MASTER

Creating an automation roadmap for manufacturing companies
combining literature and practice to come to a decision support tool

Hummel, S.W.B.

Award date:
2019

CREATING AN AUTOMATION ROADMAP FOR MANUFACTURING COMPANIES

Combining literature and practice to come to a decision support tool

Sebastian Hummel
s.w.b.hummel@student.tue.nl

Contents

Chapter 1: Research assignment

This research aims to present a decision support tool that allows companies of a specified profile—based on a case company, which will be called 'Q'—to build a long-term investment plan regarding automation activities, which will be called the automation roadmap. The design of the tool is based on the available literature on the topic, as well as observations at Q. The tool will clearly present a process outline for creating, executing and maintaining an automation roadmap, which specifies when and how to make certain investments in the automation area with unambiguously established time-frames. More specifically, the tool will be a guided process, where the user company is guided into making the right decisions and using the correct models to successfully create an automation roadmap. The support tool will be supplemented with documentation in the form of excel and word templates.

In the second phase, the tool will be tested by applying the methodology in a case study at Q. A roadmap of automation investments will be established for Q using the decision support tool, the results of this case study are then in turn used to iterate on the tool and make improvements, after which manufacturers with a similar profile as Q can use it to create their own roadmap.

1.1 Introduction Q and problem definition

Q's products are of high quality, making them high-end costly products. The whole company is organized around producing high end quality products, tailored to the client's wishes. Therefore, the amount of activities that add value indirectly, e.g. design and planning, is rather large in comparison with directly value-adding activities. Q identifies itself as somewhere between a job-shop and a mass manufacturer, since there are some products that are produced in high volumes, while still leaving much room for New Product Introductions (NPIs), which account for about 15% of sales. The latter relates highly to Q's ambition to be a customer-oriented provider, but it forms a contradiction to the desired standardization.

Q's position in the market gives good reasons to produce according to mass customization techniques. The product variety is large, but at the same time, Q offers what is among the most qualitative products of its kind, resulting in high, and growing, demand. Production capacity has long been a serious constraint for Q's sales, resulting in lost revenue. The demand in the market is growing, and due to the uniqueness of the product—and therefore small number of competitors—Q has an opportunity to increase revenue if the capacity can be expanded.

Q struggles to employ people with the right technical skills, as they are rather hard to find due to the required analytical capabilities. This results in a constraint in the wish to expand production capacity, as the human resources for this are limited. Another human resource related problem comes in the form of the weight and handleability of the products, which can be quite heavy and must be handled and placed in a specific way without damaging them. These efforts result in a poor ergonomic environment for employees in certain departments. The delicate nature of the product only exacerbates this, as even tiny mistakes in handling can result in the product being rejected.

A solution is therefore desirable in the form of automation, so that production capacity can be increased while circumventing the HR issue of a lack of competent employees. Many parts of the process show potential for automation, but a long-term vision on how to implement these is lacking. Thus, the progress in this area is too slow.

The result is a clear and expressed ambition to increase production capacity, optimizing operations by using innovative systems that increase efficiency, while remaining a service provider that can tailor products to anyone's needs.

1.2 Literature background

Automation has been a hot topic for many a year now, but still many industries see that the level of their automation is low. This can be partially explained by another recent trend; mass customization. Due to the increasing demand for uniquely-designed products, older forms of automation, such as the assembly line, can't be viable solutions anymore.

A completely new search for a solution in this problem space started in the late 80s, as the term mass customization was coined (David, 1987). This oxymoronic phrase entails a complicated mix of mass- and flexibility elements, bringing about an inherent challenge for any company wishing to operate in accordance with this production paradigm.

When automation is desirable, but must not limit the flexibility of the system, the solution space tightens, and more innovative solutions must be considered. This is where the field of robotics comes in. Industrial robots have made great progress in recent years and are now capable of performing increasingly many operations on the production floor. Flexibility is still a major challenge though, and one that is typically expensive to overcome. Therefore, making the right decisions on which automation system to employ in order to fulfil your company's needs is an essential part on the road towards flexible automated systems that fully enable a smart customization strategy. Robot selection proves to be difficult, however, and has been said to have "confounded the decision makers for at least four decades" (Koulouriotis & Ketipi, 2011).

The shift to mass customization

As is often the case with revolutionary business practices, anyone tracking the origins of the mass customization trend will end up at Toyota. In the late 1980's, Toyota was looking for the newest way to optimize their operations (Pine, Victor, & Boynton, 1993). They saw great potential in the idea to combine the low-cost practices of mass production with a flexibly designed manufacturing system, allowing for small batch sizes and high product variability. When the concept became clearer and more known in the early 90s, definitions could be proposed, such as: "the use of flexible processes and organizational structures to produce varied and often individually customized products and services at the low cost of a standardized, mass-production system" (Hart, 1995). After initial struggles to make this philosophy work, the concept became a trending topic in many industries, with more and more companies identifying mass customization as a valid business strategy.

After its introduction, mass customization was quickly able to compete with the main manufacturing paradigm at the time: mass production (Kotha, 1995). By the time the new millennium arrived, the market had changed such that "agility and quick responsiveness to changes had become mandatory to most companies" (Silveira, Borenstein, & Fogliatto, 2001), meaning that a new strategy was heavily desired.

The paradigm shift was in part caused by higher quality and/or volume demands in certain industries. This gave rise to the intense competition on quality standards of final products, resulting in manufacturers' wish to optimize their production equipment. Due to their need for customized parts that allows them to optimize their own production line, many product-specific parts are requested. Mass production simply wasn't going to cut it anymore.

Robotic systems

Many manufacturing activities have been moved to low-wage countries in recent decennia. In many industries, production can't take place in Western countries due to often big number of man-hours required; a costly resource for Western-, but not so much for low-wage countries. Automation has therefore become an "important mean for industry to meet the competition from low-cost countries" (Jörgen Frohm, Lindström, Stahre, & Winroth, 2008).

In Bauer, Bas, Durakbasa, & Kopacek (2015) it is argued that for SMEs, one of the most prominent areas to look for competitive advantage is flexibility. giving rise to the need to be able to flexibly organize their manufacturing system to allow for a wide variety of products.

Due to the wage gap with low-income countries, hiring more people to increase production capacity doesn't make sense. Additionally, finding the right employees with relevant skills often proves difficult in production companies, where a highly analytical approach is applied. Luckily, the field of robotics has made great strides in recent years, with much development and research being done already on how to implement robotic systems in a manufacturing setting. As Bauer et al. (2015) put it: "Industrial robots have been widely applied in many fields to increase productivity and flexibility and to help workers with physically heavy and dangerous tasks".

Research on the topic extends to more specific applications, as well as in the direction of decision support. "Election of a robot for a specific industrial application is one of the most challenging problems in real time manufacturing environment" (Chatterjee, Athawale, & Chakraborty, 2010). Different models for robot selection have been proposed. Classically, these are based on simple multi-attribute weighed sum models (Goh, Tung, & Cheng, 1996). More recently, most selection methods have revolved around a fuzzy definition of factors (Koulouriotis & Ketipi, 2011) (Vahdani et al., 2014) (Rashid, Beg, & Husnine, 2014), although simple ranking methods may still prove effective (Chatterjee et al., 2010).

Ergonomics

When dealing with large, heavy products, ergonomic conditions start playing a more important role. In the Netherlands, the ARBO (an institution enforcing work condition standards) has meticulous rules dictating how much weight an employee is allowed to carry, with many complicated variables that are hard to define such as carrying position, angle and distance.

At Q, some of the heavier products are causing physical problems for employees. Additionally, the products don't have an easy way to grab them and should ideally only be handled in specific ways. By reducing the number of manual maneuvers that employees must perform on the product, their personal health can be improved.

Several purposes of such systems have already been established or at least suggested; "Robot assistants can be thought to be clever helpers in manufacturing environments for fetch and carry jobs, assembly, handling, machining, measuring etc." (Hägele, Schaaf, & Helms, 2002). More specific applications also exist, e.g. the robotic exoskeleton, which "fully combines human intelligence and robot power so that robot intelligence and human operator's power are both enhanced" (Lee, Kim, Han, & Han, 2012).

1.3 Deliverables

Company deliverable

The project has a well-defined company deliverable, a roadmap for automating operations, that was discussed and agreed upon by Q, including an execution and maintenance procedure. The roadmap is a three-year plan that specifies concisely the recommendations for future actions that will allow for Q to automate production in alignment with their corporate strategy, this is to be presented in August 2018, when the company publishes their general strategic plan. The company deliverable can only partially be shown in this document—the academic deliverable—due to confidentiality of information.

Academic deliverable

This document is the academic deliverable, a decision support tool that enables and guides companies in their creation of a roadmap of automation projects. The tool itself is essentially a process flow that guides the user through the process of creating a roadmap of automation from start to finish, including several decision points. The end result will be a decision support tool specified for companies that fit the defined company profile, ready to be used in industry. The tool will fill a gap in the available literature by the defined scope of the automation roadmap, creating a tool that is more tailored to the specified context than any currently available. The tool will also present an alternative interpretation of what a roadmap can be by creating a continuously updated automation strategy that allows for many small improvements to be made over a long period of time.

1.4 Research Approach

Creation of the tool will be done based on literature and observations of the activities at Q. The experiences that Q has surrounding this topic can provide a paramount view of what type of activities are typically useful to perform in the given situation and will be seen as the starting point for the design of the tool. The tool will be in English.

The available literature on topics such as automation planning and technology roadmaps will then be used to specify the required steps in the tool. The result is then evaluated both from an academic perspective as well as from the perspective of relevant stakeholders at Q.

Although gaining a base in literature research, the tool must be created in parallel with its application in the case. The experiences and findings of the initial application of ideas will provide a stronger argument for how the roadmap may later prove useful to similar companies that fit within the specified company profile. This means that, although this report will first specify the roadmapping process and then follow-up with the case report, the results further presented are already the combination of a continuously iterated parallel process of procedural ideation and the Q case study.

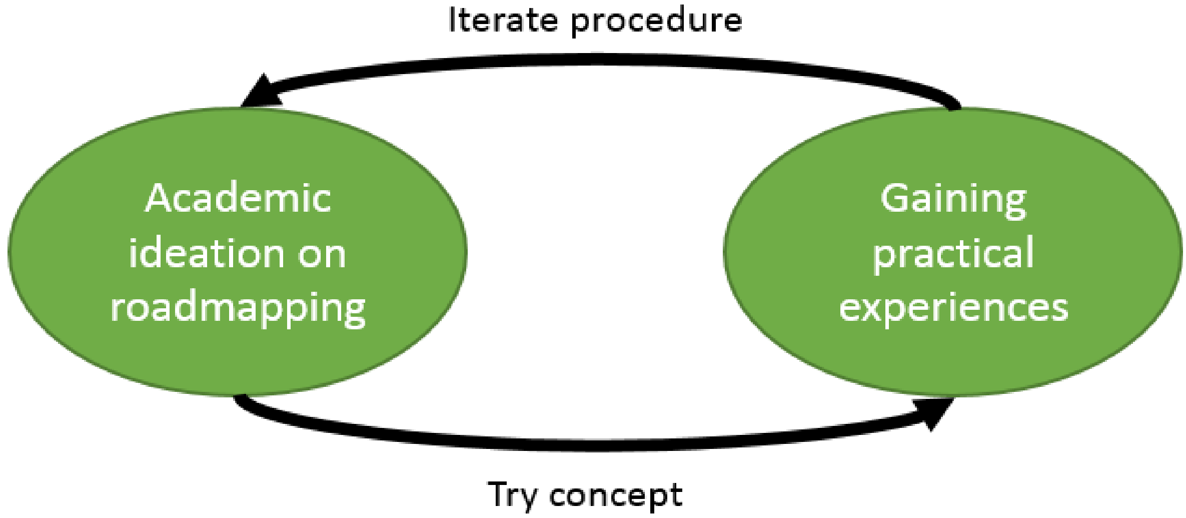


Figure 1 – literature research and practical experience are combined

Several support channels will be used during this project. For the academic part, contact with the mentoring professor will be maintained regularly to assure that the project is on track and the requirements from an academic perspective are fulfilled. This is crucial in assuring a high-quality thesis. Within Q, a steering committee will be set-up consisting of the most crucial stakeholders. Meetings will be planned regularly with this committee, which is tasked with providing feedback on the progress and making sure that the final roadmap fits their needs by steering the project in the right direction where necessary.

Q uses their own activity toolbox based on lean concepts to describe projects such as this one. This toolbox will be used to track the progress of the project within the company procedures. This is done to make sure that the communication within Q runs smoothly and all relevant stakeholders can easily be informed about the project status.

1.5 Project scope

The decision support tool will be designed for a specific company profile, based on that of Q. The scope is therefore somewhat narrow, as the subset of companies that the tool is relevant for is restricted. By doing this, however, the tool can be tailored for a specific need and may prove more applicable than a highly inclusive tool. An introduction to the case company may be found in chapter 1.1.

The tool is meant to create value as a new decision support tool that adds value in practice as well as in literature. This means that not only company characteristics should be considered when defining the scope, but a literature gap must be filled as well. Section 1.2 discusses some of the more general literature. Upon digging deeper, it appears that there is a lack of specific tools that guide companies in structural automation of the production line. Table 1 provides a summary of some of the more prominent available literature on roadmapping and elicits why it is not relevant in the case of companies like Q.

Name	Author, year	Topic	Limitations (gap to fill)
Fundamentals of Technology Roadmapping	Garcia & Bray (1997)	Introduction to technology roadmapping.	- Not a manufacturing context. - Doesn't go into detail as to how the selection decision should made. - Is not guiding enough to fully support a company in making the right decisions. - Very general.
Roadmapping as a Knowledge Creation Process: The PROLEARN Roadmap	Kamtsiou (2006)	General roadmapping approach and what can be gained from the roadmapping process.	- Focus is on training (knowledge field). - Little to no regard for the roadmap as outcome of the roadmapping process.
Roadmapping integrates business and technology	Groenveld (2007)	Technology roadmapping, which creates links with customer needs and necessary technologies.	- Different kind of roadmap (focused on the product).
Technology roadmapping—A planning framework for evolution and revolution	Phaal (2003)	Provides an overview of technology roadmapping tools and describes a general roadmapping process	- General descriptions of roadmaps based on examples, lacking the field of automation specifically. - general and summarizing.

Table 1 – an overview of some roadmapping literature and how research on automation roadmapping can add value

After examining the available literature, a gap is found in the form of a roadmapping tool specifically designed to guide a company from start to finish in creating a continuous roadmap for manufacturing automation. Such a roadmapping tool may add value in the following ways:

1) The automation roadmapping process will elicit the reasons for automation, which will be company specific, whereas currently defined roadmapping tools already have a broad goal in mind (e.g. product integration). This allows for a broader view of the benefits of automation.
2) The automation roadmap is not driven by product developments, but rather uses it as input in the decision making process.
3) Automation is expensive, and current roadmapping strategies are more applicable for big companies with big budgets. For a small/medium sized enterprise, it is more feasible to automate in small steps, rather than big leaps. The automation roadmap will accommodate for this, creating a path that may be walked in small steps when necessary.
4) Traditionally, investment decisions will be based on purely monetary basis, but automation has advantages that are often failed to be put into monetary terms. By including such benefits in the automation decision process, this problem can be solved.
5) Roadmapping is often used as a one-time tool that, once the end goal is reached, is finished. This limits the using company by setting a strict time-frame, creating solutions that are sufficient for the defined roadmapping period but may fall short thereafter. This tool will create a continuous roadmap that allows for continuous improvements to be made, planning activities on a time-line based on goals but updating these goals to assure a closed process loop.
6) This tool will provide one of few fully comprehensive roadmapping tools that describes the whole process; from goal-setting to roadmap maintenance.

Chapter 2: Detailed analysis

2.1 Goals for automation

The general problem definition at Q has been identified by management and focuses mostly on increasing the production capacity through automation. One could simply assume that this is all there is to it, but as it turns out, a more detailed analysis creates a broader problem definition, identifying more opportunities for automation.

At Q, there was a pre-existing wish to automate the manufacturing lines, with the assumption that the main goal should be capacity expansion. However, it makes more sense to initially analyze the potential of automation at Q in a broader sense. In order to more specifically define the problem and set goals, interviews with the most relevant stakeholders were held. The individuals that hold the decision power over the operations were specifically considered. By aligning the goals with the perception of managers, the problem could be correctly identified from a broad, company-wide perspective. At Q, a few individuals were chosen who manage from different hierarchical layers, from production managers to the COO. After speaking with these, the problem was defined as described in this section.

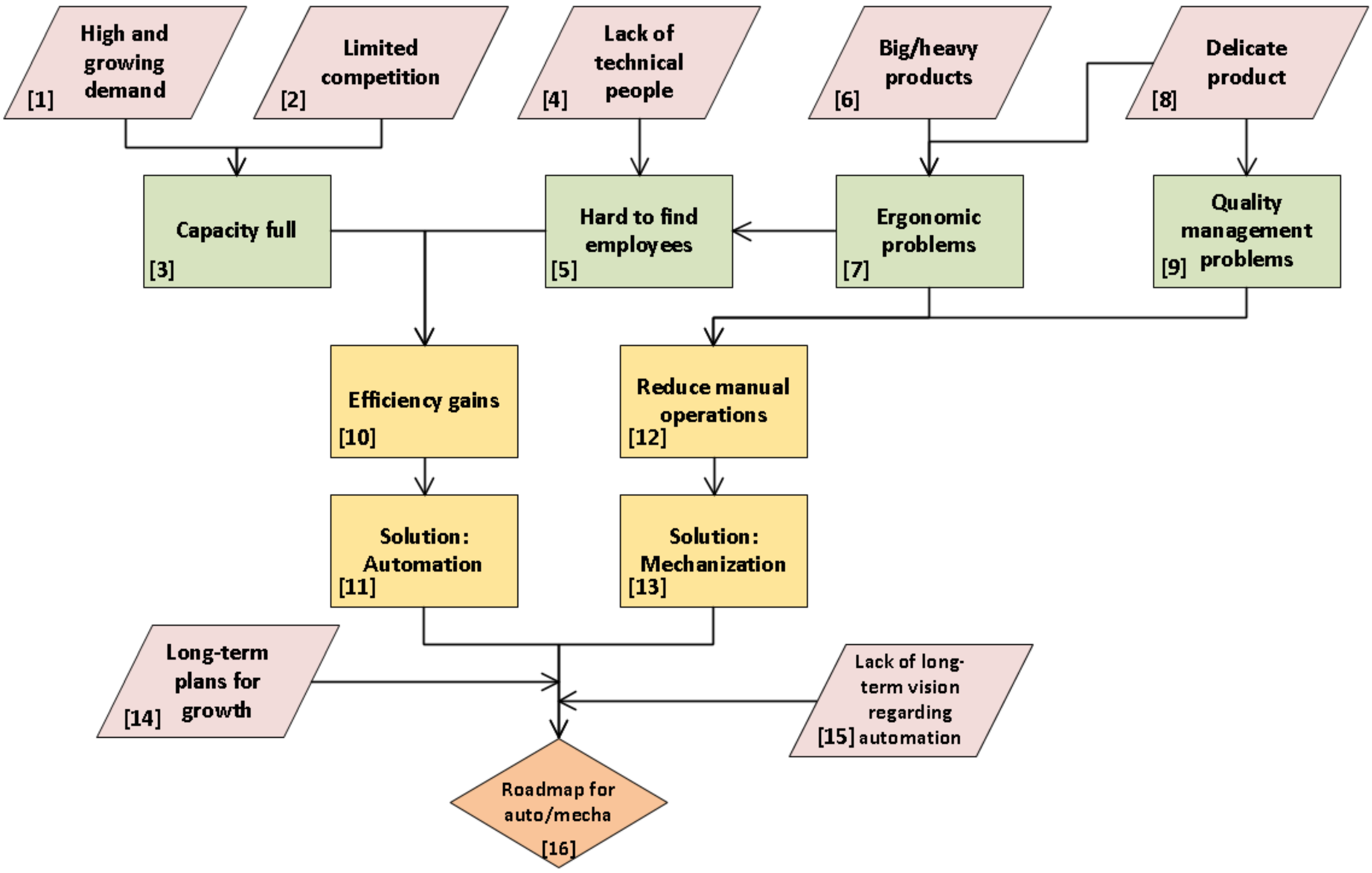


Figure 2: Problem definition flowchart

Figure 2 maps out the found, complete problem definition in a logical flow. At the top, a few observations are listed. Firstly, demand for Q's product is high [1], and the expectation is that it will continue its current growing trend. The product is rather unique and requires a lot of expertise to produce. As a result, the market is difficult to enter, giving Q a great position, being one of only a few worldwide producers of products of its kind [2]. [1] and [2] combined lead to the capacity being full [3], with millions of lost sales annually. There is a lot to gain for Q in the expansion of production capacity. This may be easier said than done though, as the job market is strained for technically inclined people with the right analytical mind-set [4]. Already, vacancies are difficult to fill and often remain open for extended periods of time [5]. Currently, Q is quite restricted by human resources in order to achieve growth. Using automation as a tool to expand production capacity is a well-established concept, even so much so that automation might be seen as a tool simply to reach this one goal. Increases in capacity are also quite easy to make financial calculations about, meaning that this is a rather straightforward benefit of automation. The picture is completed when other potential benefits of automation are considered, in this case the dependency on human resources for the company's growth, the ergonomic strain for operators and the product quality. A more detailed analysis on these, as well as more elaborate reasons for seeing these issues as relevant potential gains for automation investments is presented in Appendix A.

An argument can be made against automation as a solution to the mentioned problem areas by simply eliminating the situational causes (as shown at the top of figure 2) that result in the problem areas, removing the need for automation investments. In the case of the high and growing demand [1] and the limited competition [2], this is not desirable. The lack of technical people in the job market [4] is a problem that Q has no control over. The product being big and heavy [6] is a requirement from the clients, causing Q's products to be heavy beyond Q's control. The fact that the product is delicate [8] is again not something that can be solved. The high precision necessary on the final product is pushed by the semi-conductor and LED markets, Q can only comply by meticulously treating the products carefully. We can conclude that these causes can not be solved internally, as Q has little to no control over them. Since we can only look for solutions in our internal processes, we must accept the situation as it is and continue finding ways to deal with it, instead of trying to change the environment.

Based on the four defined problem areas, we can now reformulate to set the following general goals:

- Increase production capacity
- Become less dependent on the job-market
- Improving the ergonomic situation for employees
- Improve the quality of the product and reduce the number of rejects

From the four goals—to be called the pillars of automation—, we move towards two solution areas. Firstly, we have recognized the need for a more efficient process [10], this leads to the solution of automation [11]; enabling the process to run more autonomously or skipping/combining production steps altogether. The goal of such automation practices is to produce more with the same amount of people. Secondly, the ergonomic and quality problems can be tackled by having less manually controlled operations where an operator must physically touch the product [12]. The solution for this is mechanization [13]; leaving an operator in control of a process but giving them support systems that enable them to endure less physical strain and have less need to touch the product.

Q shows great growth ambition, with a defined growth strategy looking a few years ahead [14]. In this strategy, however, there is no long-term vision specifically on how to apply automation activities at Q [15]. Therefore, this project aims to create a strategical approach to continuously increased levels of automation by creating a roadmap that specifies the investments necessary to be made in order to help achieve the defined goals by improving the processes with regard to automation and mechanization [16].

The objective is to create a concrete and realistic three-year roadmap containing short- middle- and long-term steps. All suggested activities must be supported by a realistic business case, including among other factors a financial plan that details how the proposed activity is going to improve Q's strength as a company.

2.2 Relationship mechanization/automation

The previous section suggests a difference between working more efficiently and applying less manual handling. In literature, this difference is defined as the difference between mechanization and automation, which closely relates to the idea of Levels of Automation (LoAs). In a nutshell, the idea of these LoAs is that automation is not a binary state, but highly subjected to gradation. This gradation can be defined in many ways, figures 3 and 4 show two examples.

Both these LoA classifications show that there are multiple states of automation that can be reached. Duncheon (2002) views multiple stages between manual and automatic operations, whereas (Kern & Schumann, 1985) speaks specifically of a semi-automated state called mechanization. It will be argued here that the main difference between these two is a difference of mechanical and cognitive automation.

Mechanization: creating mechanical support for operators, but the operator stays in control on the operation and all cognitive responsibilities remain in human hands.

Automation: any activity that allows for a production process to run more autonomously, reducing/removing operator dependency.

Manual	
Semi-automatic	Automated alignment
	Automated process
	Automated cassettes
Automatic	Robotic material handling
	Automated inter-cell transfer

Figure 3 - the LoA model of Duncheon (2002)

For example, a mechanization activity may replace carrying a product by an operator with a balancer that moves this product from A to B. Such a balancer may be as simple as a pneumatic carrier that alleviates the physical carrying from the human. At this stage, the arm doesn't have cognitive functions yet, as its motion is controlled by the operator. This means that a new LoA is reached, as we moved from fully manual to mechanized. As a next step, we may choose for a robotic arm equipped with sensors that is able to place products from A to B with limited or no human interference. In this case, we have reached a certain degree of cognitive automation as well, and we move up the LoA ladder.

Pre-mechanization	Manual
	Line flow
Mechanization	Single units with manual work
	Single units with mechanical control
	Multi-functional units without manual control
	Systems of units
Automation	Partly automated single units
	Partly automated systems
	Automated manufacturing

Figure 4 - LoA model taken from Jörgen Frohm et al. (2008)*, adopted from* Kern & Schumann (1985)

2.3 Roadmapping methodology

Roadmapping Literature

Broadly speaking, roadmapping is the term used to describe any process through which a roadmap is created. In the manufacturing sphere, the phrase 'technology roadmap' is often used. An exact definition is impossible to find due to the broad applicability of roadmaps, but an indication is given by Garcia & Bray (1997):

"Given a set of needs, the technology roadmapping process provides a way to develop, organize, and present information about the critical system requirements and performance targets that must be satisfied by certain time frames. It also identifies technologies that need to be developed to meet those targets. Finally, it provides the information needed to make trade-offs among different technology alternatives."

Phaal (2004) goes one step further and lists eight types of technology roadmaps, as seen in figure 5. After analyzing these, it is hard to fit the idea of an automation roadmap into one of the existing formats. Most technology roadmaps are needs-driven from a product-focused perspective, meaning that the technologies to be developed are specifically aimed at facilitating the production of new products. This makes a lot of sense for big innovative companies that are constantly entering new markets or creating them but is not relevant for everyone.

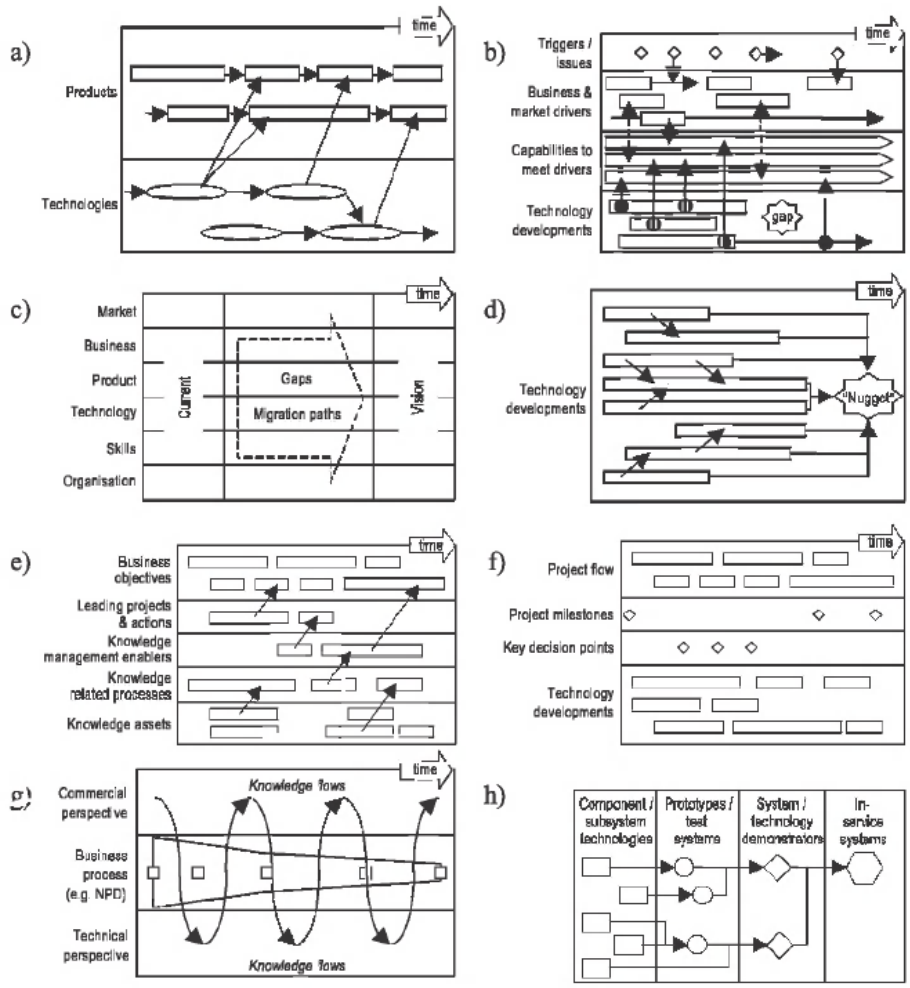


Figure 5 – Examples of technology roadmap types (purpose): (a) product planning; (b) service/capability planning; (c) strategic planning; (d) long-range planning; (e) knowledge asset planning; (f) program planning; (g) process planning; (h) integration planning. (Phaal, 2004).

The idea of needs-driven roadmaps is not unique to Phaal. Another good example is found in (Kamtsiou, 2006), who defines the roadmapping process as shown in figure 6. This process uses the company's vision as the primary input to finally define the actions necessary to accomplish said vision, and places these actions on a roadmap.

We conclude that a roadmap should be pulled rather than pushed, but the pull may come from different sources. In academic examples, there is often a clearly defined external pull (e.g. the product), that forces a company to invest in automation.

