Bluetooth based andon system

- A case study at Nock Massiva Trähus

Bachelor's Thesis in the Bachelor's Programme Industrial management and production engineering.

KONRAD POHL
JOHANNA BERGQVIST

Department of Technology Management and Economics
Division of Service Management and Logistics
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KONRAD POHL
JOHANNA BERGQVIST

Gunnar Stefansson, Chalmers
Johanna Hesslund, Virtual Manufacturing

Department of Technology Management and Economics
Division of Service Management and Logistics
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JOHANNA BERGQVIST

KONRAD POHL

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Department of Technology Management and Economics
Division of Service Management and Logistics
Chalmers University of Technology
SE-412 96 Gothenburg, Sweden
Telephone: + 46 (0)31-772 1000

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Photo of module wooden houses at Nock Massiva Trähus (Author's own copyright).

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Konrad Pohl

Johanna Bergqvist

Chalmers University of Technology

Gothenburg, Sweden

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JOHANNA BERGQVIST & KONRAD POHL
Department of Technology Management and Economics
Division of Service Management and Logistics
Chalmers University of Technology

ABSTRACT

With a background in the construction industry’s need to become more efficient and the ongoing modernization of the world industries, the potential of BLE technology has been tested for interpersonal communication in an industrial environment. Specifically, this project has built an andon system with Bluetooth buttons at Nock Massiva Trähus (NMT), a producer of wooden residential block modules on an assembly line. This was done to help NMT grow as an organization and to adopt lean philosophy.

The project consisted of specifying requirements of a modern andon system, develop and test such a system and to forecast the system’s future. That is, to predict effects caused by the system and to propose its further development.

In conclusion, the created Bluetooth based andon system depends on a strong company culture to add maximal value to its enterprise. Bluetooth low energy technology is deemed fitting for the purpose of introducing digital tools for analysis and a culture of continuous improvements in an organization. It requires few resources before benefits can appear and this enables technological and organizational development to take place simultaneously, something that leverages technology’s utility in its enterprise.

The discussion is finalized with a discussion of Bluetooth button’s potential to operate in industrial environments and a model for simultaneous lean transformation and digitization is proposed.

Keywords: Lean digitalization, Andon, Bluetooth Low Energy

SAMMANFATTNING

Med bakgrund i byggbranschens behov av rationaliseringar och den pågående moderniseringen av världens industrier, testas Bluetooth-tekniks potential för mellanmänsklig kommunikation i industriell miljö. Specifikt har det här projektet byggt ett andonsystem med hjälp av Bluetooth knappar på Nock Massiva Trähus (NMT), en tillverkare av flerbostadshus på produktionslinje. Detta gjordes för att hjälpa dem i deras organisationsutveckling med att anamma lean produktion.

Projektet har omfattat att fastställa kravspecifikation, utveckla och testa ett system, utvärdera och föreslå framtida aspekter av systemet. Alltså, att förutsäga effekter på organisationen och föreslå fortsatt utveckling av systemet utifrån de erfarenheter som gjorts.

Resultatet tyder på att Bluetooth-teknik har potential för att kunna implementeras tidigt i organisationers utveckling utan att kräva stora resurser. För detta syfte rekommenderas att tekniken initialt används till ett välavgränsat syfte för att sedan användas till att bearbeta organisationskultur samtidigt som kommunikationssystemet utvecklas vidare och flera syften behandlas. Detta gör att Bluetooth-knappar passar väl in i lean-principer om att inte överinvestera i IT, särskilt inte innan kulturen för att använda det finns på plats i organisationen.

Vidare säger resultatet att de största svårigheterna i att lyckas med implementering av teknologi i ett företag finns i arbetskulturen. Ett andonsystem kräver att kulturen uppmuntrar att rapportera problem och att alltid eftersträva en bättre organisation för att de ska kunna bidra med nytta till en organisation.

Arbetet avslutas med att diskutera Bluetooth-knappars potential i industriell miljö och med en föreslagen modell för att lyckas med digitala lean-transformationer.

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Terms

The following abbreviations and terms are used in this paper.

Andon – *Japanese,* A communication system for problems on a production line, see 3.3.
Avix - a software for standardising work assignments.
BBAS - Bluetooth Based Andon System, the technological product produced in this project.
BLE - Bluetooth Low Energy, see 3.4.
CAD/CAM - Computer Aided Design/Manufacturing
CIM/CIE - Computer Integrated Manufacturing/Enterprise, see 3.5.
Jidoka – *Japanese,* the principle to build in quality into the production.
Kaizen - *Japanese,* A concept of working continuously with improvements in lean, see 3.1.2
Lean – A concept for creating excellent organizations, see chapter 3.
NMT - Nock Massiva Trähus, the company where the BBAS is implemented.
PDCA – Plan-Do-Check-Act, see 3.7.
RFID – Radio-Frequency Identification.
VM - Virtual Manufacturing, the consultancy company helping NMT.

1 Introduction

This chapter presents a background, problem description, purpose, limitations and specified purpose to and of the study.

1.1 Background

"If the price of a Volvo would have followed the prices of the construction industry, it would cost more than twice of today's price" - Fredrik von Platen, former deputy director-general of the Swedish National Board of Housing, Buildings and Planning. (2013, author's translation) Construction processes are in great need of rationalizations and although efforts are made to make them more efficient, much work remains. Off-site production of buildings has recently started, several enterprises produce houses on production lines today. However, this way of constructing buildings is still in its early stages and such enterprises are yet to show their full potential.

As experienced production lines have been streamlining their enterprises for a long time there ought to be many things to learn from preceding actors on how to create a successful production line. A concept that has attracted a lot of attention for streamlining organizations and production lines over the last decades is lean production. Famous for eliminating wasteful activities on production and assembly lines this philosophy ought to offer some valuable principles. Although, it is a complex concept to succeed with. Furthermore, an ongoing digitalization of production industry should be able to contribute to a streamlined off-site production of houses as well.

Virtual Manufacturing (VM) is a supplier of lean-based production development services and helps one of their clients, Nock Massiva Trähus (NMT), to construct and improve their production of modular residential blocks made of cross-laminated timber. As NMT's production started recently, week 10 in 2019, there is room for improvements. One being that NMT's hall is huge and lacks efficient communication systems across the enterprise. As a result of this, the workers must search for a supervisor when they need help. This process is time-consuming and is in VM's interest to rationalize.

A widely used tool for communicating problems in lean production is andon, aiming to improve quality by visualizing the status of an assembly line and communicate this to supervisors. This procedure visualizes hidden problems in the production which enables quality from the commencement (Biotto, Mota, Araujo, Barbosa, & Andrade, 2014). An andon system can be designed in different ways. However, Bluetooth low energy (BLE) has become more frequently used in wireless indoor IT-systems on account of its broad accessibility in environmental and personal devices. The technology's flexibility and low cost is an advantage compared to other technologies (Baronti, Barsocchi, Chessa, Mavilia, & Palumbo, 2018).

1.2 Problem description

Nock Massiva Trähus is recently established and has no system to communicate when problems occur on the assembly line. If a station needs help, workers must search for a supervisor to help them solve the problem, this procedure is time consuming.

As workers have no or little previous experience of building houses on an assembly line, problems are likely to appear in this early stage of the organization. The organization's immaturity ought to put its focus on managing the most urgent problems. Thus, to develop in the right direction NMT needs tools for analysis and decision making as well as a culture of using such tools efficiently.

1.3 Purpose

The purpose of this project was to evaluate Bluetooth technology's potential to function in a lean production context. This has been done by testing a Bluetooth based lean concept in a production environment in need of rationalizations by providing NMT with an andon system. Specifically, the aim was to visualize errors in their production and enable analysis of relevant statistics from the production line. This is serving as a basis for the lean concept *continuous improvements* for NMT's organization.

1.4 Limitations

This paper is restricted to a thorough investigation of Bluetooth button's potential to operate as an andon system and to visualize NMT's production. However, no complete comparison was made of Bluetooth button models available on the market. Moreover, this project does not comprise implementation or evaluation of the physical or hardware related to aspects of visualization. Data has been collected only to provide NMT with means for creating tools for analysis of their production.

Furthermore, limited attention was given to the organizational aspects of the BBAS as VM was more interested in the technological aspects. Empirical research has focused on specification of requirements of the BBAS and analysis of NMT's organization constitutes support for suggested further development of the system. Neither is collected data from the BBAS used as basis to suggest improvements of NMT's production line.

VM has expressed a greater vision for virtually visualizing NMT's flow of units. This project is not aiming to integrate BLE-beacons, a simulation in *Visual Components*, data from *Avix* or other electrical components such as hardware dedicated to feed back when a Bluetooth button is pushed. However, the project aimed to enable the integration of such properties in the future.

1.5 Specified purpose

The following questions have been compiled to specify the purpose:

1.5.1 Specification of requirements

The first phase of the project was to determine the specification of requirements of the andon system. To do so, the following question was stated.

1. *What are the customer's needs regarding andon signals and downtime data analysis?*
    - This is answered in chapter 4 section 4.1. The answer is based on summaries of the interviews and observations executed at NMT and VM, a literature study and a benchmarking study.

1.5.2 Technological development

When requirements were specified, the second phase of the project was to develop and design the system according to customer needs. To do so the following question was stated.

2. *How should a modern andon system be designed in consideration of VM's and NMT's needs?*
    - This is answered in chapter 4 section 4.2. The answer has a focus on Bluetooth buttons' ability to satisfy customers' needs regarding andon signals and downtime data analysis.

1.5.3 Performance evaluation

The third phase of the project was to evaluate the BBAS' performance. To do so the following two questions were stated.

3. *How does the Bluetooth button andon system perform compared to customer requirements?*
    - This is answered in chapter 5 section 5.1 based on the description of the system's output in chapter 4 sections 4.2.2, 4.2.3 and the answers to questions 1 and 2.

4. *How does the Bluetooth based andon system perform generally and which scenarios could prevent output of dependable data?*
    - This is answered in chapter 5 section 5.1 based on the description of the system's output in chapter 4 sections 4.2.2, 4.2.3 and the answers to questions 1 and 2. This answer contains a more generalized analysis of the BBAS' performance.

1.5.4 Organizational aspects

After the evaluation of the performance, the fourth phase was to examnine organizational aspects associated to the BBAS. To do so the following question was stated.

5. *What effects can be expected from the BBASand how should it be utilized, from a lean productional and organizational perspective?*
    - This is answered in chapter 5 section 5.2 based on a literature study conducted to examine the connections between the BBAS and theory regarding lean productional and organizational perspectives.

1.5.5 Further potential

The last part of the project constituted an investigation of the further potential and proposed development of the system. To determine this, the following question was stated.

6. *What potential is there for further technological development and of the BBAS and what development of the system is recommended regarding aspects of customer requirements and needs?*
    - This is answered in chapter 5 section 5.3 by a description of the future possibilities discovered from observations and interviews made during the project and experiences from creating the BBAS.

2 Method

The following chapter describes the employed method and the working procedure of the study. The chosen method model describes the work procedure step by step and ends with a discussion of the project's reliability and validity.

2.1 Method model

Figure 1 presents the working procedure of the study. Startingly, unstructured interviews were held with VM and NMT to establish the specification of requirements for the andon system. Theirs result underlies the literature and empirical study. Furthermore, the design of the system is based on these results. Subsequently, the system was constructed, integrated and tested before being installed at NMT. The final stage of the implementation was to establish the system's potential for further development.

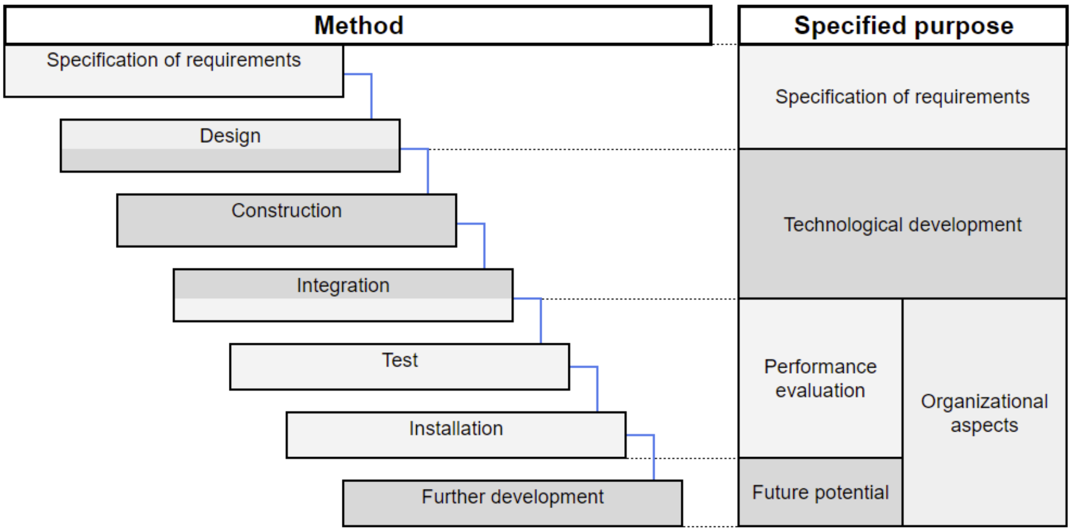


Figure 1: Method model in relation to the specified purpose. (Author's own copyright)

2.2 Problem identification

Initially, unstructured interviews were held with VM and NMT to investigate their requirements of the system, locate possible problems in NMT's production and to give a general picture of the current situation at NMT. The introductory interviews were mainly focused on the desired output of the system. However, later interviews with VM focused more on the greater picture and creating a system supporting future improvements and development.

2.3 Literature study

A literature study has been conducted in chapter 3 to give a greater understanding of the present research regarding lean production, visual management, andon, Bluetooth, digitalization, the utilized technology, organizational maturity, successful organizations and ethical aspects. Furthermore, the literature study enables problem identification considering the chosen approach and technological system. Contemporary literature has been collected from Chalmers' databases, Google Scholar and websites of the utilized technology, for finding references to strengthen the reliability of the study.

