was: Here is the drawing. But it wasn't that clear as if: Look, there's an arrow on that flow meter. But that was before I started working here"* (Franklin).

4.2.2 Lack of Traceability and Coordination

Through conversations, it has become clear that the case company has had a deficient culture of taking notes during meetings (Gerald). The extent of note-taking was unknown, but Gerald, a project manager who joined the case company in late 2023, prioritised improving this practice. He believed it would enhance the traceability of discussions and agreements made during meetings, both internally and with external partners (Gerald).

In an interview, Richard also mentioned the lack of documentation and traceability: *"Above all, I think there has been poor documentation, so also in meetings and everything in general. It has probably gotten a little better, but obviously it has been poorly documented, in what has been sent to them in the form of assembly instructions and such"* (Richard).

Furthermore, there was no standardised process for implementing design changes or other procedures when interacting with the EMP (Gerald), resulting in a lack of traceability. This includes the complete absence of joint design reviews between the case company and their EMP (Dwight, personal communication, 30/4-24). The only communications regarding design changes related to the flow sensor case were limited to the email communications presented in Section 4.1.3.

Interviews with Franklin and Dwight revealed that the case company and the EMP had weekly meetings attended by Richard, John, Franklin, and Dwight. These meetings included discussions about production and served as a weekly check-in (Franklin). However, the EMP was deficient in presenting production KPIs and issues. Franklin had to repeatedly reach out despite the recurring nature of this request in every weekly meeting. Franklin took over the responsibility of the weekly meetings on 02/09/23. The person responsible before was the previous interim production manager.

"Me, Dwight, Richard, and John. We ran this arrangement a few months after I started and then we changed it so that only me and Dwight participated in meetings. It wasn't about many KPIs, but it is true that we needed to remind them several times and that they often did not match" (Franklin).

4.2.3 Communication Channels

In the past, the case company has used multiple channels to communicate internally, with partners, and with clients. These channels include phone calls, Slack, Google Drive, email, and Confluence, among others. While all these methods offer ways to store information, the multitude of alternatives can lead to disorganisation and information loss (Franklin). Consequently, the company recently decided to phase out some of these services and implement a new project management software called *"Basecamp"* (Gerald). Basecamp is designed to help teams organise tasks, manage projects, and communicate more effectively (Basecamp, n.d.). The platform integrates many functionalities that the case company already uses, such as to-do lists, milestone management, file sharing, and message boards.

Regarding communications with their EMP, procedures and channels vary greatly and often seem to be decided based on what is most convenient for the initiating sender at the moment. During the first round of interviews, when asked through which channels communications were conducted when contacting their main EMP, the responses were highly scattered (Dwight; John; Franklin; Lyndon; Richard). Interviewees mentioned that communications had been performed via email, phone calls, SMS, Apple FaceTime, Google Meet, Microsoft

Teams, TeamViewer, and on-site visits. An on-site visit requires a roughly two-hour, 175 km car ride (Google Maps, n.d.).

It is important to note that the question only concerned interactions between the case company and their main EMP, suggesting that other channels might be used when communicating with other suppliers, clients, and partners.

4.2.4 Employee Turnover Rate

It is not uncommon for startups to struggle with retaining employees and preserving their talents (Vo, 2021). This challenge is particularly significant for companies where innovation is a key competitive advantage, such as the case company. Like many other startups, the case company has experienced issues related to high employee turnover rates. This turnover includes direct employees, consultants hired for specific periods, and interns. These human resources cannot simply be acquired; they must be nurtured over time to fully commit to and engage with their tasks (Kennedy & Daim, 2010).

Through interviews and company immersion, it has been observed that the case company's high employee turnover rate has negatively impacted its operations. During the first round of interviews, one question asked was whether the subjects had colleagues working in the same areas during the development or manufacturing of the company's previous product. When later asked which of these people still worked at the company, several names mentioned were of past, not current, employees. Some interviewees had started working for the case company as replacements for those who previously held their roles.

Between January 2023 and May 2023, three different people held the role of Production Manager (Franklin). Initially, an external consultant was responsible for communication with the EMP. It was then decided that an internal person should take on this role, leading to the recruitment for the Production Manager position. During this period, an interim employee filled the role for a few months. When Franklin was hired, it was shortly decided that all communication between the case company and the EMP should go through the Production Manager to streamline communications through a single contact person. Previously, the challenge had been the lack of a dedicated person to manage communication and coordination with the EMP (Jimmy).

Throughout the period between January 2024 and May 2024, the company consistently had 3-4 interns whose roles changed over time. These interns were largely independent in their tasks, which often included critical roles such as prototype testing and development. Some interns are offered permanent roles at the end of their education, but there are no guarantees. Between the interviews and the publication of this report, two out of the seven interview subjects had their employment terminated, either through resignation or being let go by the company.

4.2.5 How could the collaboration have looked different?

During the first round of interviews we asked the question: "*How could the collaboration between the case company and EMP have looked different?*"

Here the interviewees got a chance to reflect on the collaboration with the EMP during the entire process of the Product 1 project.

- John (13/02/24)
  “We should have relied less on them regarding product development and taken control of it ourselves. Let them handle the manufacturing. During this period, it wasn't clearly defined who was responsible for what."

- Dwight (20/02/24)
  "I don't think we should have rushed as much as we did, maybe started production a little later to give them more information and to be able to straighten out these problems before starting production. In terms of communication, it would have been better if we had a contact person from us right from the start so that everything would have gone through that person. And if we chose to communicate in one channel, via email or via SMS or in a way that allows you to track the communication.

- Franklin (15/02/24)
  "Creating routines absolutely. In the design phase I can't add much because I wasn't involved at the beginning."

- Lyndon (20/02/24)
  “I think a formal type of change request with all the documentation, because I have not seen that drawing even [blueprint of the design change]. So I do not know who sent it, in which format and to who. So a more centralised information sharing platform or something.”

- Richard (27/02/24)
  "Above all, I think there has been poor documentation, also in meetings and everything like that. It's probably gotten a little better, but obviously it's been poorly documented, what's been sent to them in terms of assembly instructions and such."

5. DISCUSSION

The section includes the discussion of the results in the light of the theoretical framework.

5.1 Theoretical Association

To assign deeper reasons as to why the flow sensors on 84 units were incorrectly installed, an analysis of the theoretical framework in relation to the results was necessary.