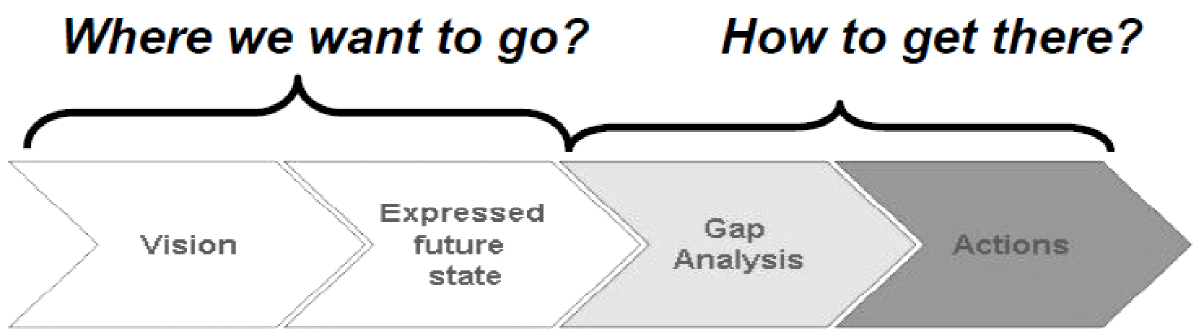


Figure 6 – the roadmapping process according to Kamtsiou (2006)

Q is a different case in the sense that there was a rather undefined gut-feeling that automation is a good step for the company to invest in, while the exact goals of automation were not clear. Since roadmapping theory strongly suggests that there should a vision for automation before it can effectively take place, it is crucial for companies such as Q to first define clear goals for automation for their specific environment, as was done for Q in section 2.1, creating Q's pillars of automation.

Literature makes it clear that roadmapping must be a goal-oriented and vision-guiding process, but this still begs the question of what the roadmap entails in more detail and what the specific process may look like.

A roadmap must, per definition, have a goal that is being worked towards. A traditional form that a roadmap may take is to strictly define an end-state, and then create the roadmap that guides the user towards that end-state. In this case, the roadmap activities are well-defined automation investments. A lot of research is being done in constructing the roadmap, doing in-depth analysis of all possibilities before exactly stipulating which actions and investments are necessary at predefined moments. Once the roadmap is finished, the end-state is reached and the project is retired. In the manufacturing sphere, with production automation as goal, this means that you have reached a certain level of automation.

The analysis involved in creating the roadmap involves brainstorming automation possibilities on all production processes that are within the scope of the desired automation, and is therefore a time-consuming activity. An example of how such a process might be envisioned is shown in figure 7.

There is a problem with such a type of roadmap for a company such as Q, which simply doesn't have the resources to invest in even the creation of such a roadmap, since all manufacturing processes must be heavily studied before an executable roadmap can be made. Q struggles with automating its production lines because there are no significant resources devoted for this purpose, and is therefore looking for a different strategy of strategic automation with a lower barrier.

Another clear downside of constructing an automation roadmap according to this methodology is that the process is not continuous; once the defined end-state is reached, there is no more continuation, there is no progress in the field of automation until a new, similar, project is started. It is arguably more sustainable to create a company culture that allows for a continuously updated roadmap with current goals, effectively allowing the company to always remain on top in terms of automation. Groenveld (2007) came to the same conclusion that "Roadmapping must be seen as an ongoing process that is a part of the business cycle".

Combining the findings that the roadmap must be constructed with limited analysis and the idea of a continuously improved automation strategy, we conclude that the roadmapping process must be seen as one of continuous roadmap maintenance. It is then clear that a strategy for maintaining the roadmap must be defined. This is also important because the initial roadmap was built at one moment in time, given the circumstances at that time. Since the circumstances around which the roadmap was built are changing, and technologies developing, the roadmap must adopt periodically, preferably even continuously.

In chapter 3, the roadmapping process proposed by this research will be specified, where roadmapping is a word that denotes not only the creation of the roadmap, but also the execution and maintenance thereof. The roadmap document itself is the central entity in this process, with an initial phase that yields the roadmap as a result, and a well-defined maintenance strategy wherein this roadmap is updated.

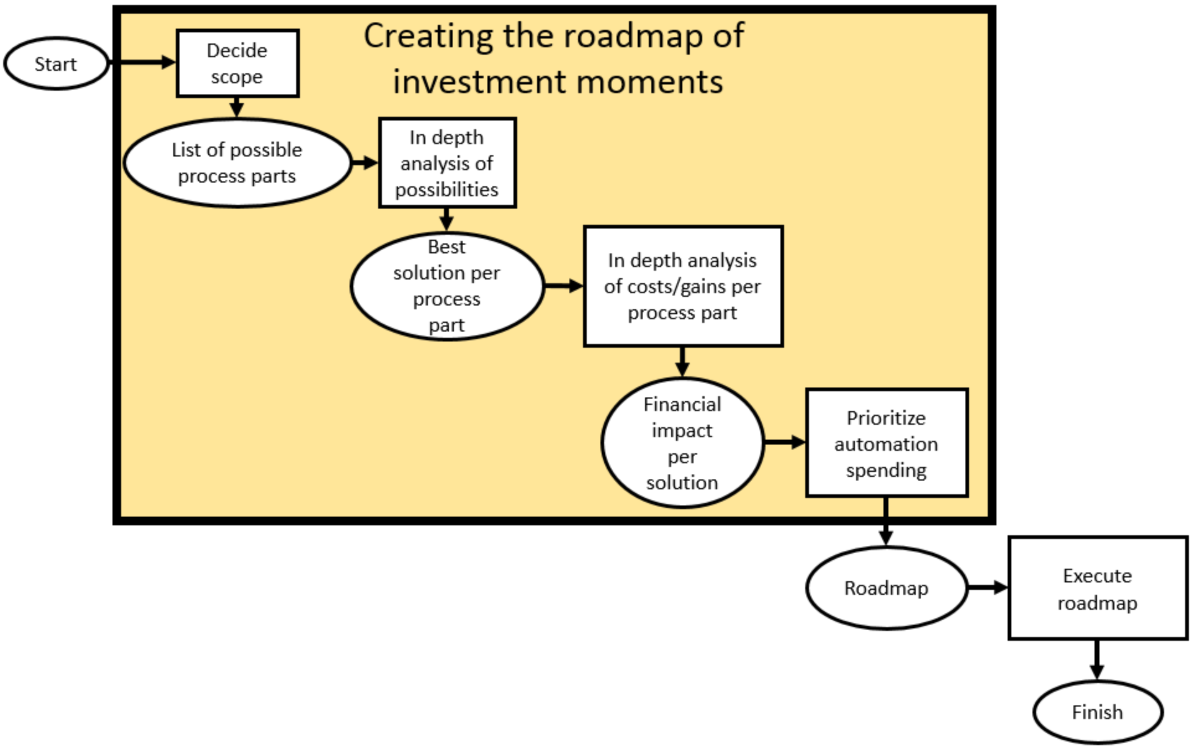


Figure 7 – an example of a more classical roadmapping process, notable are the linearity and finished end-state.

Chapter 3: Roadmapping process

This chapter will deal with the outcome of the roadmapping process, after which chapter 4 will present a case study, giving an example of the principle. The basic idea of the automation roadmapping is summarized in four phases, as explained in the following sections.

3.1 Roadmapping—Company analysis

There is no simple right or wrong answer when it comes to automation, instead it is a specific solution that needs to take into account many factors and will need a different answer for different companies. Therefore, the roadmap needs to be designed specifically for the company that will use it. The process of creating the roadmap, however, can be viewed from a broader perspective and put into simple steps, as appendix B shows.

Before one can start making an effective automation roadmap, many company specific factors must be taken into account. Firstly, this specific roadmapping tool is not applicable for every company, since it is based around the case company Q and is designed to fill a literature gap. It's also important to consider cultural, hierarchical and decision-making differences in the company that one wants to apply this tool in. Roadmapping is a complex process that may serve many different goals, even if the means are the same, and different companies will see different value in automation. Lastly, automation affects everybody in the company, and many people will have something at stake. It is important to have a good picture of who is involved, the roles they may serve and the blocks that they may prove to be.

Therefore, the company analysis section deals with the following four steps:

[3.1.1] Check company profile fit
[3.1.2] Initial analysis and scope
[3.1.3] Problem definition and goal setting
[3.1.4] Stakeholder analysis

After these initial steps, the actual roadmapping process may start with the prioritization process, followed by the execution preparation and lastly the execution.

In appendix C, an analysis is made of what should be the input and output of each roadmapping step. This will be used to guide the process, and this chapter will use the IPO analysis to explain what needs to be achieved at each step (in bold are outcomes that don't serve as input for a specific step but should be kept in mind throughout the whole process).

3.1.1 Check company profile fit

The tool must strike a balance between being too broad, providing for little context-specific effectiveness, and being too narrow, only applying to a highly select group of companies. It should also be considered that similar tools are already available in and out of literature. It is therefore important to create this tool to fit in a gap that existing tools don't cover. The initial ideas for the tool will be based on literature findings, and then tested at the case company: Q. This experience will create credibility for the success of the tool and simultaneously confirms effectiveness within the company profile.

It is then implicit that the tool must be targeted at companies of a similar profile as Q. Based on an analysis of this company, a more general profile can be set-up that specifies the scope of utility of the decision support tool.

The tool will be relevant for companies that comply with all of the following:

1) Manufacturing companies.

The tool will focus on automation production processes. It may be relevant outside of this scope, but caution should be applied.

2) Companies wishing to automate their production process, supported all the way to the top management.

Clearly, a desire to automate is necessary to stimulate the usage of the created roadmap. If this is only present at a lower hierarchical level in the company, then the roadmap will likely not have the support that it needs to be successful. If this condition in not complied with, high-level support should be created before the tool is applied. It should be noted that there is evidence that a bottom-up approach may work (Groenveld, 2007), however, this tool will is designed with a foundation in management in mind, where the wish to automate is already present, meaning that a top-down approach can be applied.

3) Companies with a lot of product variation, meaning that classical Make-To-Stock automation activities are not applicable.

Automation in the low product variety sphere poses completely different challenges than it does in a high-variety industry. For the former, many different other tools already exist, covering most bases. A lot of research has also been done about mass customization at this point, but fully comprehensive strategical automation tools are scarce and often very general. Therefore, this tool will be focused on companies that are looking for automation solutions outside of the high-volume low-variety mix. This is related to the scope of the automation tool, which will be elaborated on in characteristic 4.

4) Companies looking for an automation selection tool that allows for out-of-the box solutions, rather than a pure technology comparison model that selects from a pre-given set of options.

For custom product industries, the application area for a certain workstation might not be immediately clear. Whereas in a low-variety sphere it is often simple to deduce which application will yield the best result—the choice to be made there is more about which supplier offers the best and most suitable technology—, in a high-variety environment the solution areas may range from a standard solution (e.g. a robotic arm) to something more out-of-the-box (e.g. a complete re-arrangement of the process). Tools to compare robotic solutions exist in multitude, but they limit themselves to the comparison of different models of the same type.

As an example, let’s take a look at the automotive industry, where there is a certain set of car models that must be produced in high volume. When they are looking for a tool to move a car chassis from point A to point B, they can quite easily realize what kind of system will do this most efficiently—let’s say it should be a big robotic arm holding a mold—, and since most of the chassis will have a highly similar size and shape, the arm and mold only need a few functionality modes. The challenge in designing the most cost-effective solution then lies in the comparison of different arms from different suppliers.

In the high-variety context, this may not work because the solution needs to be way more flexible and applicable to a wider variety of product sized and shapes, a smarter and more flexible solution is needed. We will see examples of this in the case.

5) Companies lacking a structured, goal-driven automation strategy, or having one that doesn’t function properly.

The goal of the automation roadmap is to provide a structured strategical approach to automate the production lines. It is implicit that this is beneficial for those companies that don't already have such a strategical automation approach, or one that doesn't achieve its promise. Therefore this tool is specifically aimed at companies with a wish to automate, but that are lacking an effective, structured way in which to do so.

Before using the tool, these should be checked. If all are compliant, the tool is suitable. If one or more do not adhere, there are four options:

1) The tool can not be used,
2) The tool is used anyway, knowing that it may not be 100% relevant in all cases and must be used flexibly and with critical thought,
3) The condition that does not match the profile before using the tool is changed,
4) The tool is deliberately adapted for the right context before use.

If approved, the rest of the process may start, starting with the initial analysis and scope. A go decision on the profile fit means that the effortful process of producing an automation roadmap has been approved. This has implications for the whole company on the long term, but for now, only a few decisions must be made:

- Who is going to lead the project? The project encompasses the roadmapping itself as well as the maintenance and execution, although these responsibilities may be split.
- Who will be making the final decisions?
- Who are the key stakeholders?

Once these have been decided upon, the automation roadmap project can take its official start in the company.

From this point onwards, the process is not stage gate anymore, but rather a free iterative process with a guideline for the order of steps. It is not advisable to skip any of the steps, although in some cases it may be applicable.

Main process		
Input	**Process**	**Output**
- Company information	Check profile fit	- Fit approval

3.1.2 Initial analysis and scope

The initial analysis and scope decision can be started once the fit of the company with the tool has been confirmed in section 3.3.1. The procedure for this step depends highly on who is taking the lead in the roadmap creation process. The main method is going to be interviews. If the project is led by a long-time employee, this can be highly simplified, since the knowledge required is easily attained. During the rest of this step, it is therefore wise to keep in mind the different relations that exists, and base the interviewing structure on these. We also want to get a simple view of the processes in existence. The latter is especially important if an external is leading the project, in which case this part must take on an extended form in order to get to know the process well.

A vantage point from the very basics has the benefit that the roadmap creator(s) and stakeholders are on the same page and have similar or the same views about the current status of automation in the company and its potentials. This analysis is performed in parallel with deciding on the scope of automation. This makes sense because while analyzing the company's automation potential, this is immediate input for what should be in and out of the scope.

It is crucial to gain an understanding of the company culture, since "the roadmapping process will differ from one organization to the other because organizations serve different markets and have different cultures" (Groenveld, 2007). One of the outputs of the initial analysis must therefore be a good view of at least the parts of the culture that affect the decision making structure, and preferably also more broad cultural knowledge. This will be implicitly used throughout the whole process, and explicitly when creating change management and maintenance strategies in steps [8] and [9].

According to Garcia & Bray (1997), the "corporate vision drives the strategic planning effort, which generates high-level business goals and directions. Given a corporate vision, strategic planning involves decisions that identify and link at a high level the customer/market needs a company wants to address and the products and services to satisfy those needs. Given this strategic plan, technology planning involves identifying, selecting, and investing in the technologies to support these product and service requirements". The corporate vision can, for example, be expressed as KPIs defined at a high-level. Linking these to the goals of the roadmap can therefore create a strategic roadmap that plans the technological investments in alignment with the business needs that have resulted in the companies' corporate vision. This is yet another reason why it is crucial to, from an early point, have a clear view of what the roadmap needs to achieve with regards to the corporate strategy. Keep in mind that, to create a roadmap of any kind, two questions must be answered clearly: "Where do we want to go?" and "How do we get there" (Kamtsiou, 2006). First, we are figuring out the former at a high management level, this is one of the main goals of the initial analysis and scope decision.

Furthermore, the initial analysis is essentially taking a step back to view your own production process from a basic and quite shallow point of view, getting out of the entrenched views that one might currently have. The scope must consist of a clear idea of what "in scope" and "out of scope" mean.

To perform the analysis, a group of key stakeholders must be defined, which are then interviewed. The following basic questions are suggested for this interview, although one should feel free to add/remove question from this list where applicable.

1) Which parts of the process do you want to automate at company X?
2) Where do you see the biggest need for automation?
3) How would automation affect you in your job/department?
4) Why isn't automation at company X at a further level already? What is holding you back.
5) What can you automate?
6) Which problems do you expect when automating?

After the interviews have been conducted—as part of the initial analysis—, the scope must be decided upon based on the qualitative input received.

The scope decision is about defining where the automation should take place and therefore which processes may be included in the roadmap and which may not. By agreeing on this from the start, the roadmap has a better chance to successfully bring the company's operations to the next level. As an example, think of a manager A who want to include only the core manufacturing processes themselves and a manager B who aims to also include the warehouse management; if they don't solve this conflict at the start, it may be a disruptive force throughout the whole project. For this reason, it is unadvisable to skip over the initial analysis step, as it provides for input on the scope decision.

The result of this step is an unambiguous definition of what automation means to you and where its potential for application are. As an additional benefit, the main stakeholders will all have heard of this plan, creating broader knowledge in the company that this is being worked on and that things can be expected to change structurally. Do keep in mind that, due to the iterative nature of roadmap creation, the decisions made now may be subject to alteration at a later stage.

Note: the automation possibilities that fall within scope may incorporate non-production processes if deemed valid (e.g. warehousing). However, for the rest of this chapter, we will assume that we are dealing with an example where all manufacturing workstations fall within scope and nothing else.

Main process		
Input	**Process**	**Output**
- Fit approval	Initial company analysis and scope	- Understanding of company culture - Corporate vision - Production process analysis results **- Project scope**

3.1.3 Problem definition and goal setting

The scope of automation to be included in the roadmap is clear at this point, but filling the roadmap with appropriate content is not a goal in itself, rather it is a method to reach a goal. We need to have a clear picture of what the goals of the in-scope automation activities are. As Garcia & Bray (1997) put it: "The technology roadmapping process should be needs-driven rather than solution-driven".

The goal of this step is to define the project from the basics of what the company aims to achieve, what problems stand in its way, and connect the roadmap to these. This is first and foremost important for the creator(s) of the roadmap; the scope and goals can serve them as a compass, giving direction and keeping them on track. Secondly, the employees involved in carrying out the automation activities as specified by the roadmap may find use in a clear goal-setting in a similar way, although they at that point will already have their own, activity-specific goals. Thirdly, a clear problem statement accompanied by goals serves as a communication tool to gain a broad support base for the roadmap as a whole and its specified activities.

The exact form of the problem statement and goals is, again, left open for each company to play around with. The assumption is that most companies will already have practices in place for such activities, and the effect is greatest if they can follow their usual processes as much as possible. It is, however, important that the result is clearly described problem areas, with goals based around them. Examples of problem areas can be quality, job satisfaction or production capacity; they should remain broad concepts, whereas the goals may go into detail if so pleased.

By first clearly defining problem areas that exist in the company, which automation may be able to solve, the goals can follow quite intuitively by defining them around the problem areas. In order to do this, the interviews of the initial analysis may be used as inputs, or new ones may be held if found necessary. The proposed questions in the initial interview are designed such that they elicit the problem areas that exist at the company and for which automation has the potential to provide a solution.

The resulting problem areas and goals are the first concrete description of why automation, and the roadmap that facilitates it, is necessary. The company now has a clearly defined reason to automate, whereas before this might have just been an unformulated intuition. A formal definition of what automation should achieve will later help guide our decisions on which automation is most suitable.

The importance of the corporate strategy should be considered again in the goal setting phase, as the goals of the roadmap are more likely to create strong incentive among the upper management if they align clearly with the high-level strategic goals.

Main process		
Input	**Process**	**Output**
- Project scope - Coroporate vision	Problem definition and goal setting	**- Defined problem areas** **- Project goals**

3.1.4 Stakeholder analysis

Now that goals have been defined, relevant stakeholders must be analysed and managed in order to assure a good mutual understanding of the problem statement. This analysis also facilitates the control of roadmap implementation, as it helps define communication and engagement strategies to use during the creation of the plan in order to create a broad support base for the specified actions. For this project, a complete stakeholder analysis was done according to a methodology created from looking at stakeholder theory. This approach can be found in appendix D.

Main process		
Input	**Process**	**Output**
- Defined problem areas - Project scope	Stakeholder analysis	**- Stakeholder management strategy** - Link stakeholders and problem areas

3.2 Roadmapping—Prioritization

After the company specific variables have been elicited, the more concrete roadmapping process starts. Keep in mind, however, that this is not a stage-gate process, and the subsequent steps may easily overlap, at least partly, with the previous steps. If this is done, all subsequent steps must be updated according to the progression and new information found about the initial steps. To illustrate this point, imagine a company that starts in section 3.2.1 (choose and fill a LoA model), while still performing the stakeholder analysis. Upon meeting a certain high-ranking stakeholder, the chosen model may suddenly not be suitable anymore, thus this decision needs to be changed according to the new information. This example shows the danger of a process that overlaps too much, although a no-overlap strategy may result in an unacceptably high lead time for the roadmapping process. A balance must be struck depending on the company's preferences.

In this section, the production processes that fall within the project scope are evaluated on their automation potential and put into a literature model. This results in the roadmap with all its activities specified in it, where an activity denotes an automation project. In other words, the prioritization will create an order of at which workstation automation can be applied in the company, put on a timeline, where after the procedure on how each of these automation projects should be conducted is, at this point, still to be defined. Afterwards, the execution preparation section will deal with the specifics on how to prepare for the process of choosing the best automation alternative among all options for each part of the process, i.e. preparing the execution of the roadmaps project as specified as a result of this chapter. This logic is in line with (Garcia & Bray, 1997), who apply a similar method to a technology roadmap:

"*The main benefit of technology roadmapping is that it provides information to help make better technology investment decisions. It does this by:*

- *First, identifying critical technologies or technology gaps that must be filled to meet product performance targets.*
- *Second, identifying ways to leverage R&D investments through coordinating research activities either within a single company or among alliance members.*"

With the addition that, for the former, our identified critical technologies will not only be analysed on technology gaps, but also prioritized based on company input on which workstation is more urgent. For the latter, we don't limit ourselves to our own R&D investments, but rather incorporate all investment types, as long as the specified goals can be reached with the investments.

Concretely, this chapter deals with the following roadmapping steps:

[3.2.1] Choose and fill LoA model
[3.2.2] Identify and prioritize process steps

3.2.1 Choose and fill Levels of Automation (LoA) model

It has long been known that full automation often looks better on paper than in reality. In addition, it's been established decades ago that automation comes in different levels. 40 years ago, Sheridan & Verplanck (1978) already concluded that the decision to automate is not a binary one. They identified a ten-level scale system of what levels of automation exist. Since then, the concept of Levels of Automation (LoAs) has been used in industry to identify what state of automation is desired in a system. A LoA is a system that classifies different types of automation. Many LoAs have been proposed, Frohm et al. (2008) provides a nice summary of most academically suggested LoA systems.

LoAs often also describe different kinds of collaboration between the robot and the human, often distinguishing between different task divisions; as Endsley (1997) showed: to maximize performance, a mix of humans and robots must be used. It has been established that "human presence … is essential to compensate for technological limitations" (Mital & Pennathur, 2004), which implies that humans have capabilities that robots can't yet take over. These capabilities come in the form of adaptability and interpretation.

By putting the current and desired states of a process into a well-defined LoA, the path towards improvements can be guided more explicitly and structurally. This also allows for trade-off analyses between different states and analyses on how valuable a level-up is at each point, giving automation system designers a more structured way of organizing arguments for automating to the decision makers.

LoAs can also guide the designer in defining a roof for the desired state of automation. This is significant, since quite often systems will be overly ambitious in how automated they are, reducing their effectiveness because of the system working poorly due to insufficient testing.

Crucial in any automated system in which Human Robot Interaction (HRI) exists, is the safety of the human. A paramount factor is the trust of the human in the automated system. "Either overtrust or undertrust may be problematic" (Merritt et al., 2013). Overtrust may lead to reliance on the system and low vigilance when the system underperforms or when physical danger is present. Undertrust leads to suboptimal utility of the system and leaves much room for improvement. Trust is influenced by the employee's personal characteristics, such as intrinsic trust towards automation. Therefore, it may prove worthwhile to invest in creating the right attitude among employees dealing with such systems (Merritt et al., 2013).

Appendix E provides some examples of existing LoA taxonomies, classifies them and provides for a method to select the taxonomy that is most appropriate for the company that is using this tool.

Filling the LoA model

The LoA system aims to guide your prioritization process by first expressing an ambition in what level you want to reach and then indicating the current status—optionally, a low relevant minimum LoA level may also be used to show the progress that was already made. Once these two are known, the path towards it can be defined in terms of the automation activities that will be defined during the brainstorm phase of the automation decision tool. This is in line with Kamtsiou (2006), who found that creating a roadmap follows the four steps as defined in figure 6. The vision conforms to the corporate vision, as found in step [2], the expressed future state is now defined by the LoA model, the gap analysis and actions will be done for each process step to be automated individually during the automation activities.

For the expressed future state part of Kamtsiou's model, we therefore need to define, for each production process step, the current state of automation, as well as the maximum achievable, optimal situation. This is in line with Frohm, who uses a relevant minimum LoA, as well as a maximum relevant LoA, indicating the range of possibilities for the specified workstation. Figure 8 shows the example from Frohm where the LoA range is indicated.

One might argue that the relevant maximum level should always be the maximum level on the scale, but one must consider the "pitfalls of over-automation which can lead to the failure of computer integrated manufacturing systems to deliver cost-effective and flexible operations" (Almannai, Greenough, & Kay, 2008). There is a marginal decrease in the return that you gain on automation, the more extreme the automation becomes. This means that there must be a defined stopping point where it is decided that that LoA is the maximum level that is relevant to the organization, subsequent levels are not deemed profitable at this point and will not need to be considered to be in scope for this workstation.

	Mechanical and Equipment						
LoA	**Workstn. 1**	**Workstn. 2**	**Workstn. 3**	**Workstn. 4**	**Workstn. 5**	**Workstn. 6**	**Workstn. 7**
7							
6	Relevant max	Relevant max		Relevant max		Relevant max	
5				Relevant min			
4					Relevant max	Relevant min	Relevant max
3							
2	Relevant min		Relevant max		Relevant min		
1		Relevant min	Relevant min				Relevant min

Figure 8 – Frohm's idea of defining a relevant LoA range by identifying the relevant maximum and relevant minimum

Main process		
Input	**Process**	**Output**
- Production process analysis results	Choose and fill LoA model	- LoA model - LoA goals per process step

3.2.2 Identify and prioritize process steps

The roadmap will serve as a timed guide that enables the user to structurally execute automation activities, essentially a chronological list of where one should automate. This means that it's crucial for the order of the activities to make sense; we need to prioritize according to urgency. As it was important before to realise that automation is not a black-and-white matter, it is now important to understand that not all production steps—as well as anything else that has been defined to be in the scope—are equally worth of our automation attention. Otherwise, we might end up overextending ourselves trying to do everything at once, or we might be making the wrong calls in where automation can yield the best benefits, resulting is a poor use of resources.

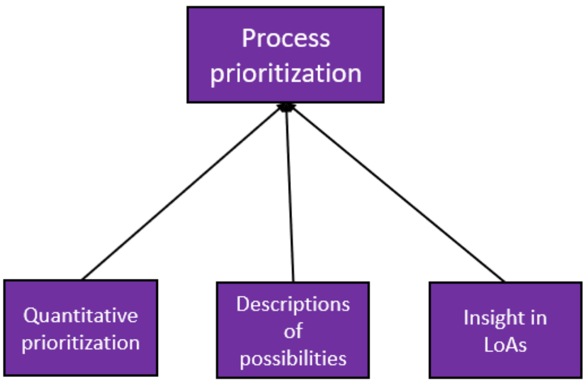


Figure 9 – the three inputs for deciding on the prioritization of workstations

For a good view on where automation may be most desirable, we want to combine three pieces of information, as seen in figure 9. The first is an index of each possible automation area and each problem area, indicating on a scale from 1 to 5 how much urgency there is for that automation possibility on that problem area. This results in an urgency table, quantifying the urgency of each workstations automation progress. Secondly, we will want to combine this with qualitative knowledge of the workstations current status and potential, in order to not miss any opportunities that are not elicited by the urgency table. The third input will be provided by the LoA model, which serves as a tool to guide the automation ambition into a guided process and can help elicit low-hanging fruits. Only the first and third of the aforementioned prioritization inputs will be further explained, as the second one is a description of workstations, which needs no further explanation.

Before we can start getting these inputs, we need a list of all the automation possibilities that are in our scope. In our example, this means a complete list of all production workstations. Once this is obtained, the modularization of workstations is to be decided upon.

Modularization

It may be desirable to pool workstations into production modules. The way in which to pool the workstations can be decided by many factors, such as (of course, more exist):

- Change in batch size
- Semi-manufactured product
- Intermediate storage moment
- Geographical location
- Customer order decoupling point

The pooling of workstations can yield the benefit that it simplifies the roadmapping by reducing the number of workstations to consider. Additionally, pooling workstations in a logical sense promotes a more general ideation of automation solutions that may therefore result in solutions that are more broadly applicable for multiple workstations that are pooled together. In the next chapter, it will be shown how this issue was dealt with by Q.

Quantitative prioritization

If the project has S automation possibilities and T problem areas (pillars of automation), then we construct a S x T matrix, where each field contains a subjective evaluation of u_{st}: the urgency of automating workstation s in order to improve on pillar t. This means that the question “How urgent or important is it for us to improve on pillar t by automating process s?” must be asked, so that the whole table may be filled eventually. Practically speaking, it makes sense to have a person as responsible for each column t, since in many cases there will be an expert on that problem area (e.g. for t = “job satisfaction” an HR manager might be responsible for filling in column t). This implies that the urgency score is a subjective evaluation of urgency of an expert at the user company. There are ways to create an objective base for the urgency scores though. We will encounter an example in the case.

For the final urgency score U_s of option s, we can take a simple average:

$$U_s = \frac{1}{T}\sum_{t=1}^{T} u_{st}$$

This is arguably too primitive, as it gives equal weight to any point given, implying that each pillar is equally important. Such a system may be used, but it is advised to make two alterations: 1) it may be desirable to make higher scores count more heavily, as to solve the most extreme inaccuracies in the factory first; a quadratic model can be used for this, and 2) a weighing score for each problem area t, giving the option to make certain problems more important to be solved. The latter can be used to, for example, align the automation roadmap with the management’s general long term ambitions. The proposal is therefore to take into account a weighing factor per problem area, turning it into a weighed factor score, as well as using a quadratic sum of urgency scores:

$$U_s = \sqrt{\sum_{t=1}^{T} (w_t u_{st})^2}$$

Where w_t denotes the weight of column t. These weights essentially indicate the balance of importance between the different problem areas, it therefore makes sense that the management decides what these values would be. By default, they all get a value of 1, totalling to a value of T. Alternatively, an allocation rule may be to give out a predefined number of points W (e.g. W is 20), and divide X over the pillars T. Another possibility is to give the column weights a value proportional to their relative sum of urgency, as in:

$$w_t = T * \frac{\sum_s^S u_{st}}{\sum_s^S \sum_t^T u_{st}}$$

It follows logically that

$$\sum_{t}^{T} w_t = T$$

The strength in this is that the given urgency scores intuitively add up to a score of how important that problem area is, as a whole, in relation to the others, meaning it would make sense to simply use the ratio of urgency sums as the problem area weighing factors. The downside of this method is that, in practice, each pillar's scores will be filled in and maintained by a company expert on that problem area. Thus, giving higher scores puts more value to 'your' automation pillar, which in turn is used as input on which workstation the automation budget should go to. The pillar responsibles might then feel inclined to give higher scores, creating an internal power struggle.