Lean production has a central part in the literature study. As Liker's literature is well-reputed, it constituted the main source for researching lean. This is presumed to be a well-established method for projects of this disposition.

2.4 Empirical measurements

Unstructured interviews and observations were performed at an early stage in the study to establish the present state of the production and the desired output of the andon system. The execution of the empirical findings is based on the problem identification and helps answering the questions in section 1.5, the specified purpose of the study.

2.4.1 Interviews

Unstructured interviews were held with supervisors from VM and NMT to determine their requirements of the output of the andon system. Unstructured interviews were also performed with employee's at NMT to evaluate the supervisor's requirements and prototypes of the BBAS. The interviews at VM took place during the beginning of the project and was executed with the project manager in charge for the NMT project, and the manager for the entire department at VM. Subsequently were unstructured interviews held with the managers at NMT to ensure that their requirements correspond to the requirements at VM. Furthermore, unstructured interviews have been performed regularly during the project in order to identify potential updates of customer requirements.

2.4.2 Observations

Observations were made in the factory to get a survey of the area and to identify present and potential future problems. These were made regularly throughout the project.

2.4.3 Benchmarking

A benchmark study has been performed to investigate properties of modern andon systems to evaluate whether the chosen Bluetooth technology is appropriate. Properties of andon systems from present-day suppliers were put together.

2.5 Design, construction and integration

A major part of the project consisted of building the BBAS. Initially, only two stations were developed and implemented as a pilot product to see if the system operated according to VM's and NMT's requirements. When feedback was acquired from the pilots and the structure of the hardware was established, the system was installed on 8 more stations. This allowed NMT to benefit from the BBAS while still allowing the software to be tested and developed at VM's office. Frequency of generated signals was monitored after installation.

2.6 Analysis and recommendations

An analysis has been conducted based on the results of the literature study and the empirical findings, with the purpose of providing knowledge on how the system should be used and further developed.

2.7 Reliability and validity

Empirical measurements are based on reliability and validity. Reliability concerning a certain indicator can be examined by investigating whether a test or experiment deliver the same output on repeated trials. However, chance errors will always occur when measurements are executed, even though the goal is to have an error free measurement (Carmines & Zeller, 1979). Validity determines the truthfulness of gathered results as a measure of whether performed studies gauged what they were supposed to measure. (Golafshani, 2003).

This project's methodology aimed to cause reliability through repeated tests of the BBAS and validity through unstructured interviews evaluating if the system measured its wanted variables.

The projects limited extent influences its reliability and validity by making room for miscommunications during unstructured interviews, misinterpretations of observations and insufficient literature studies, benchmarking and testing. Another factor that affects this project's validity is the *project paradox*, stating that in projects most decisions are made when the level of relevant knowledge is at its lowest.

3 Theory

This chapter consists of eight sections containing theory underlying the study. To begin with, the basis of lean production is presented, followed by visual control and andon. After that, research about Bluetooth and Bluetooth Low Energy (BLE), the digital factory and maturity of organizations. Subsequently, a section regarding the BBAS and successful lean implementation, and lastly ethical aspects and social incentives.

3.1 Lean production

Lean production has its origin at Toyota in Japan and became known worldwide during the 1980's. The secret behind Toyota's success is based on their production system (TPS), finalizing in a striving towards operational excellence. TPS builds partly on methods and tools aiming to create a high-quality working procedure. For instance, *just-in-time, jidoka, heijunka,* and *kaizen* are generally used to increase quality in the production when lean philosophy is applied (Liker J. K., 2004).

3.1.1 The lean temple

To cover the complete concept of TPS, lean production is often illustrated by a house or a temple. The strength of the temple depends on the foundation and the pillars. While the ceiling and the inside only can be achieved as results from the previous parts. All parts must be equally strong for peak performance. If one part is weak, it causes an imbalance which weakens the whole system. The house can have different appearances, but the essence remains the same (Liker J. K., 2004).

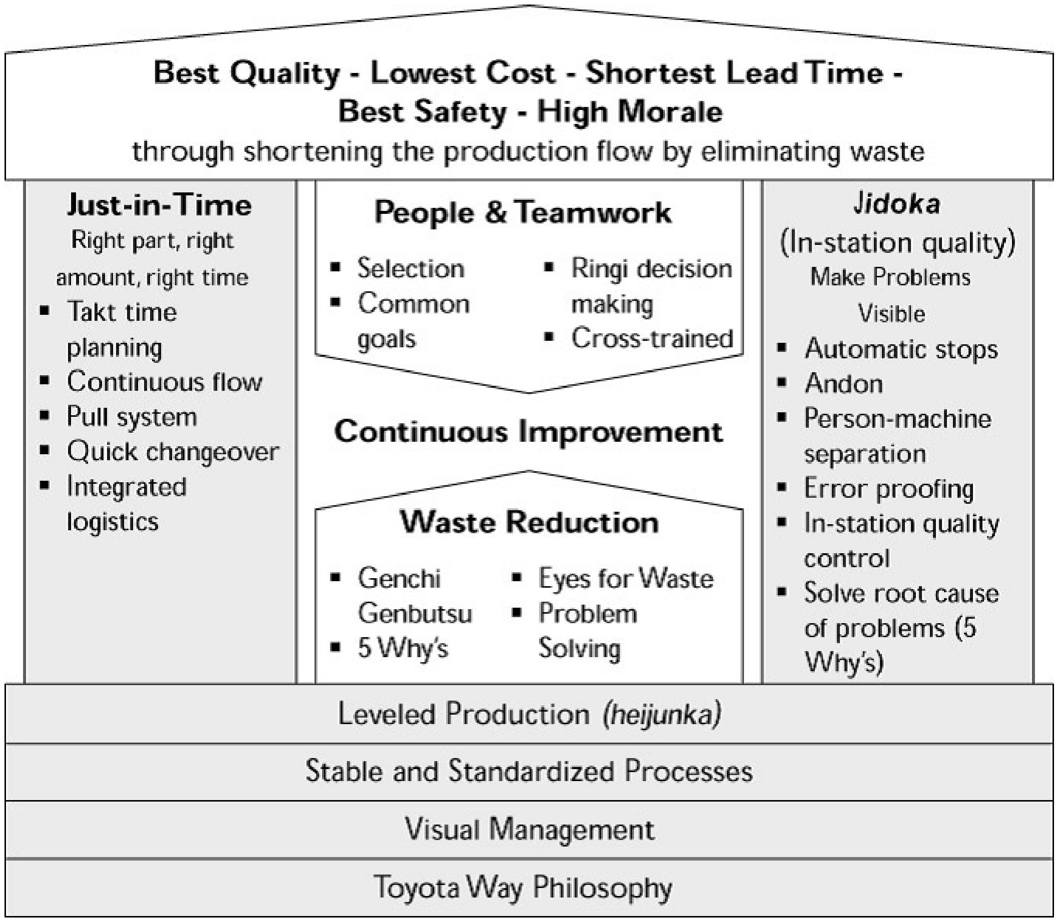


Figure 2: The TPS house. Lean is often illustrated as a house or temple to illustrate that its parts depend on one another to make the concept function well in an organization. (Liker J. K., 2004)

1. *The ceiling* demonstrates the objectives aiming to achieve the lowest cost, shortest lead time, highest quality and best security.

2. *The pillars* consist of two different parts, just-in-time and jidoka. The just-in-time concept aims to provide the workers with the right part, in the right amount at the right time. This working procedure enables a continuous flow, integrated logistics, time management, a pull system and quick adjustments. The second pillar, jidoka, aims to eliminate all errors by visualizing existing problems in the production. There are several ways to achieve this. For instance, with the use of andon, automatic stops, quality control by operators and locating the fundamental cause of the problem.

3. *The foundation* constitutes an essential part of the temple and consists of several blocks. The first block is the Toyota Way philosophy, the members of the organization must share the company's values and lines of thought. The second block is visual management, also referred to as visual control, stating that important information should be available at a glance. The third block is stable and standardized processes, a necessity for making improvements possible. The fourth block is heijunka, leveled production, aiming to equalize the production regarding variation and volume, to minimize the warehouse size and keep the system in a stable state. (Liker J. K., 2004).

4. *The inside* demonstrates the ultimate parts of lean production, people and teamwork, continuous improvements and lastly waste reduction. All three are of vital importance for a successful lean implementation.

3.1.2 Continuous improvements

Kaizen signifies working with continuous improvements of the production, aiming to eliminate expenses for the organization that does not provide value, *waste*. This leads to increased value for the customer.

3.1.3 Waste in the production

Liker (2004) claims that there are seven different main types of waste and one additional type, resulting in a total of eight types of wastes (Liker J. K., 2004).

1. *Overproduction,* when products are produced without customer demand. This procedure causes unnecessary costs by overmanning the production, moreover, generating uncalled transportations and stock-keeping.
2. *Wait,* there are several different types of wait when working on an assembly line. However, the most essential is when an operator waits for a spare part or a tool, waiting for the upcoming stage in the process, shortage of material, bottlenecks in the production, or machine downtime.
3. *Unnecessary movement or transports,* inefficient and unnecessary movements of material, products and components.
4. *Incorrect processing*, poor product design and tools may lead to inefficient processing of the product, creating inaccuracy and unnecessary operations.
5. *Overlay* is unnecessary amounts of completed products, products in process or raw material.
6. *Unnecessary work operations* are unnecessary walk distances or executed movements, unnecessary movement of all kind is considered waste.
7. *Defects* is all type of errors in the production causing defective products. The time, material and energy used for reprocessing, scrapping, repairs and adjustments are considered waste.
8. *Unexploited creativity among the employees,* it is important to listen to and involve the employees in the production, otherwise competence, ideas, time and improvements will be lost. (Liker J. K., 2004).

3.2 Visual control

> *"Visual control is any communication device used in the work environment that tells us at a glance how work should be done and whether it is deviating from the standard"* (Liker J. K., 2004).

Important information should be available at a glance (Liker J. K., 2004). Although the concept seems obvious, this cannot be stressed enough. The easier it is to comprehend a situation or a problem, the less resources will be wasted on non-value adding activities such as thinking and waiting for a solution. Liker (Liker J. K., 2004) describes the importance of visual control as the 7th of the 14 principles of the Toyota Way: "Use visual control so no problems are hidden." It is an essential part of the waste eliminating program *5S*, a part of lean so central it sometimes even is mistaken for lean itself. Furthermore, visual control permeates all of Toyotas activities. For instance, to manage work stations at one of Toyotas warehouses for spare parts, indispensable information is made accessible by directing workers to report and update information on a large board every 15 minutes. As a standard, a budget or a problem and proposed solution is reported on one A3 paper in Toyota. All to reduce the demand for visual attention to understand situations. However, the importance of visual control will only be valid if the tool is used in the correct way and Liker (Liker J. K., 2004) points out the following insights:

- IT systems are easy to use and hence easy to overuse. Information being stored in a smart system does not imply it will be used in a smart way.
- Information on a screen will likely only be used by one person. However, visual control should be accessible to everyone and enhance communication.
- Visual control should support the workers.
- Toyota prioritizes company culture before choice select technology.

> *"Using an electronic monitor does not work if only one person uses that information. Visual management charts must allow for communication and sharing"* (Liker J. K., 2004).

It must also be mentioned that the 8th principle of the Toyota Way is: "Use only reliable, thoroughly tested technology that serves your people and processes". prominent arguments from the 8th principle is that it is easy to overuse technology because it seems convenient and efficient and that new technology must add value to the enterprise. (Liker J. K., 2004)

3.3 Andon

Andon is a visual management tool aiming to provide an organization with up to date knowledge regarding abnormalities in the production. The main purpose of andon is to identify problems in the assembly line and to make them visible (Kemmer, o.a., 2006). This working procedure uncovers hidden problems and thereby enables elimination of the three types of waste described in section 3.1.3.

Andon is a part of the greater concept jidoka, one of the cornerstones of TPS (Toyota Production System). Jidoka signifies machines performing work with the intelligence of a human and is the basis for the Toyota Philosophy aiming to do the right thing from the commencement and thereby building in quality into the production. Moreover, if a problem occurs, the production stops and the problem is solved immediately, no work is proceeded with the intention of solving the problem at a later stage. This working method may affect the present productivity in a negative way, but it will be profitable in the long term since it enables countermeasures at an early stage of the production (Liker & Meier, The Toyota Way Fieldbook, 2006). Moreover, jidoka aims to make it close to impossible for errors to occur in the production, to enable this, equipment and work operations are designed to give operators the possibility to perform value adding contributions without restraint. The machines are therefore constructed to autonomously signal and stop when an error occur, to prevent the operator from being bound to the machine. (Liker J. K., 2004).

When jidoka and andon were introduced in the production industry, stack lights were commonly used on machines and work stations. The stack lights typically consisted of a set of lights displaying signals with three or four heterogeneous colors, working as a visually based andon system. However, there were some problems and uncertainties regarding the system. To begin with, the vision of multiple lights in different colors when overlooking the work area resulted in workers not paying them much attention. Furthermore, it was not obvious what message each light was signaling. Lastly, early andon systems had no sound connected to the light signal, this made them easy to ignore (Liker & Meier, The Toyota Way Fieldbook, 2006).

A common misconception is to believe an organization uses andon just because they have the lights, this is not correct. The use of andon as a tool in lean production requires a deeper understanding of its object, and furthermore to reflect on shortfalls by the use of *hansei*. Hansei is a philosophy and attitude widely executed in Japan, aiming to learn from previous mistakes. A central part in hansei is to reflect over shortcomings to prevent the same mistakes from happening again (Liker & Meier, The Toyota Way Fieldbook, 2006).