5.1.1 Previous Experiences

Perceptual constancy
The updated blueprint shared on 29/03/23, lacks bold arrows or accompanying text boxes to indicate the direction of flow for the components. This oversight can be connected to perceptual constancy as mentioned on Section 2.3. In the previous implementations of direction sensitive flow components there are several bold notations, see Figure 4. The EMP already had an impression of how the case company handles components where the assembly is particularly important, leading to them potentially expecting the same type of behaviour in future interactions regarding similar instances (Hamilton et al, 2019: Wakefield, 1976). This is also confirmed in the email form George (EMP) where he included a picture of the previous notations and said he expected the same level of information as before, see Figure 11.

It is important to note that the past experiences leading to the differences in perception not only is a factor in the misunderstanding, but also the physical point of view. One's proximity to the blueprint (Figure 14) influences the one's perception of if. This makes it clear that the arrow is very little relative to the rest of the blueprint making it very hard to see.

5.1.2 The Design Change Request

A design change is a complex process due to the technical nature of the Product 1 (Gerald, Section 4.1.2). According to the communication postulates, this results in complicated communication that needs multiple layers of interaction, from the design department to the manufacturing department (Barnlund, 1970).

Lacking designers empathy
There are challenges for the case company to ensure that the message to the EMP is understandable and well defined to ensure quality in the production. The designer's empathy towards the EMP has previously stood higher in posture, but the case with the implementation of the third flow sensor tells a different story. It shows a decline in empathy where it is perhaps overlooked by designers that the EMP may not have the same knowledge of the product (Vandevelde & Van Dierdonck, 2003). If the designers at the case company show a deeper understanding and empathy towards the manufacturing process, issues like these may be avoided or mitigated in the future.

Different perceptions
In communication, fault explanations and information are often given due to the weakness in the individuals own perceptions (Wakefield, 1976). The quote in Section 4.2.1 Lyndon shows how there is a lack of empathy towards understanding the perspective from the EMP.

However, Lyndon also said *"...as far as I understood..."* and he mentioned earlier in 4.2.5 that he has not seen the drawing and is assuming or listening to his coworkers view of the situation. This is problematic in a way because the perception of the situation puts an emphasis on the EMP that they showed a lack of care, rather than the case company lacking care or not being clear enough in their communication. Wakefield says that to avoid misunderstandings there needs to be accurate communication, and to avoid misunderstandings the perceptions must be accurate (1976).

The case company needs to enlarge their range of expectations and decrease their *"stubborn and well-established attitudes",* in this case their lack of self criticism. The case company cannot expect the EMP to understand and perceive the information the way that they do, because the case company has a very large understanding and a experienced background in their product in relation to the EMP. Franklin shows signs of admitting errors (Section 4.2.1) that can occur in the individual's own perception on reflecting and investigating the events before he started working at the case company (Wakefield, 1976).

Noise & haste

The influence of the context and the external and internal environment may have impacted the communication failures, leading to oversight and mistakes (Barnlund, 1970). The external environment, such as market pressures to accelerate production mentioned in the interview with both Dwight and John (Section 4.2.5). As well as the internal environment that includes the organisational culture and structure of how the case company and the EMP communicate. Stress and tight deadlines may have influenced the communication leading to these mistakes.

As mentioned previously, a key factor is time and where haste created poor judgements and causes important details to be missed, and one of the largest obstacles to clear perceptions are the individuals own inability to take the time to observe and reflect thoughtfully (Wakefield 1976). Through the interviews and immersion it has been made clear that the high time pressure caused employees stress (Dwight), this can also be seen as a psychological noise.

Meaning that the thoughts and feelings of the sender in this case, hinders the effective exchange of messages (Hamilton et al, 2019). As stress might have had an effect on Dwight and John on how well they communicated the changes. Dwight has also expressed that it was necessary for the design changes to be implemented quickly for the function of the Product 1 as he expressed on Section 4.2.5.

The case company also faces several organisational barriers, one being the high-speed environment staff are working in, resulting in critical processes for example product testing being overlooked (Vandevelde & Van Dierdonck, 2003). But this does not take into account that the updated blueprint was reviewed by the creator of the blueprint as well as the designer. Here, organisational barriers need to be separated from human error and negligence. From the interviews it could also be concluded that the lack of clarity in the roles were another barrier (Jimmy; John; Franklin, Section 4.2), resulting in unclear understanding of the responsibilities within the case company at the time.

Semantic noise can also be identified in the written form that the design change was requested. The receiver (EMP) of the message (design change) is in control and may read and place emphasis in a different way learning to different understandings (Vandevelde & Van Dierdonck, 2003). This is made apparent in the description of component implementation that Dwight sent to Ronald on 20/03/23 (see Section 4.1.3.2) which is an indication of direction, but it is obvious that the receiver did not interpret it as such resulting in the flow sensor being misinstalled.

Another factor that complicates the cooperation between design and manufacturing in this case is the physical barrier that is the geographical distance between the case company and the EMP. This potentially affected the frequency of in-person meetings and general effectiveness of communications. As it took several hours to travel to the EMP which made in-person meetings and visits an uncommon practice. As mentioned previously, not only words are important in communication, but body language also plays a big role, where bodily signals can reinforce or contradict the verbal message which someone is trying to convey (Nationalencyklopedin, n.d.). The distance between the case company and the EMP has resulted in the meetings taking place digitally and through emails. The geographical distance may have complicated the coordination and quick resolutions of issues that arose during manufacturing (Vandevelde & Van Dierdonck, 2003).

These barriers, noise and external environment can be seen in Figure 15. In Figure 15 there is no frame of reference overlap, this is because they do not have the same view of the situation (the design change request).