Which of these methods of calculating urgency is used is to be decided by the user company, based on what makes sense in their business environment. This decision needs to keep in mind the potential of this urgency table to align with the corporate strategy by giving higher weights to more important pillars, whether or not this is relevant will be company-specific.

A priority list can then be obtained by sorting over U, indicating which workstations or production areas are in most urgent need of automation. This provides one of the main pieces of input when designing the roadmap. A few formulas have been proposed for calculating the urgency of automation per workstation, but this is not an exhaustive list; a new method of calculating the urgency may be found to be more relevant under different circumstances.

Insight in LoAs

Besides looking at how beneficial automation is for each workstation, we also need to gain an insight in how automated all of the relevant processes already are. The filled out LoA taxonomy from the previous section should therefore be taken into account when designing the roadmap and placing activities on it. The LoA model may also help in identifying low-hanging fruit activities, where a small process change may result in a LoA improvement that yields enough benefit to be profitable and realistic in the short term.

By using the LoA in roadmap design, the roadmap becomes goal-driven, as the maximum relevant LoA indicates the goal that would be reached in the perfect manufacturing situation, and each roadmapped activity makes steps towards this goal.

Main process		
Input	**Process**	**Output**
- LoA goals per process step - Project goals	Identify and prioritize process steps	- List of prioritized activities - Roadmap structure

3.3 Roadmapping—Execution preparation

At this point, we have the outline of the roadmap, including all selected automation activities and the time at which these projects take place. The next step is to specify the procedure for each of these activities to come to the best automation alternative for each of them. This automation selection process will be discovered in step 3.3.1, while steps 3.3.2 and 3.3.3 will specify control activities that are crucial for the effective usage of- and benefit creation by the roadmap.

In short, chapter 5 will deal with the last few steps of the roadmapping process:

[3.3.1] Prepare technology selection procedure
[3.3.2] Define and execute change management plan
[3.3.3] Define maintenance procedure

After this, only the execution of the roadmap rests, which is an ongoing process of performing the activities at the specified time and maintaining the roadmap with evolving information.

3.3.1 Prepare technology selection procedure

Main process		
Input	**Process**	**Output**
- List of prioritized activities - LoA model	Prepare automation selection procedure	- ROI template - FMEA template - Workstations' goals and scope

We now have a clear idea on which options for automation will be placed in the roadmap, as well as a way to place the most urgent and promising first. Strictly speaking, at this point, the automation roadmap had been made in the form of a document that specifies at which point in time which automation project should take place. However, due to the iterative nature of this process, this roadmap document may not be completed yet and this step will run parallel to previously described steps.

Solutions must now be found for the identified opportunities. We will work with three kinds of input for the decision of which solution is best, these are:

1) The academic LoA model chosen in step 3.2.1
2) A risk analysis in the form of an FMEA
3) A financial analysis in the form of ROI

The motivation for these will be provided in their respective paragraphs below. The whole process is summarized below:

[a] Develop project team
[b] Make FMEA current process
[c] Set LoA goals
[d] Brainstorm solutions
[e] Solutions LoA definitions
[f] Solutions FMEAs
[g] Get quotation
[h] Calculate expected benefits
[i] Decision

The workflow chart in figure 10a describes the process that is to be followed for each activity in the roadmap. Each step will be explained in the next section. It is important to realize that this is not a sequential process, but generally follows the structure as indicated in figure 10a, although each color should be finished before moving on to the next. The red steps—brainstorm phase—are required for each workstation exactly once, whereas the light-blue steps—analysis phase—need to be applied to every identified solution possibility. The last, green steps—concluding phase—are again done once for each workstation.

The tool

For the whole process that is performed for each identified to-be-automated process, a tool exists in the form of an excel sheet. For each of the steps described below there is a sheet that serves as a template. Fill in the template properly for all steps, and a good overview of information is created that can ultimately support you in making the decision. Appendix F contains pictures of the template sheets.

It is important to realize that, in some cases, only one opportunity for automating is found. This means that the tool will not be used to compare different alternatives, but instead will be used to compare the current situation with the possible new one. The result in this case will be a yes or no to the proposal. In a similar way, when there are multiple alternatives, it may be the case the current situation is preferred above all of them. Whatever the outcome, the purpose of this tool is to provide guidance, structure and uniformity in making the decisions.

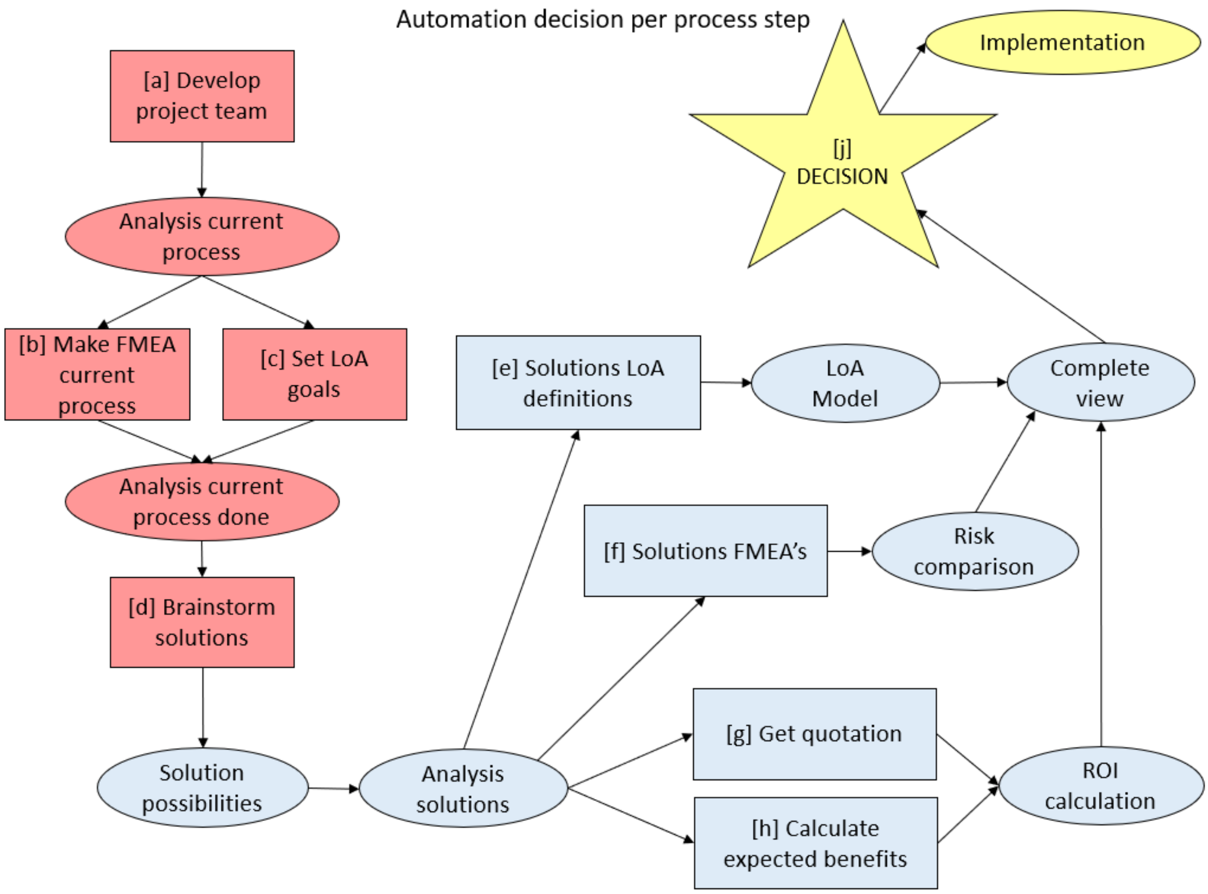


Figure 10a - the automation selection tool with a) in red the brainstorm phase, b) in light-blue the analysis phase and c) in yellow the concluding phase

[a] Develop project team

The stakeholder management strategy enabled the identification of several classes of stakeholders (see appendix D for details). This can be used to make the team for an automation activity. Ideally, a designer would take the lead over the activity, leading the discussions and taking responsibility over the final result. The rest of the team essentially just exists of at least one close passive, but preferably a few more, depending on company size and available human resources. The role of the team is to give the designer the required input, which is applicable in the following phases:

- Process FMEA—to help identify and quantify risks in the current process.
- Define future state—to ideate what the ideal situation that should be worked towards looks like.
- Brainstorm solutions—to give ideas on how to make steps up the LoA ladder to the ideal situation defined before.
- Solutions LoA definitions—to define the LoA states each solution may bring the workstation to.
- Solutions FMEAS—to identify all possible risk changes if the solution is implemented.
- Implementation planning and control—to give input on how the technology would work in a practical sense as to assure a proper implementation without unexpected hiccups due to the designer missing certain insights.

The team should be clearly defined, and each member should be aware and updated of the activity's schedule and their responsibilities in the team. All expectations of one another must be discussed before moving on with the process analysis. The company that applies the tool most likely already has certain structures for project management of this kind. The team definition should, logically, be matched with the existing systems that are in place already.

While the next step should not start before the team is created, this is an exception and does not mean that this is a stage-gate process; the rest of the process has steps that may overlap or be switched around within their own color group of figure 10a.

Analyze current process

Before one can start thinking of process improvement processes—whether in the form of automation or not—, the effort will be futile without a proper view of the current process. This process flow serves as a comparison point for all proposed solutions later.

This process flow will be a simple mapping of consequent steps, in detail, that an operator performs in order to complete his tasks.

Automation selection procedure		
Input	**Process**	**Output**
- Stakeholder management strategy - Link stakeholders and problem areas	Develop project team	- Project team

[b] Make FMEA current process

For each of the steps identified in the process analysis, the risks must be identified. We will want to compare this risk to the risk of our solution proposals, therefore, it is important to use a quantitative model that allows for direct comparison functionality. We will use this as a starting point to evaluate all alternative possibilities as one of the decision inputs (see figure 10a), and it is therefore crucial that it is accurate.

The usage of an FMEA in automation activities is not new. In Almannai et al. (2008), FMEA is used after the decision on which alternative to take has been made, its function being to check the risks and prepare for them. The flaw in this ideology is that a solution has been selected already based on other factors, which may then later be found to have many risks that are hard to account for.

Therefore, we will use the FMEA comparison of each proposed solution with the FMEA of the current process as one of the three inputs for the decision.

Each of the detailed process steps must be accompanied with all relevant risks. These risks then need to be assigned to one of the problem areas that the roadmap aims to solve through automation. The risks are then, as standard FMEA theory prescribes, evaluated on a predefined scale of occurrence, severity and detectability. It is advisable to define these scales strictly and qualitatively for each of the problem areas.

The FMEA is to be created with input from the team. The insights of close passives is crucial to determine the exact risks that are at play from a close view on the process. If no close passives are involved, things like product handling and other such issues that happen close to the process itself might be missed.

Structural actions

- Define scales for all pillars on severity, occurrence and detection
- Decide on FMEA template; if nothing is available at the company, appendix F provides a basic template which may be used as a starting point.

Automation selection procedure		
Input	**Process**	**Output**
- Project team - FMEA template	Current process FMEA	- Process FMEA

[c] Set LoA goals

We have already placed our process steps on our chosen LoA taxonomy, but this is a simple and generalized view of the situation and the potential in terms of automation. Kamtsiou (2006) found that it is wise to "invent the future first and to 'plan backwards' from there in order to link up with today". Thus, in this step, we concretely define the ideal state that we would be in in a perfect world, creating a clear view of the gap to be closed. The ideal future states may be strictly defined per workstation where applicable, but it may make more sense to do so for groups of workstations that are related to each other.

For this step, we again need input from the team in order to gain understanding of the ideal situation for the close passives, who will have to directly work with the new system.

When the desired future state is clear, we have all inputs necessary to start brainstorming.

Structural actions

- Decide on a LoA model (should have be done in step 3.2.1 already, details can be found in this section)
- Gain a clear image of the ideal future state of the production process, either per workstation or with workstations pooled up.

Automation selection procedure		
Input	**Process**	**Output**
- LoA goals per process step	Define future state (LoA)	- Ideal state definition

[d] Brainstorm solutions

Certain roadmapping steps are highly dependent on the company in questions, and will therefore not be defined strictly by the tool. The brainstorming is an example of this, as there are many variables such as company culture and hierarchy that will be important to consider when describing the brainstorming method. However, the required outcome can be described accurately; all possible technical automation solutions that solve the problems as described for this to-be-automated process, listed in logical order where applicable, see appendix F.

The solution proposals may go in very different directions, but it is also conceivable that one solution is expanded in several steps. In order to define such a solution, the LoA concept may be used to work backwards from the ideal situation, and then define steps that get the production step there, an example will be provided in the case.

The found possible solutions may include anything, including but not limited to the following:

- Already existing ideas
- Ideas tried in the past, but not pursued because the
    - technology hadn't advanced enough yet
    - budget was too low
    - company wasn't ready for automation
- Solutions resulting from benchmarking activities
- Out-of-the-box ideas

Automation selection procedure		
Input	**Process**	**Output**
- Workstation's goals and scope - LoA goal for process step - Process FMEA	Brainstorm solutions	- Solution proposals

[e] Solutions LoA definitions

In order to see which solution progresses you in what way along your selected LoA taxonomy, we need to add a classification for all proposed systems. This will serve as one of three inputs for our final decision.

Sheet 4 of the template is, at this point, filled with the current and desired states. Add to that the proposed solution systems and the picture is complete. In some cases, where solutions build upon one another, it is likely that the level increases incrementally along different scales. It is worth noting that it is not required to reach the level of the desired state, although if this is realistic is would be optimal to do so. Is it however likely that this is out of reach and that smaller investments are only possible, moving up the scale towards the ultimately desired state, but not quite reaching it. This is not a problem, as it still guides the company on the track to achieve the desires level of automation, and relevant and realistic steps are taken, this is the goal of the roadmap.

Automation selection procedure		
Input	**Process**	**Output**
- Solution proposal - LoA goals for process step	Solutions LoA definitions	-Solution LoA comparison

[f] Solutions FMEAs

As the second of the three inputs for the final decision on which alternative to pick, the FMEA of the current process must be compared to FMEAs of all proposed solutions. In order to get a realistic view of what risks might be created/removed or increased/reduces, it is wise to discuss with at least operators and suppliers, as the operators know the process best and suppliers know their technology best.

Automation selection procedure		
Input	**Process**	**Output**
- Solution proposal - Process FMEAs	Solutions FMEAs	- Solution risk comparison

[g] Get quotation

When possibilities for automation solutions are defined, it is wise to quickly start talking to suppliers about what they can offer and gather quotations for the proposed systems. This should be done early because some suppliers may take quite long to get you a quotation, and this information is required as input for the ROI calculation, which in turn is necessary for the final decision. It is therefore advisable to continue with the rest of the steps in parallel with the contact with suppliers.

Automation selection procedure		
Input	**Process**	**Output**
- Solution proposal	Contact supplier	- Quotation

[h] Calculate expected benefits

The ROI calculations needs two figures: the costs and the benefits. This step focuses on getting an estimation for the value that the technology may bring, as opposed to the cost information that is being gathered from suppliers.

Classically, such a calculation will be bothered with only more traditional production metrics, such as maintenance, lead times and production rates. While these should obviously be included, we found that in automation there are many more factors, that are easily overlooked. Therefore, the predefined pillars of automation, the areas wherein automation may be beneficial at the user company, should be used to define the financial benefit.

This means that for each pillar, a benefit calculation should be drawn up, consisting of the same factors for each operation. For a pillar ‘ quality’, the cost factors may include rejects, additional processing costs, and some other standard cost metrics. Such a calculation, including all pillars, is already an improvement over simply making a generic production output calculation because it may help you include factors that you wouldn’t otherwise think about. That is how the structure of the pre-defined pillars may help you throughout the roadmapping process, since we know that each pillar has the potential for being improved through automation.

This may still leave gaps though, since indirect, long-term effects are not considered (e.g. for a quality pillar we may think of the long-term dissatisfaction at clients, which costs us money). Such factors can often not be calculated accurately, but we can include them anyhow by creating, for each pillar, an ‘exacerbation factor’ can be compiled. This is a percentage that indicates how much worse the problem will be in 1 year, if no improvements are made. This number will always be an estimate, so it is crucial to make the exacerbation factors in cooperation with company experts that can make right assumptions.

By using this strategy for creating an ROI, we don't undervalue the total effect that automation may have, as we include costs that would otherwise be missed. For further explanation, refer to [Appendix A].

Automation selection procedure		
Input	**Process**	**Output**
- ROI template	Value estimation	- Benefit estimation

[i] Decision

The decision maker of the automation roadmap project must now be contacted to make the decision on which alternative to pick. This is done based on several information sources; 1) the LoA progression and goals, 2) the risk analysis and 3) the ROI calculation. There is no distinct guideline on how to decide from this point. The decision maker needs to understand which factors should weigh more heavily compared to the others in that situation. This means that the decision is ultimately still subjective, the tool does not aim to quantify the decision itself. The tool, however, adds value by creating a structured approach towards constructing a complete picture so that the decision can be made with all factors considered, without taking the actual decision away from the management, and providing for a quantified base from which to draw the conclusion.

Automation selection procedure		
Input	**Process**	**Output**
- Solutions LoA comparison - Solutions risk comparison - Solutions ROI comparison	Decision	- Automation system decision

3.3.2 Define maintenance procedure

Once the roadmap has been created, the remaining, and ongoing, activities are 1) execution of the defined automation activities (for which the procedure was defined in step 3.3.1) at the specified time (result of step 3.2.2) and 2) maintaining the roadmap. In order to maintain the roadmap, a proper maintenance procedure must be defined, which is again a step which can be started earlier in the process, parallel to previously described steps.

The frequency at which the roadmap is evaluated is company-specific, since it is most realistic to align this process with the ongoing strategic practices that exist at the company. For example, if the company in question evaluates their high-level KPIs on an annual basis, then it makes sense to update the roadmap at the same time, given that the roadmap should be aligned with the corporate strategy. Thus, the maintenance procedure can't be generalized much, leaving this step rather open to the companies' preferences.

There are, however, some standard activities that will almost always result from the roadmapping procedure, these are listed below:

- The roadmap must be updated if circumstances change, and it must be extended into the future. Ideally, this is done continuously as an inherent part of strategic management, but it is more realistically achieved by periodically planning a moment to do so. By defining triggers that may require a change in the automation strategy (e.g. a product introduction), the right evaluation moments can be specified.

- The urgency table needs to be updated periodically so that the roadmapping can be done accurately and with correct information. The table must be up to date when the abovementioned roadmap update is performed.
- The weighing factor of each pillar in the urgency table must be kept synchronized with the high-level strategy of the company, so that the automation activities will keep matching the companies vision.
- Review the teams that are currently working on activities and update the roadmap to match the current progress.
- After an automation project is done, update the LoA model of the whole production line to reflect recent changes.
- The ROI sheet is likely to contain specific figures which must be kept up-to-date, such as the productivity per worker or the costs of a vacancy.

Main process		
Input	**Process**	**Output**
- Understanding of company culture	Define maintenance procedure	- Maintenance procedure - Defined roadmap responsibilities

3.4 Roadmapping—Execution and maintenance

Now that the roadmap is created, and each process to be performed during roadmap execution has been specified, it is time to start the execution phase. This consists of performing the activities specified by the roadmap, while maintaining the roadmap as specified in the maintenance plan.

3.5 Roadmapping—full picture

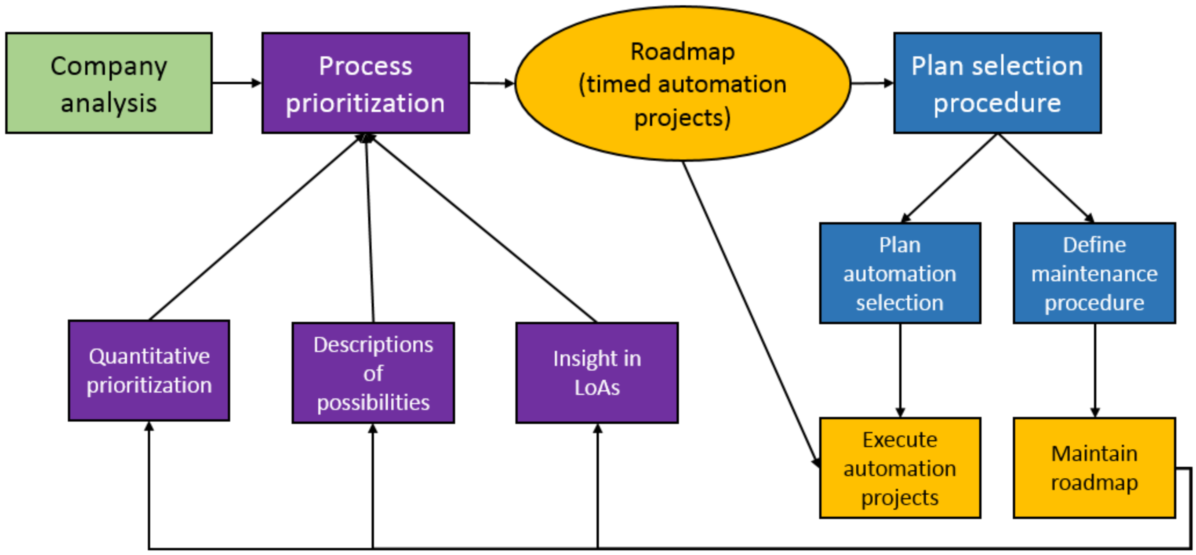


Figure 10b - general view of the roadmapping process in four stages

Figure 10b shows the results of this chapter as a process flow, where it is clearly visible that the roadmapping process is a continuous effort that keeps making steps into the desired direction. The first (green, elaborated upon in section 3.1) phase's main goal is to build a foundation for the rest of the process by analyzing the company and its needs. This phase is also crucial for creating a broad support base for the roadmap, so that execution can be controlled more easily later.

The second (purple, elaborated upon in section 3.2) phase is focused on prioritizing, i.e. defining the parts of the manufacturing process that have a higher urgency for automation than others. This step will form the basis for the structure of the roadmap document, deciding which workstations should be included in the automation strategy as a project and in what timeframe. At the end of this phase, the timeline for the roadmap is done, but the way to deal with each automation decision has not been defined yet. The roadmap is, at this stage, a timeline with projects placed on it, where each project will, when its time comes, go through an automation selection procedure which is still unknown.

The third (blue, elaborated upon in section 3.3) phase will deal with exactly that; creating the procedure that will guide each project team towards the optimal decision that moves the level of automation of the factory in the right direction. After this phase, the decision tool is finished, and the result will be a clear plan on how to continuously automate the manufacturing plant.

The last (yellow, elaborated upon in section 3.4) phase is ongoing and entails the execution of the roadmap as specified in the purple and blue phases. The roadmap will be created with a predefined timeframe in mind, but this does not mean that the whole project ends in this period. As the challenges and company goals will be updated over time, so must the roadmap be extended such that it always looks towards into the future. This means that besides the execution of the roadmap, there must also be a maintenance procedure.

The four phases consist of multiple steps to achieve its purpose. These steps are detailed in appendix B using the same colors as figure 10b.

To show the difference between this proposed method comparative to the traditional view of roadmapping as discussed in section 2.3, figure 11 shows a process outline conforming to the style of figure 10b. The linearity of this process is obvious, resulting in a less adaptive and sustainable automation strategy.

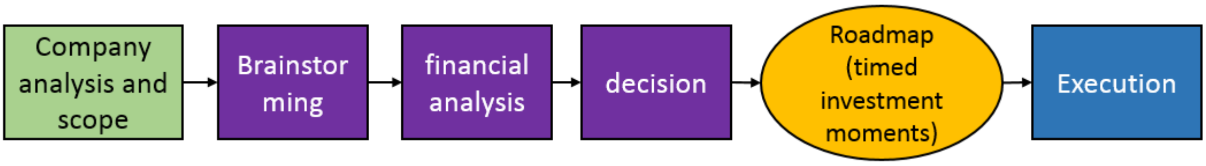


Figure 11 – the traditional linear view of roadmapping

Chapter 4: Case Q

Check company profile fit

Since this research is based on the case at Q, it follows automatically that it fits the company profile.

Initial analysis and scope

The questions posed by the tool in chapter 3 are answered below:

- Who is going to lead the project? The project encompasses the roadmapping itself as well as the maintenance and execution, although these responsibilities may be split.

The roadmapping is done by a hired intern who works on it as a graduation project. A responsible for the maintenance and execution is to be decided upon by the management. Usually, this decision would be taken already, but since it is a graduation project there is no guarantee of a significantly useful result, so no resources have been pre-assigned to the outcome.

- Who will be making the final decisions?

The final decision about whether the roadmap will be approved or not is to be made by the COO of Q.

- Who are the key stakeholders?

The key stakeholders are the production managers, logistics manager, Process Technology manager, Product Development and Engineering manager, Operational Excellence manager, and the COO. These have been put in what is called a steering committee, which meets about every six weeks to discuss the progress in the project and 'steer' the project in the right direction where necessary.

Since the initial analysis was done by an intern, many interviews were held with stakeholders in order to come to the required outputs. For each output, the result is described below.

Understanding of company culture

Q is a medium-sized company with a lot of product development effort. This results in a relatively high percent of indirect value-adding activities. This makes creating a lean production process difficult. Q is constantly improving on the efficiency of the production lines, although such efforts are easily overwhelmed by day-to-day problem solving responsibilities. There is a big focus on quality; it is a palpable force constantly driving employees to enforce tighter standards. Product quality is of more value to Q than any attempt of increasing cost-efficiency, resulting in a good market position towards customers, while leaving improvement points on the efficiency aspect.

Q employs a standard corporate hierarchical structure, with a project culture controlled from the top to the bottom. Therefore, the opinions and stances of the upper management are of high value to everyone aiming to gain momentum for their project. The hierarchical distance is small, creating an open atmosphere through all levels and short communication lines.

The currently strained job market affects Q's culture as well; as a growing company in a technology-driven field creates a focus on attaining and maintaining the right people. Having flexible, technical people is crucial.

Q is subject to demands from its mother company. Investments are heavily controlled and are therefore made with great consideration. The current strategic decision making appears scattered, creating inconsistent patterns of which projects are accepted and which aren't. This was identified before starting the automation roadmap project, and is one of the driving forces behind the wish for a more structured approach to strategically automating the production line.

Due to a combination of a fire and the quick growth of the company, the company changes quickly, and with it potentially its culture. This should be controlled with regard to the automation roadmap, as a cultural overhaul might impact the spending patterns.

Corporate vision

Q employs a three year strategic plan with clearly identified and tracked KPIs. These guide the investment plans and therefore also the different roadmaps that exist in the company. The idea of consistently applying roadmaps in different areas, connected by a main strategic vision, is quite new at Q, and can be said to still be in development.

Q operates based on three main values: technology leadership, pure service provider, and operational excellence. These indicate the wish to lead in terms of technology and customer service.

More can not be said about the corporate vison due to confidentiality combined with low relevance with the automation roadmap.

Production process analysis

Production is clearly divided two production departments (we will call them PD1 and PD2 respectively). These are very different fields of work, and follow each other sequentially, with PD1 taking the lead and providing for the semi-manufactured base products, after which PD2 is focused on providing the highest quality end-product. In the middle of PD1 and PD2 there is a logical temporary storage where the production methodology logically splits.

Generally, the PD2 is considered the more challenging part of the process, because it is unique. This makes it almost impossible to benchmark, and production standards have to be made internally. Process control is also more challenging in the PD2.

Project scope

The scope at Q is decided to be strictly the production processes, excluding activities such as intermediate warehousing, data management, product traceability etc. Furthermore, for a manufacturing process P, the in- and outputs have been pictured in figure 12, where the relevant factors for the roadmap are checked in green, and the out-of-scope in- or outputs have been marked with a red cross. It should be noted that, for this project, the collection of data should be considered when thinking of automation solutions, but the incorporation of this data in the process control falls out of the scope.

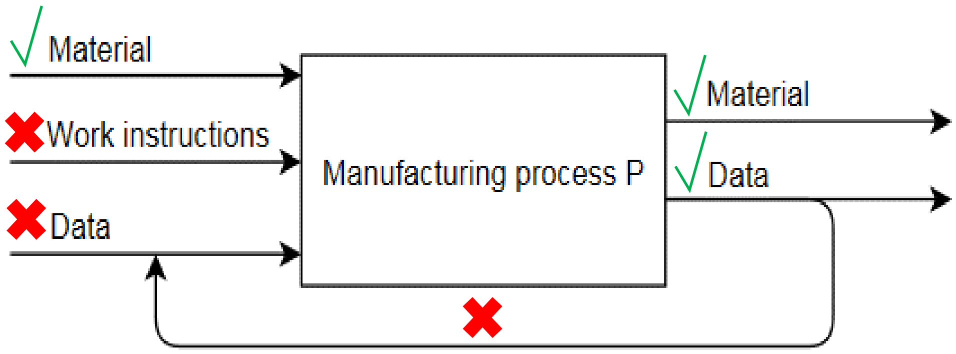


Figure 12 – in/out of scope for each manufacturing process

Problem definition and goal setting

The problem definition and goal setting for the automation roadmap have been discussed at the start of this report, more specifically in section 2.1. To recap, the following four goals of the roadmap (pillars) have been identified in no particular order of importance, supplemented with an abbreviation to be used in figures and working documents:

- Expanding production capacity (Prodcap)
- Lower dependency on human resources (HR dep)
- Creating an ergonomically less straining production process (Erg)
- Increasing the final product quality (Qual)

Stakeholder analysis results

The stakeholders analysis was performed as described in chapter 3, Appendix D elicits the result per stakeholder, while below some general conclusions can be found.

Conclusions stakeholder analysis

- The difference in PD1 and PD2 is highly significant, and activities in either department must be differentiated distinctively. The main differences are:
    - PD1 has a well-known process that allows for benchmarking or other usage of industry knowledge, whereas PD2 has a process unique at Q, meaning that all problems must be solved internally.
    - PD1 has little problems with ergonomics, partially because more support systems have already been installed there, therefore, mechanization efforts may be expected to focus on PD2.
    - Compared to PD2, little value is added to the product at PD1.
    - The PD2 environment is harder to control due to the way the factory is set-up in smaller rooms rather than one big room with overview. In the PD1, the floor is more open, giving more opportunity for managers to control the process.
    - Using robots in PD2 might be more complex than in PD1 because of the more difficult environment among other factors. Therefore, automation is more plausible in the PD1 department.
- All pillars are related to one another, everybody realizes this but may see a different goal as a starting point to snowball into the others, the only difference is one of priority.
- The designers of individual activities also realize the lack of a coherent plan.