An important principle in andon is to “stop the production” when an error occurs, this does not have to imply that the whole production stops. It simply means that the parts concerned should react or stop immediately. Which action to be taken depends on the problem. However, the principle may be difficult to apply. Sometimes it is possible to stop the production to locate and solve the problem immediately and other times it may be preferable to keep the production going and to simply send out experts to analyze and solve the problem (Petterson, o.a., 2015).

3.4 Bluetooth Low Energy, BLE

The Bluetooth Special Interest Group (SIG) have developed a prominent wireless technology called Bluetooth Low Energy (BLE), purposed for communication within short ranges. This new design of Bluetooth is a low-power solution aiming to monitor and control applications. Several other wireless technologies using low-power solutions exist. For instance, Z-wave, 6LoWPAN and ZigBee are technologies growing in application domains demanding multihop networking. BLE however, is a solution using single-hop networking and can therefore be applied in other areas of use, for instance consumer electronics, security, healthcare and smart energy (Gomez, Oller, & Paradells, 2012).

Bluetooth technology is widely used in laptops, mobile phones, automobiles etc. and this could leverage the implementation of BLE on account of the many similarities between the technologies. Moreover, published forecasts claims that BLE will be implemented in billions of devices the next coming years (Gomez, Oller, & Paradells, 2012).

BLE is known for flexibility, low energy consumption and low cost and since the technology is available in several different smart devices, it is practical for indoor proximity detection. Moreover, multiple third-parties have begun to produce their own products, which is only used for indoor proximity detection, employing BLE (Kim, Kim, Choi, & Jin, 2015).

Indoor proximity detection is in a broader sense just communication of small amounts of data. And Flic has showed that BLE can be used for other applications than proximity detection (Flic.io, 2019).

3.4.1 Bluetooth's near future

Even though Bluetooth is acting on a highly competitive market, its future looks promising. SIG announced specifications of a new version of Bluetooth 2018 that aims to satisfy the needs of Internet of Things applications. When developing a Bluetooth technology, 3 main factors needs to be taken into consideration: Energy consumption, data rate and range. Previous versions of Bluetooth, including the type used in this projects Bluetooth buttons, has had a maximum range of 100 m. The coming Bluetooth 5 version is made in 3 different versions, of which one has optimized range and energy consumption by reducing data rate, compared to its peers. And "Bluetooth 5 aims to quadruple the range of BLE devices. In fact, in the worst case, this range should be 200 m outdoors and about 40 m indoors" (Collotta, Pau, Talty, & Tonguz, 2018).

Flic announced during this project that they are releasing a Flic 2 button. Its exact specifications are unknown, however they disclose that the range will be improved (Flic.io, 2019).

3.5 The digital factory

Optimum use of modern computers and digital tools is essential for any producing enterprise today and links well to the wastes in production targeted by kaizen work. As computer-aided design (CAD) and computer-aided manufacturing (CAM) "can improve productivity, product quality, and profitability. Computers can eliminate redundant design and production tasks; improve the efficiency of workers; increase the utilization of equipment; reduce inventories, waste, and scrap; decrease the time required to design and make a product; and improve the ability of a factory to produce different products. Today most manufacturers employ CAD/CAM to varying degrees." And further on: "Together with improved techniques for software engineering, this makes CAD/CAM increasingly cost-effective even for small companies … CAD/CAM has become an essential tool for economic success" (White & Richards, 2014).

However, to the tools CAD and CAM has existed long enough to not provide any competative advantage and has been succeeded by the concepts of computer integrated manufacturing (CIM) and computer integrated enterprise (CIE). The ideal of CIM/CIE is to create a network of digital tools "in which every part of the enterprise works for the maximum benefit of the whole enterprise" in order to streamline the organization's functions. CIM differs from its predecessors in the way that it also covers data collection from processes in an enterprise. Collected data then aids the modelling of the enterprise (Wisnosky, 2014).

Finally, it is stated that "digitalization is making more information about processes available, but it is first when data is informing decisions in an organization it will add value" (Bärring, M., 2019)

3.6 Maturity of organizations

The main purpose of a maturity model is to describe maturity paths and stages (Paulk, Curtis, & Chrissis, 1993). By applying continuous improvements as a part of the working procedure, the organization will over time be able to deliver higher performance, meaning that the organization will become more mature. By using a maturity model, an organization can systematically describe the different levels of maturity and techniques and methods for achieving particular levels. The overall goal is to reach excellence, this is accomplished by constantly aiming at a higher level in the specific areas (Kosieradzka, 2016).

The following table is retrieved from (Kosieradzka, 2016) and describes the different maturity levels of a productivity improvement model.

Maturity level	**Status of production processes**	**Description**
Level 1	Effectively executed production processes	Targets are met (adequate products are manufactured in the right quantity and on time) – but these processes are not iterative or predictable, which makes it impossible to control progress
Level 2	Managed production processes	Production targets are met as a result of implementing plans, and progress is monitored for consistency with plans
Level 3	Defined product processes	Production targets are met in processes defined (described) in line with the process approach parameters
Level 4	Quantitatively managed production processes	Quantitative and qualitative targets and performance control tools have been defined for individual processes and their constituents (operations)
Level 5	Optimized production processes	Processes are continuously improved and adapted to changing environment and corporate strategy

Table 1 “Maturity levels for production processes”, table retrieved from (Kosieradzka,2016)

3.7 Successful organizations

Liker & Franz (2011, p. 6-8) argues based on Collins And Waterman’s work, that successful companies succeed in the long term because they strive for excellence and that the striving results from “having vision, being innovative and having strong sets of shared values”. It is essential that management prioritizes building an excellent company before financial profits. Moreover, Liker & Franz (2011) states that many lean transformations fail as a result of the top management’s impatience with financial results and lack of understanding of when results should be expected from lean management.

We believe that the model of continuous improvement that Toyota applied broadly in the company, especially in manufacturing, is the best path toward excellence that we know” (Liker & Franz, The Toyota Way to Continuous Improvement, 2011)

M.L. Emiliani (2005) agrees with Liker & Franz on the importance of the top management’s engagement and finds that a reason for failed implementations is that “...most senior managers currently understand and practice lean as a set of tools – simple add-ons to conventional B&Q business practices – and also view lean as a way to reduce labor costs, typically through layoffs”. That the principle *respect for people* often is overlooked because it is hard to grasp. To only use the tools of lean is referred to as *imitation lean*, something that in the long run may cause more harm than good. “With ’Imitation lean’, the rate of improvement is low. A company’s competitive environment may not allow it the luxury of improving slowly.” Implementing lean is not an easy way to earn quick money, it is a long-term working procedure, aiming to make continuous improvements as long as the organization exists.

The workers’ motivation and engagement must be viewed and treated as a highly potent asset for the organization. Liker & Franz (2011) emphasizes that workers must have incentives to do a good job and be given a desire to do excellent work. An anecdote for the importance of this is described by Duhigg (2014, ch. 4) Alcoa’s president in the years 1987-2000, Paul O’Neill, quintupled the stock value of one of the world’s largest companies, excluding dividends, by managing said assets. Rather unconventionally, O’Neill focused his leadership only on worker’s safety. Since that was a well-thought-out and firm resolve, the consequences became extensive. Working for improved safety had no opposition in Alcoa, yet improving safety involved increasing the general understanding of Alcoa’s processes. Improving a desired aspect of Alcoa’s activities made improvements spreading like a wildfire through the enterprise. Subsequently, kaizen-like activities had become part of the organizational routines and workers started reporting all kinds of suggestions for improvements at Alcoa. Merely as a result of careful management of the employee’s motivation and engagement. Continually, this is the result of finding the Alcoa's *Keystone habit* and using it the right way. It is stated that “cultures grow out of the keystone habits in every organization, whether leaders are aware of them or not” and that just like the right keystone habits give amazing results, the wrong one’s can create disasters (Duhigg, C., 2014, p.157).

Lastly, Liker & Franz (2011) states that enterprises which are good at continuous improvements have great capacity for organizational learning and that correct use of the cyclic work method Plan-Do-Check-Act (PDCA) is the basis for this. Distinctions between W*estern PDCA* and *Toyota’s PDCA* are submitted where the most prominent difference is that Western PDCA assumes that processes can be controlled and predicted, and that work is finished when a problem is solved. Whereas, Toyota’s PDCA is focused on improving processes and

“Outlearning the competition is the only sustainable way to win the race...in the long term” (Liker & Franz, The Toyota Way to Continuous Improvement, 2011).

the people running them, and that the learning itself is the ultimate objective. Furthermore, western PDCA often transforms to just “Do” in stressed settings. Although, this work method does not necessarily implicate lost success. P. Barnevik was for instance notorious for his do-culture when he transformed the Swedish-working Asea to the world leading ABB (Barnevik, 2011, s. 441). However, do-culture will prevent lean culture in any organization.

3.8 Ethical aspects and social incentives

Ethics is about what type of actions a person consider to be right or wrong to perform, more specifically it concerns a person’s set of values. However, it is difficult to generally determine what is the right or the good thing to do, due to it often being specific for a given context. (Hedenus, Persson, & Sprei, 2015). There is an ongoing discussion is regarding if technology is good or bad for society. Both sides have relevant arguments, but a third-party claim this to be unnecessary since technology is to be considered neutral, it is the user who determines if they want to use it for good or bad aims (Hansson, 2009).

Börnfelt (2018) describes how a worker’s possibility to control his surroundings leads to satisfaction and impacts his inner motivation to do a good job. Additionally, there always exists a subjective psychological contract comprising an employee’s expectations on his employer. If this contract is broken, motivation may diminish to the extent that the employee quits his job. Broken contracts have proven to eradicate worker’s motivation to improve their workplace and contribute to continuous improvements.

4 Creation of the BBAS

The main object of this project was to create and implement the BBAS. This chapter presents the specification of requirements, the design, and the product description of the system.

Principles for reaching the aims of the specified purpose was to consider VM's in-house resources and competencies when chosing technology and aim for solutions to be in line with both VM's vision, current research about andon systems and the principle of visual control.

4.1 Specification of requirements

This section presents the empirical measurements of the project and clarifies the specification of requirements documented from discussions and observations at NMT. Furthermore, the chosen design of the andon board is explained and illustrated. All this answers research question 1:

What are the customer's needs regarding andon signals and downtime data analysis?

4.1.1 Empirical measurements

During early interviews with VM, NMT's enterprise was suggested as a good environment for this type of project. "They want to be like Volvo, but in the construction industry" was said when discussing aspects of lean and effective production. An ambitious vision that surely requires proper implementation of lean and CIM. VM had tracking of NMT's production with BLE technology as the primary scope. However, as interviews aimed to comprehend VM's complete vision for digitizing NMT, these concepts were expressed as well:

- Bluetooth buttons for hourly work progress reports integrated with *Avix*, a software for standardising work assignments. Realtime work progress reports could be compared to the work plan. This comparison would then be used to direct surplus work force in order to balance the production line.
- A Bluetooth based andon system.
- Connecting all collected data to their virtual model of NMT's hall in *Visual Components* to create a complete real-time visualization of NMT's factory.

VM claimed to successfully have connected the technologies Google sheets, Avix, Visual Components as well as *Flic's* Bluetooth buttons in previous projects. They also indicated that they wanted to keep costs at a minimum *(2019-01-21).*

Early interviews with NMT concluded that they had a positive standpoint to the project but had little time to get involved themselves. "Do whatever you want, just don't be in the way" Was said in a friendly tone, as they were just about to start their production *(2018-12-12).* Further discussions with VM concluded that the BBAS was the most urgent matter and consensus was reached that it should comprise the project's focus *(2019-02-22).* Later discussions with VM gave no new input on how the BBAS should function, however common checks were made whenever problems occurred, and input was given when minor questions appeared.

Requirements of the BBAS expressed by VM or NMT concluded that the BBAS should have the following properties:

- Via text or email instantly alert managers at Nock with the status of each station.

- Provide survey of the status of each station.
- Collect relevant data for analysis of NMT's production. Presenting this data must be comprehensive.
- The system should be able to generate the four signals: *help soon, help now, help arrived,* and *problem solved*. "Help soon" would mean that the problem is too urgent to be written on the daily management board beside the station, but that the employee can proceed working. "Help me now" would mean that a worker has an urgent problem that prevents further work, this could be an accident, lack of material or lack of knowledge at a critical point. "Help arrived" would be for the managers at NMT. When they reached the station, they would push this one to inform the other managers to prevent them from running to the same station. "Problem solved" would generate the signal needed to enable analysis of down time and was not desired to be communicated to other managers.
- The BBAS should be designed to be easy to use in accordance with visual management.
- VM suggested that hardware from Flic is used based on their previous experience with similar projects and had suggested an outlined plan to create an andon system for NMT. The outlined plan concluded that Flic buttons can communicate via a service called *IFTTT (If This Then That)* and that this could be useful. VM considered an evaluation of this technology valuable and deemed this project fit for this purpose.
- As NMT's workforce is of many nationalities, the system was desired to be presented in Swedish, English and Polish.

Subsequent interviews with NMT revealed:

- That they expected the BBAS to be useful, especially when new workforces are introduced in the factory and when new projects are taken in.
- They did not want too many kinds of signals and deemed assignments in their enterprise straightforward enough to not generate many help signals after a new worker's first weeks, when most uncertainties ought to be sorted out.
- NMT regarded the most valuable variables to be WT and an indicator of how well the supervisors use the system, the quotient: (Generated signals for solving problems)/(Generated signals for needed help)
- However, they did not deem the data analysis tools to be useful in the near future as they had more urgent matters focus on. Late in the project, one supervisor wished for a dictaphone to be connected to his headset and went on to ask for a connection between the desired dictaphone and the BBAS.