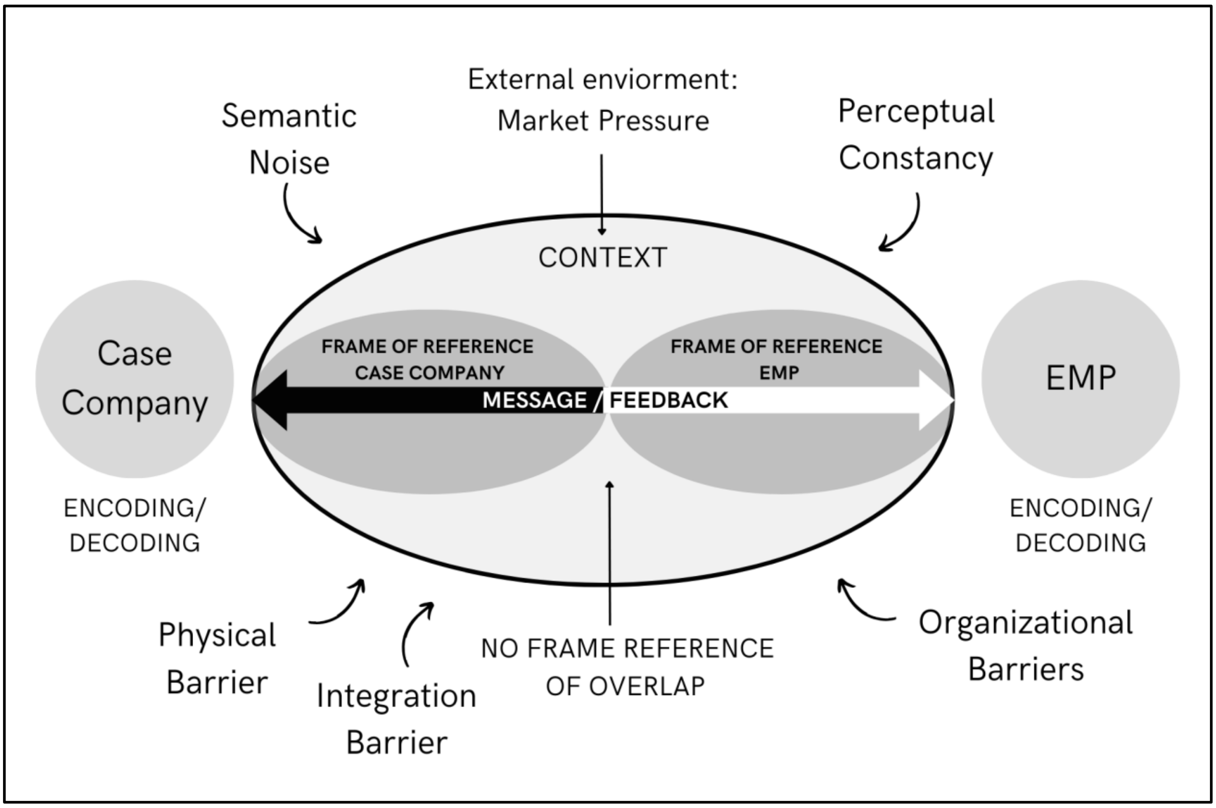


Figure 15: *Case company & EMP in the transactional model of communication*

5.1.3 Discovering the problem

Insufficient dialogue & feedback between design and manufacturing

During the design and production of the Product 1, both the design team at the case company and the manufacturing team at the EMP needed to share a common understanding of the product's requirements, having a frame of reference overlap (Hamilton et al, 2019). The misunderstandings in the design change occurred because the design documents and communication were not clear or comprehensive enough, resulting in an incorrect interpretation (Hamilton et al, 2019).

Communication is dynamic, circular and continuous (Barnlund, 1970). In this case, the absence of a circular communication flow meant that when the design change was sent from Dwight to the EMP there was very little back-and-forth communication to ensure that each party's understanding was aligned with the actual requirements of the design change. Effective communication could have involved continuous exchanges where feedback from the EMP could lead to immediate clarifications or revisions by the case company's designers.

Because the EOL-tests did not identify the misinstalled flow sensors at start, the mistake was not identified until later unrelated service operations. A discussion around the actual implementation of the flow sensors in the weekly meeting did not occur because both the EMP and the case company believed that the implementation had been successful, since the EOL-tests showed no signs and that the assembly instructions that Ronald created were based on the blueprint. These effective feedback loops need to be used not only after the implementation but also before, ensuring that the perception and understanding of the design change is accurate.

Without effective feedback loops, the small initial errors went unnoticed and accumulated. Resulting in significant issues when the problems started to arise. Feedback loops are also critical for continuous improvement (Barnlund, 1970). Feedback loops can also be used to check the perception by checking with other people, checking the observation and recalling previous experiences (Wakefield, 1976).

5.1.4 Aftermath and General Analysis

Hoecht & Trott (2006) discusses the risks that are associated with becoming overly dependent on external expertise. This can be seen in two aspects through the case company's case, both with the EMP but also with consultants that work internally at the case company. As previously mentioned on Section 4.2.4, the role as Production Manager was held by three different individuals during a short period of time. The employee turnover rate in this position means that the competencies of an individual are lost when that person is let go or resigns, unless documented.

The other risk was that the case company could become overly dependent on external expertise through filling knowledge gaps through the help of an EMP or with specialised consultants. Doing this may lead to a weakened internal capability where the case company's ability to innovate and control its processes diminishes over time. It is important to mention that involving an EMP in the design process and collaborating with them is not the negative aspect, as it could lead to improved manufacturability (Javadi & Chirumallam, 2024). It is the possibility of becoming overly dependent that could become problematic (Hoecht & Trott, 2006).

John also mentioned how the case company should have relied less on the EMP regarding the product development (Section 4.2.5). This shows that there has been an overly dependency from the case companies side during the Product 1 collaboration.

Javadi and Chirumalla (2024) presents strategies that empirically have been proven to improve the information contents in communications. Studying the case company and their relationship with their main EMP in relation with these strategies show that:

- **Absence of formal design and production coordination plan**
  Joint design reviews and production coordination plans are essential for successful product development, especially in low-volume manufacturing contexts. The case company has on no occasions hosted or participated in joint design reviews together with staff or representatives of the EMP, leading to discrepancies in the design specifications and information as well as misunderstandings about product requirements (Dwight, personal communication, 30/4-24). There have been regular interactions as mentioned before where the weekly meetings took place, but this has not been enough to create critical feedback loops between manufacturing and design (Franklin, Section 4.2.2).

- **Absence of a structured lesson learned management plan**
  The case company has not had a systematic approach of capturing and analysing lessons learned from the Product 1 project. Not doing this, it is likely that the case company will repeat the same mistakes, such as repeated quality issues and miscommunications. The implementation of a structured lesson learned management plan could prevent future delays, avoid quality issues as well as improve their future projects and efficiency. This combined with the relatively high employee turnover rate (see Section 4.2.4) and risk associated with consultants (Hoecht & Trott, 2006) further increases the importance of establishing lessons learnt.

