Master's thesis

NTNU
Norwegian University of Science and Technology
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Department of Ocean Operations and Civil Engineering

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Lean Automation and Discord communication platform improving usability and efficiency of a 3D printer Factory

IP501909
MSc thesis, discipline oriented

Master's thesis in Product and System Design
Supervisor: Ola Jon Mork
Co-supervisor: Paul Steffen Kleppe
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NTNU
Kunnskap for en bedre verden

Preface

This thesis marks the end of my Master of Science degree in Product and System Design at NTNU Ålesund. And the start of a new chapter.

I want to thank my supervisors Ola Jon Mork and Paul Steffen Kleppe, for invaluable support during this semester. I truly could not have completed the thesis without their aid in challenging times.

I also want to express my gratitude to the people at the Manulab. They supported me with equipment and supplies to be able to work from home when work at the school was not possible.

Abstract

This thesis explores the impact of implementing Lean Automation and the communication platform Discord to an 3D printer Factory.
With an experimental method the production process before the implementation is mapped and compared to the resulting production process. The changes in the production process is the basis for the results.

The results show that the 3D printer Factory now to a large extent is aligned with lean principles, and this raises the efficiency and the usability. The 3D Printer Factory can now be operated from the Discord platform, which is web – based, with access to millions of users of the Discord platform. The Discord platform is easy to use, and becomes a foundation for establishing a resourceful open community, creating an accessible and adaptable 3D printing control center, creating a platform for learning and sharing of knowledge, and gathering of data that be used for further improvements of lean principles.

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1 Introduction

NTNU in Ålesund has in recent years developed a high-tech manufacturing lab, called the Manulab. The Manulab is based on the new Industry 4.0 standard, where automation with smart solutions is the ultimate goal. The Manulab is supposed to be an area where students and companies can learn and discover the new manufacturing tools, and also how to use them, like shown in figure 1. In figure 2 we show an overview of how the factory Manulab, in theory, could assemble.

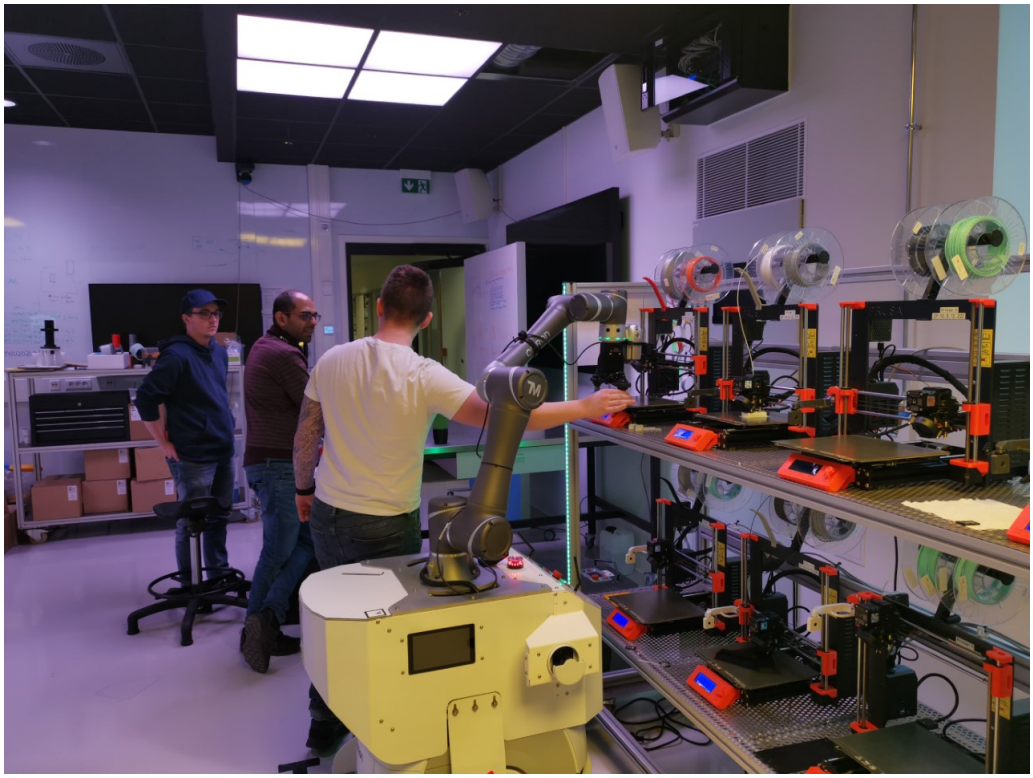

Figure 1: 3D printers at Manulab.