Observations at NMT concludes:

- Supervisors were hard to find among the large units and the distances are long. This setup is likely to cause time waste and cut down motivation.
- NMT has not established a steady workforce, major parts of the work force were to be changed after the first months. And the supervisors on the shop floor are busy and work only in a firefighting manner, although enjoying their work. The worker's tasks, regarding processes, seem well thought-out.
- Interviews with the supervisors were usually made on the go due to their high workloads.
- Workers seemed hesitant to use the BBAS due to concerns about how management and peers would treat them if they asked for help. A conversation with one of the

employees stated this as a possible scenario. He said that this is the construction industry, therefore no one will push the buttons. If they do, it will somehow be in their disadvantage. Either by getting exposed to provocative comments from managers or co-workers, or by picturing themselves as someone unable perform a given assignment.

- The production is designed to have a cycle time of 4 hours per station.
- The office has enough screens to put up a visualization when needed.

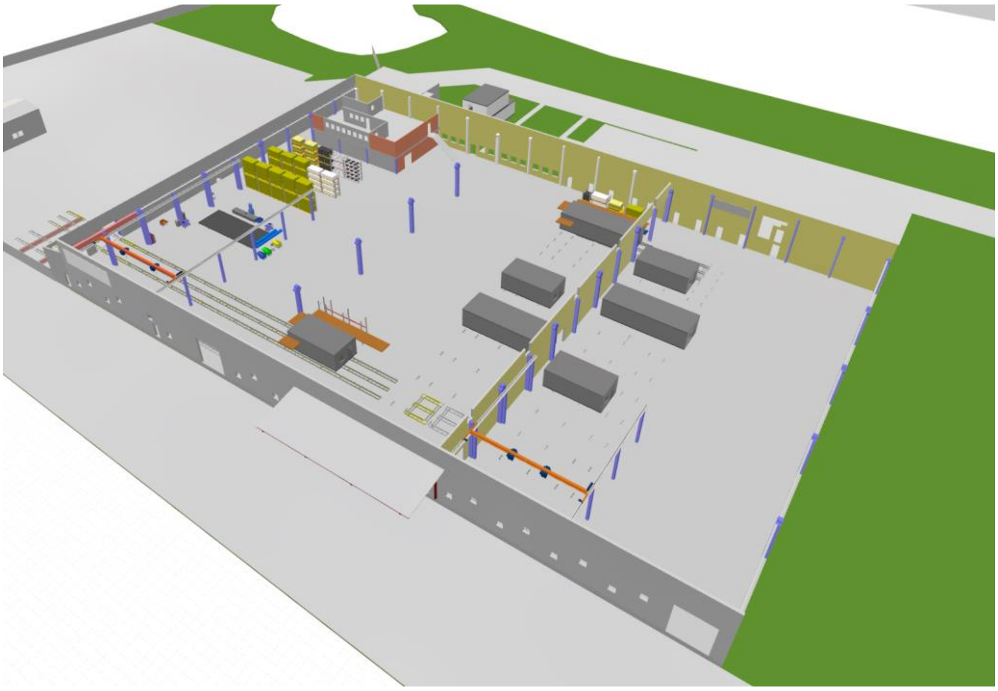


*Figure 3: Virtual model of the layout at Nock Massiva Trähus. For scale, unit on the production line measures up to 13*4 meters. (Virutual Manufacturing, 2019)*

4.1.2 Benchmarking

The following suppliers were investigated in the benchmarking:

- SageClarity – Insight of manufacturing (SageClarity, 2019).
- PINpoint (PINpoint, 2019).
- PingFlow (PingFlow, 2019).
- Electro-Matic Visual Products (Electro-Matic Visual Products, 2019).
- Avani. (Avani., 2019).

Their systems present similar technology and all of them hold customization of the andon system as a main selling argument, which is why they are not compared separately. Instead the following list concludes their systems prominent properties:

- Cloud stored data
  - Software tools for data analytics
  - Desired data presented in a comprehensive and customized way
  - Display data presentation on screens, put up on desired places in the factory
  - Possibility to customize signal addresses, so that only the respective supervisor is noticed
  - Ability to supplement the system with product tracking.

  - Visual and audial signals
- Individual data for every worker
- Integrated line stoppage for certain signals

Comparing the created BBAS to these properties, the first is already completed, the following six are possible and recommended to improve the BBAS with and the last two are not possible to integrate, however neither asked for. Individual data was explicitly not demanded and integrated line stoppage is deemed unnecessary since the line is moving slowly. A drawback for the BBAS is the need for battery changes and its young age. However, its plain disposition ought to make it price effective and easy to refine.

4.1.3 Analysis of specification of requirements

NMT's expectations on the systems reverberate with lean philosophy as they wished for effective communication through a simple and comprehensible system to reduce wait, incorrect processing, unnecessary work operations and defects. However, they did not express much thought of work with continuous improvements, although understandable since an enterprise must ensure stable cashflow before it can start improving general processes. This indicates that they are in the earlier levels of productivity improvement described in section 3.6.

VM expresses extensive plans to move NMT to higher levels of productivity improvements, especially regarding the CIM concept, they know that data is valuable and recognizes that a CIM-model must have connection with activities on the shop floor.

Further requirements were sought for as well, in an understanding that some qualities of a product may be hard for a customer to express. Expectations can be subconscious without being expressed and other qualities may not be thought of, and it requires work to find those viewpoints (Bergman & Klefsjö, 2017, ss. 320-323). Those were sought after through benchmarking, literature studies and the author's innovational capabilities. Two more properties were found during the constructing phase; the need to minimize maintenance as this was regarded a wasteful activity, and the BBAS' ability to confirm whether a signal has been sent.

No significant distinctions were found between requirements expressed by the customers and qualities of other modern andon systems, lean philosophy or technological constraints. However, an andon system relies on the use in its organization to determine how valuable it becomes. This subject is discussed further on.

4.2 Technological development

This subsection describes the planned and executed design of the BBAS, its need for maintenance, its performance and empirical measures of NMT's use of the BBAS.

4.2.1 Design

This section aims to analyze the two research questions considering the technological development of the system. Research question 2 is:

How should a modern andon system be designed in consideration of VM's and NMT's needs?

The purpose of an andon system is to make problems visible (Liker J. K., 2004). It is important that the andon system generates signals not overloading the recipient with information. An excess of information could make the recipient disregard andon signals. At the same time, andon signals may contain important information that prevents problems from staying hidden. This information must be available to everyone at a glance. (Liker J. K., 2004).

The system should not contain complicated IT-structures that makes its output difficult to access (Liker J. K., 2004). Especially management must deem the system's output comprehensible to analyze, as they are key to successful implementation of lean. (Liker & Franz, The Toyota Way to Continuous Improvement, 2011) Lean philosophy consists of various parts that must to function together, but the most central part for an andon system are visual management and jidoka. Visual management concludes that the system must provide only important information at minimized need for visual attention. This aids the function of jidoka, the greater lean principle in which andon reside. By visualizing the production for everyone in the organization, quality can be built in from the commencement which reduces the probability for errors to occur in the production. By this principle, the organization employs parts of a proven successful working method (Liker J. K., 2004).

Benchmarking with other modern andon systems gives insights on some technological qualities that can help fulfill the customers' requirements listed above. A system customized to customer requirements ought to imply that it is comprehensible enough for management to use. Developing the system together with the customer also gets them involved in and prepared for changes that will occur with the andon system. Additional aspects found from the benchmarking study sum up to effective use of IT technology and creating a virtual model of the customer's activities.

The conclusion of the customers' pronounced needs is that NMT wanted to have the signals *help soon*, *help now* and *help arrived* sent directly to the supervisor's smartphones. VM requested that the signal *problem solved* is generated as means to analyze down time variables. Furthermore, VM requested that the system constitutes means to fulfill their vision to digitize NMT's enterprise. That is, to enable the integration of systems for work progress reports and unit tracking and to visualize all the data in Visual components. Some organizational aspects may be considered needs as well. But as such aspects do not affect the logical flow of information in the technology, they are discussed in section 5.2.

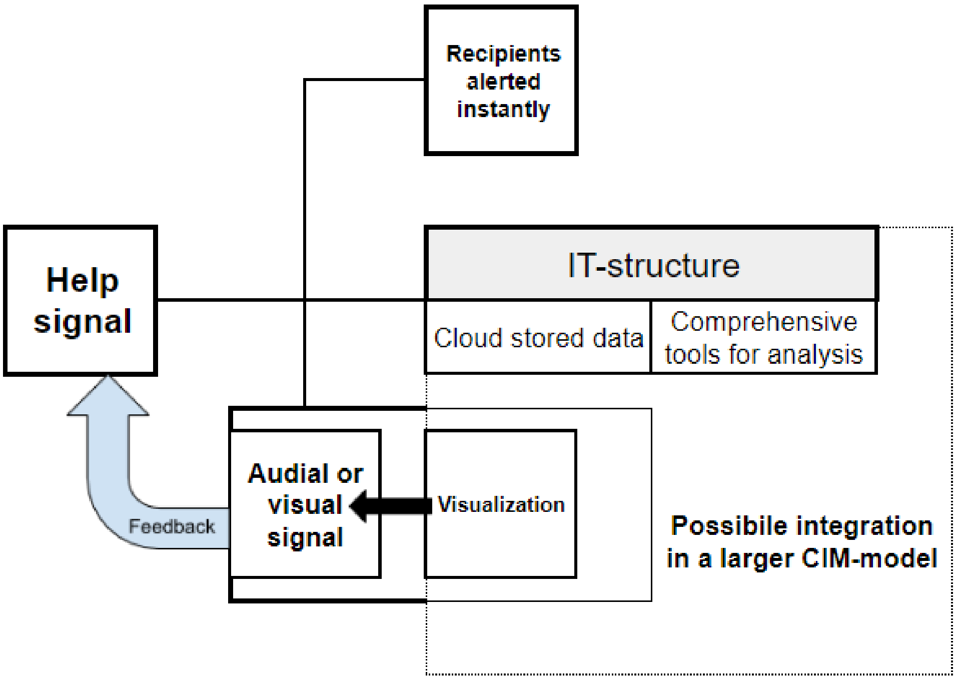


Figure 4. An illustration on how information is supposed to flow in a modern andon system according to the specified requirements. Feedback means that the sender of a signal must get a confirmation that the signal is sent. As a suggestion this is done by making the visualization of the stations' status accessible to the sender. If this is deemed too expensive initially, a more straightforward solution could fulfill this purpose. (Author's own copyright)

The suggested technology, Flic buttons, are Bluetooth buttons able to communicate up to three signals each together with a timestamp and an ID for the button. The Bluetooth buttons can communicate with a reciever, a *Flic hub* or a smartphone that can forward data via their software the service IFTTT. This web service can redirect data from various applications to others. Among these applications are ordinary email, that can be used for instant communication, and *Google sheets*, an online replica of *Excel* sheets where analysis and visualization of the signals can be done. In accordance with visual management, each station ought to have three Bluetooth buttons rather than two in order to avoid confusion among workers about how to send the different signals.

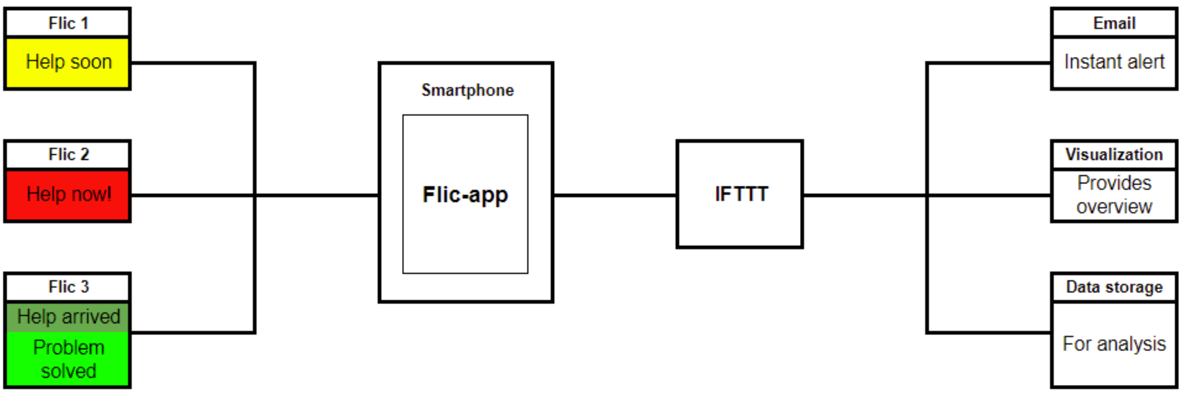


Figure 5: Illustration of the planned flow of data in the BBAS. (Author's own copyright)

The email gives the supervisors an instant alert when signals are sent to reduce waiting time during the downtime of a station. The visualization made in Google sheets provides a survey of the shop floor’s status. To reduce the demand for visual attention, each representation of the stations should communicate signal type, time and position of the station.This function can be used to prioritize between andon signals and for feedback on whether signals are sent or not. Data storage should enable analysis of failure frequency, time to failure (TTF), waiting time (WT), time to repair/solve a problem (TTR) and total down time (DT). The tools for analysis should be created with the aim to provide the most valuable data for NMT in a comprehensive way.

The board should be designed to appear clearly and comprehensible in accordance with the principles of visual management.

4.2.2 Product description

This section describes how the final product is constructed, what maintenance it demands, how it performs technically and how the development process was.

4.2.2.1 Hardware

The following hardware is used in the BBAS:

- Flic buttons
    - Bluetooth buttons able to send 3 different types of signals together with an ID, a timestamp and GPS coordinates to a receiver within 15 meters of range. They are supposed to work within 50 meters, but 15 meters was the limit found for a reliable signal.
- Samsung Galaxy S8 and S9 smartphones
    - These are not optimal for the BBAS; however, they were available at VM and fit the requirements to test the system. Flic hubs would probably replace the smartphones for 1/7 of their price and with a more stable connection, but they require a network connection.
- External servers from Flic, IFTTT, and Google
    - Even though the system seems to work properly, bugs and problems may exist.
- Screens for visualization of the system's output.
    - To be chosen by the customers at a later stage, NMT and VM.