By analysing the case company's situation through the four dimensions that Flankegård et al. (2021) presents, solutions can be found to some of the problems faced. The source is written with mainly the supplier's interests in mind but still carries considerable value from a customer perspective. Flankegård et al. (2021) suggests that while it is important for suppliers to know the needs of their customers, customers knowing the needs of their supplier also is important. In the case of this thesis, the case company acts as the customer while their EMP has a supplying role. Below are issues presented by Flankegård et al. (2021) (see Figure 2) that have also been identified through interviews and immersion at the company.

- People
  - **Insufficient dialogue between design and manufacturing & poor exchange of project information**
    Both of these issues have proven to be challenges even in this case. As it eventually led to the flow sensor being consecutively misinstalled on multiple units. Something that likely could have been avoided with better supplier knowledge of the products, a thorough review of the updated blueprint among other things. The overall lacking description of how implementation of the flow sensor would go about and the amount of further questions the EMP asked indicates insufficient project planning.

- Process
  - **Absence of a product development process**

A key take away from what is established based on the chronological events on Section 5.1.2 is the obvious absence of a product development process. As there seems to be no standardised way of communicating the changes proposed and seamlessly implementing these.

- Tools / Technology
  - **Product requirements that allow multiple interpretations**
    Product requirements that allow multiple interpretations can be described as a dominating reason behind the development of the case. As was established on Section 5.1, staff at the EMP most likely believed that the flow travelled the other direction in the section where the component was implemented. Little effort was also made by staff at the case company to correct this belief, as they believed the provided information to be sufficient enough. Something that short-term could have been achieved with a more detailed introduction of the change and a more thorough review of the blueprints.

    The blueprints created by the case company are the foundation to the assembly instructions created by Ronald at the EMP (Section 4.2.3). Therefore it is important that the product requirements are clear and do not allow multiple interpretations, otherwise mistakes in the assembly instructions can be created without the case company's knowledge, since they at that time did not verify the instructions.

- Interaction
  - **Contact persons not clearly identified**
    A great challenge for suppliers can be contact persons not clearly defined. The case company's contact person at the EMP was Ronald and occasionally George, as the timeline shows. The case company themselves did not have the same structure as during this case, they had no designated contact person within the company.

  - **Communication across competencies**
    This is something that has mostly proven to be a challenge for the customer or the case company in this case. As the limited knowledge and product relevant competencies of the contact person or other staff at the EMP resulted in all the flow sensors, consistently being misinstalled.

  - **Contradiction information from customer representatives**
    The last one being contradicting information from customer representatives with the typographical error discovered in the blueprint as earlier mentioned on 4.2.2. This was caused by the case company and to some extent contradicts the previously provided mounting instructions.

In summary, there are a lot of different reasons why the flow sensor was assembled in the wrong direction. It is important to note that the nature of the case is unique with the Product 1 being complex and a new concept, in an environment with a market pressure that created stress and haste. The case company is a small startup company where it is not uncommon for one person to have several responsibilities. Although, some of the problems that had arised could be avoided even in a stressful environment like this one. One single individual cannot not be blamed. This is because a lot of the causes are organisationally rooted where there is a lack of routines and a lack of standardised processes to handle, for example, design change requests. However, each individual has a responsibility to take accountability and to learn from their past mistakes in order to avoid future ones.

5.2 Suggested Improvements

If these routines below could have been implemented before the start of the design change, this case would likely have had a different outcome. In response to the problems within design, and between design and manufacturing as listed above on Section 5.1. Some suggestions apply to multiple problem causes discussed.

5.2.1 Implement a Design Change Request Protocol

By implementing a ticket system for design changes, communication would be clear, structured and informative. Research emphasises the importance of structured communication for reducing errors and improving product quality, particularly in complex product environments (Hamilton et al., 2019; Vandevelde & Van Dierdonck, 2003). These studies show that detailed and well-documented communication protocols help bridge the gap between different departments and ensure all parties have a clear understanding of changes.

The design change request consists of two parts, one spreadsheet and one ticket specific document, see Figure 16. The purpose of the spreadsheet is to keep an overview of all the design changes requested/implemented as well as to give an overview of the current status of the design changes. The document is used to discuss the design change and that the different departments agree on the change as well as open up for feedback and discussions. The document in comparison to the spreadsheet documents the actual design change meanwhile the spreadsheet documents the actual process and implementation.

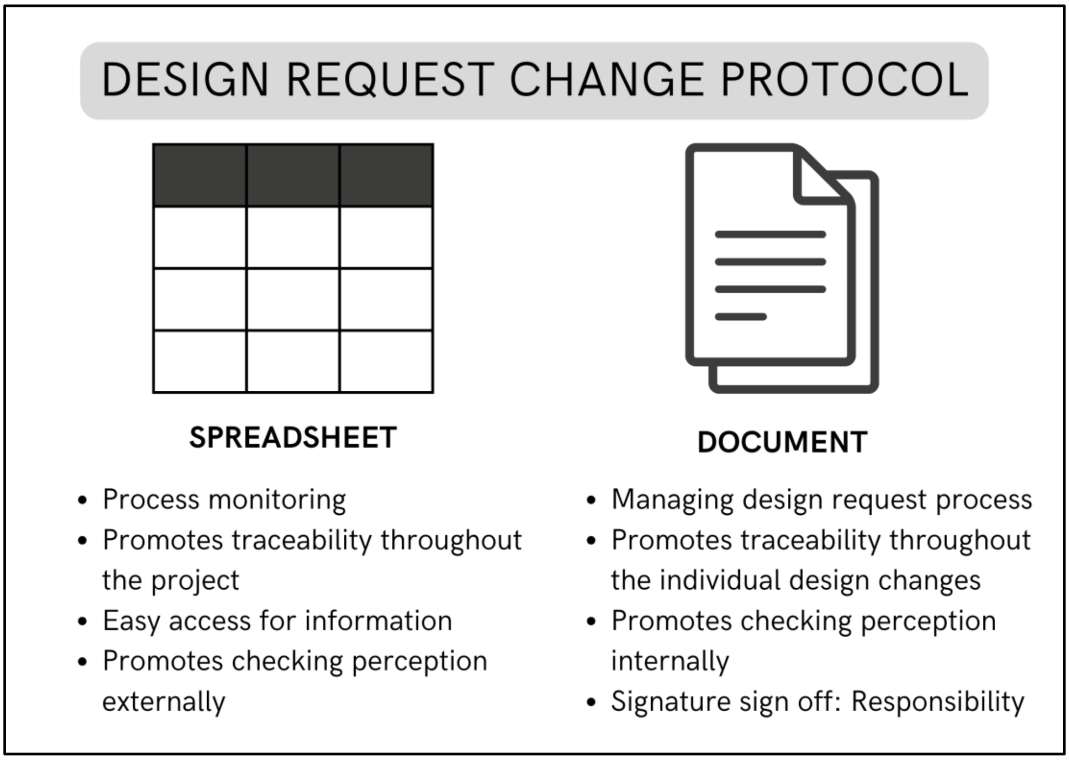


Figure 16: *Design request change protocol*

The spreadsheet should for example include the following titles:

- Ticket ID
- Status: Approved, pending or declined
- Date issued
- Old article nr
- New article nr (if components are replaced or consolidated)
- Description of change
- Reason of change
- Comment
- Change impact: A scale from 0-3. How critical is the change for the function of the product
- Affected departments
- Responsible (person in charge of ticket)
- Requesting department (who ordered the change)
- Date of decision (when approved or declined)
- Date of implementation

This gives the case company a way of managing the design change in terms of when the process starts and who is responsible for it. It also gives a clear view for the EMP to understand the product and the reasoning why the design change is implemented. The EMP would have continuous access to this spreadsheet and the updated blueprints.

The document is a form that should include:

- Requested by
- Article nr

- Replacement of article nr
- Planned into production (date)
- Production intro (clean cut/ use up stock)
- Save old article for spare parts (yes/no)
- Information and description of the design change including picture/3D rendering
- Department approval signatures: Including the different departments for example R&D, Production, Design, Finance, After Sales
    - Comment section for each department
    - Approval (yes/no)
    - Approval by: Here a individual from each department sign, showing that they have approved/not approved the design change request
- Appendix: New article nr, old article nr, what to do with old parts

This document gives the case company a structured way on how to manage design change requests with good traceability. Here the departments work together and also sign that they approve the design change, showing that the design change is well worked and thought out, as well as how it affects the product and company as a whole.

Both of these measures would help communicate the implications of changes and to address the cause of assembly errors (Javadi & Chirumalla, 2024). It also addresses the lack of traceability as well as minimising the human errors as people get more clearly defined roles in the design change request process. It would furthermore, help consolidate information about changes and make it more comprehensible, compared to how changes were solely communicated via several emails in the case studied. This change would potentially be beneficial for the designated contact person at the case company that has been tasked with communicating with the EMP, as well as for staff at the EMP.

This also gives the designer and the other individuals at the case company an opportunity to check their perception using several of the methods mentioned in 2.3 (Wakefield, 1976):

- Being observant and attentive of what happens in the surroundings.
- Admitting errors that can occur in the individual's own perception.
- Checking with other people, presenting the information to someone else can verify a perception. If the different departments have a specific opinion or idea about the design change this gives the case company a change to explore these.
- Check by repeating the observation. By repeating an observation, the individual has an opportunity to check their own perception.
- Check by recalling past experiences. If an individual gets a feeling in a situation, the person can recall past experiences when they were in the same situation. Here the individuals involved can think of previous experiences and what the lessons learned from them was.

Implementing this type of system may require time to execute as well as adapting to. There may also be a resistance to change among employees trying to get accustomed to a more formal communication method (Vandevelde & Van Dierdonck, 2003). The feeling of more workload due to more processes being established can arise, but it is important to inform the employees of the importance of clear communication and the way that it can decrease the workload by eliminating future potential problems.

5.2.2 Develop a Robust Feedback and Review Process

Effective communication is dynamic and involves continuous feedback loops (Barnlund, 1970). By implementing a regular feedback and review process, the case company can ensure that communications are both received and that requirements are correctly interpreted (Javadi & Chirumalla, 2024). This also aligns with Jacobsen & Thorsvik's (2021) emphasis on the continuous and iterative nature of organisational communication.

The case company and the EMP had not had a formal design or production coordination plan (Dwight personal communication, 30/4-24). By implementing joint design reviews and involving both the designers and representatives or operators at the EMP, feedback loops can be created to enhance communication quality (Javadi & Chirumalla, 2024; Barnlund, 1970), as well as improving dialogue between design and manufacturing (Flankegård et al., 2021). Design change protocols, as presented on Section 5.2.1, would be reviewed and discussions would be held about possible complications. These meetings can be either digital or physical. But it is important to have a meeting and not only a chat or email based conversation as what has previously been done. This may lessen the challenge of communication across competencies (Flankegård et al., 2021) as design updates have previously only been communicated via centralised contact people at the EMP. Without the operators having the ability to directly review the changes with the product designers.

This also gives the opportunity to check the perceptions of both the case company and the EMP, promoting accurate communication and minimising misunderstandings (Wakefield, 1976). If the design change of the flowsensor would have been discussed in a feedback and review process, the expectations of what the email and blueprint included would have instead become verified rather than an assumption.

As mentioned in 5.2.1 this also gives the designer and the other individuals at the case company an opportunity to check their perception but with the EMP. Making sure that the case companies perception and EMP´s align (Wakefield, 1976):

- Being observant and attentive of what happens in the surroundings. Especially in this case, within the case company internally and the EMP externally.
- Admitting errors that can occur in the individual's own perception.
- Checking with other people, presenting the information to someone else can verify a perception.
- Check by repeating the observation. By repeating an observation, the individual has an opportunity to check their own perception.
- Check by recalling past experiences. If an individual gets a feeling in a situation, the person can recall past experiences when they were in the same situation.

5.2.3 Communication Platforms & Meeting Protocols

Communication efficiency within organisations are benefited from integrated communication systems that can reduce noise and enhance message clarity (Hamilton et al., 2019). Consolidating a communication platform that can address the issues as organisational barriers, semantic noise and misunderstanding by providing a single, clear and consistent medium for all messages.

In the current state there are very many different types of communication channels used as mentioned on Section 4.2.3. Not only are there very many different methods used but the documentation of the communication is very sparse and not inclusive to the people it may be relevant to. This new project management plattform Basecamp that the case company will implement in the coming months is a big step in the right direction. But it is important to note that the merged communication platform should be used in a more efficient way, not just moving the communication.

Both Dwight, Lyndon and Richard express that they would want improvement in the way the case company communicates both internally and externally and mentioned this in Section 4.2.5.