- All stakeholders are positive about change, and see that it is necessary. Although differences exist in focus area, there are no stakeholders that clearly want to restrict automation or mechanization from happening.

Per role, the following can be concluded (referring to the summarized diagrams found in the last few pages of appendix G):

- Decision makers place the focus on ergonomics. This is an unintuitive result since the decision makers are higher management and would be expected to give more value to the more commercial goals of increasing production capacity and product quality. This shows the relatively high level of involvement with the safety for employees. One reason for this is the belief that improving the ergonomics can snowball into a better control of the process.
- Designers show a slight preference for quality improvements and capacity expansion. Analyzing this group's interests, one finds that designers are often focused on quality because they see this as Q's main competitive advantage and production capacity because they find it the best way to increase profits.
- Distant passives slightly prefer the HR related goal, with quality improvements as a close second. The difference between goals in this group is small, but when comparing the individual assessments, a wide range of opinions is found. The distant passive group all have highly specific interests relating to their field of work, which averages in a rather symmetrical overall view from this stakeholder group.
- Close passives are slightly in favor of ergonomics, followed by quality. This was expected, since this group includes those who have to physically deal with the products, and therefore are the most directly affected with ergonomic problems, although it should be noted that this effect is much stronger for the PD2 than for the PD1. The high importance that this group places on quality is also logical since assuring good quality products is their job and people can take pride in leading the global market on this front.

When overlapping all stakeholders' weights (see last page appendix G), a rather well-balanced spread of goal focus is found. This indicates that all goals are similarly relevant and must be developed side-by side. However, it should be kept in mind that the decision makers want to place the focus on the ergonomic situation and make improvements there first.

Given the differences between the PD1 and the PD2 at Q, it is clear that more mechanization steps have been employed at the PD1 than at the PD2, which is still more primitive in the sense of product handling. Therefore, it can be stated that PD1 already has a higher LoA than does PD2. As it may be wise to move in small steps of automation, PD2 should then focus more on mechanizing, whereas PD1 should focus more on automating.

These findings should be kept in mind throughout the remainder of the process of designing a roadmap, as well as during the execution. The information in appendix G should be referred to when helpful.

Choose and fill Levels of Automation (LoA) model

As explained in appendix E in order to find the appropriate taxonomy at Q, all taxonomies were tested on the same application. Based on the results, the most relevant model for Q's needs was identified. This application was for the wiping workstation, where products are wiped before going on to the next processing step. The resulting figures can be viewed in appendix H. It was found from experience that the qualitative version of Frohm's model is the most desirable and relevant. This was also the outcome of the decision tree (details can be found in appendix E), of which the result can be seen below.

Question nr.	Question	Answer
1	Are all dimensions (Save and Parasuraman) relevant?	No
2	Do the descriptions from Frohm make sense in your context?	Yes
3	How much effort can you afford to spend on classifying the relevant processes?	Low
4	Do the LoA values need to be comparable?	No

Table 2 – Q's answers to the questions

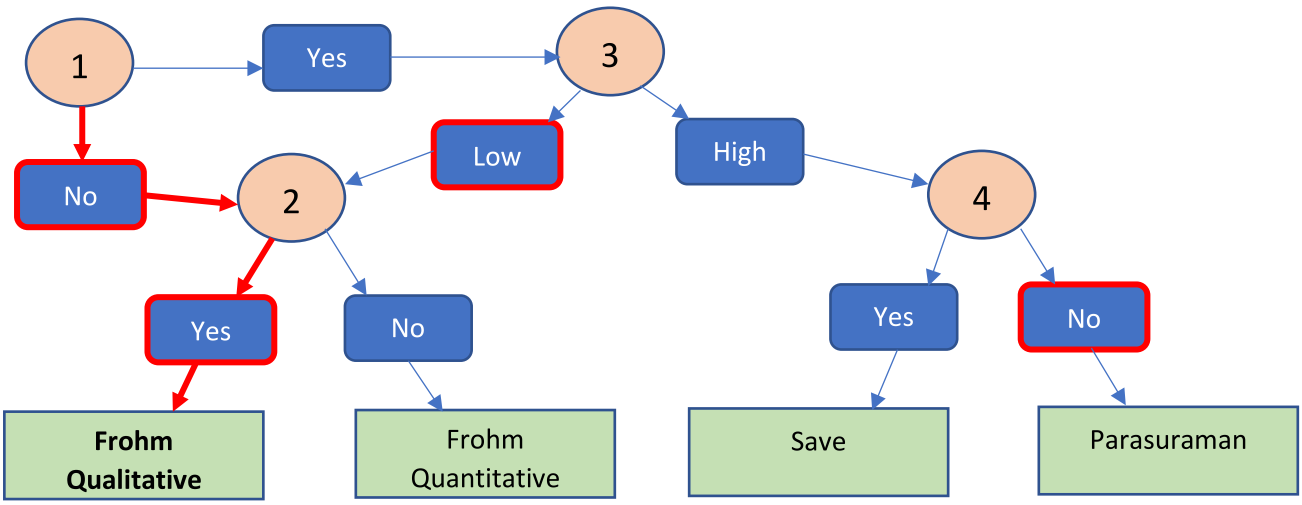


Figure 13 – Frohm's qualitative model is the outcome of the decision tree for Q

Not all of the scale definitions in Frohm's original model are relevant at Q, some adjustment were therefore made to the descriptions before using the model further.

Once the taxonomy decision was made, the filling of the model began. The result is shown in figures 14 and 15 below, color-coded per production segment (PD1 is one segment and PD2 was split in four logical segments, to be elaborated upon in the next section).

Mecha										
1						min/cur1		min/cur		
2				min		cur2	min/cur		min	min/cur
3						max			cur	
4	min/cur1	min			min/cur					
5	cur2/max	cur1	min/cur1		max					
6		cur2/max	cur2/max	max/cur			max	max	max	max
7										
Cogni										
1							min	min	min	
2		min			min/cur	min	cur	cur	cur	min/cur
3						cur1/2/max				
4	min									
5					max					
6	cur/max	max						max	max	
7			cur/max				max			max

Figure 14 – Frohm's qualitative model applied for Q (1)

Mecha											
1	min/cur	min/cur			min/cur	min/cur		min			
2			min/cur	min			min/cur	cur	min/cur1	min	
3				cur						cur	
4									cur2		min
5											cur/max
6	max	max	max	max	max	max	max	max	max	max	
7											
Cogni											
1				min						min	
2			min/cur	cur			min/cur	min/cur	min	cur	min
3	min/cur	min/cur			min/cur	min/cur			cur1	max	cur
4											
5									cur2/max		
6	max	max		max	max	max					max
7			max				max	max			

Figure 15 - Frohm's qualitative model applied for Q (2)

Identify and prioritize process steps

Modularization

At Q, the production floor is divided into two production departments, PD1 and PD2 respectively. This split is made on the base of a different batch size and temporary storage moment. Q can then consider to split PD2 into four smaller segments on the grounds of geographical location. These four segments each happen in a different room. This means that when automating, it may make sense to pool the workstation into these five total segments. The benefit of this is that a solution in one room may service all workstations in that room.

Q decided to not work according to this modularization, because the idea is to keep making small, incremental investments that each have a low barrier. It was therefore decided to work with each individual workstation, as this allows for smaller steps to be taken, requiring smaller investments.

Analysis of process steps

For the roadmap it is crucial that one can make informed decisions about the priority that different automation projects have. By talking with production managers, an overview of the process steps can be drawn up, accompanied by an indication of how fruitful automation may be at this particular step. It may, however, prove difficult to do so on any other base than a qualitative analysis. We would ideally like to have a quantitative base for the process prioritization as well.

This has been done by creating a table with on each row a process step and in each column a different problem area. For each problem area, the key stakeholder (e.g. for ergonomics the EHS officer) was asked to rank from one to five the urgency of that specific problem area at each process step. By having a main responsible for each problem area give the prioritization, one can come a trustworthy total score indicating the level of urgency for improving that process step, as well as give guidance as to what the main goal should be for the to be implemented automation system at that process step. The result of this can be seen in table 3 as an example of what such an urgency table may look like. It should be noted that this does not mean that the first-priority-step must be first in the roadmap, since there are other factors to consider, but this should be used as input when making the decision.

It should be noted that the urgency scored will generally be subjective evaluations of company experts, although it is conceivable that an objective base is desired. This can be accomplished by looking at the pillars creatively. As an example, take the ergonomics pillar at Q: the ergonomic strain can be subjectively assessed by an expert at the company, who talks to employees and has a good idea of how much physical strain is expected at each workstation. If, however, Q wants to have an objective and unbiased evaluation, it might employ what are known as KIM scores. In this German point-based system, experts asses (on-site) the value of strain by applying a formula that accounts for all relevant straining factors, such as weight, carrying position and amount of repetitions. By tying these KIM scores to the urgency scores (e.g. by using a conversion table), they can be objectively argued for, instead of the urgency scores being based only on expert opinion. Which method is preferred is up to the user company and the reliability of its company experts.

Step nr.	Prodcap	HR dep	Erg	Qual	Quad score	Prio nr. sum	Prio nr. quad
19	5	5	5	5	10,00	1	1
20	5	4	5	5	9,54	2	2
12	5	3	5	5	9,17	3	3
13	5	3	5	5	9,17	3	3
16	5	3	5	5	9,17	3	3
17	5	3	5	5	9,17	3	3
8	5	3	3	5	8,25	4	4
9	5	3	3	5	8,25	4	4
7	3	1	5	5	7,75	5	5
10	1	3	5	5	7,75	5	5
15	3	3	5	3	7,21	5	6
5	3	4	1	5	7,14	6	7
21	3	1	5	3	6,63	7	8
14	3	3	3	3	6,00	7	9
18	3	3	3	3	6,00	7	9
6	1	1	3	5	6,00	8	9
22	1	1	5	3	6,00	8	9
1	1	1	5	1	5,29	10	10
3	3	4	1	1	5,20	9	11
4	1	1	3	3	4,47	10	12
11	1	1	3	3	4,47	10	12
2	1	1	1	1	2,00	11	13

Table 3 – prioritization of workstations

Conclusions of prioritization

Problem areas

The four identified problem areas should be considered of equal importance as a result of the stakeholder analysis. For different process steps, however, different areas are more urgent (see table 3, and for each automation project, it should be clear what it aims to achieve based on the four areas.

All problem areas snowball into each other, e.g. an improvement in quality results in greater yield which in turn increases the effective production capacity. This contributes to the idea that all of these areas are relevant, although the balance is highly dependent on the specific workstation.

Mechanization/automation

The LoA concept is highly relevant for creating an automation roadmap as it helps you define what LoA is relevant and realistic for you, and it may support in finding low-hanging fruit solutions. For Q, general focus should be on PD2, more specifically on mechanization (i.e. automating mechanical activity) rather than on automation (i.e. automating cognitive activity). The PD1 is in less need of automation, as it is already quite well mechanized and is therefore already further along the LoA ladder. PD1 is also a less crucial bottleneck currently.

The roadmap

At this point, the actual roadmap is created with as input the urgency scores, the LoA goals and a qualitative analysis of possibilities (such as low-hanging fruit gains) that come to the final conclusion of which workstation should be automated when. This was constructed in an excel file for Q, and can be started once the procedure for each project (i.e. workstation) has been prepared.

Prepare technology selection procedure

Now that we have a schedule for the first few years of manufacturing automation, as well as a vision of which aspects should be focused on in these cases, we have to specifically design the procedure for these projects and prepare all necessary documents. Appendix F illustrates the resulting excel sheets that Q is now using. What follows is an example of the selection procedure using Q's wiping workstation.

Analyze current process

Before one can start thinking of process improvement processes—whether in the form of automation or not—, the effort will be futile without a proper view of the current process. This process flow serves as a comparison point for all proposed solutions later.

This process flow will be a simple mapping of consequent steps, in detail, that an operator performs in order to complete his tasks.

For the wiping procedure, the result can be found below in figure 16:

Nr	Step
1	Move from oven to wiping table
2	Attain piece of cloth
3	Wipe first side
4	Turn product around
5	Wipe second side
6	N2 purge in plughole
(7.1)	Move product to plug table
(7.2)	Insert plug in product

Figure 16 – the current wiping process

[b] Make FMEA current process

For each of the steps identified in the process analysis, the risks must be identified. We will want to compare this risk to the risk of our solution proposals, therefore, it is important to use a quantitative model that allows for direct comparison functionality. We will use this as a starting point to evaluate all alternative possibilities as one of the decision inputs (see figure 10a), and it is therefore crucial that it is accurate.

The usage of an FMEA in automation activities is not new. In Almannai et al. (2008), FMEA is used after the decision on which alternative to take has been made, its function being to check the risks and prepare for them. The flaw in this ideology is that a solution has been selected already based on other factors, which may then later be found to have many risks that are hard to account for. Therefore, we will use the FMEA comparison of each proposed solution with the FMEA of the current process as one of the three inputs for the decision.

Each of the detailed process steps must be accompanied with all relevant risks. These risks then need to be assigned to one of the problem areas that the roadmap aims to solve through automation. The risks are then, as standard FMEA theory prescribes, evaluated on a predefined scale of occurrence, severity and detectability. It is advisable to define these scales strictly and qualitatively for each of the problem areas.

For the wiping robot, part of the FMEA can be seen in figure 17. In the top-right corner, the total risk priority number is denoted. When we make comparison FMEAs later, these values can be compared.

Key Process Step or Input	Goal?	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN
What is the Process Step or Input?		In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM occur?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?	994
Move product to wiping table	Qua	Product is damaged by rough handling	Product quality severy lower or even rejected	10	Loss of concentration or physical control	1	Instructions	4	40
Move product to wiping table	Qua	Contamination due to human touch	Contaminated product	7	Dirty hands of operator	4	Gloves	1	28
Move product to wiping table	Erg	Causes long-term ergonomic problems	Employee health	4	Way of carrying	4	Instructions	4	64
Wipe first side	Qua	Nonuniform wiping	Less well-wiped parts more prone to contamination	4	Human characteristics	7	Work instructions	7	196
Wipe first side	Qua	Contamination due to dirty cloth	Contaminated product	4	Wrong estimation of cloth purity	4	Visual check by operator, instructions	1	16
Turn product around	Qua	Product is damaged by rough handling	Product quality severy lower or even rejected	10	Loss of concentration or physical control	1	Instructions	4	40
Turn product around	Qua	Contamination due to human touch	Contaminated product	7	Dirty hands of operator	4	Gloves	1	28
Turn product around	Erg	Causes long-term ergonomic problems	Employee health	4	Way of carrying	4	Instructions	4	64

Figure 17 – FMEA for the wiping operation

The FMEA is to be created with input from the team. The insights of close passives is crucial to determine the exact risks that are at play from a close view on the process. If no close passives are involved, things like product handling and other such issues that happen close to the process itself might be missed.

Structural actions

- Define scales for all pillars on severity, occurrence and detection
- Decide on FMEA template; if nothing is available at the company, appendix F provides a basic template which may be used as a starting point.

[c] Set LoA goals

We have already placed our process steps on our chosen LoA taxonomy (Frohm's qualitative model), but this is a simple and generalized view of the situation and the potential in terms of automation. Kamtsiou (2006) found that it is wise to "invent the future first and to 'plan backwards' from there in order to link up with today". Thus, in this step, we concretely define the ideal state that we would be in in a perfect world, creating a clear view of the gap to be closed. The ideal future states may be strictly defined per workstation where applicable, but it may make more sense to do so for groups of workstations that are related to each other.

For this step, we again need input from the team in order to gain understanding of the ideal situation for the close passives, who will have to directly work with the new system.

The wiping robot example's ideal state is defined as shown in figure 18.

	Mechanical	Cognitive
Current	1	2
	The mechanical operation happens completely manually.	The operator has all cognitive responsibility, but there is a work order for each product that comes in.
Desired	7	7
	In the desired situation the robot can completely autonomously perform the wiping operation. In addition, the product will arrive to the robot not by the hands of an operator, but by a transportation system, making the supporting functions automated as well.	The robot must be capable of analysing and deciding which wiping procedure will yield the requested result on the product that the robot has in front of it.

Figure 18 – current and desired LoA states

When the desired future state is clear, we have all inputs necessary to start brainstorming.

Structural actions

- Decide on a LoA model (should have be done in step 3.2.1 already, details can be found in this section)
- Gain a clear image of the ideal future state of the production process, either per workstation or with workstations pooled up.

[d] Brainstorm solutions

Certain roadmapping steps are highly dependent on the company in questions, and will therefore not be defined strictly by the tool. The brainstorming is an example of this, as there are many variables such as company culture and hierarchy that will be important to consider when describing the brainstorming method. However, the required outcome can be described accurately; all possible technical automation solutions that solve the problems as described for this to-be-automated process, listed in logical order where applicable, see appendix F.

The solution proposals may go in very different directions, but it is also conceivable that one solution is expanded in several steps. In order to define such a solution, the LoA concept may be used to work backwards from the ideal situation, and then define steps that get the production step there, an example will be provided in the case.

The found possible solutions may include anything, including but not limited to the following:

- Already existing ideas
- Ideas tried in the past, but not pursued because the
  - technology hadn't advanced enough yet
  - budget was too low
  - company wasn't ready for automation
- Solutions resulting from benchmarking activities
- Out-of-the-box ideas

Figure 19 shows the result of this phase at the wiping workstation.

Current	Operator has full responsibility over the process. When a work order is received, he places the product on the table manually and wipes it manually, based on his own judgement of the situation
Optimal	The product feed to the wiping robot as well as the wiping procedure are automated so that no operator needs executive responsibilities. The operator will be used purely for control.
Sol1.0	The operator receives the work order and places the product in front of the robot. The robot waits for the operator's start signal, upon which it performs a safety check. When all is clear, the robot starts the operation after determining the starting position. The robot is programmed to always perform the same programme, and is therefore only usable for 1 product.
Sol1.1	The robot has multiple pre-programmed wiping procedures and is now applicable for multiple products. The operator must indicate which product is
Sol1.2	The robot is now capable of deciding which product it has in front of it, and needs no more operator instruction on which wiping procedure to start. It still waits for the start-signal from an operator.
Sol1.3	The robot is fed the products through an automated system, such as a conveyor belt, which places the product in the working area of the robot.

Figure 19 - the solutions after brainstorming

[e] Solutions LoA definitions

In order to see which solution progresses you in what way along your selected LoA taxonomy, we need to add a classification for all proposed systems. This will serve as one of three inputs for our final decision.

Sheet 4 of the template is, at this point, filled with the current and desired states. Add to that the proposed solution systems and the picture is complete. In some cases, where solutions build upon one another, it is likely that the level increases incrementally along different scales. It is worth noting that it is not required to reach the level of the desired state, although if this is realistic is would be optimal to do so. Is it however likely that this is out of reach and that smaller investments are only possible, moving up the scale towards the ultimately desired state, but not quite reaching it. This is not a problem, as it still guides the company on the track to achieve the desires level of automation, and relevant and realistic steps are taken, this is the goal of the roadmap.

The result for the wiping application is shown in figure 20. It can be seen that an end-state has been defined, with multiple small steps (which can be seen as investment moments) that guide the company to the ideal state. By defining the end-state and then formulating small steps that get you there, the LoA model can be used as a compass that continuously guides the process in the right direction.

	Mechanical	Cognitive
Current	1	2
	The mechanical operation happens completely manually.	The operator has all cognitive responsibility, but there is a work order for each product that comes in.
Desired	7	7
	In the desired situation the robot can completely autonomously perform the wiping operation. In addition, the product will arrive to the robot not by the hands of an operator, but by a transportation system, making the supporting functions automated as well.	The robot must be capable of analysing and deciding which wiping procedure will yield the requested result on the product that the robot has in front of it.
Sol1.0	5	1
	The operation happens on request and for 1 product type only, making this a static workstation with mechanical support.	The operator is in control of the situation and makes the decisions, the robot only has to make process-supporting decisions such as decisions about safety.
Sol1.1	6	1
	The machine can now be reconfigured for different tasks, pushing it to level 6.	
Sol1.2	6	7
		A huge leap is made when the robot becomes responsible for the decision on what action to take. Suddenly the action is decided on not by human but by machine.
Sol1.3	7	7
	By including supporting functions (product handling) in the automated system, we reach level 7.	

Figure 12 – wiping robot LoA

[f] Solutions FMEAs

As the second of the three inputs for the final decision on which alternative to pick, the FMEA of the current process must be compared to FMEAs of all proposed solutions. In order to get a realistic view of what risks might be created/removed or increased/reduces, it is wise to discuss with at least operators and suppliers, as the operators know the process best and suppliers know their technology best.

It is too tedious to show here all solutions' FMEAs, but it was found that the first solution steps created a higher risk due to failure risk of the robot, but once the later solution stages were reached, the risk decreased significantly due to less ergonomic and quality issues.

[g] Get quotation

When possibilities for automation solutions are defined, it is wise to quickly start talking to suppliers about what they can offer and gather quotations for the proposed systems. This should be done early because some suppliers may take quite long to get you a quotation, and this information is required as input for the ROI calculation, which in turn is necessary for the final decision. It is therefore advisable to continue with the rest of the steps in parallel with the contact with suppliers.

[h] Calculate expected benefits

The ROI calculations needs two figures: the costs and the benefits. This step focuses on getting an estimation for the value that the technology may bring, as opposed to the cost information that is being gathered from suppliers.

Classically, such a calculation will be bothered with only more traditional production metrics, such as maintenance, lead times and production rates. While these should obviously be included, we found that in automation there are many more factors, that are easily overlooked. Therefore, the predefined pillars of automation, the areas wherein automation may be beneficial at the user company, should be used to define the financial benefit.

The whole ROI could not be calculated for the wiping operation due to time constraints.

[i] Decision

The decision maker of the automation roadmap project must now be contacted to make the decision on which alternative to pick. This is done based on several information sources; 1) the LoA progression and goals, 2) the risk analysis and 3) the ROI calculation. There is no distinct guideline on how to decide from this point. The decision maker needs to understand which factors should weigh more heavily compared to the others in that situation. This means that the decision is ultimately still subjective, the tool does not aim to quantify the decision itself. The tool, however, adds value by creating a structured approach towards constructing a complete picture so that the decision can be made with all factors considered, without taking the actual decision away from the management, and providing for a quantified base from which to draw the conclusion.

For the wiping example, this means that the decision needs to be made for any of the solutions. Since the solutions build up on each other, it seems logical to start with solution 1.1, although in some cases this may be considered too slow and tedious, in which case a bigger jump may be made. Alternatively, the analysis may show that none of the solutions are profitable, in which case the decision should be made to not change this workstation at this moment, and reconsider in the future.

Define maintenance procedure

The maintenance procedure for the automation roadmap consists mostly of updating the roadmap and its projects, and synchronizing with the corporate strategy. At Q, the latter means aligning the roadmap, and its goals, not only with the high-level KPIs, but also creating a coherence with other roadmaps that exist; several roadmaps exist, to which the automation roadmap will be an addition. Other relevant roadmaps are the technology roadmap and operations roadmap. The former focusses on what technologies are necessary in order to keep complying to customer demands, and the latter plans activities that improve operations and includes all big operational projects.

1) Predefined automation roadmap maintenance moments

Three times a year, a general evaluation moment takes place in which all relevant aspects of the roadmap (e.g. urgency scores, pillar weighing factors, workstation placement on roadmap as a project) must be reviewed. This happens in alignment with the creation of the annual investment plan and/or other general strategical reviewing moments.

2) Operations roadmap events relevant for automation

When significant projects are adopted into the operations roadmap, there should be a trigger to think about possible implications for the automation roadmap.

3) New product introductions/market changes

When a new product is introduced in the market or another significant market change takes place, there should be a trigger to review any effects of the new product mix for the automation strategy.

By using these triggers as evaluation moments and having defined responsibilities over roadmap components that need regular evaluation, the maintenance procedure is complete, and all that is left is execution.

Chapter 5: Conclusions

The field of automation advances every day, as increasingly more technologies and tools become available, it was found that no functional decision support tool exist to guide medium sized manufacturing companies in automating their production lines in a structured and strategical way. Tools that exist follow a roadmapping methodology that is unsustainable for companies with limited investment resources and the wish for continuous automation improvements. Based on experiences at Q, a tool was tailored that works specifically for their needs, which can be extrapolated to companies that fit within the defined company profile. The tool resulting from research and the case study supports organizations in creating a strategical and continuous approach towards production automation. This tool was later adopted by Q in their corporate strategy, a swimlane-style roadmapping process specifically tailored to their business processes can be viewed in Appendix I.

It was found that it is desirable to base decisions on quantitative data, being contradicted by the often lacking availability of such data. Thus, the decision must be made subjectively, but supported by figures where available and fair assumptions otherwise. The benefit is that a uniform decision process is followed and documented, creating a red thread in automation strategy, while keeping the final decisions in the hands of decision makers. In this way, the decision is not forced upon the company management as a result of the tool. Rather, the tool guides the management in the decision-making process.

The initially defined goal of automation was just a small part of the full potential that automation may yield. By not realizing all the benefits, an under-evaluation of the concept may take place, leading to a situation where the company is not leading the field, but instead following its competitors. To overcome this, a full picture must first be obtained that includes all business fields where automation may be expected to yield results.

Crucial to roadmapping is obtaining and maintaining a goal-driven approach. Making use of a academic LoA model has proven to be highly beneficial in this case, as such a model can create a path towards the future that guides the user into taking the right steps forward. Without clear goals and an understanding of LoAs, automation may seem like an unovercomable barrier. This tool makes continuous automation reachable for many companies that may previously have felt unable to properly automate.

Ultimately, the decision support tool created in this case can greatly enhance the strategic approach of automation of the production line in the defined context. By combining the available literature with a practical test-case, the tool combines the best of both theory and practice.

Limitations

This research has some limitations that should be taken into account. Firstly, the found methodology was only tested at one company. The results are assumed to be relevant for companies that fit the same company profile, but no testing has been done on this.

Secondly, not all parts of the methodology could be fully tested. An example of this is the cycleability of the process, which could not be tested due to time constraints. Such aspects of the tool are the result of literature research and previous findings at the case company, so they can be assumed to work at least in that context, but transferability of those ideas is not guaranteed.

To come to more reliable conclusions about this tool, it needs to be further tested at a wider range of companies and for a longer time-period.

References

Almannai, B., Greenough, R., & Kay, J. (2008). A decision support tool based on QFD and FMEA for the selection of manufacturing automation technologies. *Robotics and Computer-Integrated Manufacturing*, *24*(4), 501–507. https://doi.org/10.1016/j.rcim.2007.07.002

Bauer, J. M., Bas, G., Durakbasa, N. M., & Kopacek, P. (2015). Development Trends in Automation and Metrology. *IFAC-PapersOnLine*, *48*(24), 168–172. https://doi.org/10.1016/j.ifacol.2015.12.077

Becker, B. (2002). The alignment conference: A stakeholder's way to create a competitive advantage. *Creativity and Innovation Management*, *11*(2), 115–121. https://doi.org/10.1111/1467-8691.00243

Chatterjee, P., Athawale, V. M., & Chakraborty, S. (2010). Selection of industrial robots using compromise ranking and outranking methods. *Robotics and Computer-Integrated Manufacturing*, *26*(5), 483–489. https://doi.org/10.1016/j.rcim.2010.03.007

David, S. (1987). Future Perfect. *Addison-Wesley*.

Duncheon, C. (2002). Product miniaturization requires automation - But with a strategy. *Assembly Automation*, *22*(1), 16–20. https://doi.org/10.1108/01445150210697096

Endsley, M. R. (1997). Level of Automation: Integrating Humans and Automated Systems. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *41*(1), 200–204. https://doi.org/10.1177/107118139704100146

Freeman, R. E. (1984). *Stakeholder Management: Framework and Philosophy*. *Strategic Management*. https://doi.org/10.1017/CBO9781139192675.006

Frohm, J., & Bellgran, M. (2005). A model for parallel levels of automation within manufacturing. *18th International Conference on Production Research*.

Frohm, J., Lindström, V., Stahre, J., & Winroth, M. (2008). Levels of Automation in Manufacturing. *Ergonomia - an International Journal of Ergonomics and Human Factors*, *30*(3), 1–28.

Garcia, M. L., & Bray, O. H. (1997). Fundamentals of technology roadmapping, *4205*(April). https://doi.org/10.2172/471364

Goh, C., Tung, Y. A., & Cheng, C.-H. (1996). A REVISED WEIGHTED SUM DECISION MODEL FOR ROBOT SELECTION.

Green, & Hunton-Clarke. (2003). A TYPOLOGY OF STAKEHOLDER PARTICIPATION FOR COMPANY ENVIRONMENTAL DECISION-MAKING. *Business Strategy and the Environment*, *299*, 213–214.

Groenveld, P. (2007). ROADMAPPING INTEGRATES Product-technology roadmaps require a good understanding of markets and. *Research Technology Management*, (May), 49–58.

Hägele, M., Schaaf, W., & Helms, E. (2002). Robot assistants at manual workplaces - Effective co-operation and safety aspects. *Proceedings of the 33rd International Symposium on Robotics (ISR)*, 6.

Hart, C. W. L. (1995). Mass customization: conceptual underpinnings, opportunities and limits. *International Journal of Service Industry Management*, *6*(2), 36–45. https://doi.org/10.1108/09564239510084932

Hill, N. S., Seo, M.-G., Kang, J. H., & Taylor, M. S. (2012). Building Employee Commitment to Change Across Organizational Levels: The Influence of Hierarchical Distance and Direct Managers' Transformational Leadership. *Organization Science*, *23*(3), 758–777. https://doi.org/10.1287/orsc.1110.0662

Kaber, D. B., Omal, E., & Endsley, M. R. (1999). Level of automation effects on telerobot performance and human operator situation awareness and subjective workload. *Automation Technology and Human Performance: Current Research and Trends*. https://doi.org/10.1080/001401399185595

Kamtsiou, V. (2006). Roadmapping as a Knowledge Creation Process : The PROLEARN Roadmap The Proposed Roadmapping Process and its implementation in. *Knowledge Creation Diffusion Utilization*, *1*(3), 163–173.