Three buttons in different colors are put in groups on boards containing a sign showing the number of the station, laminated card explaining the meaning of each button. There are three different cards with the same layout but in three different languages, English, Swedish and Polish. All three cards were hanged on the boards to enable an easy switch between them. See figure 6 for reference.

Figure 6: One of the andon boards in the BBAS. (Author's own copyright)

The approximate price to set up a general BBAS would be 10 000 sek for 10 stations.

12 stations have been produced for NMT's 12 stations, 2 of them has not yet been installed at NMT to enable further development of the BBAS.

4.2.2.2 Software

The Flic app is in general easy to use although it seems to contain some bugs. Switching which phone a button connects to is also comprehensible. Bluetooth buttons have been named systematically after their position in the BBAS.

IFTTT-applets are small programs working like an if - then construct where some type of event in one device or service automatically triggers an action in another, here Flic - email and Flic - Google sheets. The BBAS relies on about 100 applets. Note that the applets can be turned on and off.

The Google Drive containing the Google sheets for data storage and visualization is quite sensitive to changes since the applets from IFTTT are bound to communicate with a specific cell in a specific google sheet in a specific folder in the Drive.

The visualization sheet gets a cell updated with information of "Name of Bluetooth button as it's supposed to be * Click type * Timestamp" the data is transformed into numerical values and the highest value, the last signal, is sorted for each station is sent to a simple representation of NMT’s production line. This representation visualizes the stations’ statuses with a text and color that corresponds to the last signal, timestamp of the last signal and each station’s position in NMT’s hall.

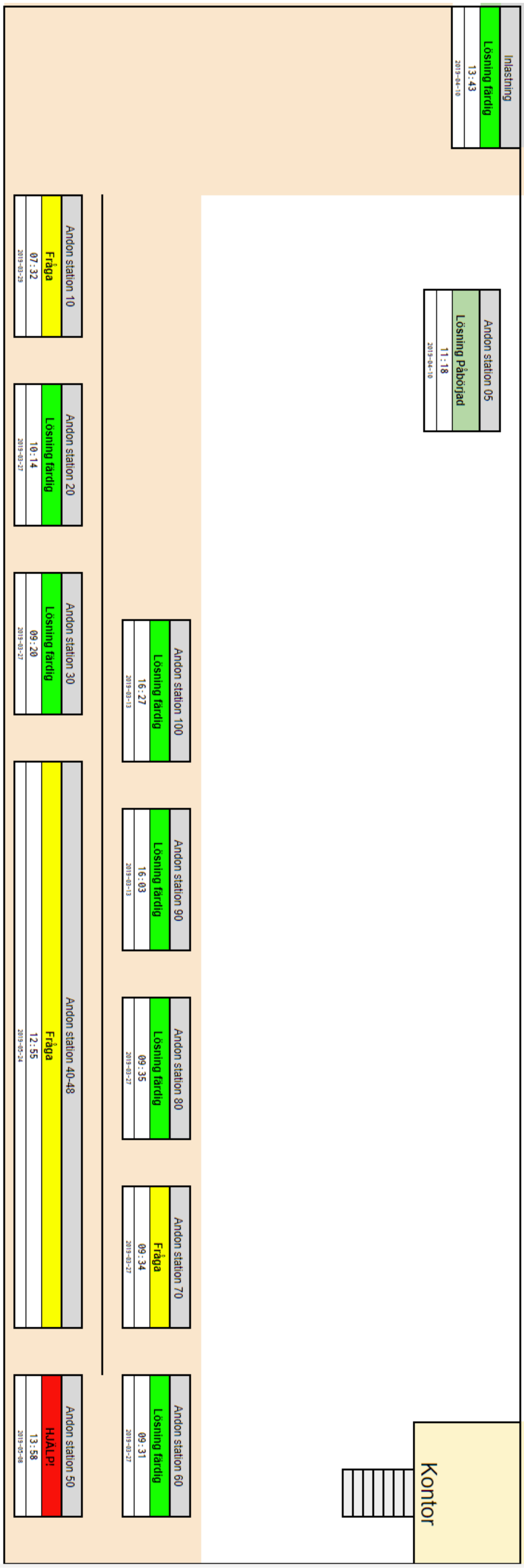

Inlastning
Lösning färdig
13:43
Andon station 05
Lösning Påbörjad
11:18
Andon station 10
Fråga
07:32
Andon station 20
Lösning färdig
10:14
Andon station 30
Lösning färdig
09:20
Andon station 40-48
Fråga
12:55
Andon station 50
HJÄLP!
13:58
Andon station 100
Lösning färdig
16:27
Andon station 90
Lösning färdig
16:03
Andon station 80
Lösning färdig
09:35
Andon station 70
Fråga
09:34
Andon station 60
Lösning färdig
09:31
Kontor

Figure 7: A picture of the visualization providing survey over stations in NMT's hall. A copy of the sheet is presented in appendix II. Note that the visualization is suited for wide screens and that the signals are fictitious. (Author's own copyright)

The data saving sheets have the same structure in the beginning as the andon sheet but represent only one station each due to certain limitations of Google sheets ability to express logical structures, hence the BBAS contain 12 such sheets. The difference of these sheets is that they run a script every time a change occurs in the sheet. Changes occur when a signal from a Bluetooth button is imported. The script waits 3 seconds, reads a specific cell that joins valuable data, and rewrites it on the first empty row in the same sheet. Summed up, signals from IFTTT are imported into Google sheets in text format, the timestamp is converted to a numerical format, the numerical values are used to sort out the last signal and to calculate waiting time, time to failure and down time for the station, a script that is triggered by any change in the sheet rewrites all valuable information on the first empty row in the sheet. The data is then ready for analysis. However, further development of the data handling is recommended. Copies of both types of sheets and the script rewriting data are presented in appendix II.

4.2.2.3 Maintenance

The BBAS requires little maintenance. The software is developed with the aim to minimize the need for it, but the sheets requires old data to be stored in separate files. Currently, this needs to be done manually although the process ought to be possible to automate. The hardware may require change of broken buttons. Moreover, the current setup with smartphones operating as receivers for BLE signals require regular refills of data to connect to the 4G-network. A more detailed description of the BBAS required maintenance is found in appendix I.

4.2.2.4 Technological performance

The range of the Bluetooth buttons signal was measured to 15 meters to ensure no signal was lost. The measured value fits the expectations from (Collotta, Pau, Talty, & Tonguz, 2018) stating that this type of BLE has a range of "10/20 m in indoor environments".

The BBAS was tested on site two times. The first time (13/3), the BBAS performed satisfactorily. All buttons generated signals without problem. The second time (27/3), the system still performed satisfactorily technically. However, one of the buttons had a flipped battery. Probably due to incorrect restoration of a loosened cap. One telephone had its Bluetooth turned off and one telephone was missing. Problems occurred could easily have been prevented by simple solutions. The boards could contain an illustration of which way batteries must be applied and smartphones could be put in locked boxes. However, the smartphones ought to be switched to hardware more fit for the task of processing the BBAS' signals.

4.2.2.4.1 Potential errors

Based on the BBAS technological structure, the following constraints could prevent output of reliable data.

- Buttons pushed the same minute. Tests of the software, BBAS google sheets, shows that when buttons are pushed the same minute, the software cannot consequently sort them correctly by time. However, the more seconds that passes between the pushes within the same minute, the more likely it is that the software sorts them correctly. A solution for this is proposed in appendix III.

- Unregistered signals are not feedbacked satisfactorily, therefore a worker that pushes a defect button may not realize that the signal has not been sent. A proposed solution for this is made in section 5.3.
- Missed reports for “help arrived” and “problem solved” will result in incorrect DT data compared to real DT values. Although it is possible and recommended to approximate the quantity of missed reports, a proposal for this is made in section 5.3

4.2.3 Use by NMT

NMT used the BBAS quite sparingly. During a control period during its first two weeks, 11 signals are registered between the 13th and 27th of May. NMT experienced no technological problems with the BBAS according to an interview performed the 27th of May. Later measurements showed that the frequency of signals has not surpassed the control period during the time of this project. An interview performed with VM in June revealed that NMT must focus on other aspects of its enterprise.

5 Analysis

The following chapter contains an evaluation of the BBAS' performance evaluation, an analysis of the organizational aspects of the created andon system and an analysis of potential for further development. This chapter answers research questions 3-6.

5.1 Performance evaluation

This section aims to analyze research questions 3 and 4 considering the performance evaluation of the BBAS.

5.1.1 Specific performance evaluation

Research question 3 is:

How does the Bluetooth button andon system perform compared to customer requirements?

The BBAS performs accordingly to pronounced customer requirements. NMT's requirements are met as the BBAS successfully sends emails providing the managers with the requested information. Although VM's vision to throughly digitize NMT requires further development of the BBAS, the system is considered to perform accordingly to their requirements as well. Data collection is done by the current BBAS and tools for efficient analysis is possible to create by developing the Google sheets contained by the system. At the present situation, down time data variables are stored but cannot be considered available to anyone in the NMT's organization since it is not structured. This is a requirement for implementing the lean culture of continuous improvemnts and NMT's employees does not have time to read unstructured data. not have time to read unstructured data. It also seems possible to integrate and develop a larger CIM-system with the technology. Lastly, the BBAS requires little maintenance and when the visualization is accessible for everyone in NMT, the feedback function will be sufficient as well.

A help signal is sent that alerts supervisors, is used in a visualization of all stations realtime status and in a system for data storage and analysis in the cloud. An audial signal is used to report if the signal was sent although the improved way would be to use the visualization for this purpose as it should be available to everyone anyway. Collected data must be structured to provide comprehensive tools for analysis of the factory's problems. Lastly, the data, the tools for analysis and the visualization seems possible to integrate with a larger CIM-model.

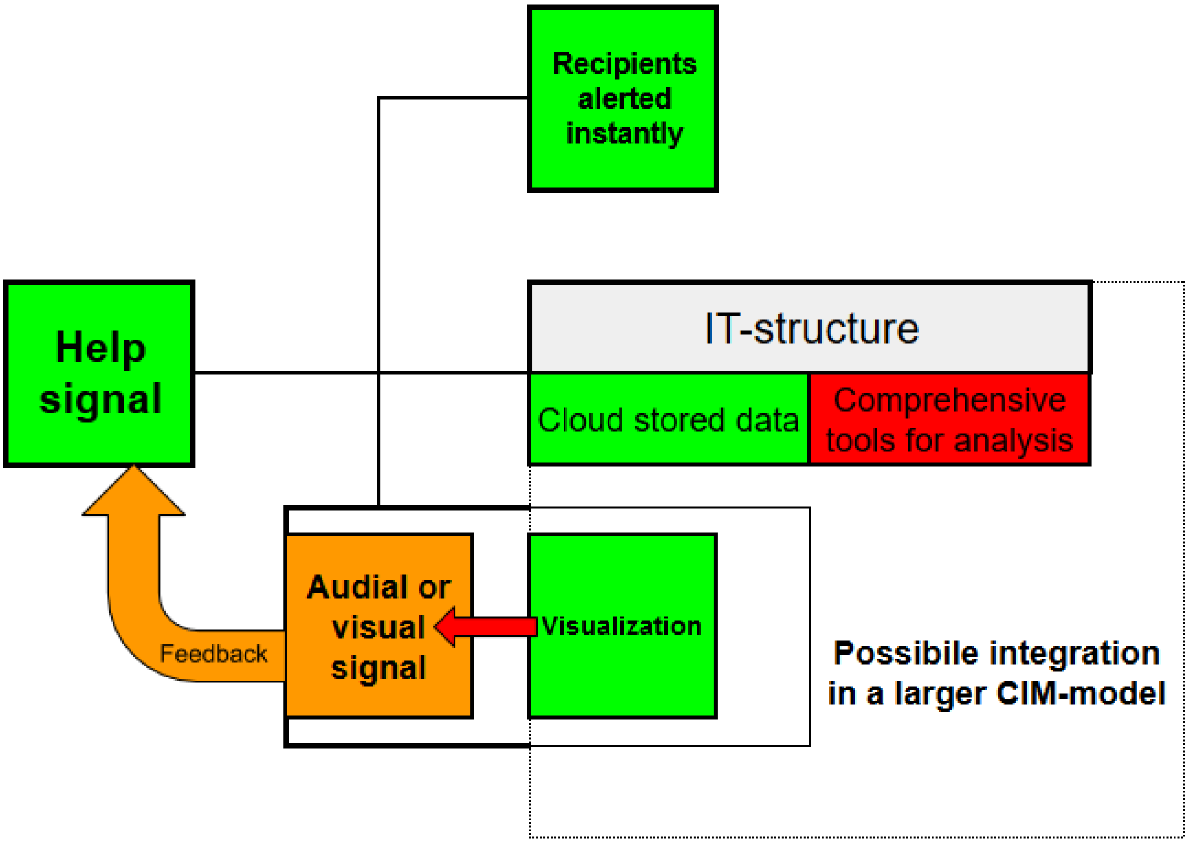


Figure 8: A representation of fulfilled and unfulfilled specified requirements in the contemporary BBAS. Green represents fulfilled functions, orange represents insufficiently fulfilled functions and red means functions that are not fulfilled. (Author's own copyright)

There is an indicator that the BBAS does not satisfy NMT's requirements. If it is presumed that NMT's use of the system does not match the quantities of needed help, some discrepancy could exist between their requirements and the BBAS functions. However, VM stated that this is not the reason as NMT had to focus on other aspects than fairly small problems on their production line during the time of this project.

5.1.2 General performance evaluation

Research question 4 is as follows:

How does the Bluetooth based andon system perform generally and which scenarios could prevent output of dependable data?

The BBAS' advantages are its ease of use, flexibility and low cost. The logical structure of the system is straightforward and possible to suit to various organizations. Suiting a system for another enterprise only requires the needed amount of andon boards and that the premises is drawed in a Google sheet with correct cell references to each station's last signal. The BBAS' cost is considered low as long as there is a marked need for such a system. Approximately, one employee costs 500 000 sek a year and if a BBAS can increase profits of the employees, 10 000 sek is a low-priced investment even for a one-man enterprise.