To improve traceability and the internal communication Basecamp, (Section 4.2.3), or another chosen type of document sharing platform should include a centralised documentation system that can track all changes, decisions, communication and project activities. Including features as version control with timestamping and user tracking to ensure that the information can be traced back to its origin.

To develop a more structured way of documenting meetings and the verbal information that is shared there should be implemented a meeting protocol that could include:

- Attendees
- Topic of meeting
- General notes
- What was agreed upon

Implementing a centralised system as mentioned is an investment that costs both time and money. The case company has already chosen to invest in Basecamp and are at the time of publishing, working on implementing the platform into their organisation. Challenges associated with this may be resistance to change from staff that are unaccustomed to level of documentation requirements as well as the initial learning curve associated with new systems (Vandevelde & Van Dierdonck, 2003).

There are large advantages of implementing a documentation system and meeting protocols, being able to quickly identify and correct errors, and easily being able to track the evolution of the project. Being able to preserve information and knowledge within the company when employees leave or change roles is very important, especially at a smaller company where one individual may have many different areas of responsibility and valuable knowledge within the company.

5.2.5 Lesson Learned Management Plan

It is important to capture and utilise lessons learned in a project. Implementing a structured management plan for lessons learned can significantly improve project outcomes by allowing the case company to learn from their past successes and failures (Javadi & Chirumallam, 2024). This is especially important when they are soon, as of the date of publishing, to be entering the production phase of their new and improved Product 2. Thereby being able to understand the effectiveness of their product introduction strategies.

This can be done through capturing, analysing and sharing lessons learned from each product lifecycle using debriefing sessions at key milestone projects and after project completion.

Here the process should involve documenting successes, failures and recommendations in the centralised system so that the information is accessible to the employees of the company.

Ensuring that a consistent participation in these learned lesson debriefing sessions and the process as a whole may be challenging. There are many advantages of implementing lessons learned, it can potentially significantly improve processes efficiency, product quality and broaden employee knowledge (Flankegård et al., 2021). By learning from past mistakes and successes, the case company can avoid expensive and time consuming mistakes and innovate a better product.

Some of these lessons learnt can be established from the studied case in this thesis. An example of this is when entering a new project it is important to establish one or more designated contact persons within the company. This to ease communication and minimise misinformation as well as being more accessible to external partners.

6. CONCLUSION

The purpose of this work was to explore the potential causes of a communication problem between design and manufacturing and how to mitigate those. The purpose has been addressed through an analysis of cases that was studied using theoretical and empirical data.

For research question 1 "*What are the potential causes of problems in communication between design and manufacturing?"*

The discussion performed on the presented results, highlights the causes that lay behind the problem with the 84 incorrectly installed flow sensors. These causes need to be addressed in order to make future improvements and to avoid other problems of similar nature. The following are the established causes categorised into three different groups, see Table 2:

Table 2: *Categorised causes*

Individual causes	**Organisational causes**	**Interaction causes**
• Lacking designer's empathy • Different perceptions • Product requirements that allow multiple interpretations • Perceptual constancy	• Absence of a product development process • Absence of formal design and production coordination plan • Absence of a structured lesson learned management plan • Contact persons not clearly defined • Communication across competencies • Noise & haste	• Insufficient dialogue & feedback between design and manufacturing • Poor exchange of project information • Contradicting information from customer representatives

- *Individual causes*
  Causes that can be attributed to each individual person that is part of the case problem and works for the case company.

- *Organisational causes*
  Causes that have been found to be deeply rooted in the organisational culture of the case company and requires the establishment of processes and standards in order to be mitigated.

- *Interaction causes*
  Causes that stem from the interaction between design and manufacturing at the case company and the EMP,

For research question 2 "*What could have been done differently?"*

There are four main points as to what could have been done differently to possibly change the outcome of the misinstalled flow sensors. These four points directly address the causes presented in Table 2:

- Implementing a design change of design request protocol.
- Developing a robust feedback and review process.
- Having a centralised communication platform and a structured way of documenting meetings.
- Developing and implementing a lessons learned management plan.

Based on the findings from our data collection, literature study and the case study several causes have been identified. The research questions that were answered provided both a diagnostic view of the existing causes and a prognostic view through the view of what could have been done differently.

There are several limitations to this research and what has been established. The research was conducted without being in contact with the EMP, thus neglecting external factors such as the EMP’s perspective of the situation and how market pressures affected the EMP. The data used are limited to qualitative data from interviews and email logs that may not capture all aspects of the communication issues faced. For future research, implementing the four main points and studying their effectiveness could prove to be valuable. It would mean analysing the effectiveness of the potential solutions and determining if they have a mitigating effect on the problem causes.

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APPENDICES

Apendix 1: Interview 1 questions

Allmänt & Kommunikation

1. Vad heter du och vad har du för position på the case company?
2. Vad har du arbetat med i Product 1?
3. Har du vid ett eller flera tillfällen haft kontakt med EMP?
4. Gällande vilka områden hade ni kontakt?
5. Har du någon kollega som hade kontakt med EMP gällande samma ansvarsområden som du?
6. (Om "Ja" på F5: vad heter personen/personerna?)
7. (Om "Ja" på F5: Jobbar de fortfarande kvar på the case company?)
8. Under vilka faser av tillverkningen av Product 1 hade ni kontakt?
9. Genom vilka kanaler sköttes kommunikationen? (kanaler är Face2Face, telefon, SMS, mail, sociala medier, med mera)
10. Hur ser processen ut när du har något du vill ta upp med EMP?
11. När/Vilket syfte kontaktar du EMP?
12. Hur ser processen ut när EMP kontaktar dig?
13. När/vilket syfte kontaktar EMP dig?
14. Vad var din kontaktfrekvens?
15. Har du fortfarande kontakt med EMP?
16. (Om "Nej" på F15: När var senaste gången ni hade kontakt?
17. För Product 2 har du kontakt med potentiella tillverkare?
18. (Om "Ja" på F17: Gällande vilka områden har ni kontakt?)
19. (Om "Ja" på F17: Vad är din kontaktfrekvens?)
20. (Om "Nej" på F17: Kommer du i framtiden ha kontakt med kommande tillverkare.)