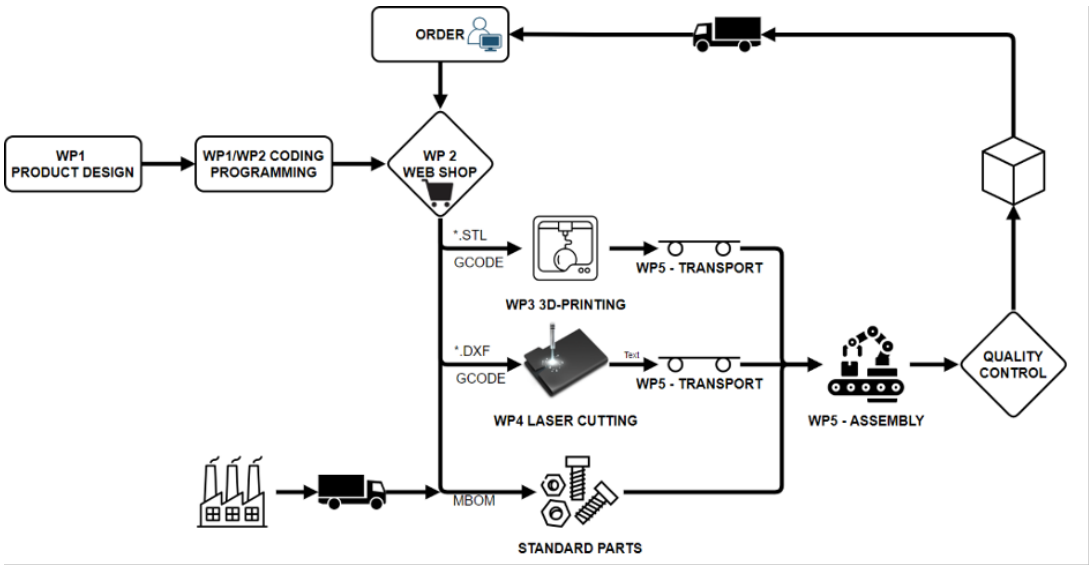

Figure 2: Flowchart of the Manulab.

Discord on the other hand is a social platform for friends or communities. Users can commu-

nicate via voice, text and video, and often gather in communities called "servers". Software that is similar to Discord and bring some of the same functionalities are: Microsoft Teams, Slack and Zoom. However Discord is aimed at a younger audience similar to the users and students of the Manulab.

Discord also have developer tools that can be used to automate actions. We hope to use these tools to improve the 3D printing facility at the Manulab.

1.1 Problem

One of the main goals in the Manulab is to be an area where all, independent of background, students can discover new and exciting manufacturing solutions. 3D printers have become a very valuable tool that can be utilized by many in the Manulab. However in times where people cant gather and travel as easy as before the Manulab has become less beneficial for many. Because to use the facilities that are available at the Manulab you need to be there in person. This has led to less usage of the Manulab and this is the opposite of what the Manulab aim to be.

1.2 Motivation

In some of my courses as a student, I have been fortunate enough to be able to use the 3D-printers that are available in the Manulab in some of my projects. And for me, it has been invaluable to be able to make rapid prototypes of concepts we have made digitally. When you can make the parts you design digitally you encounter new challenges and gain new perspectives that are very valuable in the design process. It is also very motivating to work when you know that you can create the part you are designing digitally.