The fail rate of the employed Bluetooth buttons is satisfactorily as no significant technological faults has been detected. Although more tests would increase the reliability of this statement.

The technology's constrictions make the BBAS unsuitable for certain environments. Production lines with a high pace could not use a system where a minute must pass between signals in order to generate reliable output. However, this problem could be worked around. Enterprises without WiFi and long ranges between work stations would demand technology significantly more expensive than 10 000 sek. However, if workers' smartphones can be used as recievers of the button's signals this problem could be worked around too.

Bluetooth's future in industrial environments looks promising since SIG strives to win market shares in the ongoing industrial revolution regarding data processing. In addition, new Bluetooth buttons are being developed. The range of the Bluetooth buttons used in this project, 15 meters, is expected to be enlarged to 40 meters.

Something that could prevent the BBAS from delivering reliable data is that the feedback function of the BBAS is insufficient. An audial signal is given by the smartphone when a signal is registered properly. However, the signal is relatively weak and hard to interpret for the workers. Presumably, this makes the them unaware of whether the signal was sent or not, this is visualized in Figure 8. Hence, if a button stops working, there is therefore no way for the workers on the station to immediately detect the error. It will be detected first at a later stage when it is obvious that help has been needed but the managers have not received an email. This scenario could damage the workers trust in the BBAS and result in them not using it.

Based on the low costs of BLE technology and its widespread use and the findings from developing the BBAS, BLE buttons are deemed fitting technology for organizations taking their first steps to becoming CIEs. Reaching this aim can be initiated by implementing a modern andon system based on Bluetooth buttons. In a more general sense, Bluetooth buttons are fit for the purpose as they do not require significant amounts of resources before they can provide benefits for an organization aiming to collect data from its shop floor.

Although the BBAS has potential for further development, the most important aspect of its design is to put it in the correct organizational environment. Then to develop it further so that it reaches its full potential. This is because any andon system is merely a part in the more extensive and complex lean concept.

5.2 Organizational aspects

This section aims to answer the research question considering the organizational aspects of the BBAS and its implementation. Research question 6 is as follows:

What effects can be expected from the BBAS and how should it be utilized, from a lean productional and organizational perspective?

To understand the effects of the BBAS, its position in the lean temple and which lean principles it relates to must be understood. This section analyzes the BBAS place in the lean temple in subsection 5.2.1. the same subsection contains an analysis of which lean principles to expect as a result of the BBAS. Then an analysis of the BBAS' relation to other organizational aspects are made in subsection 5.2.2. And finally, recommendations for its use are made in subsection 5.2.3.

5.2.1 BBAS in the lean temple.

Here, the BBAS is principally viewed from properties of ordinary andon, its essential representative in the lean temple. Andon systems are means to acieve the concept of jidoka, meaning that it should contribute to technological systems "performing work in an intelligent way" and that the organization strives "to do the right thing from the commencement" (Liker, 2004). The concept of jidoka relies on a solid foundation of elaborate philosophy that unifies employee's values and lines of thought, the concept of visual management and stable processes and production. It is essential to recognize an andon's position as subordinate to these concepts even though it may contribute to them as well. When technology exists to work with sophisticated philosophy, the philosophy is also more easily implemented in the organization. When the concept of visual management is introduced, it can spread through the organization more easily. When technology exists to make processes more stable, processes can become more stable and this evens out the production. A symbiosis exists between the principles of lean production, but andon is just a part of the extensive lean concept and the effects of an andon system should not be expected to become significant until this symbiosis has been recognized and aimed for.

An andon system can also be expected to reduce waste in the production. As NMT produces large units essential for even larger end products that ties a lot of capital, some wastes that usually relates to andon should be taken care of by other functions in NMT's enterprise. The BBAS can be expected to directly reduce wait and incorrect processing. Wait is reduced as this was the primary objective for the BBAS and finding supervisors when needing help is hard in the big hall. Incorrect processing would be reduced as a result from making support more accessible. Overproduction and defects should be avoided primarily by other functions, such as planning and clear instructions to workers.

Another aspect to consider is that large benefits from an andon system requires employees to reflect on mistakes by the use of hansei. If this is done, the waste lost creativity can be reduced. However, hansei is a japanese concept and may be hard to implement in Swedish enterprises. However, a well-designed visually based communication system of problems on the line can be seen as means to support employees' reflection over occurred problems.

Based on the abscense of focus on cultural aspects in the projects scope and results of unstructured interviews it is a bit equivocal whether VM truly builds their work on the lean philosophy or acts as typical westerners. A typical westerner in lean context would signify organizations claiming to work in accordance with lean philosophy, when they actually just implement lean's technological tools. Emiliani (2005) is clear that such an approach is dangerous, and Liker and Franz are critical to western attitudes as well (Liker & Franz, The Toyota Way to Continuous Imrovement, 2011)

5.2.2 BBAS and other organizational aspects

One important aspect to consider in the evaluation of the BBAS, is the maturity state of the organization. The present state of the organization has potential for improvements in order to make use of the full potential and advantages of the data collection. According to observations and performed interviews, NMT is assumed to belongs to level 1 of the maturity model in section 3.6 In the present situation their focus is to locate and solve urgent problems in the production and cannot pay much attention to the stored data. This could potentially cause forgotten button pushes. However, when the organization changes to a more mature phase, the employees at NMT will have time to analyze the data and use it for working with continuous improvements. Regarding organizational maturity, the BBAS cannot be considered to have an absolute relation to the model it table 1. But it may be a valuable tool for an organization to move upwards in the table's full spectrum. (Paulk, Curtis, & Chrissis, 1993).

5.2.2.1 Motivation and ethical evaluation

It appears that the BBAS's input relies on premises connected to motivation and that its output is related to motivational factors in order to generate benefits for NMT's organization. The premises for BBAS function related to motivation are:

1. workers' psychological contract as they can have significant effects on both the input to and the utility of the BBAS. Further research of these contracts is recommended. However, it can be presumed that they contain this proposition:
   "Since a system has been set up for communicating when help is needed, one should get help when one communicates via the system."
2. Moreover, if the workers' possibilities to control their surroundings are improved, they will experience satisfaction and improve motivation to do a good job (Börnfelt, P-O., 2018).

The second premise interacts with lean's end goal, continuous improvements. If workers feel they can use the BBAS to control their surroundings by improving them, they will be motivated to do a good job and they will experience their work environments as healthy.

These two premises proceed to be affected by the organization's keystone habits. The workers' perception of their enterprise's aims and purpose has a significant effect on motivation and organizational performance.

From an ethical perspective, the technology itself would initially be considered neutral and its ethical effects a result of its use. However, the BBAS relies on the workers' motivation to push its buttons and this motivation seems to rely on healthy conditions for the workers.

Note that thorough empirical research regarding BBAS relation to motivational factors was outside the limitations of this project and that this subject ought to be further researched.

5.2.3 Utilization of the BBAS

This section comprises the recommended utilization of the BBAS with regards to jidoka, continuous improvements, motivation and cultural development, the digital factory and organizational aspects to regard in further development.

5.2.3.1 Jidoka

One of the foremost features of the BBAS is its position in jidoka. It constitutes a potent tool for introducing values among workforces to"identify problems on the assembly line and make them visible" (Kemmer, o.a., 2006) and to "do the right thing from the commencement and thereby building in quality into the production" (Liker). To achieve this, it is recommended that supervisors and co-workers encourages the use of the BBAS and that reporting problems is rewarded. Substantially since it has been indicated that this is not the case.

5.2.3.2 Continuous improvements

The use of the BBAS should have the long-term goal to achieve working methods that accord with continuous improvements. Striving after this goal must be led by management with a long-term commitment to lean philosophy as an implementation of lean tools alone is considered to be “imitation lean” and may do more harm than good. In order to achieve this, collected data should be analyzed to identify which problems that appear to be important and feasible to solve. The identified problems should then be treated with PDCA, as the rest of NMT’s peoples and processes, to instill the value that learning itself is the ultimate objective. Lean must be regarded as a learning-based management system and a vision for NMT that fits this purpose would be to use the BBAS’output to outlearn the competition. Although, outlearning the competition may require more tools than just the BBAS. A culture of continuous improvements is essential for successful lean implementation and will also maximize the benefits contributed by the BBAS.

5.2.3.3 Motivation

A culture of continuous improvements depends on worker’s motivation to contribute to their employer. Although a complex subject, it is important for managers to be aware of as it is considered a determinant for success. As a start for managing this motivation, it is recommended to find and work with keystone habits as well as acknowledging employee’s psychological contracts. The concept of keystone habits could enable administration of unexploited creativity among employees and also prevent harmful culture from growing within the organization. In this way the benefits generated from the BBAS could be leveraged.

Supervisors ought to supplement the workers’ presumed psychological contracts with stating: “one should get help when one communicates via the BBAS, and asking for help will always be encouraged”. This is emphasized by the existing empirical measurements, as they indicate that workers’ current conception of the BBAS contains worry about how reporting problems will be regarded. Problems will not become visible if not workers are motivated to make them visible. In conclusion, motivational factor’s are significant for the BBAS to successfully result in benefits for NMT’s organisation.

Accordingly, a clear purpose for the data collection needs to be formulated and communicated to the entire organization, to give the workers incentives to push the buttons. If the corporate culture advocates continuous improvements in different ways and employees wants to be a part of that working procedure, they more likely will appreciate the data collection.

To make use of the full potential of the BBAS, the work culture at NMT must be controlled and improved. NMT must seek a culture where behavior that fits a learning organization is promoted and practiced. Employees must be permitted to report problems by supervisors and co-workers and learning from their mistakes must be promoted. Andon and jidoka is about making problems visible and then solving them, something that seems to be detained by NMT’s current culture.

5.2.3.4 Digital aspects

The most important aspect of the BBAS' digitally oriented properties is that the output from the system must inform decisions in the organization to create value. in some ways it already does as it provides a basis for supervisors to decide where their attention should focus. However, to differ from an ordinary andon system, data must be collected as means to analyze DT variables and these analyzations should lead do directed improvements of NMT's production line. Optimally, such data is used all the way through the organization but as a first step, data should be used by management.

Liker's 8th principle is: "Use only reliable, thoroughly tested technology that serves your people and processes". A misinterpretation of this principle would be that this project is off target. However, the BBAS is not that farfetched as the principle sums up to that it is easy to overuse technology because it seems convenient and efficient and that new technology must add value to the enterprise. The BBAS can certainly can add value to NMT's people and processes since its goal is to suit a basic technology from lean production philosophy for NMT's operations. Moreover, the BBAS is not flawless and there is some risk in using it. But since the Bluetooth buttons perform well, the criteria of principle 8 are fulfilled.

5.2.3.5 Further development

The theory concludes the following principles important to consider when developing the BBAS further:

Section 3.2 stresses that IT and technological systems must not be overestimated. It is the people in a company that makes it excellent, not its technology. Additionally, an andon system must result in information essential for solving problems that is visually available to everyone in the organization. If few people can see the problems, few people will solve problems. In its current state and use, the BBAS has somewhat no significant output. As the system's output can be accessed by few people, and they use it infrequently, it does not lead to the desirable principles of jidoka. This is important, simultaneous cultural and technological development must be performed.

In addition, it is important to not overinvest in IT systems. Consider this, if the BBAS does not develop with the purpose to introduce a culture of working with continuous improvements, the system is already overworked as this makes data collection unnecessary. If this is the case the BBAS would only have to constitute of the Bluetooth buttons sending emails to the managers. Developments of the BBAS has to fulfill an objective within NMT.

When further developments are made, contemplate the lesson to be learned from early andon systems: An excess of information stands in contrast to information being available at a glance and may result in workers not paying them much attention.

Moreover, the principle to "stop the production" when an error occurs is suggestibly applied by taking care of the supervisor's idea to integrate a dictaphone function with the BBAS. This would enable documentation of occured problems so that they can be thoroughly analyzed later, while still allowing the supervisors to keep working in a high pace. Before such a system can be integrated, it is recommended to instruct workers to document significant problems and especially their causes. This lays a foundation for root cause analysis.

5.3 Further potential

This section aims to analyze the research question considering the further potential of the BBAS. The last and 7th research question is:

What potential is there for further technological development and of the BBAS and what development of the system is recommended regarding aspects of customer requirements and needs?

The BBAS has the following potential for further development, sorted in a suggested order by urgency and required resources:

- *Improved hardware,* the current setup requires monthly expenses that are necessary as long as no WiFi is accessible. However, a stable network connection and proper recievers of Bluetooth signals would make the BBAS more reliable.
- *Making valuable data easily accessible*. By developing the data saving sheets, up to date bar charts over stations downtimes and other relevant statistics would be available at a glance. Furthermore, some software bugs exist. Possible statistics to be generated are WT, TTF, DT, TTR, quantities of signals and quantities of lacking signals.
- Connecting a *dictaphone* to the BBAS does not have to be done by a computer. Any dictaphone transscript could be manually compared with saved data from the BBAS. Although, it would be favourable to automate this process.
- *Visualization for everyone* can be obtained by putting up screens showing the overview in figure 7 on strategic locations in NMT's halls.
- *Real time position data of production units* can be obtained with different methods. Suggestibly, a pilot technology is put up to introduce the concept at a low cost. A dedicated Bluetooth button could signal when units are moved on the production line. The units' positions depend strictly on the surrounding ones. Furthermore, as one unit can only be going one step forward, one button could signal that every unit is moved and where they were moved. However, this only works for the house modules and not the smaller units. RFID technology has been used in off-site construction of houses to track smaller units' positions (Altaf, M. S., Bouferguene, A., Liu, H., Al-Hussein, M., & Yu, H., 2017). This technology could be used to develop a more sophisticated system for unit tracking.
- *Cycle time data collection* was proposed by VM to do by integrating A Bluetooth button system with Avix, a software for standardising work assignments. Observe that such a system may not have the same favourable incentives for pushing buttons.