Kennon, N., Howden, P., & Hartley, M. (2009). Who really matters? A stakeholder analysis tool. *Extension Farming Systems Journal*, *5*(2), 9–17. Retrieved from http://www.csu.edu.au/__data/assets/pdf_file/0018/109602/EFS_Journal_vol_5_no_2_02_Kennon_et_al.pdf

Kern, H., & Schumann, M. (1985). Das Ende der Arbeitsteilung? - Eine Herausforderung für die Gewerkschaften. *Gewerkschaftliche Monatshefte*, (1), 27–39.

Kotha, S. (1995). Mass Customization: Implementing the emerging Pardigm for Competitive Advantage. *Strategic Management Journal*.

Koulouriotis, D. E., & Ketipi, M. K. (2011). A fuzzy digraph method for robot evaluation and selection. *Expert Systems with Applications*, *38*(9), 11901–11910. https://doi.org/10.1016/j.eswa.2011.03.082

Kumar, Rahman, & Kazmi. (2016). Stakeholder identification and classification: a sustainability marketing perspective. *Management Research Review*, *39*, 35–61. https://doi.org/10.1108/EL-01-2017-0019

Lee, H., Kim, W., Han, J., & Han, C. (2012). The technical trend of the exoskeleton robot system for human power assistance. *International Journal of Precision Engineering and Manufacturing*, *13*(8), 1491–1497. https://doi.org/10.1007/s12541-012-0197-x

Merritt, S. M., Heimbaugh, H., Lachapell, J., & Lee, D. (2013). I trust it, but i don't know why: Effects of implicit attitudes toward automation on trust in an automated system. *Human Factors*, *55*(3), 520–534. https://doi.org/10.1177/0018720812465081

Miles, S. (2017). Stakeholder Theory Classification: A Theoretical and Empirical Evaluation of Definitions. *Journal of Business Ethics*, *142*(3), 437–459. https://doi.org/10.1007/s10551-015-2741-y

Mital, A., & Pennathur, A. (2004). Advanced technologies and humans in manufacturing workplaces: An interdependent relationship. *International Journal of Industrial Ergonomics*, *33*(4), 295–313. https://doi.org/10.1016/j.ergon.2003.10.002

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a Theory of Stakeholder Identification and Salience: Defining the Principle of Who and What Really Counts. *Academy of Management Review*, *22*(4), 853–886. https://doi.org/10.5465/AMR.1997.9711022105

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A Model for Types and Levels of Human Interaction. *IEEE Transactions on Systems Man and Cybernetics Part A Systems and Humans*, *30*(3), 286–297.

Phaal, R. (2004). Technology roadmapping - A planning framework for evolution and revolution. *Technological Forecasting and Social Change*, *71*(1–2), 5–26. https://doi.org/10.1016/S0040-1625(03)00072-6

Pine, J. B., Victor, B., & Boynton, A. C. (1993). Making Mass Customization Work Making Mass Customization Work. *Harvard Business Review*, *71*(93509), 108–119. https://doi.org/Article

Rashid, T., Beg, I., & Husnine, S. M. (2014). Robot selection by using generalized interval-valued fuzzy numbers with TOPSIS. *Applied Soft Computing*, *21*, 462–468. https://doi.org/10.1016/j.asoc.2014.04.002

Save, L., & Feuerberg, B. (2012). Designing Human-Automation Interaction: A New Level of Automation Taxonomy. *Proc. Human Factors of Systems and Technology*, 43--56. Retrieved from http://www.hfes-europe.org/wp-content/uploads/2014/06/Save.pdf

Sheridan, & Verplanck. (1978). Human and Computer Control of Undersea Teleoperators.

Silveira, G. Da, Borenstein, D., & Fogliatto, H. S. (2001). Mass customization: literature review and research directions. *International Journal of Production Economics*, *72*(1), 1–13. https://doi.org/10.1016/S0925-5273(00)00079-7

Turban, D. B., Forret, M. L., & Hendrickson, C. L. (1998). Applicant attraction to firms: Influences of organization reputation, job and organizational attributes, and recruiter behaviors. *Journal of Vocational Behavior*, *52*(1), 24–44. https://doi.org/10.1006/jvbe.1996.1555

Vahdani, B., Mousavi, S. M., Tavakkoli-Moghaddam, R., Ghodratnama, A., & Mohammadi, M. (2014). Robot selection by a multiple criteria complex proportional assessment method under an interval-valued fuzzy environment. *International Journal of Advanced Manufacturing Technology*, *73*(5–8), 687–697. https://doi.org/10.1007/s00170-014-5849-9

Vos, J. F. J., & Achterkamp, M. C. (2006). Stakeholder identification in innovation projects: Going beyond classification. *European Journal of Innovation Management*, *9*(2), 161–178. https://doi.org/10.1108/14601060610663550

Weisenfeld, U. (2003). Engagement in innovation management: Perceptions and interests in the GM debate1. *Creativity and Innovation Management*, *12*(4), 211–220. https://doi.org/10.1111/j.0963-1690.2003.00284.x

West, & Farr. (1990). Innovation and creativity at work: Psychological and Organizational Strategies. *John Wiley & Sons*, 265–267.

Appendix A—Additional goals of automation

Human Resource Dependency

A growing company such as Q needs to maintain a strong position on the job market in order to keep attaining the right people. The current situation for Q is straining on this aspect; there is a lack of trained people in the job market, and Q experiences much competition, often from companies with better work conditions. It is well-established, and intuitively logical, that there is a strong link between job characteristics and employee attraction (e.g. Turban, Forret, & Hendrickson, 1998). Thus, it becomes crucial to design the work conditions such that employees can be found, and investments to change work conditions can pay off.

Automation can provide a benefit here in the form of a strategic method to increase the revenue while circumventing the problems that classical capacity increasing methods (in this case hiring people) hold. This is a different benefit than the previously mentioned capacity expansion goal because reducing the dependency on human resources yields different short and long-term savings than can be expressed in capacity terms.

While making decisions on which automated systems to employ, a financial aspect is obviously required, creating the wish to put any found automation benefit into financial terms. There are factors that can quite easily be quantified, such as the costs per turnover, consisting of all costs incurred for an open vacancy (e.g. HR employee hours for recruitment, management hours for interviews, lower initial productivity for new workers). Other factors, mostly playing a role in the long term, are however harder to put into financial terms, and will rely heavily on assumptions. Such factors may include the following.

- Effect of growth of Q on HR dependency
- Effect of unpleasant work on Q's reputation on the job market
- Higher demands of job-seekers due to abundancy job offers
- Emotional effect on remaining employees when turnover happens frequently

If we take the first example, we can quite easily understand that, if the company keeps growing exponentially, the costs created by open vacancies can become exponentially worse as vacancies are harder and harder to fill and remain open for longer. A reduction in this dependency on human resources can therefore save a lot of trouble in the future, without this being taken into account when doing cost calculations now. A similar effect happens for the other given examples. By not including such indirect costs into investment decisions, the value of automation can easily be underestimated, while the company stays in a following role, always being one step behind on the field of automation.

In order to overcome this, an 'exacerbation factor' may be considered. This is proposed as a factor that estimates for each of the identified long-term problems the rate with which the problem increases per year. As an example, let's say that estimated costs incurred by open vacancies are expected to increase with ten percent per year, we then use an exponential factor of 1.1 in our Return on Investment calculation, similar to how an interest rate would work in a loan cost calculation. This allows us to incorporate long-term cost-savings and other opportunities in our financial investment decision.

Going back to figure 2, combining [3] and [5], one can point clearly to a solution area; efficiency [10], i.e. doing more work with less labour. Q must produce more without needing more people, and while keeping their current flexibility and customer-oriented style.

Another problem area is caused by the way products need to be handled. Due to the increasing size of products [6] and their highly sensitive nature [8], operators have a hard time with physical handling of the product. This creates problems regarding workers' ergonomics [7].

Ergonomics

The ergonomic work conditions are problematic, and the effects are palpable. Sick leave due to injuries happen at an increasing rate. The Dutch authority on work conditions (ARBO) was already hired to investigate and pinpoint improvement areas, and some improvements in the process have been made accordingly. Still, the issue of employee health is taken very seriously at Q and continuous improvements are necessary.

As was the case with the human resource dependency goal, the financial effects on automation on the ergonomic situation are difficult to quantify. Some costs can be estimated, such as the cost of sick days, whereas other costs are harder to include in calculations, such as:

- Products expected to get bigger
- More order containing big products
- Chance for repeated injuries
- Aging workforce

As in the case of human resource dependency, it is desirable to include such indirect effects in the investment decision. Therefore, again, an exacerbation score may be used. To illustrate why this is called the exacerbation rate, consider figure 21, which shows an example of how unquantified factors can create a long term exacerbation of an existing problem.

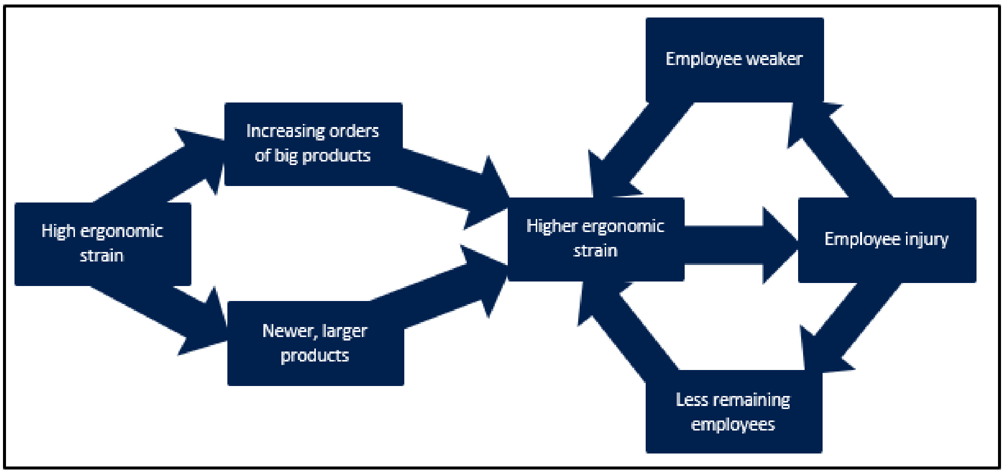


Figure 21 – a model for the exacerbation of ergonomic strain

It's worth noting that a relationship is present between the ergonomic situation [7] for employees and the problem of filling vacancies [5], since ergonomic conditions can make work unattractive, making it harder to find people willing to do the job.

Returning to figure 2, the delicate nature of the product makes it important, but ironically challenging, to control the final product quality [9]. Graphite is an inherently fragile material that can be eroded off quite easily, shedding dust from the outer layer.

Quality

For an analysis of quality, and how costs may be saved, a product reject database was used that contains all the scrap over the period of a year. This data contains the reason for rejection, the workstation where rejection took place, the amount of rejected products per instance and the costs of these products. Based on these figures, an analysis was made on the quality problems that occur at Q. This data is only about products that were rejected, and therefore lacks insights on quality problems that do not lead to product rejection but can nonetheless cause repetition of production steps or problems with clients. Data is lacking on the former and to include the latter, extended contact with clients would be required which is not feasible within the given timeframe, so scrap will be used as a basis for conclusions on product quality.

It is important to detect the cause of the scrap, which will almost always be earlier in the process than where it is found. This is, however, difficult because the process is not standardized at many points and is highly subjected to personal work-styles of employees. This creates a low level of analytical power, making it hard to pinpoint exactly what causes the error. In many cases, we just know where the error was found, rather than where it was made. We can indicate what was observed that made the product to be rejected, giving us some insight in what failure modes are most relevant.

The benefits of using scrap, of which data is available, as a representation of the quality problems that exist at Q is that it immediately elicits what other costs might be incurred due to the quality pillar. Due to the lack of data, these will be difficult to put into figures, but estimations can and should be made in order to come to an accurate financial assessment of automation projects. At Q, the quality factors that can either be quantified based on data, or otherwise reasonably be estimated based on a combination of intuition and data, includes the following:

- Cost of scrap
- Cost of customer complaints
- Extra process cost due to repairs

Some things are harder to quantify, but can still contribute significantly to quality costs on the long term:

- Value of analytical power
- Long-term negative effect on customer relation when complaints occur
- Relative improvements of competitors (with the idea that standing still is the same as falling behind)

Such factors can be included, but this will need to happen, again, in the form of an exacerbation factor.

Appendix B—Roadmap process

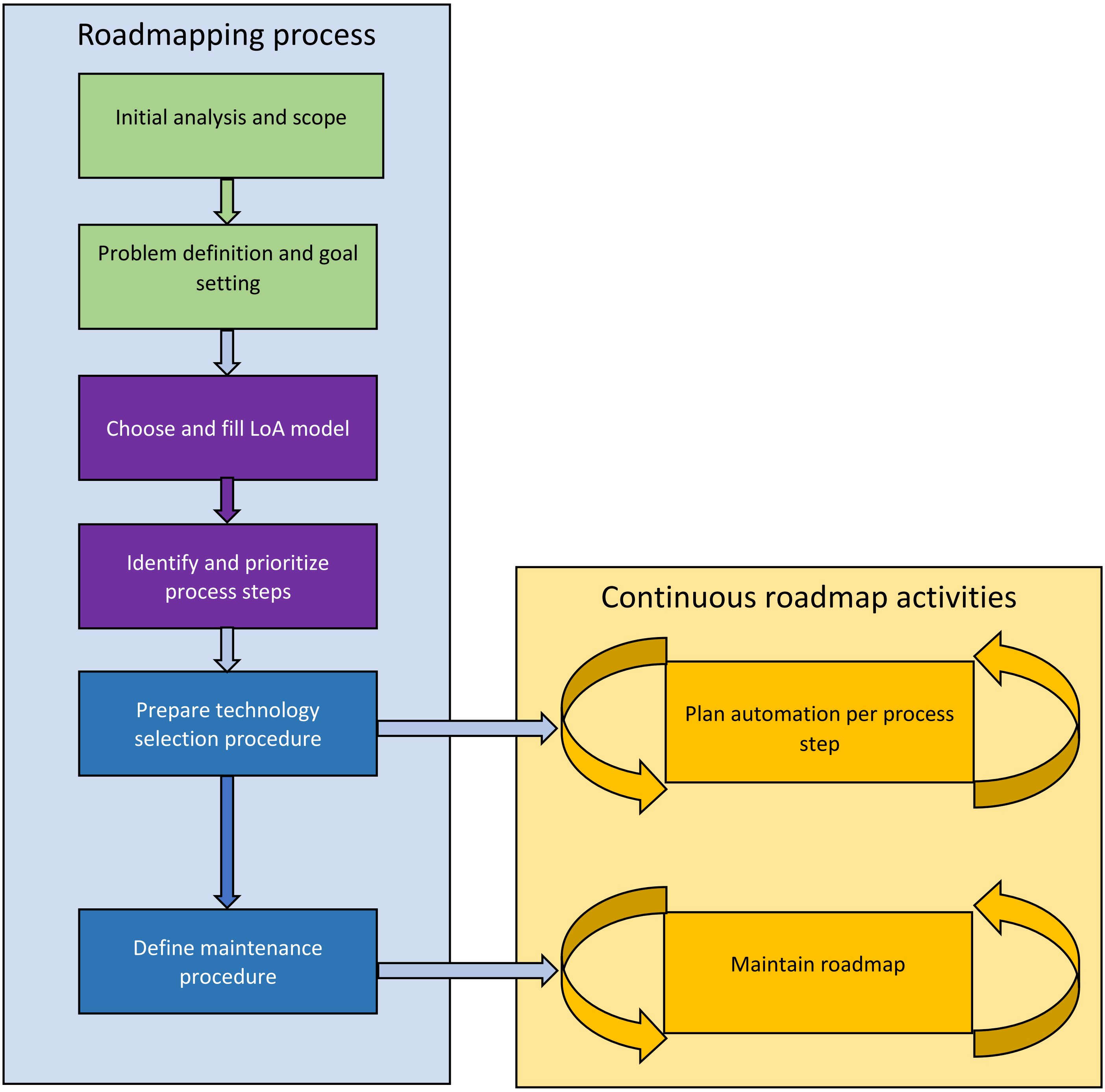


Figure 22 – the roadmapping process

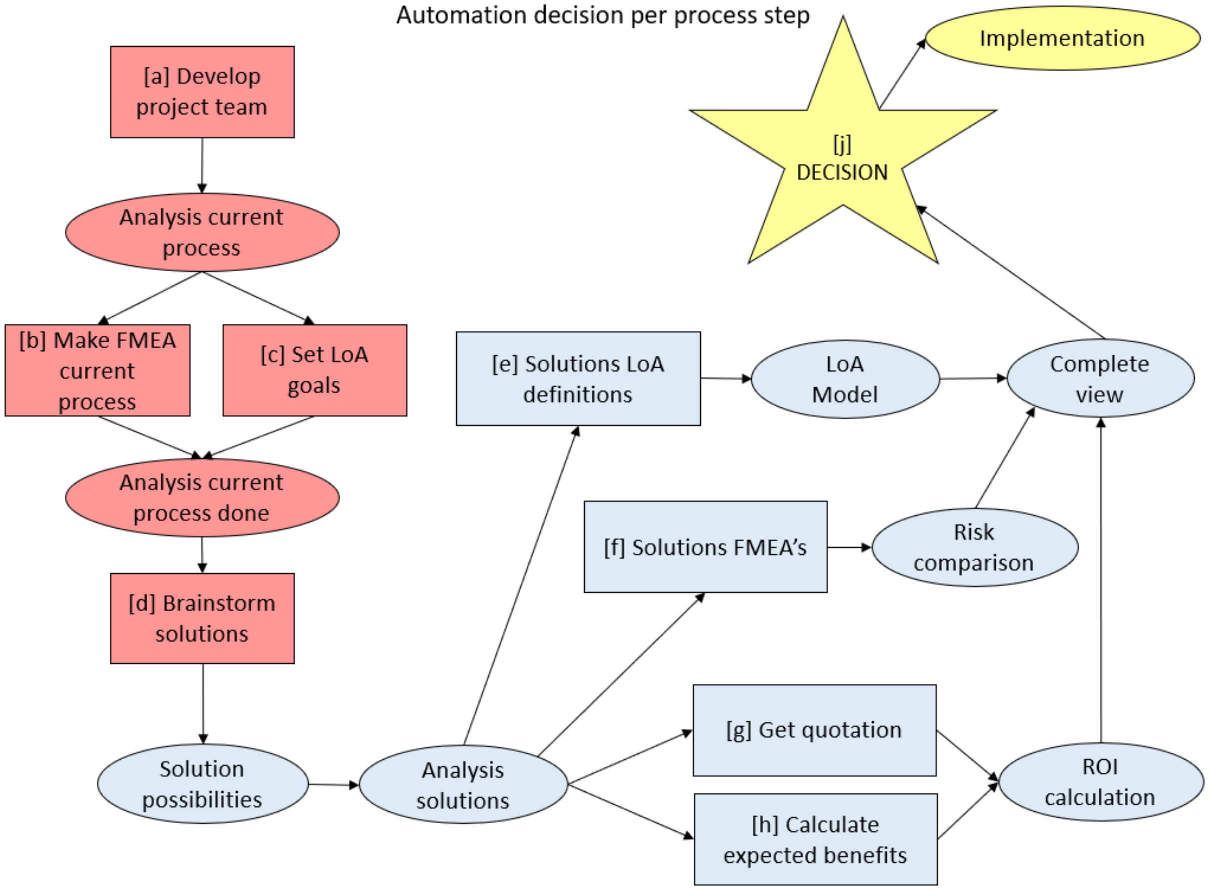


Figure 23 – the steps to decide on which automation alternative is best per automation activity

Appendix C—Decision tool IPO analysis

Main process		
Input	**Process**	**Output**
- Company information	Check profile fit	- Fit approval
- Fit approval	Initial company analysis and scope	- Understanding of company culture - Corporate vision - Production process analysis **- Project scope**
- Project scope - Coroporate vision	Problem definition and goal setting	**- Defined problem areas** **- Project goals**
- Defined problem areas - Project scope	Stakeholder analysis	**- Stakeholder management strategy** - Link stakeholders and problem areas
- Production process analysis	Choose and fill LoA model	- LoA model - current and max LoA per activity
- LoA goals per process step - Project goals	Identify and prioritize process steps	- List of prioritized activities - Roadmap structure
- List of prioritized activities - LoA model	Prepare technology selection procedure	- ROI template - FMEA template - Workstations' goals and scope
- Understanding of company culture	Define change management plan	- Change management plan
- Workstations' goals and scope - LoA goals per workstation - LoA model - FMEA template - ROI sheet	Execute roadmap activities	- Automation solution
- Maintenance procedure	Maintain roadmap	- Iterated versions roadmap

Figure 24 – Input Process Output (IPO) analysis for the main roadmapping process

Automation selection procedure		
Input	**Process**	**Output**
- Stakeholder management strategy - Link stakeholders and problem areas	Develop project team	- Project team
- Project team - FMEA template	Current process FMEA	- Process FMEA
- LoA goals per process step	Define future state (LoA)	- Ideal state definition
- Workstation's goals and scope - LoA goal for process step - Process FMEA	Brainstorm solutions	- Solution proposals
- Solution proposal	Contact suppliers	- Quotation
- Solution proposal - LoA goals for process step	Solutions LoA definitions	-Solution LoA comparison
- Solution proposal - Process FMEA	Solutions FMEAs	- Solution risk comparison
- ROI template	Value estimations	- Benefit estimation
- ROI template - Quotation - Benefit estimation	Calculate ROI	- Solution ROI
- Solutions LoA comparison - Solutions risk comparison - Solutions ROI comparison	Decision	- Automation system decision
- Automation system decision	Implementation planning and control	- Implementation and control plan

Figure 25 – IPO analysis for the decision process per automation activity

Appendix D—Stakeholder analysis

Stakeholder theory was originally proposed by Freeman (1984), who defines a stakeholder as "any group or individual who can affect or is affected by the achievement of the organization's objectives". Since then, many alternative definitions have been proposed, creating much confusion in its conceptualization and making it increasingly difficult to select the right tool to use in your specified context (Miles, 2017). For our decision tool it is therefore of utmost importance to know which models may be useful for the specified company profile.

It can easily be argued that managing stakeholders correctly and methodically increases the likelihood of any innovative project's success (e.g. (Kennon, Howden, & Hartley, 2009)). As Becker (2002) puts it; "The human side of the equation is equally important as the technical side", i.e. without a good strategy for managing all involved parties, the success of the project can easily become endangered.

(Kennon et al., 2009) agree, concluding on four reasons to avoid using an ad-hoc stakeholder management style. Based on real findings they found that:

1) *"Time and resources were being wasted.*
2) *Stakeholders were not being managed efficiently because project teams were not sharing their knowledge and understanding.*
3) *Important stakeholders were being neglected in the intuitive assessment of the project environment.*
4) *Project leaders and teams were working on untested assumptions about the relationship of stakeholders to their project."*

The follow-up question then logically becomes one not of 'if' but of 'which'. Many stakeholder analysis tools exist, and often the validity of models has been verified through research. This type of analysis often revolves around the classification of stakeholders into refined groups, after which a communication and involvement strategy is made for each group to manage the expectations and access to information. Tools regarding stakeholder management may range from highly simplified to rather extensive. The level of formality required must be decided on based on contextual input such as company culture and problem statement.

Based on context, relevant literature and managerial insights, the classification model should be set in stone as a first step. By considering input from multiple sides, the final classification system combines intangible things such as local communication practices, with established information, such as academic conclusions. For each of the types of stakeholders included in the class system, a stakeholder involvement and communication strategy must be developed.

Once the classification system has been created, the stakeholders to incorporate must be identified. Once known, all stakeholders should be classified according to the model that was picked earlier. Each of the stakeholders now has a defined strategy regarding their engagement to- and role in the project.

A logical approach to managing stakeholders therefore includes the following steps.

1) Defining the classification model
2) Defining a strategy per role
3) Identification
4) Execution of strategy

The result after following these steps is an instrumental strategy on how to achieve the desired goals regarding stakeholder engagement, communication, or any other goals that may have been identified in each class-specific strategy.

Defining the classification model

The selection of the classification model must be the first step, as it paves the road for the rest of the stakeholder analysis process. (Vos & Achterkamp, 2006) has researched this topic specifically for an innovation context, thus this section will rely largely on the outcomes of that paper. Vos created a classification system based on stakeholder roles, that aims to solve the difficulty of applying such a classification model to any real situation. Since it is required for the classification to be valuable in a practical sense, their finding will be used and adapted to suit the company context.

Before we do so, however, we must consider if the innovation context really suits our purposes. To define innovation, the paper refers to a definition from West & Farr (1990) *"The intentional introduction and application within a role, group or organization of ideas, processes, products or procedures, new to the relevant unit of adoption, designed to significantly benefit the individual, the group, organization or wider society*". This definition suits automation practices. Even when such projects aren't necessarily new to the world, they are highly likely to be new to the relevant unit of adoption.

In a slight variation of Freeman's stakeholder distinction of "affects" and "can affect", Vos concludes that each stakeholder is either actively or passively involved. More specifically, each stakeholder must be passively involved, and may in addition also play an active role, as visualised in the Venn diagram in figure 26. The boundaries of passively involved stakeholders are hard to define, indicated by the dotted line, whereas actively involved stakeholders may be more strictly bounded. In general, passively involved means any individual or group that has no decision power over the outcome but is affected by it, or any individual or group representing such a party.

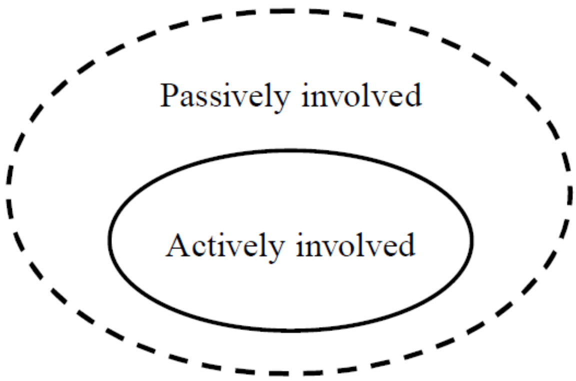


Figure 26 - Actively and passively involved stakeholders (Vos & Achterkamp, 2006)

Vos then goes further in defining the roles of the actively involved stakeholders, an overview can be seen in figure 27.

Role	Definition
Party involved, actively and passively	A party involved is any group or individual who can affect: (1) the achievement of the innovation's objectives; or (2) who is affected by the achievement of these objectives. The first category is labeled the actively involved; the second category is labeled the passively involved
Client	A client is the party whose purposes are being served through the innovation
Decision maker	A decision maker sets requirements regarding the innovation and evaluates whether the innovation meets these requirements
Designer	A designer contributes expertise to the innovation process and is responsible for the (interim) deliverables
Passively involved; representative	A passively involved is affected by the outcomes of the innovation project without being able to influence these outcomes. A representative is a person who has been selected to act on behalf of another, i.e. the passively involved

Figure 27 - Roles of active stakeholders (Vos & Achterkamp, 2006)

In our context of automating internal processes, we can tighten the group of stakeholders significantly to only include internal people of the organization. The new system's achievement impacts the organization's achievement and therefore has relevance for clients and possible other external stakeholders, but taking all stakeholders of the company in general means that external parties will have to be included in what is inherently an internal matter. The client's needs and wishes should be used in goal-setting, but not in system design. For example, the client has certain standards for the quality of the product, which must be enforced and maintained with any new automation system implementation. This does not mean, however, that the client should have much of a say in exactly how the product comes to be and using which methods, as long as the quality is verified. The client has control over the product specifications, but not over the processes used to come by these specifications. Therefore, unless an exception should clearly be made, only internal stakeholders should be considered in internal processes.

By talking with stakeholders at Q it became clear that passively involved people come in two forms; those very close to the production process and those at a further distance. This idea fits nicely with construal level theory. According to this theory, the bigger the distance between an individual or group and the implementation area, the more abstract their perspective will be. The increase in distance that acts as cause to an abstract perspective is in this case not defined in a temporal sense, but rather in the context of a hierarchical discrepancy. Hierarchical distance is previously known to affect attitudes towards change (Hill, Seo, Kang, & Taylor, 2012). Relating this information back to construal level theory, it is expected that an operator, ranking lowly in the hierarchy, experiences less distance with the production process itself and will therefore view it more concretely compared to a member of the management team, see figure 28. In this figure, we also identified that decision makers are far from the physical proces, and that designers are in the middle, based on interviews with employees at Q. The figure also shows how much decision power different groups have.

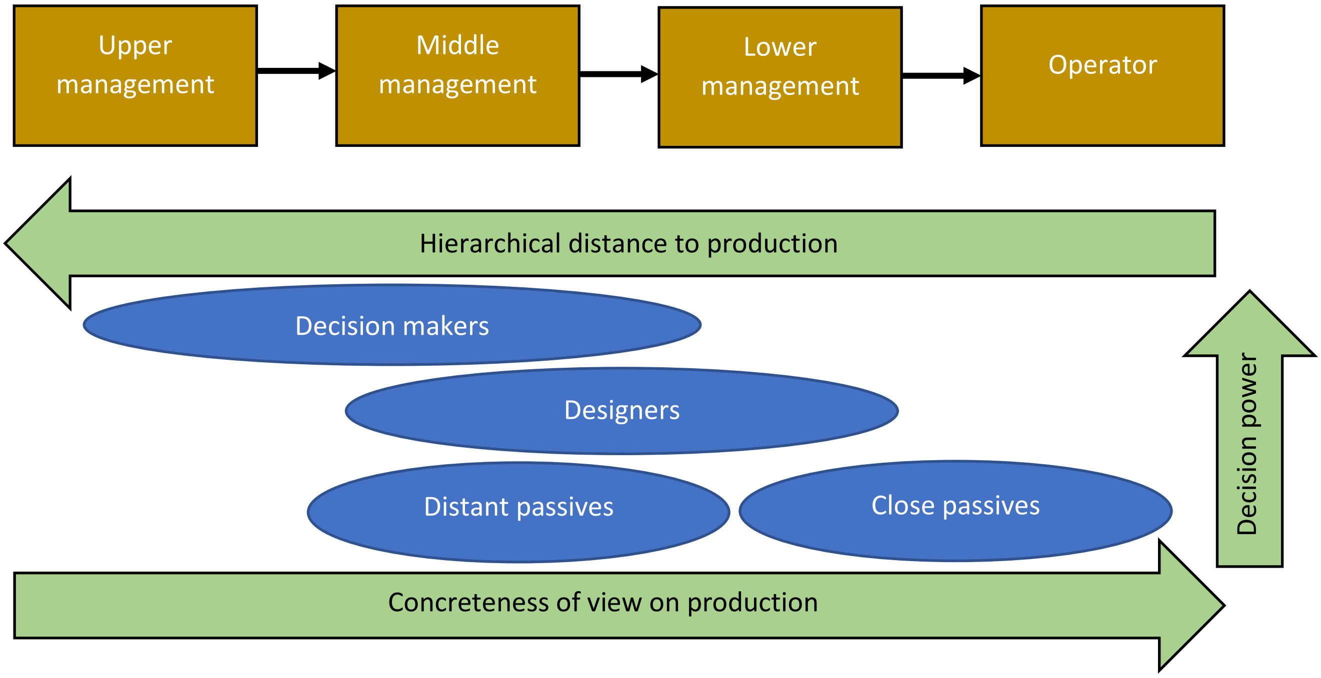


Figure 28 - Position of different stakeholder groups

This means that we will identify stakeholders in one of four roles: Decision maker, designer or close passive or distant passive.