But one thing the 3D printers have lacked is the ability to connect to them online. Prints usually take at least a few hours to finish, so to be able to monitor the prints on the go would be great. If we can combine the two I think it would add great value to the 3D production.

1.3 Scope

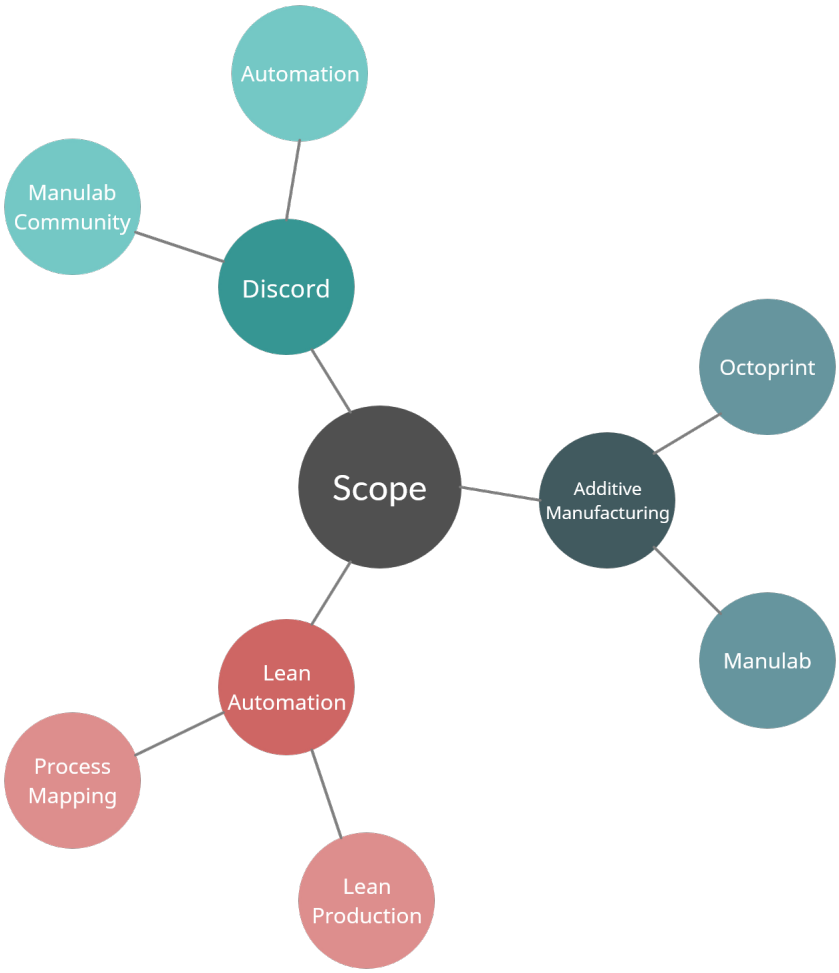

Figure 3: The scope of the project.

In figure 3 we show the scope of the thesis.

1.3.1 Discord

Discord is a software that can be used to connect people to the 3D printers. This way we add functionality to the 3D printers that can be beneficial for users.

1.3.2 Additive manufacturing

Additive manufacturing is the technology we are going to work with and try to improve. The printer that we use is from the brand Prusa. The printers run with the software Octoprint, which is open source and has plug-in functionality. The plug-in functionality is something we might utilize as a part of our solution.

1.3.3 Lean Automation

Lean Automation is the theory that we use to identify areas that can be improved and also gives us methods we can use to improve the processes.

1.4 Research Questions

These are the research questions we aim to answer. They will be important when reviewing our results later.

1. **RQ1:** How does the printing process work as it is?
2. **RQ2:** How does Discord change the printing process?
3. **RQ3:** What are the functionalities Discord bring to the printing process?
4. **RQ4:** What other areas does Discord affect?

2 Literature Review

2.1 Lean Automation

The paper "Lean Automation enabled by Industry 4.0 Technologies" [1] gives an overview of existing combinations of Lean Production and automation technology, also called Lean Automation.