The developments' required resources and urgency are illustrated in figure X. Note that this is an estimation based solely on the authors' experiences from this project.

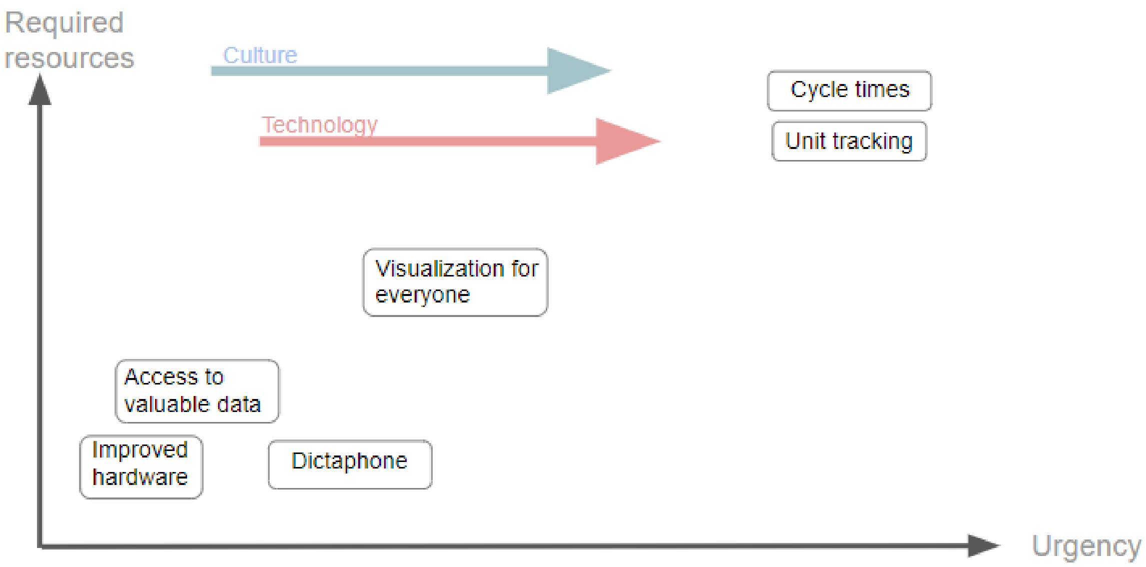


Figure 9. Proposed developments required resources and urgency in relation to each other. Cultural development should take place parallel to technological development. Note that the relations are roughly approximated, and the figure is not to scale. (Author's own copyright)

More information about these developments were given to VM as suggested ways to reach these aims. This information is presented in appendix III.

Consequently, the BBAS has the potential to constitute as a first step for building a larger CIM-model. The contemporary BBAS is fulfilling its primitive purposes, signaling and digitally visualizing when problems in occur production. However, projected analyzing functions can be utilized as soon as they are developed since the data collecting function is started.

Small scale development would make the BBAS more prone to add value by providing basis for decisions, more stable, reduce running expenses and make available the visualization of the system.

Large scale development would enable thorough analysis of cycle times of the work stations.

These development projects are recommended to be done parallelly with organizational development of NMT to optimize returns given on investments in technological systems. As the contemporary BBAS has potential to add some value by reducing perceived wasteful activities such as searching and waiting for a supervisor, it could be used as an initiator to motivate kaizen work. At the time when small scale development could be done and released gradually, with pace of organizational improvements, to maintain a continuous sense of progress.

6 Conclusions and discussion

This chapter contains the conclusions of the project in regard of the specified purpose and a discussion of statements made in the report, proposed further research, how Bluetooth buttons' useability could increase and a proposed general working model for similar projects.

6.1 Conclusions

This section presents the conclusions for each section of the project: The specification of requirements, technological development and performance evaluation, organizational aspects and further potential.

Specification of requirements

The specifications of requirements align with the properties of modern andon systems and the digitalization trend in production industry. Moreover, the full customer requirements are reachable but were not within the limitations of this project.

Technological development & Performance evaluation

The technological development has overcome all found obstacles and the basis is made for fulfilling the customers' requirements. BLE buttons can both directly signal where help is needed and generate data to achieve VM's aim to digitize NMT. The BBAS complies with NMT's requirements.

Organizational aspects

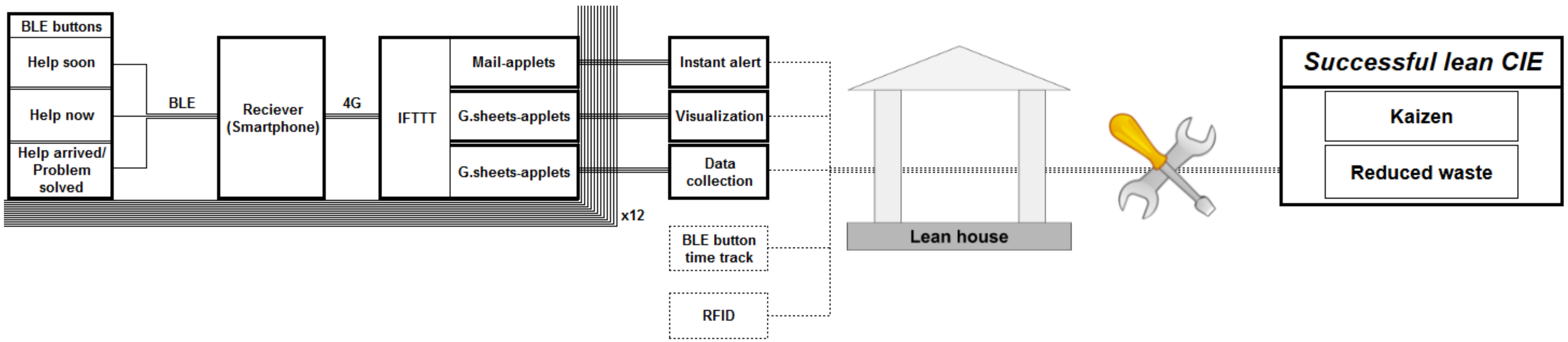
To understand the effects of the BBAS, its position in the lean temple must be acknowledged. An andon system cannot be expected to bring significant effects on its own as it is merely a part of the greater principle jidoka, "to do the right thing from the commencement". focusing on the complete lean concept will maximize the benefits of the BBAS in the long term and prevent the harm that an imitation of lean may cause.

The usefulness of the BBAS depends on the using organization's culture. And the following aspects must be considered:

- Information collected by the BBAS must support decision-making for the system to provide any value to its organization.
- The important information from an andon system, must be available to all employees if they shall be able to work with continuous improvements.
- Workers must be motivated to use the system and to work with continuous improvements. Especially, the incentives for requesting or not requesting help ought to be examined. A healthy work environment will increase motivation.
- Keystone habits forms the foundation for culture within an organization.
- Further technological development ought to be done simultaneously with cultural development.

Further potential

It is possible to integrate the BBAS with a greater CIM-model of NMT. Small-scale development is recommended for the near future and large-scale development can be done to move NMT towards CIM.



BLE buttons
Help soon
Help now
Help arrived/ Problem solved
BLE
Reciever (Smartphone)
4G
IFTTT
Mail-applets
G.sheets-applets
G.sheets-applets
x12
Instant alert
Visualization
Data collection
BLE button time track
RFID
Lean house
Successful lean CIE
Kaizen
Reduced waste

Figure 10. The BBAS functions according to the solid parts of the illustration to the left and it can be complemented with other technologies to reach its full purpose. However, to result in proper benefits, technology must be recognized in its lean context as a tool for creating an excellent organization. (Author's own copyright)

In conclusion, the BBAS depends on a strong company culture to add maximal value to their enterprise. BLE technology is deemed fitting for the purpose of introducing CIM and a culture of continuous improvements in an organization. It requires few resources before benefits can appear and this enables technological and organizational development to take place simultaneously, something that leverages technology's utility in its enterprise.

6.2 Discussion

This section contains the authors' thoughts after finishing the project. First, some statements from the paper are reflected upon. The same section also considers proposed further research. Then some reflections upon the technology are presented, this discussions changes into a more organizationally orientation that finalizes in a proposed model for a digital lean transformation.

6.2.1 Uncertainties and research proposal

Some statements in this paper suggests uncertainty regarding the level of understanding of the complete concept of lean production among the organizations involved in this project. The reader should consider that any such statements are based on observations made in a project with mainly a technological orientation and gives the empirical measurements questionable reliability. However, the found empirical measurements seem to agree with theory and it is important to point out that incorrect use of lean principles may cause more harm than good, this makes the matter important to research further.

Other conclusions in this paper suggest that Bluetooth buttons has a promising future in, among others, industrial environments. These conclusions are expected to be strengthened in the future by an ongoing rapid development of Bluetooth button technology. However, rival technologies have not been researched within this project.

In addition to the recommended utilization of the BBAS described in section 5.2.3 it is assumed that an important aspect to consider when implementing an andon system is that the andon principle itself focuses on errors and problems. If there is a percieved lack of balance between negative and positive aspects within an organization, this may have a demotivating effect as well. The end goal of lean is a culture of continuous improvements, but the word improvements may be negatively interpreted if used in the wrong context.

Further research in addition to the proposed further development of the system could constitue:

- Examination of NMT's culture in regard of motivation and incentives for requesting help, what keystone habits exist at NMT and the managements conception of and commitment to lean philosophy.
- Broader examination of available technology for creating modern andon systems.

- Other dimensions that a BBAS should be able to generate. It could for instance be beneficial if the system could signal an estimation of required TTR.

6.2.2 Technological and organizational perspective

From a close perspective on the technology, Bluetooth-buttons with functions to generate, store and communicate simple data ought to have a promising future in many environments, especially industrial. In order to capitalize on this possibility, the producers of Bluetooth buttons must make this data easily accessible. This is not the case in the author's experience of the chosen technology, as a huge part of this project was spent on creating a system that generates desired data. We propose that functions to save simple data in Google sheets or similar applications is integrated with the software connected Bluetooth buttons. Specifically, the quantities of simple data are specified to be:

- That a button has been pushed, enabling counting of events associated with certain button pushes.
- When a button is pushed, enabling time analysis of of events.
- The time differences between different button pushes, enabling a more complex time analysis.

Bluetooth buttons would have great chances to fulfill needs of a modernizing industry if these quantities were possible to save according to an individually customized structure. It is also deemed essential that the customized structure is comprehensible to carry out. The quantity of time is a fundamental quantity of basic research and ought to be an interesting variable to examine for any organization striving to map and rationalize its processes. As a suggestion, providing an easily customized structure could be done by developing a function in the software that allows its users to set up a graphic representation of how the data saving structure should be organized. A flow chart-interface with functions to choose and organize input and output of defined variables may significantly reduce the time required to set up a BBAS and similar systems.

Industrial environments is not the only area that could use cheap comprehensible technology for data collection. Other areas of use would include communication in classrooms, hotels and restaurants. A system technologically similar to the BBAS could enable teachers to provide help to pupils in a fair sequence and distribute their attention more fairly. At hotels, a central unit in the hotel could generate a signal for any aspect of a hotel room that have not received proper service. This could increase quality by directing workforces to where they are most needed. Restaurants could use a BBAS-like system to have their waiters attend their customer's in a fair sequence and analyze whether they are prone to being understaffed. Generally, it is expected that buttons will be pushed as long as incentives exists for pushing them and, while they are presented in a comprehensible way in accordance with visual management. We emphasize that teaching, providing service at hotels and restaurants are stressful professions and careless use of the described technology could increase work related stress. Therefore, it is advocated that a main object when implementing a BBAS or similar system is to reduce stress by taking control of processes. Rationalizing processes must come at a later stage, with consensus to do so within the organization.

Further aspects to consider before implementing Bluetooth buttons to an enterprise is the 8th principle of the Toyota Way (Liker J. K., 2004) and that "The premise of CIM is that a network is created in which every part of the enterprise works for the maximum benefit of the whole enterprise." (Wisnosky, 2014). From experiences of this carrying this project through, it is concievable that individuals responsible for carrying a similar project through could overestimate the function and the importance of the technology to be deployed. Even though it may be unclear whether the technology would serve its people and processes, if it is reliable (Liker J. K., 2004) or “if it would work for the maximum benefit of the whole enterprise”.