The decision maker is in charge of deciding the activities that may or may not be included in the roadmap, as well as the order and planning of these activities. Their responsibilities are defined in general terms for the roadmap as a whole.

The designer makes the considerations regarding project specifications, and should be seen as responsible for a project's outcome. This means that a designer is not necessarily involved in the roadmap as a whole, but for certain specified activities included in the roadmap.

The close passive is affected by certain activities of the roadmap, but not the roadmap as a whole. They should therefore be included in the design of individual system's that are relevant for them, but they will not make any decisions on system specifications.

The distant passive is affected by the whole roadmap, not the specific activities, and has no decision power. His closeness to the process is in the middle of the spectrum.

Defining a strategy per role

Each stakeholder group needs a different communication and engagement strategy. Green & Hunton-Clarke (2003) identify three levels of stakeholder participation;

1) Informative—stakeholders are informed about the project and its progress, but there is no dialogue. If there is any two-way communication, it is simple, e.g. in the form of a survey, and its goal is to draw general quantitative conclusions about the context.
2) Consultative—characterized by an effective and qualitative two-way communication stream where the input from stakeholders is actively used in decision making.
3) Decisional—the highest form of involvement; these stakeholders have actual decision power over the resulting plan.

These match up nicely with our roles. A passively involved stakeholder (both kinds) needs an informative engagement approach, a designer needs a consultative approach, and a decision maker a decisional approach.

Drawing on the assumption that different roles have a different distance, we can use this information in our communication strategy towards the decision maker stakeholder group and distant passives. For stakeholders who are far from the production process, the specifications of the automation systems are less relevant than are their implications on the company from a wider perspective. Communication with these stakeholders must therefore focus on broad outcomes of all activities planned in the roadmap, rather than specific implications of each system.

In a similar way, closely passively involved people, who are affected by the outcome but have no say in it, can be expected to generally have a more concrete view of the implications of any change on the production floor, as they are closer to it. This close proximity is not likely to be relevant for all planned activities in the roadmap though. That means that for this type of stakeholder, it is wise to identify which of the planned projects affect them before proceeding. Then, in order to assure that they are on board with the plans that are being made, it is important to give them frequent status updates on the project.

Designers reside in the middle, and the focus with them should be on collaborating on all of the activities that they are involved in. That means that, also for designers, it must first be decided which activity as specified in the roadmap is relevant for them.

From Weisenfeld (2003), we learn that “with regard to innovations, the relationship between the company and its relevant stakeholders will be affected by the perceptions and interests associated with the innovation”. Perceptions are general observations about the processes, whereas interests are what the party wants from the outcome, they are the stakeholders’ needs. Therefore, these two aspects must be determined for each stakeholder (group) involved. We argue here that for parties closer to the production floor, interests elicitation becomes more valuable since these are the people who will use the automation systems in a practical sense. If the system specifications don’t match the interests of, for example, operators, then the effectiveness of the innovation is reduced since there is a lower motivation to work with the innovation as the system’s output didn’t match their needs. For decision makers, on the other hand, the proposed systems must match their perception of automation in relation to the company. In order to convince the decision maker that implementing a certain system is a good decision, the system must match their vision. By also matching the distant passives’ perceptions, a broader support base for the roadmap is created. The designer takes neither end of the spectrum on this issue, thus a combination of perceptions and interests must be elicited with no clearly defined focus.

To summarize these findings, table 4 lists the roles with their characteristics. Finally, a qualitative strategy is described in the next subsections.

Role	**Involvement level** (Green & Hunton-Clarke, 2003)	**Hierarchical distance**	**Scope**	**Focus (from)** (Weisenfeld, 2003)	**Focus (towards)**
Close passive	Informative	Small	Specific activities	Interests	Progress updates for relevant projects only
Distant passive	Informative	Medium	Whole roadmap	Perceptions/ interests	Inform on roadmap milestones
Designer	Consultative	Medium	Specific activities	Perceptions/ interests	Collaboration on relevant projects only
Decision maker	Decisional	Big	Whole roadmap	Perceptions	Communicate about broad effects

Table 4 – a summary of the identified stakeholder roles

Close passive

For this group, the most important initial activity is eliciting their interests with regards to automation. An interest can be anything from improved product handling to less data management. By finding out what, for example, an operator finds important about his/her work, the automation systems can be tailored to the needs of the people who are going to ultimately be working with them, based on the assumption that passively involved stakeholders are often those who work closely with the systems compared to the other stakeholder roles.

Other than the gathering of interest input, this stakeholder group must be managed by clearly informing them regularly of any changes in the systems that are relevant for them. This could be defined periodically, but it makes more sense to inform only when there is something to inform on. Therefore, this group should be informed any time there is a major update relevant for them.

Before this can work, an overview must be drawn up specifying which people have a stake in which activity. This can only be done once an overview of desired roadmap activities exists, and thus happens later in the process.

In short, the strategy is summarized as follows:

1) Elicit their needs and interests regarding automation
2) Once there is a draft roadmap, or at least an idea of what it will include, identify which activity is relevant for whom.
3) Any time a major update exists, inform relevant actors.

Distant passive

The main differences between the close and distant passives is that the distant passive is interested in the aggregate outcomes of the roadmap as a whole, as opposed to specific activities, and that the focus should lie on matching their perception rather than eliciting their needs or interests. The main goal of including this type of stakeholder is to increase the support for the roadmap company wide, so that the outcomes may be more easily controlled. The strategy therefore looks like:

1) Gather their perceptions and interests
2) Link with roadmap goals
3) Inform at major roadmap design milestones

Designer

The designer is involved from a different perspective, and must be seen as a consulting party that supports setting-up the roadmap by being involved/responsible for specific activities to be included in said roadmap. They each might be designing a different roadmap activity, so it is again important to create an overview of relevance for this group once this is possible.

This group has decision power over individual activities, but not the roadmap as a whole. Therefore, they fall in the middle of the other stakeholder roles. Their perceptions and interests are likely to shape the design of their activity, and a focus must therefore lie on gathering both from them.

For this role, the plan is as follows:

1) Elicit their perceptions and interests regarding automation
2) Include their projects in the roadmap where relevant by collaborating with them on their projects
3) Inform of roadmap progress

Decision maker

The decision maker has decision power over the roadmap as a whole, and has a lot less to do with specific activities. Therefore, their involvement is mostly decisional, while gathering their input in the form of perceptions of the effects of automation is crucial for controlling the roadmap's success.

This role must be informed about the roadmap progress, with a focus on analysing and explaining the effects of the projects on the company as a whole.

The strategy then goes:

1) Gather their perceptions
2) Link perceptions with roadmap goals, you may want to make changes to the goals if necessary
3) Meet regularly in order to inform of the progress and gather input on the direction it is taking.

Identification

The process wherein only the most relevant and/or influential stakeholders are identified is a crucial first step in any stakeholder analysis. As much as practitioners might want to, "managers simply cannot attend to all actual or potential claims" (Mitchell, Agle, & Wood, 1997). Identifying stakeholders that are relevant for your project can take two main forms; "stakeholder identification can be done with the help of previous studies, with support from managers or via a combination of both" (Kumar, Rahman, & Kazmi, 2016). By using various outcomes from other researchers, mainly drawing on Vos, and combining this with input from managers, this research uses a combination.

For the creation of a roadmap to be successful, we need a broad support base in the company, with stakeholders from different departments and hierarchical levels. However, the identified stakeholders must reside over knowledge of activities and processes that are in the scope of the roadmap. It is wise to refer to the scope definition to check whether a stakeholder can provide relevant input for the creation of the roadmap.

Execution of strategy

Once the list of stakeholder is known, we need to gather an overview of how much they relate to different automation goals, as defined in the previous step. By having each stakeholder fill in an importance factor for each problem area from 1 to 10 (1 meaning “I don’t find this important at all” and 10 meaning “this is absolutely crucial to improve”), a radar figure—see figure 29, filled arbitrarily for Q’s problem areas—, can be created that indicates which identified problem is viewed as more important, this information will be used later on. These importance weighings will be elicited in an interview wherein also the interest/perceptions (whichever is relevant according to the stakeholder’s role) are also discussed.

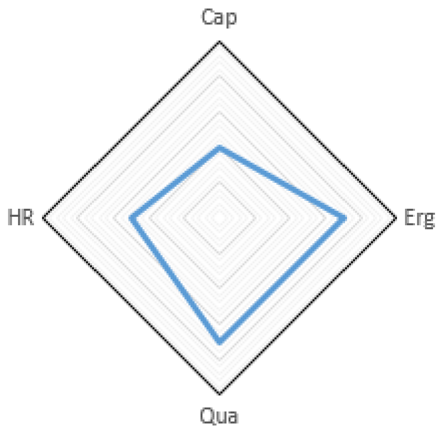


Figure 29 – an example of a radar chart that shows the importance of each pillar

After having spoken with each stakeholder at least once, the overview per stakeholder should be made (see appendix G for an example). From here onwards, the strategies for communication and involvement as specified earlier should be followed structurally, while allowing for exceptions where necessary.

Appendix E—LoA taxonomies and selection

Finding the right taxonomy

When looking at the first defined LoA taxonomy in figure 30 (Sheridan & Verplanck, 1978), it becomes clear that this describes systems that make decisions and take actions to enforce these decisions. The model is undescriptive in how the system is enabled to make these decision in the first place.

Low	1	The computer offers no assistance, human must take all decisions and actions
	2	The computer offers a complete set of decision/action alternatives, or
	3	Narrows the selection down to a few, or
	4	Suggests one alternative, and
	5	Executes that suggestion if the human approves, or
	6	Allows the human a restricted veto time before automatic execution
	7	Executes automatically, then necessarily informs the human, and
	8	Informs the human only if asked, or
	9	Informs the human only if it, the computer, decides to
High	10	The computer decides everything, acts autonomously, ignores the human

Figure 30 – the LoA model of Sheridan & Verplanck (1978)

In order to solve that issue, and to further define the full range of functions that humans and robots must divide amongst themselves, (Parasuraman, Sheridan, & Wickens, 2000) concluded from their research that there are four main functions that an automated system must perform; 1) information acquisition, 2) information analysis, 3) decision and action selection and 4) action implementation. This creates a more complete picture of the whole process from data gathering to action. Another group of researchers independently found a very similar result, defining the four roles as shown in figure 31, where each role is assigned to either the human, a computer or both, creating 10 levels of autonomy (Kaber, Omal, & Endsley, 1999).

	Roles			
Level of automation	Monitoring	Generating	Selecting	Implementing
(1) Manual control	Human	Human	Human	Human
(2) Action support	Human/computer	Human	Human	Human/computer
(3) Batch processing	Human/computer	Human	Human	Computer
(4) Shared control	Human/computer	Human/computer	Human	Human/computer
(5) Decision support	Human/computer	Human/computer	Human	Computer
(6) Blended decision making	Human/computer	Human/computer	Human/computer	Computer
(7) Rigid system	Human/computer	Computer	Human	Computer
(8) Automated decision making	Human/computer	Human/computer	Computer	Computer
(9) Supervisory control	Human/computer	Computer	Computer	Computer
(10) Full automation	Computer	Computer	Computer	Computer

Figure 31 – the LoA model of Kaber et al. (1999)

Such models have proven their value, but are also limited (Save & Feuerberg, 2012). Firstly, the models of Sheridan & Verplanck (1978) and Kaber et al. (1999) leave empty spaces within their qualitative definitions, meaning certain automation projects may not fit anywhere in the model on certain functions. The model of Parasuraman et al. (2000) already solves this by not strictly defining responsibilities, but allowing for a relative scale system to be used to identify the desired level of automation for each of the four defined functions—it may look something like figure 32.

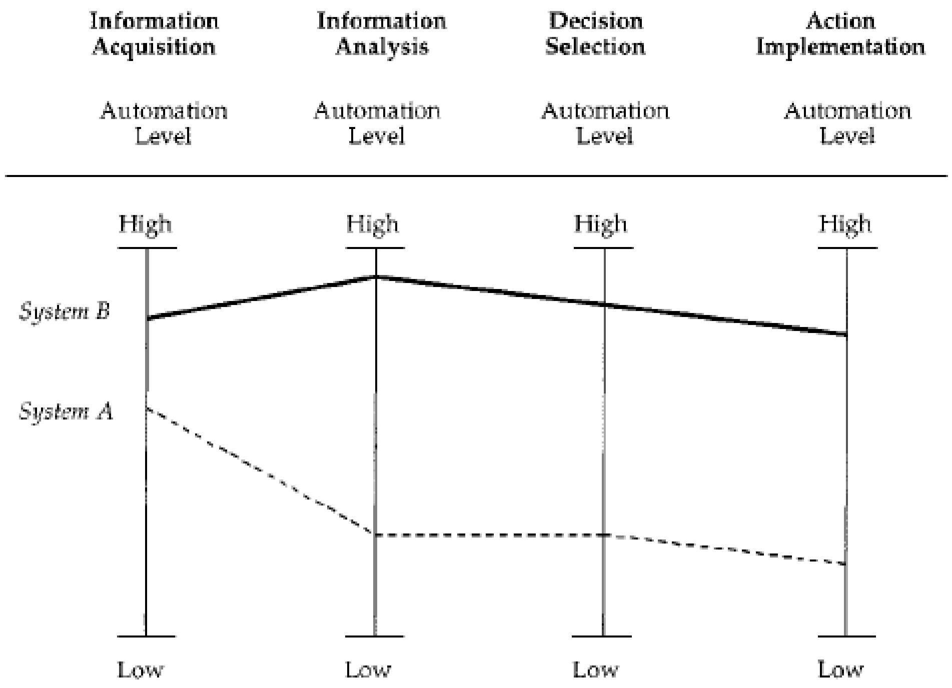


Figure 32 – the LoA model of (Parasuraman et al., 2000)

An advantage of this is that it allows for a good comparative analysis on different possible systems for a certain process. A downside is that the values given don't have a strictly defined meaning and are therefore meaningless on their own, only having value in comparison.

Save & Feuerberg (2012) see value in the model from Parasuraman, but prefer a qualitative model. This is achieved by creating strict definitions of the levels defined for each of the four functions, where Parasuraman left this completely open to subjectivity. Save's model definitions can be found in .

Depending on the automation context, the models of Parasuraman and Save might serve to be of great value. Assuming that all of these four defined functions are relevant, it is suggested to use this model. In manufacturing, however, it may be the case that only a subset of these roles is relevant. As an example, imagine a production company that operates as a job-shop, and has to deal with high levels of product variety. The company might not have the (financial) means available to automate on the decision-making aspect, since this requires intelligent robotic systems that are capable of making judgement calls. In such a case, this model might be overdoing it, since at least one of the four functions are simply not relevant for that context. Another easily imaginable scenario is a company that does not currently have the ambition to work more with data acquisition and analysis, but merely wants to improve the level of automation in the action/implementation phase, where the only relevant improvement is one that makes a machine better capable of autonomously running prespecified tasks.

For this reason, we must look for a simpler model that comes from a manufacturing context. A model proposed by (Jörgen Frohm et al., 2008) offers support. By analyzing many different LoA taxologies, Frohm defines his own model that is specific for the manufacturing context.

Frohm still splits functions of an automated system, but this time it is simpler; tasks classically performed by the human can be divided into mechanical and cognitive tasks. This means that when an automation takes over tasks from the human, this can either be by mechanization—resulting in a technical system—or by computerization—resulting in a control system (figure 33) (J Frohm & Bellgran, 2005).

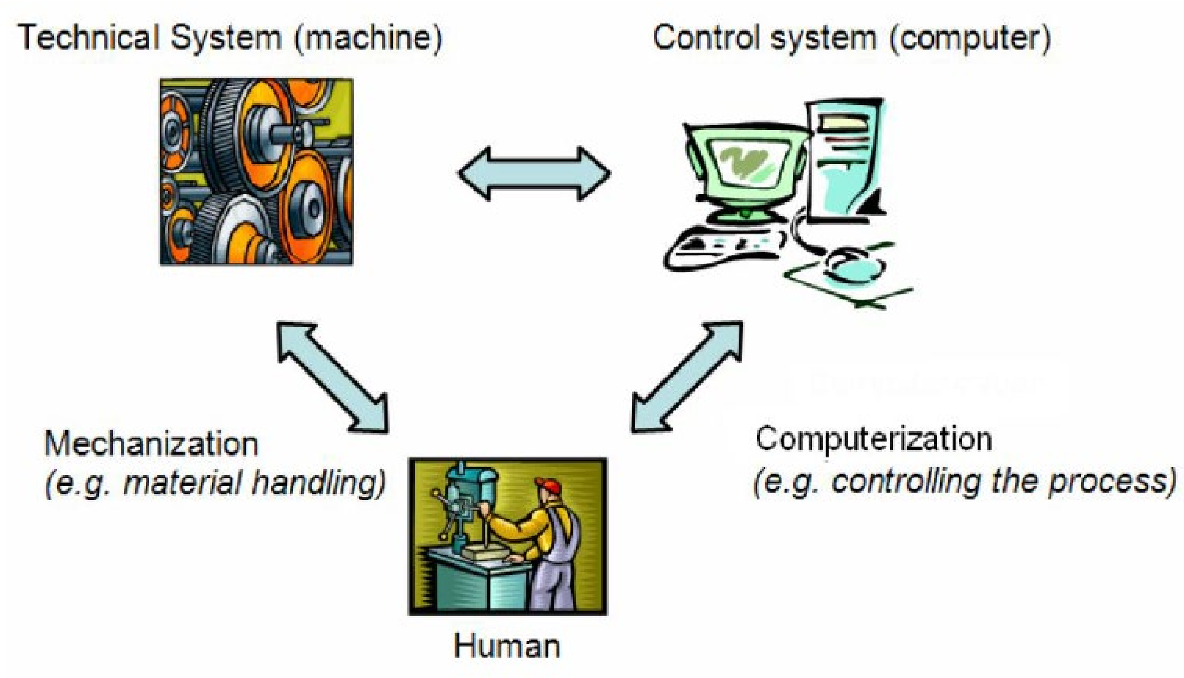


Figure 33 – the relationship between the human, computer and mechanical system

This results in a two-function division of the whole process responsibility, defined as 1) mechanical and equipment and 2) information and control.

Frohm then proposes a 7-scale system on both of these axis (figure 34), giving a clear image for each processing step the level of automation achieved. After a case study using this taxonomy, the conclusion can be drawn that for each process step, a relevant and realistic range can be determined in each axis, resulting in a view of what the goal may be for each step.

LoA	Mechanical and Equipment	Information and Control
1	**Totally manual** - *Totally manual work, no tools are used, only the users own muscle power. E.g. The users own muscle power*	**Totally manual** - *The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The users earlier experience and knowledge*
2	**Static hand tool** - *Manual work with support of static tool. E.g. Screwdriver*	**Decision giving** - *The user gets information on what to do, or proposal on how the task can be achieved. E.g. Work order*
3	**Flexible hand tool** - *Manual work with support of flexible tool. E.g. Adjustable spanner*	**Teaching** - *The user gets instruction on how the task can be achieved. E.g. Checklists, manuals*
4	**Automated hand tool** - *Manual work with support of automated tool. E.g. Hydraulic bolt driver*	**Questioning** - *The technology question the execution, if the execution deviate from what the technology consider being suitable. E.g. Verification before action*
5	**Static machine/workstation** - *Automatic work by machine that is designed for a specific task. E.g. Lathe*	**Supervision** - *The technology calls for the users' attention, and direct it to the present task. E.g. Alarms*
6	**Flexible machine/workstation** - *Automatic work by machine that can be reconfigured for different tasks. E.g. CNC-machine*	**Intervene** - *The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. E.g. Thermostat*
7	**Totally automatic** - *Totally automatic work, the machine solve all deviations or problems that occur by it self. E.g. Autonomous systems*	**Totally automatic** - *All information and control is handled by the technology. The user is never involved. E.g. Autonomous systems*

Figure 34 – the LoA system from (Jörgen Frohm et al., 2008)

LoA selection

Since there exist many LoA taxologies, and one may be more relevant than the other depending on the context, a decision tree will be proposed that guides the user towards usage of the most applicable taxonomy. After the right model is selected, this section will focus on how to use the chosen model to identify and classify the opportunities for automation, and if necessary adapt it to fit the context more accurately.

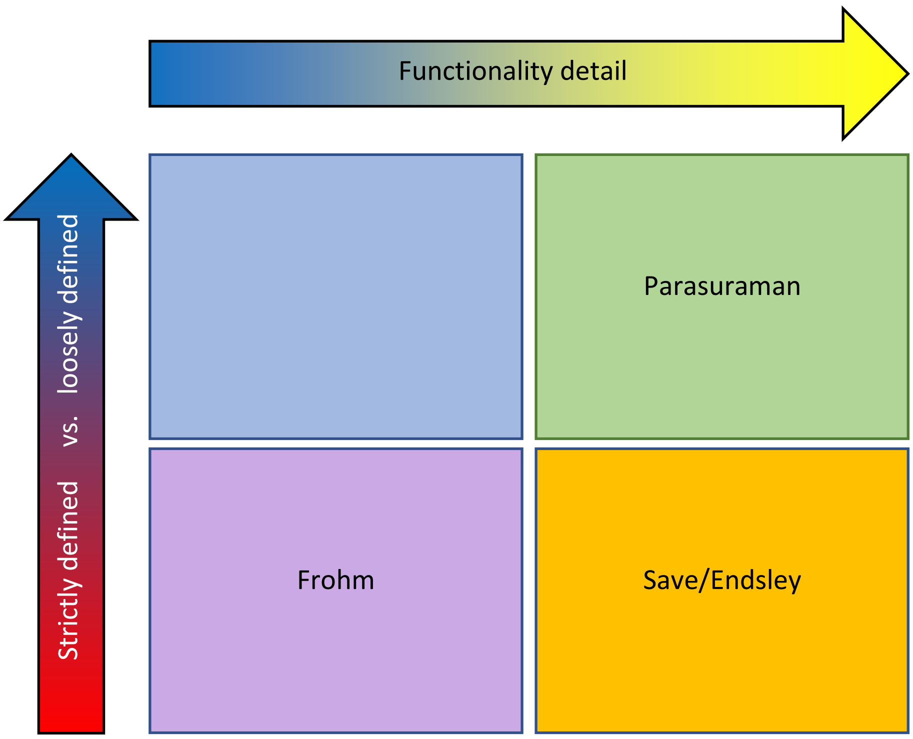


Figure 35 – three LoA taxonomies classified on their functionality detail and level of definedness

We have seen two important differences between several analyzed taxonomies; 1) the degree of detail in the function divisions and 2) quantitatively defined rankings versus qualitatively defined rankings. When putting these two differences on a two-axis system, a structure such as in figure 35 is achieved. In this figure, the models from Parasuraman, Save, Frohm and Endsley have been put in their corresponding place. We observe that there are two models with a high level of detail of functions and a strictly defined scale system. Ideally, we would have 1 model per square, so a choice must be made. The model from Endsley merely defines whether the computer or the human performs each of the 4 functions, whereas Save creates a real description of the collaboration between human and robot at each level. Additionally, Save's taxonomy is directly derived from Parasuraman, creating a more comparable step when switching from a strictly defined to a loosely defined model. Therefore, Save's model will be chosen to be used in the decision tree. The place for a low function detail and a loosely defined scale is empty. To solve this, we will adapt the model from Frohm to be used quantitively, throwing out the qualitative descriptions per level and allowing for a more subjective evaluation. These changes result in figure 36.

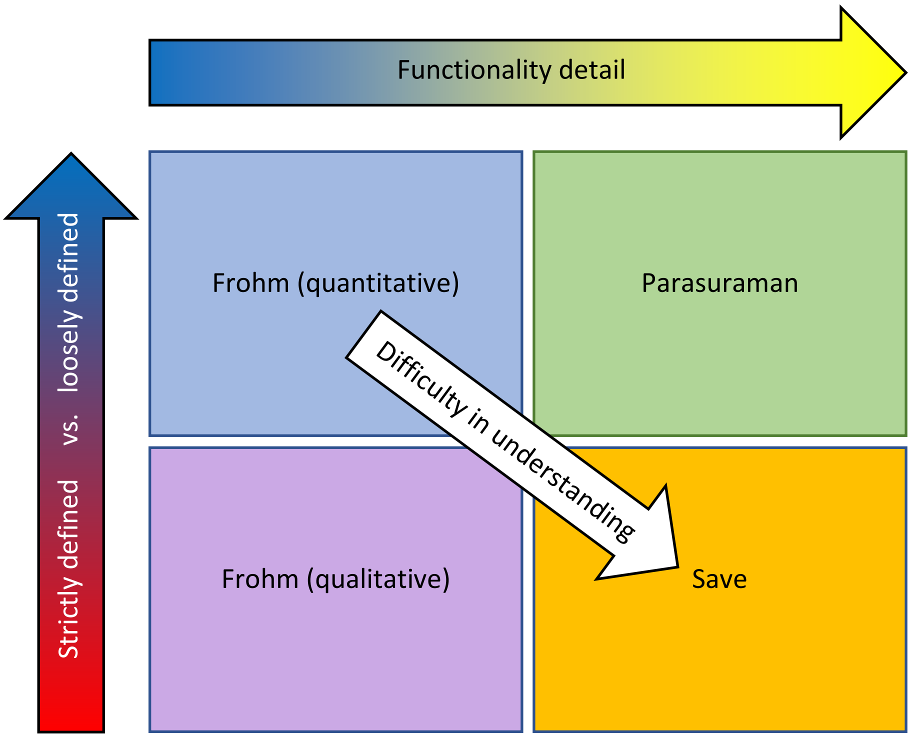


Figure 36 – four LoA taxonomies, each with different characteristics

The characteristics of the quadrants is expressed in tables 5 and 6.

Functionality detail low	**Functionality detail high**
Easy to explain to management	Harder to explain to management
Tasks less specifically defined	Tasks more specifically defined
Is always relevant in manufacturing	May define irrelevant functions
Less effort	More effort

Table 5 – the main differences between low/high functionality in LoA models

Quantitative	**Qualitative**
Subjective	Objective
Robust	System may fall in gap
Hard to interpret on its own	Easy to interpret on its own
Only comparative in own opportunity	Comparative across whole roadmap

Table 6 – the main differences between quantitative and qualitative LoA models

Choosing the right model

We must make the right decision on which model is most usable in our company because it shapes the whole process from this point onwards, where different models may have vastly different roadmap outcomes. If time and other recourses are abundant, it is suggested to pick one of the automation opportunities identified and simply try out each of the LoA models for it. This way, each model's relevance can be evaluated upon and the best one can be chosen based on experience in the proper context.

In case that this is too tedious and costly of a decision process, an alternative is suggested in the form of a decision tree. In order to come up with the right way to design this decision tree, a case at Q was performed. The four models have been applied for a wiping robot application. This resulted in the conclusions listed in table 7.

Model	**Pros**	**Cons**
Parasuraman	- Easy to fill - Easy to explain/understand	- Not particularly meaningful to use so many dimensions when the scales aren't comparable across process steps
Save	- Great at defining/guiding an iterative improvement process with multiple solution steps	- Very high in effort - Difficult to explain/understand
Frohm (quantitative)	- Easiest to fill - Flexible in scale improvements - Broadly applicable for different manufacturing steps	- No standardization among scale terms - Hard to compare across projects
Frohm (qualitative)	- Great at defining/guiding an iterative improvement process with multiple solution steps	- Product handling hard to include in the mechanical scale - Not all cognitive scale definitions make sense in all contexts, scale increases not always clearly more autonomous

Table 7 – pros and cons per LoA model

Based on these, a decision tree has been constructed below:

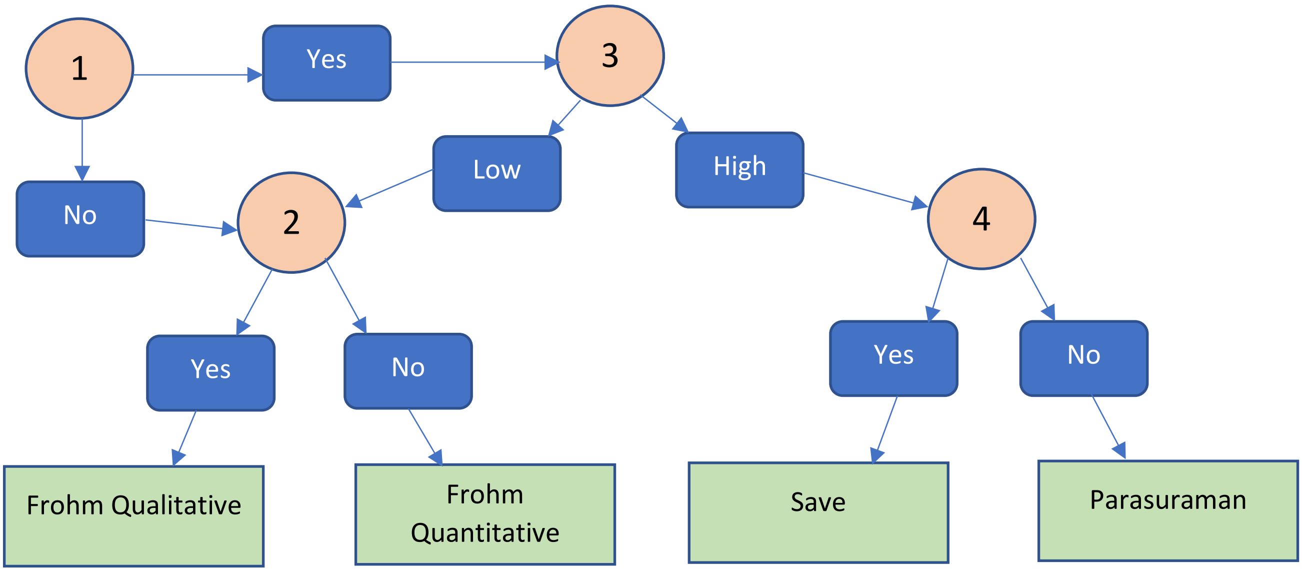


Figure 37 – the optimal LoA taxonomy can be selected through a decision tree

Questions	
1	Are all dimensions (Save and Parasuraman) relevant?
2	Do the descriptions from Frohm make sense in your context?
3	How much effort can you afford to spend on classifying the relevant processes?
4	Do the LoA values need to be comparable?