Problem

21. Inom dina ansvarsområden, vilka problem har du stött på?
22. Hade EMP/produktionen en medverkan i dessa?
23. → 5 varför (fyll i diagram nedan)
24. På vilket sätt hade EMP en medverkan i dessa?
25. Gällande Product 2, vad tycker du hade kunnat förbättras med produktionen, kommunikationen och samarbetet i allmänhet?
26. Hur hade samarbetet kunnat se annorlunda ut?
27. 5 varför:

Varför 1	Varför 2	Varför 3	Varför 4	Varför 5	Lösning
Varför är detta ett problem för oss? Grundorsak 1:					
Varför är detta ett problem för oss? Grundorsak 2:					

Varför är detta ett problem för oss? Grundorsak 3:					

Övriga kommentarer
27. Har du någonting du vill tillägga

Appendix 2: Interview 2 questions

1. Meaning: Sätta in en flödessensor, när var detta? (Datum)
2. Encoding: Hur kommuniceras detta första gången?
    a. Vad för ritningar skickades, hur många och vad var kvaliteten på dessa?
    b. Övriga specificerade instruktioner i första kommunikationen?
3. Transmission: Genom vilka kanaler skickades budskapet?
4. Transmission: Feedback processen där mottagaren av meddelandet ger en respons tillbaka till sändaren. Denna återkoppling kan vara ett nytt meddelande som har kodats och skickas tillbaka genom kommunikationskanalerna, vilket slutför en kommunikationscykel.
    a. När svarade EMP?
    b. Vilken kanal?
5. Decoding: Vad svarade EMP? Handlade de övriga frågorna om instruktionerna eller ritningarna?

Appendix 3: Original quotes in Swedish

- Dwight, personal communication 10/5-24:
    - *"Innan den tredje flödessensorn implementerades fanns det 2 st flödessensorer i Product 1. Detta är en uträkning för hur många Product 1 som kan byggas med 3 flödessensorer i genom att ta flödessensorer från tidigare Product 1. Det går inte att bygga lika många enheter eftersom det krävdes fler sensorer, det gick från 2 st till 3 per enhet."*
    - *"Jag, John, Lyndon och de från konsultföretaget, Namn 1, Namn 2, Namn 3 tror jag. Och EMP, vet inte vilka dock"*

- Dwight, interview 20/2-24:
    - *"Mail, telefon, SMS, Facetime, jag deltog även på veckomöten"*
    - *"Jag tror inte att vi skulle skyndat oss fullt så mycket som vi gjorde, kanske startat igång produktionen lite senare för att ge dem mer underlag och att kunna räta ut de här problemen innan man drar igång en produktion. I kommunikationen så hade det varit bättre om vi hade en kontaktperson från oss redan från börGeorge så allt hade gått genom den personen. Och om vi*

valde att kommunicera på ett sätt, via mail eller via sms eller på något sätt som gör att man kan spåra kommunikationen."

- John, interview, 13/2-24:
  - *"Grejen med de flödesgivarna vi använder är att de fortfarande ger mätvärden om de monteras åt fel håll men att dessa nödvändigtvis inte speglar verkligheten…"*
  - *"På plats både hos dom och hos "the case company", email, telefon"*
  - *"Vi skulle egentligen förlitat oss mindre på dem gällande produktutveckling och tagit kontroll över det själva. Låta dem göra tillverkningen. Under denna perioden vad det inte klart gjort vad som är vad."*

- Franklin, interview, 9/4-24:
  - *"Return on investments påverkas kraftigt. Vattenåtervinningsgraden mäts av flödessensorerna, om de visar vilseledande värden kan det leda till en mindre nöjd kund, vilket kan leda till att de kanske inte vill köpa fler produkter?"*
  - *"Ronald gör monteringsanvisningar som operatörerna använder. Ronald baserar monteringsanvisningarna på ritningarna som vi i case company förser. Han har mycket god kunskap om hur Produkt 1 fungerar*"

- Franklin, interview, 20/2-24:
  - *"Mail, bilder, SMS, Facetime, mycket på plats i början, telefon"*
  - *"Vi skickade en uppdatering på ritningen när det var en design change med flödes sensorn. Men det var: Här är ritningen. Men det fanns inte tydligt så som: Kolla, det finns en pil på den flödesmätaren. Men det var innan jag började arbeta här"*
  - *"Jag, Dwight, Richard och John. Vi körde det här arrangemanget några månader efter att jag började och sedan ändrade vi det så att bara jag och Dwight deltog i möten. Det handlade inte om många nyckeltal, men det är sant att vi behövde påminna dem flera gånger och att de ofta inte stämde överens"*
  - *"Skapa rutiner absolut. I designfasen kan jag inte tillägga så mycket eftersom jag inte var med i början"*

- Richard, interview, 27/2-24:
  - *"Majoriteten är Mail men även Google Meets, Mail, SMS, Facetime"*
  - *"Det [flödessensor] var ju något som jag upptäckte under en service av en enhet."*
  - *"Framförallt tror jag att det har varit dålig dokumentering, även i möten och allting liksom. Det har nog blivit lite bättre, men uppenbarligen har det dokumenterats dåligt, vad som skickats till dem i form av monteringsanvisningar och så"*

Appendix 4: Emails and Meetingnotes

Från: Dwight (CDO)
Ämne: Problem/Lösnings slides
Datum: 20 mars 2023 09:36:12 CET
Till: George (EMP), Ronald (EMP), previous case company employee, John (Designer)

Hej,

Här kommer några slides med bla. de problembilder jag visade:

Figure A: *20/03/23*

20 mars 2023 kl. 10:15 skrev Ronald (EMP)

Hej Dwight

Förstår jag rätt? Vi skall byta ut en av Flow Sensor (den för pump) med Flow Sensor
Alltså detta påverkar Com med några nya Component. Kommer vi behöva ha också fler av de tjocka packningarna, som vi byter ut i Flow Sensor Vi kommer behöva om kontaktera ledning till Flow Sensor

Figure B: *20/03/23*

Från: Ronald (EMP)
Ämne: SV: Problem/Lösnings slides
Datum: 20 mars 2023 13:05:31 CET
Till: Dwight (CDO)
Kopia: George (EMP), John (Designer)

Hej,

Alles klart!