From an organizational perspective, we found that a symbiosis between technological and cultural development is essential for organizational development. The following model is suggested for facilitating this symbiosis in projects aiming to digitize enterprises simultaneously with a lean transformation. See figure 11 and the list below:

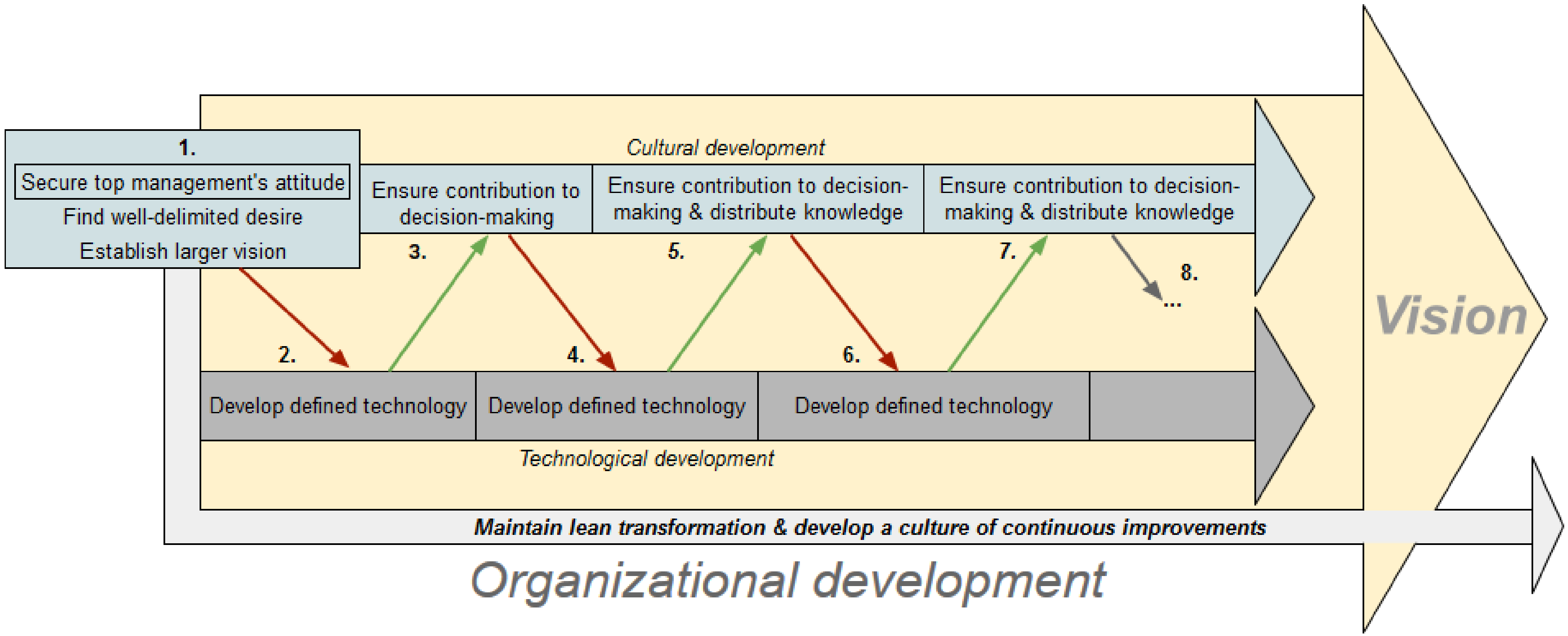

1.
Secure top management's attitude
Find well-delimited desire
Establish larger vision
Cultural development
Ensure contribution to decision-making
Ensure contribution to decision-making & distribute knowledge
Ensure contribution to decision-making & distribute knowledge
2.
3.
4.
5.
6.
7.
8.
...
Develop defined technology
Develop defined technology
Develop defined technology
Technological development
Maintain lean transformation & develop a culture of continuous improvements
Organizational development
Vision

Figure 11. A suggested model for simultaneous digitalization and lean transformation. Maximized benefits from investments in technology results from well-planned implementation of digital tools. Every progress in technological development must be *considered a cost (red arrows) that cannot yield profits until the use of the tools is made habitual and supports decision-making in the organization (green arrows). A constant striving in the work with lean transformation will constitute a foundation for successful organizational development (bottom arrow).(Authors' own copyright)*

1. **Secure and establish top management's attitude**
   Secure and establish that top management understands lean in its deeper sense and is motivated to commence a lean transformation that will go on for many years to come. Furthermore, secure that quick financial results are not the aim, nor should they be expected. The end goal must be operational excellence. (Liker, J.K., & Franz, J.K., 2011), (Emiliani. M.L., 2005)

   Find well-delimited desire
   Identify a desire in the organization that is well-delimited, that would have prominent incentives to use a presumed technology and that could be satisfied with inexpensive technology. Examine and define the specification of requirements for this technology.

   Establish larger vision
   Establish a vision of the ultimate objective regarding organizational development.

2. **Develop defined technology**
   Create the desired technology and install it in the enterprise.

3. **Ensure contribution to decision-making**
   As a result of 1 and 2, introduce the technology to certain key employees and ensure that the technology contributes to decision-making in parts of the organization. This creates value for the enterprise (Bärring, M., 2019) that justifies further investments in technology and leads to desire for higher levels of integrated technology. Identify another need in the organization, apt to be satisfied with technology. Examine and define the specification of requirements for this project.

4. **Develop defined technology**
   Create the new desired technology and install it in the enterprise.

5. **Ensure contribution to decision-making & distribute knowledge**
   Repeat step 3 but introduce the created digital tools for larger parts of the enterprise to ensure that decision-making based on made investments becomes more widespread in the organization.

6. **Develop defined technology**
   Create the new desired technology and install it in the enterprise.

7. **Ensure contribution to decision-making & distribute knowledge**
   Repeat step 5 and spread the created digital tools even further is possible.

8. **Iterate steps 6 and 7** until the vision from step 1 is accomplished. However, if the use of the model was successful it would probably be better to formulate a new vision as the striving for building an excellent organization should never end (Liker, J.K., & Franz, J.K., 2011).

Note that the striving for a culture of continuous improvements must be ongoing and that the principle of visual management facilitates reaching the purposes of digital tools.

For identifying a desire in step 1, an andon system would generally be an interesting thing to consider as relieving workers experiencing problems lies in the interest of many parties in an organization. However, every organization must find its own subject to consider, and andon may not be the right thing to spend resources on, especially not as a first step.

No absolute obstacles prevent this model from being crashed as long as there exists grounds to believe that the cultural development will be successful. But consider that reasons for failed lean transformation rarely is caused by lack of technology (Liker, J.K., & Franz, J.K., 2011), (Emiliani. M.L., 2005).

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8 Figures

9 Appendix I - Maintenance

Following is a description of the BBAS's required maintenance. This was given to VM as means to evaluate the use of the BBAS and to maintain it if needed.

9.1 IT-maintenance

The system is built with the aim to minimize the need for maintenance and make the maintenance as easy as possible. Many of the problems that occurred during the development of the system were related to a constriction in the relation between IFTTT and google sheets:
An applet that writes a new row in a sheet will create a new sheet after writing 2000 rows, even if the content of the rows is deleted. Which would create a scattered need for maintenance when sheets start to get full.

The current structure of the system allows sheets to hold up to 5 million cells, according to Google when the system was created. The structure also allows clearing data from cells to make more space in the sheets, meaning maintenance can be done less frequently and in one single occasion for all sheets. Save old data in a separate file before deleting it.

In its current state, the BBAS requires all smartphones to be refilled with data once a month.

9.2 Hardware maintenance

To change a battery, twist open the Flic button and change the battery. Be careful to not ruin the attachment of the button. The buttons use CR2016 batteries.

To Switch a Flic button, do the following:

1. Connect the button to its receiver, log in to the flic account.
2. Connect all signals to IFTTT and name the button its 3-digit numerical code
3. Open all 3 applets in IFTTT (this google account) and change the name of the Flic to its correct name.

10 Appendix II – Google sheets

The following links lead to copies of the google sheets used in the BBAS:

Sheet for overview:
https://docs.google.com/spreadsheets/d/1ewVtm4kXwXC7ozw7xYmpWGgWBDPEnONfENZsnYbvtCM/edit?usp=sharing

Example of data saving sheet:
https://docs.google.com/spreadsheets/d/10mKqdelKqvqh9qMVZFvOs-32-bBDx4soGCLRvQNQiis/edit?usp=sharing

The following script is the function triggered by any change in the data saving sheets to rewrite data on separate rows in each sheet:

```
// function to save data
function saveData() {
  Utilities.sleep(3000);                                  %Wait 3 seconds
  var ss = SpreadsheetApp.getActiveSpreadsheet();         %Work in this spreadsheet
  var sheet = ss.getSheets()[0];                          %Operate in she first sheet
  var cell1 = sheet.getRange('Blad1!AD10').getValue();    %Get value from cell AD10
  sheet.appendRow([cell1]);                               %Write value in first empty row
}
```

11 Appendix III

The following text suggests an outline for how the development projects described in section 5.3 could be carried out. These suggestions are written with employee's at VM as targeted readers.

11.1.1 Access to valuable data, for NMT.

Level: Easy. Workload: Medium.

Requires technological and cultural development in NMT's enterprise. As of now, the BBAS generates and stores data from the production. NMT has said that they don't think they will benefit from the data analyzing tools in the close future as they work in a firefighting manner and don't have time to analyze data. However, when this time comes it is of great importance that the culture to push the buttons is confirmed among all employees at NMT.

Technically, the system ought to generate data in a very understandable and useful way. Interviews with NMT have rendered that they would benefit most from having a bar chart showing the waiting times (WT(F) and WT(H)) of each station and the percentage of correct sequences pushed on the buttons. Something that suggestible could be done by:

a. Implementing a function that sorts out the realistic WT values in the WT columns. The way the system is used now, there is a possibility that forgotten button pushing generates extremely high values, those must be taken away. Then sum the WT for each station and generate a diagram for NMT to use.

b. Counting the amount of each type of signal. Ideally, they should be equal, however there is great chance that some "Help arrived" and "Help is done" signals will be forgotten. If the function described above is implemented, the quota:

   $$MR(WT)=Q(HA)/(Q(HS)+Q(HN))$$

   will correlate with the summed waiting times so that Real WT can be approximated as:

   $$\text{Real WT} = \text{Summed WT}/MR(WT)$$

   For sufficiently large amounts of data. Where
   MR(WT) is the percentage of missed "Help arrived" reports
   Q(HA) is the quantity of "Help arrived" reports
   Q(HS) is the quantity of "Help soon" signals
   Q(HN) is the quantity of "Help now" signals.

   Other variables, TTF and DT could be dealt with in a similar way.

TTR is simply calculated as DT-WT=TTR.

To generate the desired bar chart as easily as possible: Import data from the separate data saving sheets into one single sheet with the Importrange-function. Write a macro that generates the bar with a single click on the mouse. Or why not a Flic button?

Moreover, the system may require more testing as bugs may exist. As of now, the events that could cause incorrect data are not thoroughly investigated. The current flaws are identified in the BBAS:

i. Analysis of collected data needs to consider the non-working hours of NMT's enterprise.
ii. Redesign the visualization. The current state of the spreadsheet visualizing the state of each station is fit for very wide computer screens. However, it would supposedly be favorable to fit the visualization to smaller screens. This could be done by a remake or by creating a separate model in a new sheet
iii. The minute restriction prevents use in environments with higher pace. It can be coped with in the data saving function of the BBAS by splitting the data saving sheets into one sheet per signal and write a script writing a timestamp with the second of the generated signal, also triggered by every change in the sheet.

11.1.2 Improved hardware

Level: Easy. Workload: Medium.

Wi-Fi network enables change from smartphones to Flic hubs and reduced costs.
As described earlier, the receiver for the Bluetooth signals from the Bluetooth buttons are quite expensive smartphones. Smartphones are necessary as long as no other network connection is accessible in NMT's halls, since they can connect to 4g-network. However, NMT plan to set up a Wi-Fi network in their halls in the near future. After that, the smartphones ought to be replaced by Flic hubs, a receiver for Bluetooth buttons that seemingly is more stable that cost about 1/7 compared to a high-end smartphone. Furthermore, Flic hubs would remove the need for regular refills of surf for the smartphones, currently costing 400 sek/month.

11.1.3 Visualization for everyone

Level: Easy. Workload: Much.

Currently, only the supervisors have access to the spreadsheet visualizing the state of the stations. However, if this image was accessible by every andon board no operator would need to worry if their signal had been registered or not. This aim could be reached in multiple ways, either by putting up screens close to each andon board. An easier way would be to enable the workers to get the same emails as their supervisors on their respective smartphones. Just be cautious to not hand out access to this google account at the same time.

Currently, the only way for workers to know if the signal is registered is to listen to the phone if it pings. However, there will be some time before they are familiar with the Flic app's sounds and no effort has been made to introduce this knowledge to them.

11.1.4 Real time position data.

Level: Advanced. Workload: Very much. Although an easy suggestion is made in point b.

For each NMT house module inside and outside the factory building. Suggestions for indoors data has revolved around building a system with kontakt.io: s BLE beacons working like this:

When a module is entering the production line, it is tagged with a beacon. Position data is collected through receivers stationed at certain checkpoints on the production line.

Although tests indicate that such a system is possible, it would be ineffective for its purpose. Firstly, in NMT's production flow every house module's position is highly dependent of its predecessor and successor. Meaning that when one unit moves, all units move, and the order of the units does not change. Although this pattern may become more complex in the future it will never be complex enough to demand more than a Boolean value and an ID for certain checkpoints. Secondly, Kontakt.io equipment would be rather expensive for this purpose and complex for the employees to use. Another issue with kontakt.io was that their support didn't care to answer a mail sent to them stating that we wanted to work with their technology in this project.

Suggestions for outdoors data have been to implement GPS tracking of the truck carrying the house module. This has not been researched.

Further research is suggested, thoroughly clarifying the needs of the production site leader and investigating possible simpler technology for indoors position tracking. Other ideas for technology for indoors data collection are:

a. RFID, this technology has been used in another off-site production of wooden houses with good results and enables tracking of smaller units in the factory as well, something that would enable significant progress towards making NMT a Computer-Integrated-Enterprise (CIE) (Altaf, Bouferguene, Liu, Al-Hussein, & Yu, 2017).
b. Bluetooth buttons, if correctly used. Only one Bluetooth button is required to generate every house modules position on the production line. Although this system would probably be to primitive to fully satisfy NMT's needs, it is very easy and inexpensive to develop and implement. Hence, it could make a good pilot product for investigating the product specifications of NMT.
c. Mechanical sensors on the line, registering every time a unit passes their position. If the input to the line is logged on a computer, this ought to satisfy the needs of NMT.
d. Bar code scanners, could work as a combination of a. and c.

11.1.5 Cycle time data collection

Level: Easy-advanced Workload: Very much.

Bluetooth buttons seem to work satisfactory. Hence, they could be used to log the time of following events: Work started (WS), Intermediate target reached (ITR), Work finished (WF). WF-WS would render cycle times of each station and ITR-WS could, compared with its expected value, notice the supervisors of NMT if a station is behind schedule. Hence, system losses could be minimized as help could arrive before the targeted cycle time has passed.

The expected value of ITR and WS needs to be taken from the Avix for each station,

seemingly a complicated task.
The real cycle times would be valuable for perfecting the Avix:es and reducing balancing losses.