Table 8 – the questions corresponding with the decision tree

Following this decision tree will result in a LoA classification taxonomy that best suits your needs. For more information on the scales of each of these taxonomies, refer to appendix J.

Appendix F—Template sheets, used for each automation activity

Sheet 1—Current process analysis and FMEA risk list

Nr	Step	Risk 1	Risk 2	Risk 3	Comment
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					

Figure 38 – template for detailed process

Sheet 2—Detailed FMEA and risk scores

Key Process Step or Input	Pillar	Potential Failure Mode	Potential Failure Effects	SEV	OCC	DET	RPN

Table 9 – template for FMEA

Sheet 3—Brainstorming the possible system solutions

System	Description	RPN	RPN difference	Comments
Current				
Optimal				
Sol1.0				
Sol1.1				
Sol1.2				
Sol1.3				

Figure 39 – Template for possible solutions sheet

Sheet 4—Loa current, desired and solutions, every solution to be added

	A	B	C	D
Current	Fill white spaces with the numerical value	Fill white spaces with the numerical value	Fill white spaces with the numerical value	Fill white spaces with the numerical value
	If relevant, fill the orange spaces with an explanation	If relevant, fill the orange spaces with an explanation	If relevant, fill the orange spaces with an explanation	If relevant, fill the orange spaces with an explanation
Desired				
Sol1.0				
Sol1.1				
Sol2.0				
Sol2.1				

Figure 40 – Template for Save's model

Version	A	B	C	D	Comments
Current					
Desired					
Sol1.0					
Sol1.1					
Sol2.0					
Sol2.1					

Figure 41 - Template for Parasuraman's model

	Mechanical	Cognitive
Current	Fill white spaces with the numerical value	Fill white spaces with the numerical value
	If relevant, fill the green spaces with an explanation	If relevant, fill the green spaces with an explanation
Desired		
Sol1.0		
Sol1.1		
Sol2.1		
Sol2.1		

Figure 42 - Template for Frohm's qualitative model

	Mechanical	Cognitive	Comments
Current			
Desired			
Sol1.0			
Sol1.1			
Sol2.0			
Sol2.1			

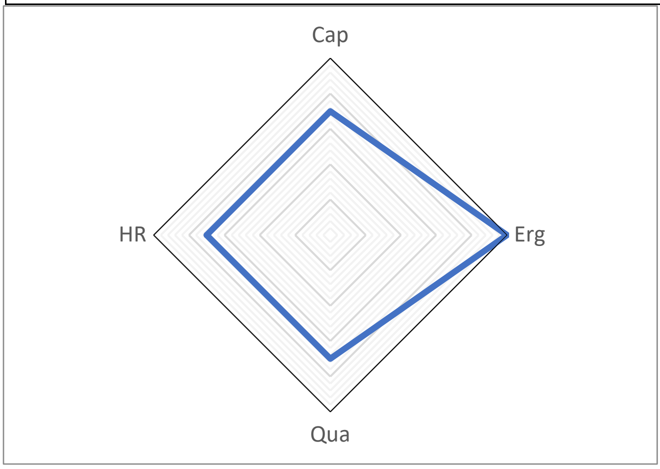
Figure 43 - Template for Frohm's quantitative model

Sheet 5—Solution FMEA, to be copied for every solution

The template is the same as sheet 2.

Appendix G—Overview of stakeholders Q

Function	Production Manager PD2	
Role	Designer	
Goal	**Score**	**Out of**
Cap	7	10
Erg	10	10
Qua	7	10
HR	7	10



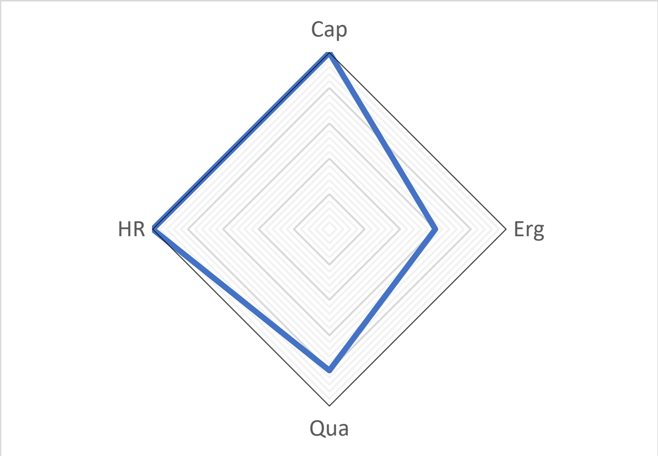
Perceptions

- PD2 has a higher complexity due to working with 3d set-ups instead of 2d like in PD1
- Additionally, PD2 has a unique process whereas PD1 performs operations that can largely be benchmarked.
- Manual loading of reactors has many negative implications. Set-ups are made initially outside of the reactor to practice and test, and are then taken apart and replicated in the reactor (all machine downtime). A robot could be more efficient. The downside of robotization here is that reactors often have to be loaded with NPIs, for which there are no loading instructions, resulting in a judgement call from an operator. This is something that humans excel at and robots struggle with.
- Vulnerability of the material makes it hard to implement a solution with a gripper.

Interests

- Finding a solution for manual loading:
- Finding a better way to load/unload.
    - Manual loading causes errors and product rejects due to manual handling mistakes
    - Manual loading is bad for ergonomics and often doesn't comply with regulations (Dutch ARBO law)

Function	Production Manager PD1	
Role	Designer	
Goal	**Score**	**Out of**
Cap	10	10
Erg	6	10
Qua	8	10
HR	10	10



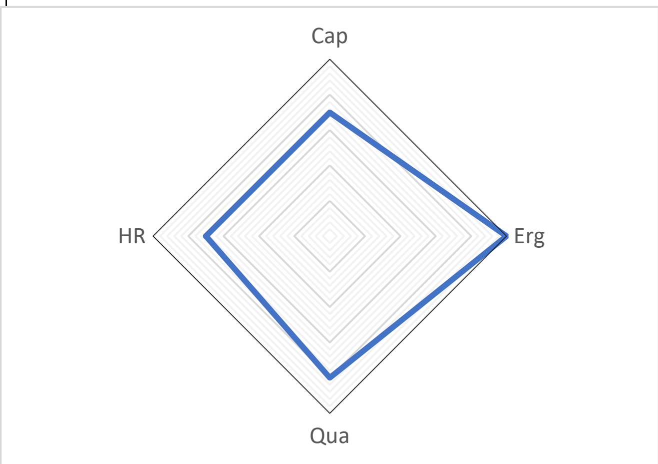
Perceptions

- Plans for automation are quickly put on hold due to the lack of focus surrounding automation.
- E.g. a project done by an intern on automatically switching tooltips, which has a great ROI, has been researched quite extensively and only constitutes a small investment (the machines already have the technical capability for this, but the module must be installed). This is still not implemented although there is no good argument not to.

Interests

- Flexibility of production must always be taken into account due to the high number of NPIs.
- Long-term projections must be accounted for. Investments that work on the short-term but limit you on the long-term may not always be desired.

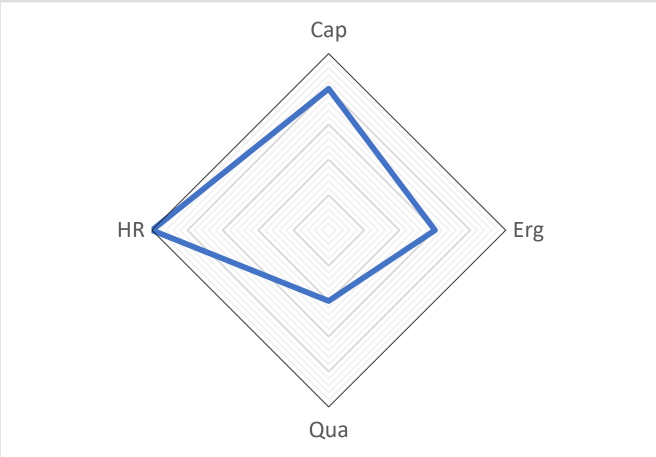
Function	COO	
Role	Decision maker	
Goal	**Score**	**Out of**
Cap	7	10
Erg	10	10
Qua	8	10
	7	10



Perceptions

- The slow way of implementing plans is frustrating.
- Disagrees that there is a lack of vision. After some nuancing we agreed that there is a vision in general, but not specifically with regards to automation and/or mechanization.
- The goal should be described as the roadmap, the investments should be seen as the means to reach the goal. In other words, the roadmap must paint a picture of how production should run, and then the investments are the way we will incrementally improve the situation.
- The biggest problem is ergonomics, because safety is always number one.
- Quality is the unique selling point of Q, it mustn't degrade.
- Management must keep pushing for automation activities to be implemented.

Function	Strategic Logistics Management	
Role	Distant passive	
Goal	**Score**	**Out of**
Cap	8	10
Erg	6	10
Qua	4	10
HR	10	10



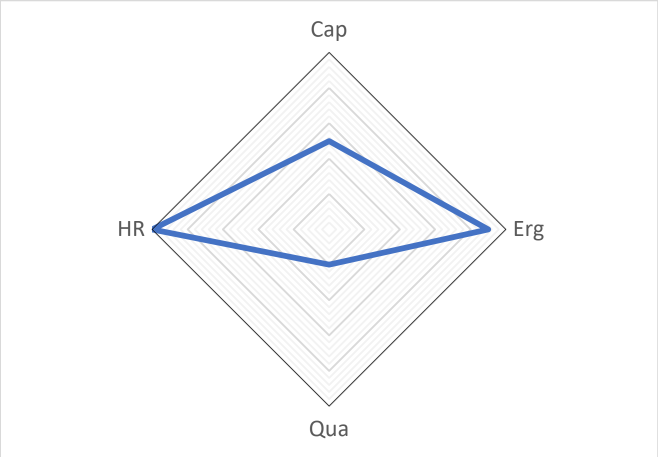
Perceptions

- Most activities revolve around crisis management. Long-term goals have been set but with the current 'firefighter' attitude there are no resources for planning to achieve these goals.
- The company culture is that costs and investments should be made very carefully. This limits improvement projects that may be desirable by everybody but still don't happen because it seems too costly to the management.

Interests

- Predictability is the most important interest, because it makes planning easier and therefore will always increase efficiency, even when other things, such as lead-time, decrease.
  - Process stability --> predictability
  - Improving ergonomics --> avoiding absenteeism --> more predictability
  - Improving workers' motivation --> more predictability
- Lead-time reductions also have high importance

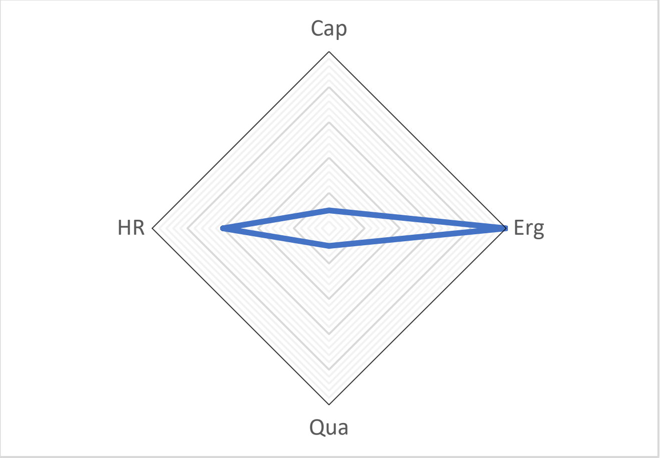
Function	Product Design & Engineering Manager	
Role	Decision maker	
Goal	**Score**	**Out of**
Cap	5	10
Erg	9	10
Qua	2	10
HR	10	10



Perceptions

- Engineers think in solutions, problems can always be discussed constructively on that department.
- Automated systems will never be able to handle 100% of products, this is not always necessary, if you reach 80%, then the other 20% can run with operators instead of autonomously. If there is a significant increase in productivity then it's worth it.

Function	EHS	
Role	**Distant passive**	
Goal	**Score**	**Out of**
Cap	1	10
Erg	10	10
Qua	1	10
HR	6	10



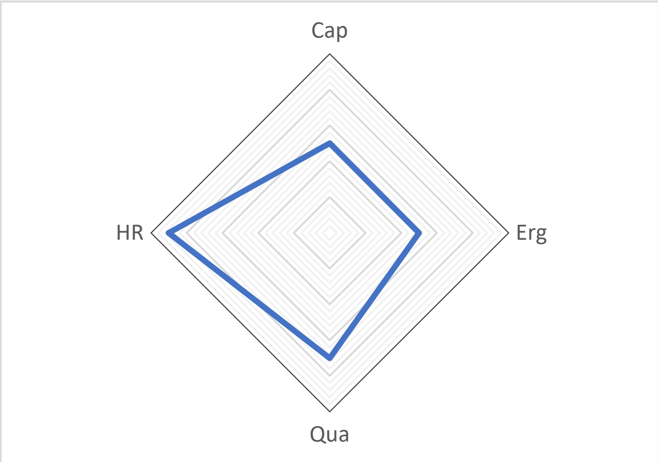
Perceptions

- Handling is an increasing problem, trend is that products get bigger, the red bull (coated) is already 18 kg.
- Another trend that exacerbates this is that employees' average age is increasing, therefore limiting the amount of physical strain they can handle.
- Yet another problematic trend is that employees should be able to work for more years as the age of retirement increases. This means that the load should be shorter to compensate.
- The biggest challenge is to set-up robots such that they can take over analytical skills from humans (e.g. loading a reactor).
- At Q, automation is absolutely necessary, especially in the PD2, where the biggest problems reside.

Interests

- Improvements must be thought through with a broad view of the process. In other words, improvements should not only make that specific step quicker, but should yield a result in the overall process.

Function	HR Manager	
Role	Distant passive	
Goal	**Score**	**Out of**
Cap	5	10
Erg	5	10
Qua	7	10
HR	9	10



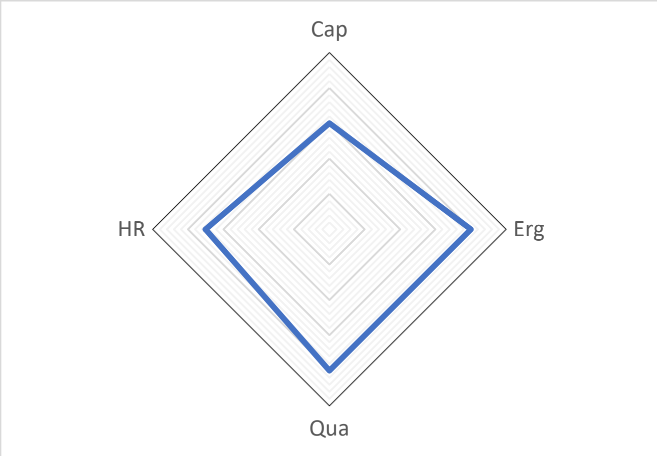
Perceptions

- PD2 has open vacancies that are hard to fill, on PD1 it is currently still fine but barely.
- PD2 has more and more overloaded workers physically, and the willingness to do overtime is decreasing, putting even more strain on the workload and capacity.
- Automating doesn't mean people get fired, this is often how operators perceive it, but will not happen. We will produce more with the same people rather than produce the same with less people; tasks will merely change, not disappear. It is crucial to ensure that this is how it is perceived, by engaging operators in the discussion.
- Working with five generations in one company brings about challenges in perception of automation.
- Snowball: more absenteeism lead to a higher workload leads to more absenteeism.

Interests

- Mechanization has to bring about changes in behavior, this is hard to control, i.e. you can make all sorts of instructions on how to use a gripper, but employees will likely use it however suits them best. In order to have operators adhere to guidelines more, it is important to involve them in the system design to see how they want to use the system.
- Problem should have been identified and acted upon a long time ago already; we are late. Now action should be taken sooner rather than later.

Function	BB: Operational Excellence	
Role	Designer	
Goal	**Score**	**Out of**
Cap	6	10
Erg	8	10
Qua	8	10
HR	7	10



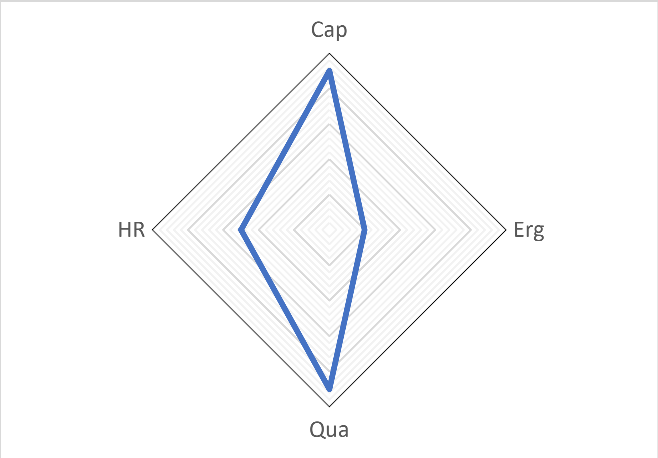
Perceptions

- Long-term plans don't usually work because of time constraints and priorities. To control project dissemination, think about investment timing (long lead-time also for investments) and assigning realistic responsibilities.
- Efficiency gains can be achieved through operator mentality and structural changes. E.g. In the cleanroom it is very hard for a shift-leader to verify if operators are doing their tasks according to the instructions, and it's harder to support a communal culture wherein employees think and work together. An open floor (such as PD1 currently already has and even more so with the new building) promotes the required level of social control more and allows for managers to take more effective control of the process. A solution to this could be to assign in each department a foreman who takes initiative on improving process flow, although it is questionable if this would be effective.
- A fear of a low utilization exists at Q, this is one of the causes for the high lead time currently experienced.

Interests

- The focus should be on reducing rejected products, as this will automatically lead to higher capacity.

Function	CFO	
Role	Distant passive	
Goal	**Score**	**Out of**
Cap	9	10
Erg	2	10
Qua	9	10
HR	5	10



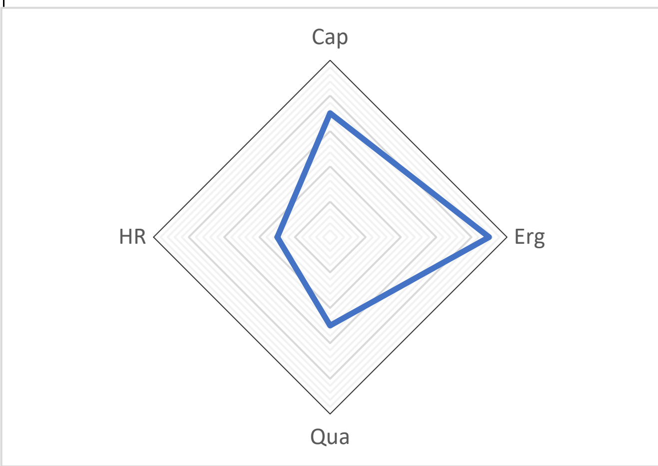
Perceptions

- Automation on operations is necessary. Their role in this is supporting in the sense that they can provide calculations (e.g. ROIs) on certain projects.
- For an innovative company like Q it should be obvious that automation is important and should get a good share of attention and investment.
- By automating we can rely less on human operators, making us more prepared for future growth since the harsh recruitment environment is way less of a roadblock for expansions.
- By improving ergonomic conditions, recruitment can become easier because we make Q a more desirable place to work.
- ROI can be hard to express when it comes to improved ergonomics. It might be better to approach these types of activities through the increase in quality that goes hand in hand with improvements in ergonomics (i.e. quality gains are more easily quantified than are ergonomic gains). It is perfectly fine to supplement an investment plan with qualitative arguments when it is reasonable to state that they any attempt at quantification is inaccurate by nature.

Interests

- All investments above a certain limit must contain an ROI calculation. This also goes for grouped investments (e.g. 1 balancer might not go above the threshold while the same project for 20 balancers does).

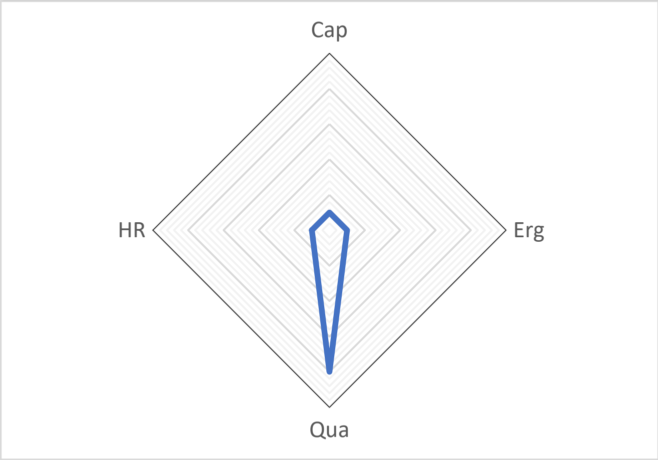
Function	Process Technology Manager	
Role	Decision maker	
Goal	**Score**	**Out of**
Cap	7	10
Erg	9	10
Qua	5	10
	3	10



Perceptions

- By creating a safe process, all other goals will also be satisfied since you will be forced to think constructively about your processes, thereby cleaning them up.
- Control of the outcome of the roadmap should be a focus while designing the activities, since there is a pattern of making plans that eventually fall through.

Function	Maintenance	
Role	Distant passive	
Goal	**Score**	**Out of**
Cap	1	10
Erg	1	10
Qua	8	10
HR	1	10



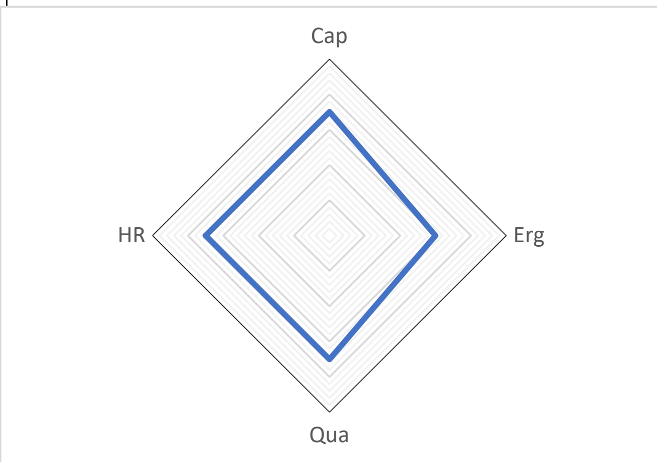
Perceptions

- The mechanics are generally busy, innovating has the risk that the workload becomes too high initially when new systems are installed at the same time, so spread it out over time in order not to exhaust resources.
- Automated systems are expected to need many software mechanics, of which Q has three. This must be considered and planned for accordingly when complex systems requiring much software engineering are implemented to not overload the mechanics and cause downtime of systems.
- These new activities can be considered a challenging and fun new task for maintenance engineers.
- The mechanics currently employed are capable in general, but may require specific training when automated systems are used.
- More and more complaints from operators are received, and he expects that absenteeism due to physical constraints will become more common if nothing changes.
- Certain tasks must always be performed by human operators, simply because they are more suitable for it and are more flexible.

Interest

- Work load for maintenance must be planned and controlled.
- Applied automated systems must be reliable, as they run autonomously and can therefore cause a complete stop of production in case they break down. System suppliers must offer support services such as training and/or repairs.
- Timing of systems must be considered in relation to other relevant activities that impact the workload and other aspects of the maintenance department.
- Flexibility in the systems is desirable, so that they may be more broadly applicable.

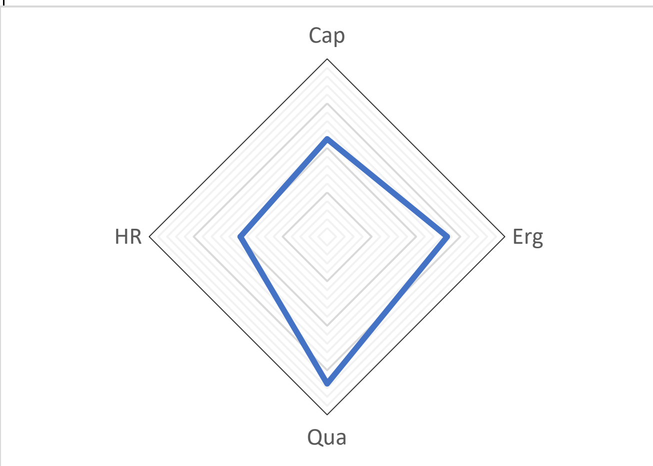
Function	Shiftleader PD1	
Role	Close passive	
Goal	**Score**	**Out of**
Cap	7	10
Erg	6	10
Qua	7	10
[illegible]	7	10



Interests

- Focus on the PD1 department should not be on ergonomics, but rather on quality
- Quality improvements can be best achieved by less manual contact

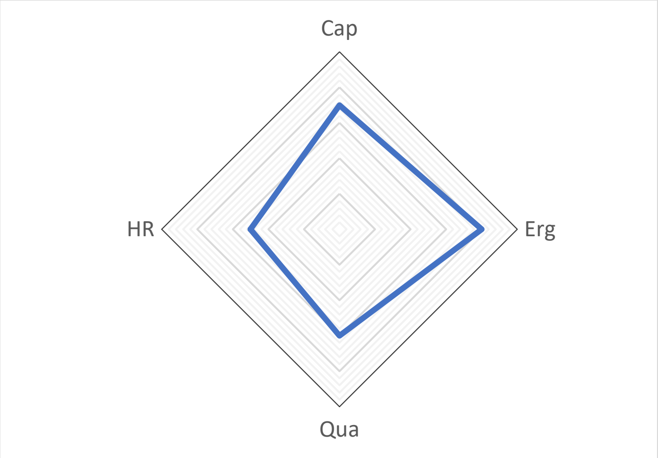
Function	Operators PD1	
Role	Close passive	
Goal	**Score**	**Out of**
Cap	22	40
Erg	27	40
Qua	33	40
	19,5	40



Interests

- Quality is the most important value, the focus of operators is on making sure the quality is high and trying to reduce rejects.
- Problems with quality are caused by the way they are supposed to perform certain tasks, improvements can be made here.
- Improvements on the ergonomic aspect are welcome, but it’s not a huge problem currently for their tasks.

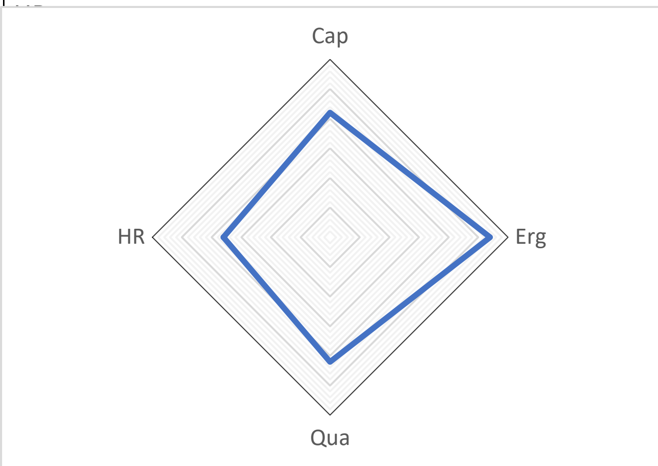
Function	Shiftleader PD2	
Role	Close passive	
Goal	**Score**	**Out of**
Cap	7	10
Erg	8	10
Qua	6	10
HR	5	10



Interests

- Data must be streamlined, because a lot of data is entered in different places, which makes dealing with it tedious.
- Short term change is required, but employees must understand that these activities simply take time.

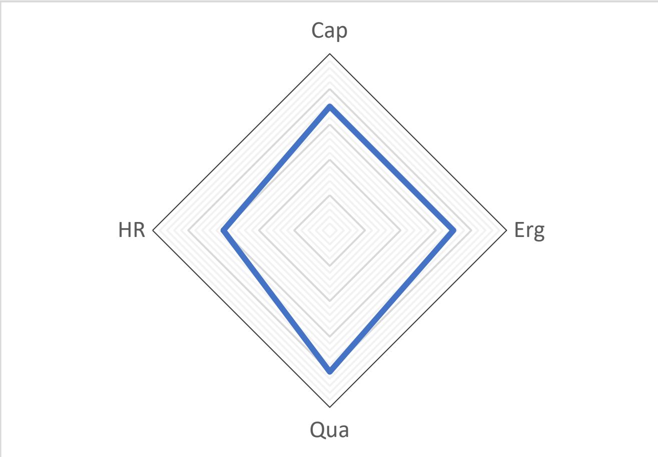
Function	Operators PD2	
Role	Close passive	
Goal	**Score**	**Out of**
Cap	21	30
Erg	27	30
Qua	21	30
HR	18	30



Interests

- Mechanization systems must be flexible, so employees with, for example, different lengths can use the same system.
- Physical strain is a big problem, and the products are only getting bigger. The main focus should be on reducing the amount of manual operations
- Changes must happen on short term, since already a lot of ergonomic problems exist in operators, mostly shoulder related.
- The work is not only straining, but also very repetitive. If a robot can perform a repetitive task it would make work more interesting for operators.