Figure C: *20/03/23*

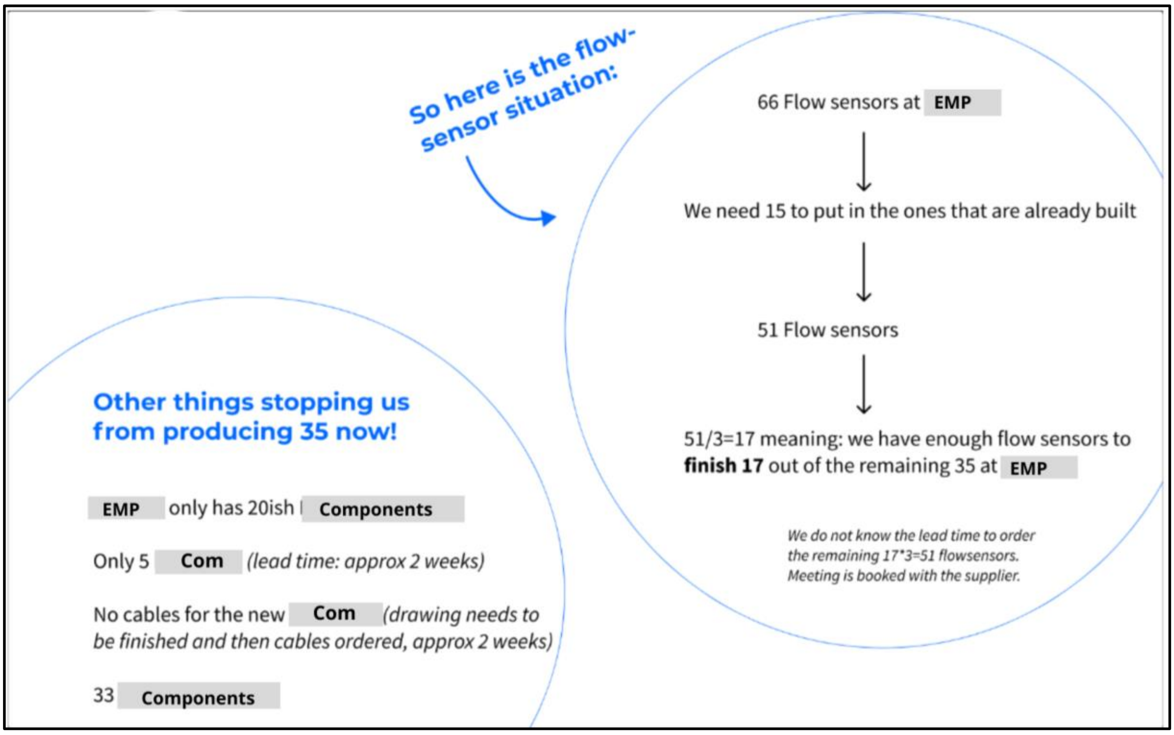

Figure D: 27/03/23

Från: Dwight (CDO)
Ämne: update
Datum: 28 mars 2023 15:15:29 CEST
Till: Ronald (EMP), George (EMP), previous case company employee, John (Designer), Lyndon (Software)

Hej Ronald (EMP)

Här kommer några punkter med Info från oss:

- Ni kan montera in den extra Flow Sensor och köra med befintligt sluttest! (se bilder)

- Bara en Flow Sensor skall kopplas in, den som är märkt med

- på 2 av 5 Units var en Components sätt (se bilder)

Images attached in this email are not included because of censorship

Figure E: 28/03/23

Från: Ronald (EMP)
Ämne: SV: update
Datum: 28 mars 2023 15:58:41 CEST
Till: Dwight (CDO), George (EMP), previous case company employee, John (Designer), Lyndon (Software)

Hej Dwight (CDO)

Jag förstår nu hur skall den extra Flow Sensor monteras, skall den kopplas in i Components

Jag beklagar att Com var trasiga, vi lägger extra fokus på detta och säkerställer att de är OK i försättningen. Behöver ni några extra Components

Figure F: 28/03/23

Från: Dwight (CDO)
Ämne: Re: update
Datum: 28 mars 2023 16:07:11 CEST
Till: Ronald (EMP)
Kopia: George (EMP), Company X employee, John (Designer), Lyndon (Software)

Hej,

Den ska kopplas på Com Se bild)

*bild

Vi behöver inga Com hade några extra här. Men jättebra om ni håller lite koll på de!

Figure G: 28/03/23

From: John (Designer)
Date: Wed, Mar 29, 2023 at 10:38 PM
Subject: Material upplagt
To: Dwight (CDO), George (EMP), Ronald (EMP)

Hej,

Nu ligger Uppdaterade ritningar och ett par modeller här:

Dokument > General > 04. Released for Manufacturing > RELEASED 2023-03-29

Namn

- 1003365-53_REV-G.PDF
- 1003365-53_REV-G.STEP
- 1003365-243_REV-F.PDF
- 1003365-333_REV-C.PDF
- 1003365-373_REV-H.STEP
- 1003365-171_REV-E.PDF

Kommer ta fram 2D-underlag för plåt och uppdatera excel-BOM först i på nästa vecka.

Allt gott!

Figure H: 29/03/23

Case Company update

- Changes (in product, assembly or other)
  - ACTIONS ON MISSING COMPONENTS

Component	Action	Owner
Flow sensors	Ordered	EMP
Components	69 reamianing	EMP & Case Company
Components	Delivered	EMP check with supplier
Components	x create new drawings/decision asap	Case Company
Components	Sent to x	Case Company
Components	Ordered	EMP
(Components s	30 + 10 Check if we can reuse Components	EMP
New package Components	x create new drawing	Case Company

- Time plan

x = supplier

EMP bygger 6st denna vecka, skickar nästa (v.15)

- Drawings and other material
  - New material for "bottenplatta" and flow sensors coming this week
  - Updated 2d drawing on metal chassi
  - Cable drawings will contain cables for Flow sensor & Components
- Quality and function (feedback from the field)
  - No more changes planned for now
- Other
  - EMP test new glue for mesh Component

Figure I: *03/03/23*

Från: **Dwight (CDO)**
Ämne: Fwd: Problem/Lösnings slides
Datum: 16 augusti 2023 12:00:05 CEST
Till: **Franklin (Production Manager)**

Hej,

Jag hittade ytterligare lite dialog, min Ronald (EMP) och George (EMP) angående den fermenterade Flow Sensor Inte supertydligt, men jag har skrivit att det skall läggas till en Flow Sensor på slangen "från pumpen till ventilpaketet". Det indikerar ju en riktning.

Figure J: 16/08/23

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