Function	Project Manager Operational Excellence	
Role	Designer	
Goal	**Score**	**Out of**
Cap	7	10
Erg	7	10
Qua	8	10
HR	6	10



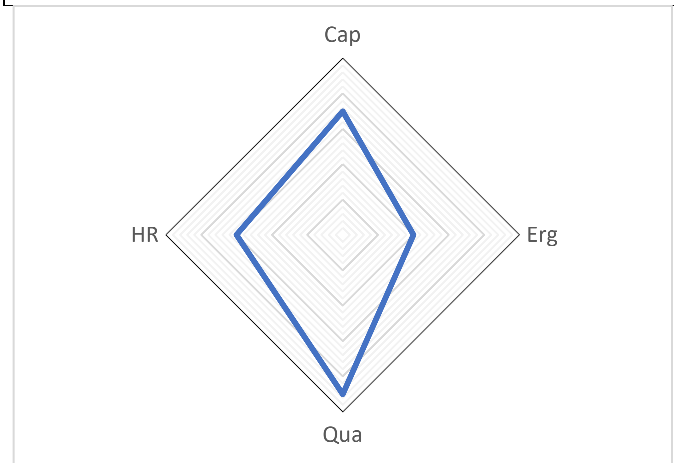
Perceptions

- Employees won't have any problems with mechanization, since it only serves to improve their working conditions while leaving them responsible for the same tasks. On the other hand, automation may pose an actual threat to them (whether real or just in their perception).
- Expects resistance to come later when plans become more concrete.
- More space may give more flexibility for movement of systems and therefore provide more flexibility in their applicability. Because Q is building a new building, there will be more space.
- Operators don't always adhere to guidelines in certain production steps (e.g. taking product out of the reactor before having been annealed to the predetermined temperature, leaving fingerprints on the unhardened coating).
- Some parts of the PD2 have a rather messy work environment.

Interests

- Most important is increasing efficiency.
- When reducing lead-times of certain operations, look broadly in the process as to not simply create a new bottleneck with little overall gains.
- Flexibility towards the future is crucial, look at long-term trends.

Function	BB: Technology Leadership	
Role	**Designer**	
Goal	**Score**	**Out of**
Cap	7	10
Erg	4	10
Qua	9	10
HR	6	10



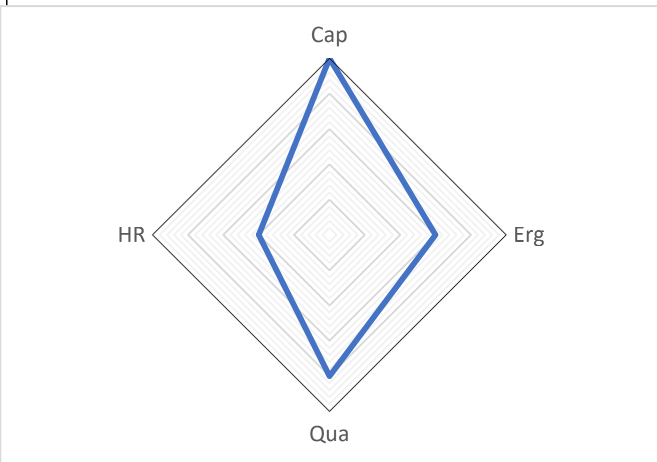
Perceptions

- There is no differentiation of measurement reporting for different products, this is inefficient since many measurements are done without being required by the client.
- Also on product differentiation: costs are attributed per product category, not per product type. This means that the margins that we work with are not specific for the product, but rather an aggregate of the category. Automation can reduce this since it standardizes factors such a runtime and, quality and generally costs. By making this more standard over product types, the aggregate numbers become more accurate as the variability in the process is lower.
- Manual operations cause a high process variability.
- Because of company culture, there seems to be a fear of presenting ambitious and uncertain investment plans.

Interests

- Focus on product quality, as this is the main USP that keeps Q ahead of competition (who often have smaller lead-times and are cheaper). Quality is also the main expression of level of technology leadership.
- Future planning must consider all risks. E.g. trends in demand may be too high due to customers moving to competitors if they stop accepting our long lead-times, also; competitors might close the gap in product quality, which would reduce our competitive advantage.

Function	Process Technology	
Role	Designer	
Goal	**Score**	**Out of**
Cap	10	10
Erg	6	10
Qua	8	10
	4	10



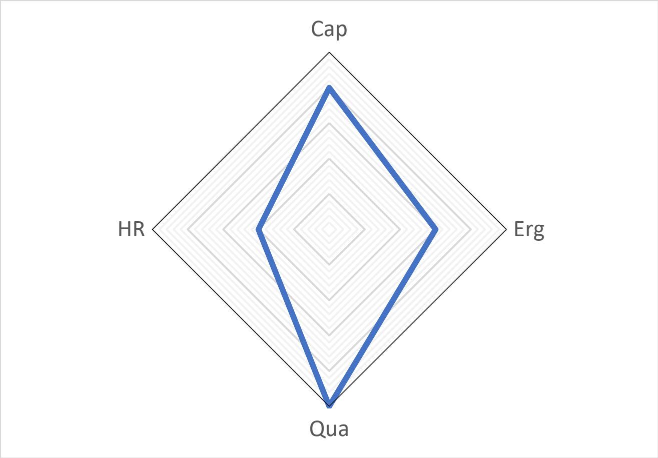
Perceptions

- Sometimes a big new system isn't necessary, as the same impact can be made with a small but smart change in how a process is set-up.
- Every operator may handle a product in a slightly different way, this already causes significant changes in the final product

Interests

- The focus should be on increasing production capacity, because this is what has most potential to bring the company to the next level.
- Is currently working on several automation activities, so naturally is interested mostly in the outcomes of these.

Function	Process Technology	
Role	Designer	
Goal	**Score**	**Out of**
Cap	8	10
Erg	6	10
Qua	10	10
HR	4	10



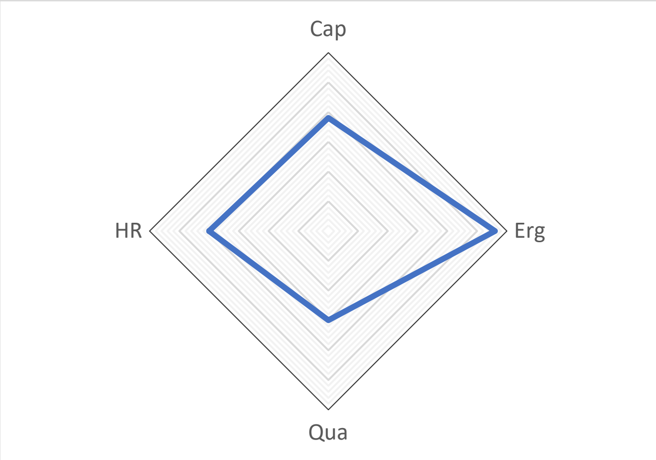
Perceptions

- A good report on the ergonomic situation (ARBO report) was made recently. This elicits the problems in this aspect, as the national limits for physical strain are exceeded.
- When changing one part of the process, one must be careful not to negatively affect another part. Think about how a single change may affect surrounding processes so that the big picture becomes better instead of local improvements.

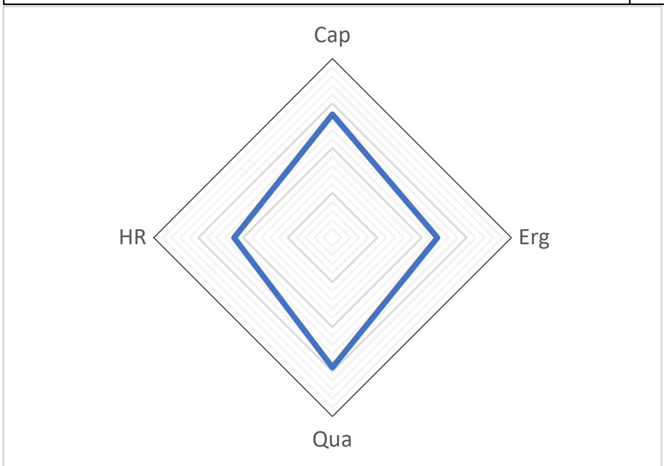
Interests

- Focus on quality, because this is essentially what Q sells.
- Is currently working on several automation activities, so naturally is interested mostly in the outcomes of these.

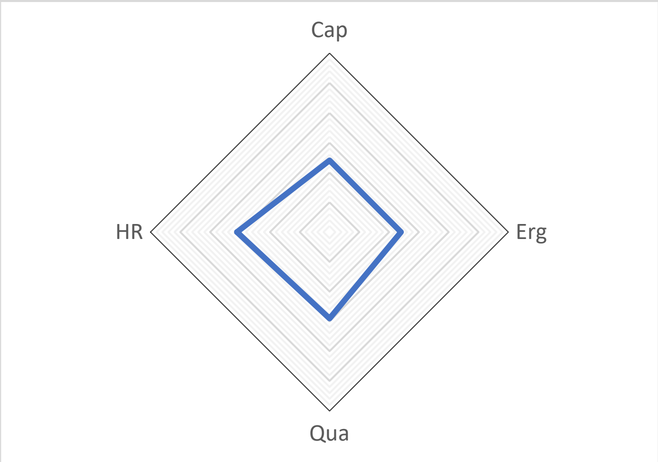
Decision makers		
Goal	**Score**	**Out of**
Cap	19	30
Erg	28	30
Qua	15	30
HR	20	30



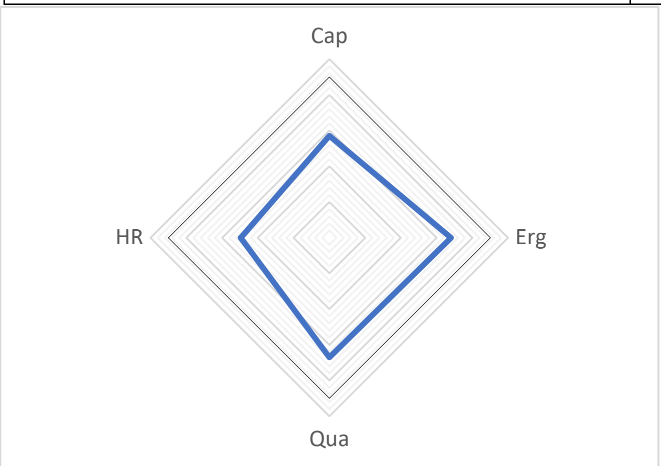
Designers		
Goal	**Score**	**Out of**
Cap	55	80
Erg	47	80
Qua	58	80
HR	44	80



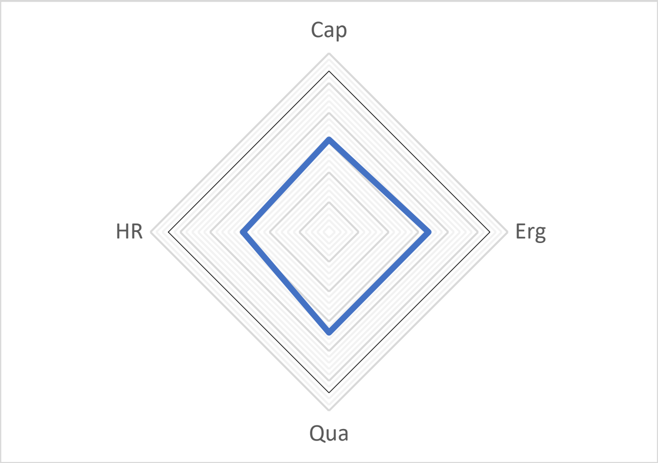
Distant passives		
Goal	**Score**	**Out of**
Cap	24	60
Erg	24	60
Qua	29	60
HR	31	60



Close passives		
Goal	**Score**	**Out of**
Cap	57	90
Erg	68	90
Qua	67	90
HR	49,5	90



All		
Goal	**Score**	**Out of**
Cap	155	270
Erg	167	270
Qua	169	270
HR	144,5	270



Appendix H—Example of all LoA taxonomies for wiping robot

For the wiping process step, one solution has been worked out in a step-by-step process improvement plan, wherein each solution expands on its predecessor. Each proposed LoA model is then tested using the wiping operation.

Current	Operator has full responsibility over the process. When a work order is received, he places the product on the table manually and wipes it manually, based on his own judgement of the situation
Optimal	The product feed to the wiping robot as well as the wiping procedure are automated so that no operator needs executive responsibilities. The operator will be used purely for control.
Sol1.0	The operator receives the work order and places the product in front of the robot. The robot waits for the operator's start signal, upon which it performs a safety check. When all is clear, the robot starts the operation after determining the starting position. The robot is programmed to always perform the same programme, and is therefore only usable for 1 product.
Sol1.1	The robot has multiple pre-programmed wiping procedures and is now applicable for multiple products. The operator must indicate which product is
Sol1.2	The robot is now capable of deciding which product it has in front of it, and needs no more operator instruction on which wiping procedure to start. It still waits for the start-signal from an operator.
Sol1.3	The robot is fed the products through an automated system, such as a conveyor belt, which places the product in the working area of the robot.

Figure 44 - the solutions explained

	A	B	C	D
Current	0	0	0	0
	No information about the process is formally gathered. Information is only gathered through the human's sensory organs.	Information processing is purely manual and is not recorded in any way.	Decisions are made ad-hoc by the operator.	The operation is executed by an operator with little control over the process.
Desired	5	5	5	6
	visually or through any other means gather information about the product that is placed in front of it, as well as be aware of its direct surroundings. This should be done at the design level without operator interference.	The robot must be able to analyse the gathered data into a judgement on which product (type) it is dealing with.	Based on the assessment of product type, the right wiping procedure must be selected. This happens without operator interference. Another decision to be made by the robot is whether or not the situation is safe.	The wiping action should be done autonomously by the robot, while the operator needs to retain the power to stop the robot at any moment if he assesses that this is necessary.
Sol1.0	5	3	0	4
	Even for this simple version of this robot, all data about the environment must be gathered for safety reasons. Information on the product location must also be acquired, but this happens on demand.	When the operator presses the start button, the analysis of environment and product location is performed.	The robot makes no decision, but is rather told what to do.	Execution happens autonomously after the human gives a start-signal. The human must be able to interupt the robot.
Sol1.1	5	4	0	4
		One higher level is reached because the operator must define parameters (which product type) to the robot before it can start.		
Sol1.2	5	5	4	4
		Maximum level is reachead here because the operator doesn't have to specify any information to the robot, it assesses the product type itself, making the data analysis autonomous.	The robot now has to make a decision on which procedure to run and informs the operator as a check.	
Sol1.3	5	5	5	6
			The desired level is reached as the robot now autonomously decides what action to take. The operator may request information from the robot about what decision it is making when desirable.	The execution now happens autonomously without an operator's start-signal.

Figure 45 - Save's model applied

Version	A	B	C	D	Comments
Current	0	0	0	0	Nothing is automated
Desired	3	3	4	5	The goal is to standardize the wiping execution itself, so it's the most important dimension
Sol1.0	1	1	1	5	The mechanization of wiping has been achieved with little data acquisition/analysis
Sol1.1	1	1	1	5	The system becomes more broadly applicable but the LoA doesn't change
Sol1.2	3	3	3	5	The robot must acquire and use data to determine which product it is dealing with
Sol1.3	3	3	4	5	The decision making is increased because the robot must decide on its own when it should start the operation

Figure 46 - Parasuraman's model applied

	Mechanical	Cognitive
Current	1	2
	The mechanical operation happens completely manually.	The operator has all cognitive responsibility, but there is a work order for each product that comes in.
Desired	7	7
	In the desired situation the robot can completely autonomously perform the wiping operation. In addition, the product will arrive to the robot not by the hands of an operator, but by a transportation system, making the supporting functions automated as well.	The robot must be capable of analysing and deciding which wiping procedure will yield the requested result on the product that the robot has in front of it.
Sol1.0	5	1
	The operation happens on request and for 1 product type only, making this a static workstation with mechanical support.	The operator is in control of the situation and makes the decisions, the robot only has to make process-supporting decisions such as decisions about safety.
Sol1.1	6	1
	The machine can now be reconfigured for different tasks, pushing it to level 6.	
Sol1.2	6	7
		A huge leap is made when the robot becomes responsible for the decision on what action to take. Suddenly the action is decided on not by human but by machine.
Sol1.3	7	7
	By including supporting functions (product handling) in the automated system, we reach level 7.	

Figure 47 - Frohm's qualitative model applied

	Mechanical	Cognitive	Comments
Current	1	1	No automation
Desired	7	6	Full automation with human supervision
Sol1.0	4	2	Mechanical main task performed by robot. The robot also checks environment and therefore needs congnitive function.
Sol1.1	4	2	Broader applicability but no increase in level of autonomy
Sol1.2	4	5	Mechanically the same, although cognitively the decision on which programme to run is now taken over.
Sol1.3	7	6	Product handeling not required anymore for this specific step, making it fully autonomous. The

Figure 48 - Frohm's quantitative model applied

Appendix I—Roadmapping tailored for and in use by Q

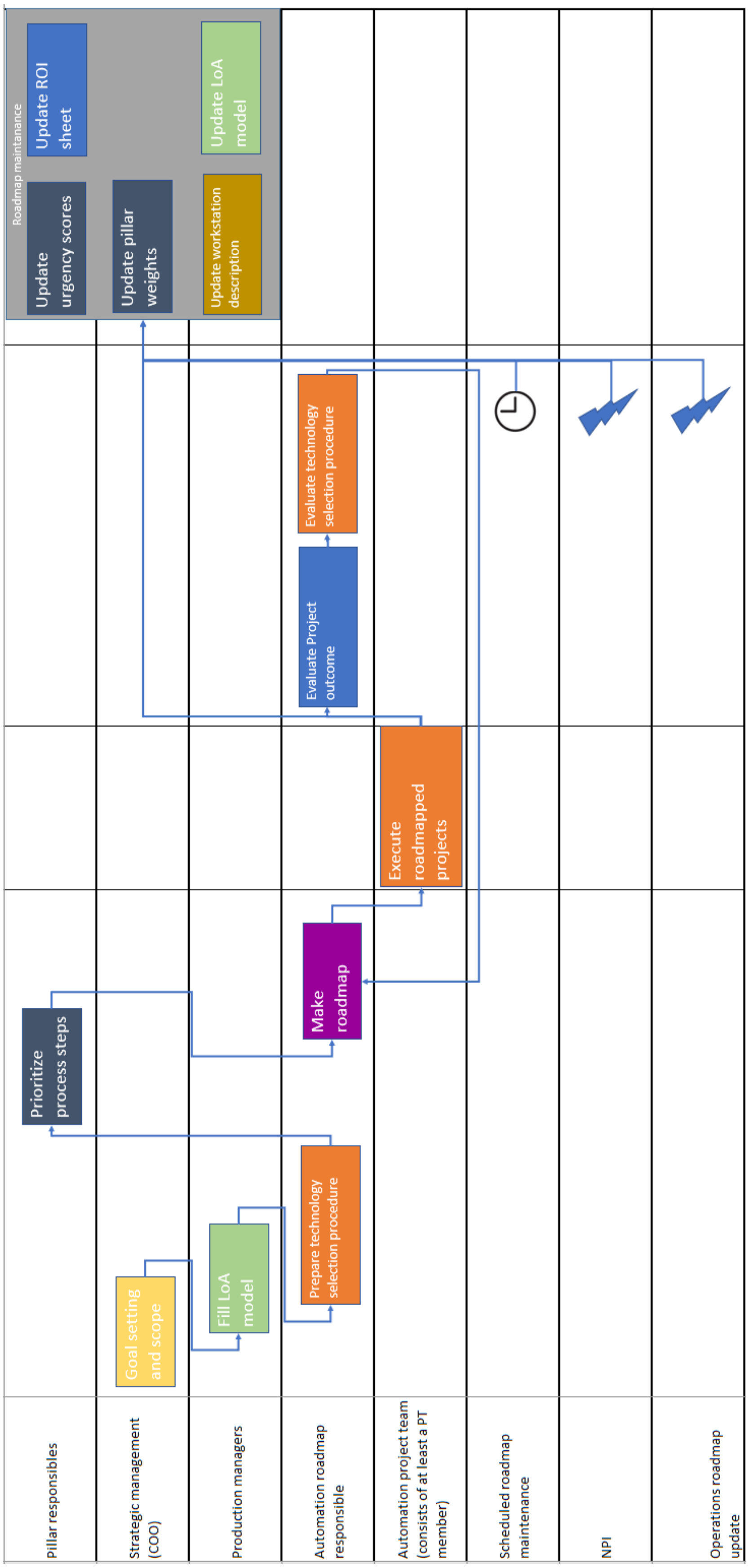


Figure 49 – the swimlanes that Q uses to define responsibilities

Appendix J—LoA taxonomy details

This section will show the four LoA taxonomies as presented by their original researchers. For two of them (Frohm qualitative and Save), the scales have a specified definition per level. The other two don't have this, as they are to be filled quantitatively based on relative comparison.

D.1—Frohm (quantitative)

LoA	Mechanical and Equipment	Information and Control
1	**Totally manual** - *Totally manual work, no tools are used, only the users own muscle power. E.g. The users own muscle power*	**Totally manual** - *The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The users earlier experience and knowledge*
2	**Static hand tool** - *Manual work with support of static tool. E.g. Screwdriver*	**Decision giving** - *The user gets information on what to do, or proposal on how the task can be achieved. E.g. Work order*
3	**Flexible hand tool** - *Manual work with support of flexible tool. E.g. Adjustable spanner*	**Teaching** - *The user gets instruction on how the task can be achieved. E.g. Checklists, manuals*
4	**Automated hand tool** - *Manual work with support of automated tool. E.g. Hydraulic bolt driver*	**Questioning** - *The technology question the execution, if the execution deviate from what the technology consider being suitable. E.g. Verification before action*
5	**Static machine/workstation** - *Automatic work by machine that is designed for a specific task. E.g. Lathe*	**Supervision** - *The technology calls for the users' attention, and direct it to the present task. E.g. Alarms*
6	**Flexible machine/workstation** - *Automatic work by machine that can be reconfigured for different tasks. E.g. CNC-machine*	**Intervene** - *The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. E.g. Thermostat*
7	**Totally automatic** - *Totally automatic work, the machine solve all deviations or problems that occur by it self. E.g. Autonomous systems*	**Totally automatic** - *All information and control is handled by the technology. The user is never involved. E.g. Autonomous systems*

Figure 50 – Frohm's scales adjusted to suit Q better

D.2—Frohm (qualitative)

Same as quantitative but without the descriptions per level per scale. In this case, the amount of levels is also not restricted to 7, but may be decided upon based on the relevant context.

D.3—Parasuraman

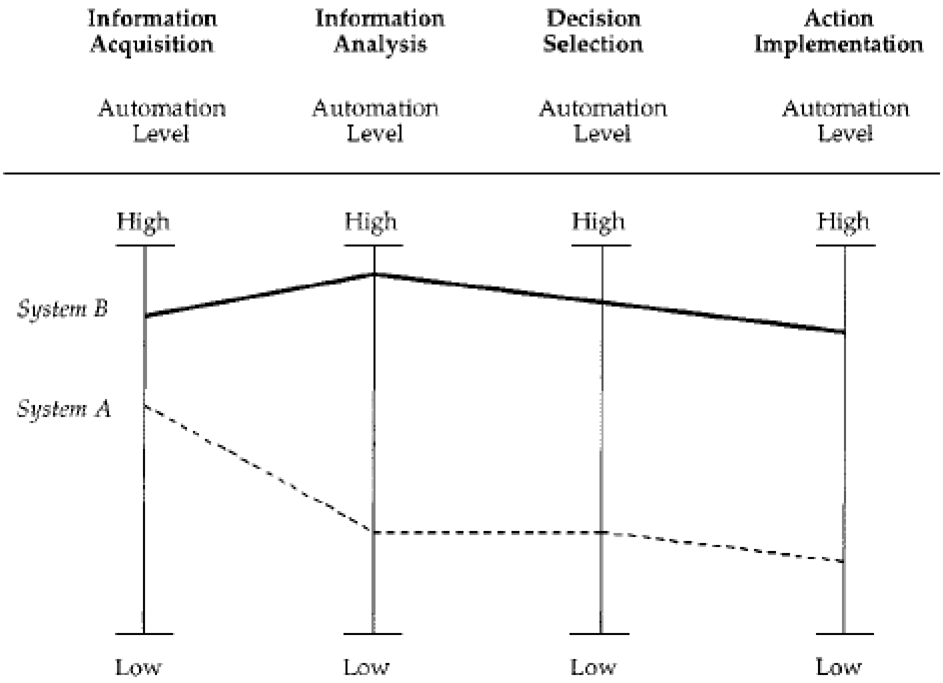


Figure 51 – Parasurama's model

D.4—Save

A **INFORMATION ACQUISITION**	B **INFORMATION ANALYSIS**	C **DECISION AND ACTION SELECTION**	D **ACTION IMPLEMENTATION**
A0 **Manual Info Acquisition**	**B0** **Working Memory Based Info Analysis**	**C0** **Human Decision Making**	**D0** **Manual Action and Control**
The human acquires relevant information on the process s/he is following without using any tool.	The human compares, combines and analyses different information items regarding the status of the process s/he is following by way of mental elaborations. S/he does not use any tool or support external to her/his working memory.	The human generates decision options, selects the appropriate ones and decides all actions to be performed.	The human executes and controls all actions manually.
A1 **Artefact-Supported Info Acquisition**	**B1** **Artefact-Supported Info Analysis**	**C1** **Artefact-Supported Decision Making**	**D1** **Artefact-Supported Action Implementation**
The human acquires relevant information on the process s/he is following with the support of low-tech non-digital artefacts. *Ex. 1) Identification of aircraft positions on an aerodrome/airport according to Procedural Air Traffic Control rules and without use of radar support.*	The human compares, combines, and analyses different information items regarding the status of the process s/he is following utilising paper or other non-digital artefacts. *Ex. 1) Use of flight strips to compare altitudes/levels/pl. times of different aircraft and to pre-plan future traffic.*	The human generates decision options, selects the appropriate ones and decides all actions to be performed utilising paper or other non-digital artefacts.	The human executes and controls actions with the help of mechanical non-software based tools. *Ex. 1) Use of a hammer or leverage to increase the kinetic energy of human gesture.* *Ex. 2) Use of a mechanical or hydraulic rudder to achieve a change in direction.*
A2 **Low-Level Automation Support of Info Acquisition**	**B2** **Low-Level Automation Support of Info Analysis**	**C2** **Automated Decision Support**	**D2** **Step-by-step Action Support:**
The system supports the human in acquiring information on the process s/he is following. Filtering and/or highlighting of the most relevant information are up to the human. *Ex. 1) Identification of aircraft positions in the airspace by way of Primary Radar working positions.*	Based on user's request, the system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed. *Ex. 1) Activation by ATCOs of Speed Vectors for specific tracks on the CWP, in order to anticipate potential conflicts in a defined time frame.*	The system proposes one or more decision alternatives to the human, leaving freedom to the human to generate alternative options. The human can select one of the alternatives proposed by the system or her/his own one. *Ex.1) AMAN visualization of the proposed sequence of aircraft.*	The system assists the operator in performing actions by executing part of the action and/or by providing guidance for its execution. However, each action is executed based on human initiative and the human keeps full control of its execution. *Ex. 1) The aural and visual component of TCAS RA in current TCAS II version 7.0 (also LOA C5)*

Figure 52 - Save's model (1)

A3 **Medium-Level Automation Support of Info Acquisition**	B3 **Medium-Level Automation Support of Info Analysis**	C3 **Rigid Automated Decision Support**	D3 **Low-Level Support of Action Sequence Execution**
The system supports the human in acquiring information on the process s/he is following. It helps the human in integrating data coming from different sources and in filtering and/or highlighting the most relevant information items, based on user's settings. *Ex. 1) CWP allowing ATCOs to set flight level filters to display only certain traffic on the screen.*	Based on user's request, the system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user. *Ex. 1) ERATO Filtering and What-if function.* *Ex 2). VERA Tool to display the closest point of approach between two aircrafts.*	The system proposes one or more decision alternatives to the human. The human can only select one of the alternatives or ask the system to generate new options.	The system performs automatically a sequence of actions after activation by the human. The human maintains full control of the sequence and can modify or interrupt the sequence during its execution. *Ex. 1) Explicit initiation of an electronic coordination with adjacent sector via digital input (replacing use of telephone).*
A4 **High-Level Automation Support of Info Acquisition**	B4 **High-Level Automation Support of Info Analysis**	C4 **Low-Level Automatic Decision Making**	D4 **High-Level Support of Action Sequence Execution**
The system supports the human in acquiring information on the process s/he is following. The system integrates data coming from different sources and filters and/or highlights the information items which are considered relevant for the user. The criteria for integrating, filtering and highlighting the relevant information are predefined at design level but visible to the user. *Ex.1) D-TAXI tool (including graphical route information)*	The system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed, based on parameters pre-defined by the user. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user. *Ex. 1) MTCD visual alerts (allowing some tuning of parameters by the user)*	The system generates options and decides autonomously on the actions to be performed. The human is informed of its decision. *Ex.1) Aural and visual component of TCAS RA in current TCAS II version 7.0 (also LOA D2)*	The system performs automatically a sequence of actions after activation by the human. The human can monitor all the sequence and can interrupt it during its execution. *Ex.1) Acknowledgment by pilot of a clearance received trough CPDLC (data-link) and automatically sent to FMS and autopilot.* *Ex. 2) Autopilot following the FMS trajectory.*

Figure 53 - Save's model (2)

A5 **Full Automation Support of Info Acquisition**	B5 **Full Automation Support of Info Analysis**	C5 **High-Level Automatic Decision Making**	D5 **Low-Level Automation of Action Sequence Execution**
The system supports the human in acquiring info on the process s/he is following. The system integrates data coming from different sources and filters and/or highlights the information items considered relevant for the user. The criteria for integrating, filtering and highlighting are predefined at design level and not visible to the user	The system performs comparisons and analyses of data available on the status of the process being followed based on parameters defined at design level. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user. *Ex. 1) STCA visual and aural alerts.*	The system generates options and decides autonomously on the action to be performed. The human is informed of its decision only on request. (Always connected to to an *Action Implementation* level not lower than D5.)	The system initiates and executes automatically a sequence of actions. The human can monitor all the sequence and can modify or interrupt it during its execution. *Ex. 1) Implicit initiation of an electronic co-ordination with adjacent sector as agreed exit conditions (according to Letter of Agreement) cannot be met anymore after changes to the a/c trajectory has been made.*
		C6 **Full Automatic Decision Making**	D6 **Medium-Level Automation of Action Sequence Execution**
		The system generates options and decides autonomously on the action to be performed without informing the human. (Always connected to an *Action Implementation* level not lower than D5.)	The system initiates and executes automatically a sequence of actions. The human can monitor all the sequence and can interrupt it during its execution. *Ex.1) TCAS AP/FD during a corrective TCAS RA.*
			D7 **High-Level Automation of Action Sequence Execution**
			The system initiates and executes a sequence of actions. The human can only monitor part of it and has limited opportunities to interrupt it.
			D8 **Full Automation of Action Sequence Execution**
			The system initiates and executes a sequence of actions. The human cannot monitor nor interrupt it until the sequence is not terminated.

Figure 54 - Save's model (3)