Industry 4.0	Lean Production	
	Principle: Just-In-Time	**Principle: Jidoka**
	Method: Kanban system	**Method: Andon**
Smart Operator	Employee gets information about remaining cycle time via augmented reality	Wearable computing systems receive failures and display it in real time to the employee
Smart Product	Smart Product contains information of Kanban to realize an order-oriented production	-
Smart Machine	Machines offer a standardized interface for receiving and sending Kanban	Machines send failures directly to Smart Operators and call other systems for fault-repair actions
Smart Planner	IT systems reconfigure production lines and update Kanban according to the new configuration	-

Figure 4: Example of use cases to combine industry 4.0 with Lean Production.

2.2 Discord

"Discord is a free voice, video, and text chat app that's used by tens of millions of people ages 13+ to talk and hang out with their communities and friends." [3].

Discord's core function is to connect friends and communities, mainly in the form of voice, video and text. This could either be done directly between friends and friend groups, or in closed servers. These servers are often made for bigger friends groups, for people with similar interests and for communities. The servers are built up by text and voice channels. The text channels gives the users the ability to post messages, upload files and share images. In the voice channels users can communicate with voice and also stream content for others. Discord is also available on most operating systems which makes it accessible to most people. In figure 5 Discord is presented on both a mobile device and a computer.

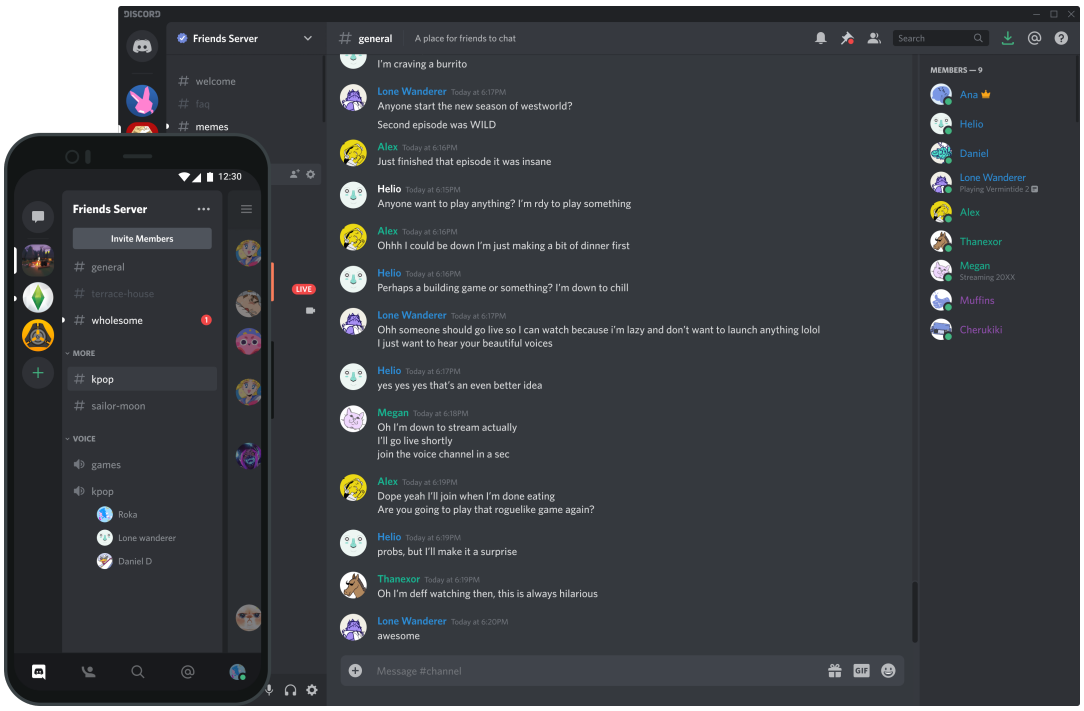

Figure 5: Discord on both mobile and computer. [3]

2.3 Industry 4.0 - Automation Pyramid

The automation pyramid shows how you need to start from the bottom when implementing the theory from Industry 4.0. This is from i-scoop.eu [2], section about Automation Pyramid.

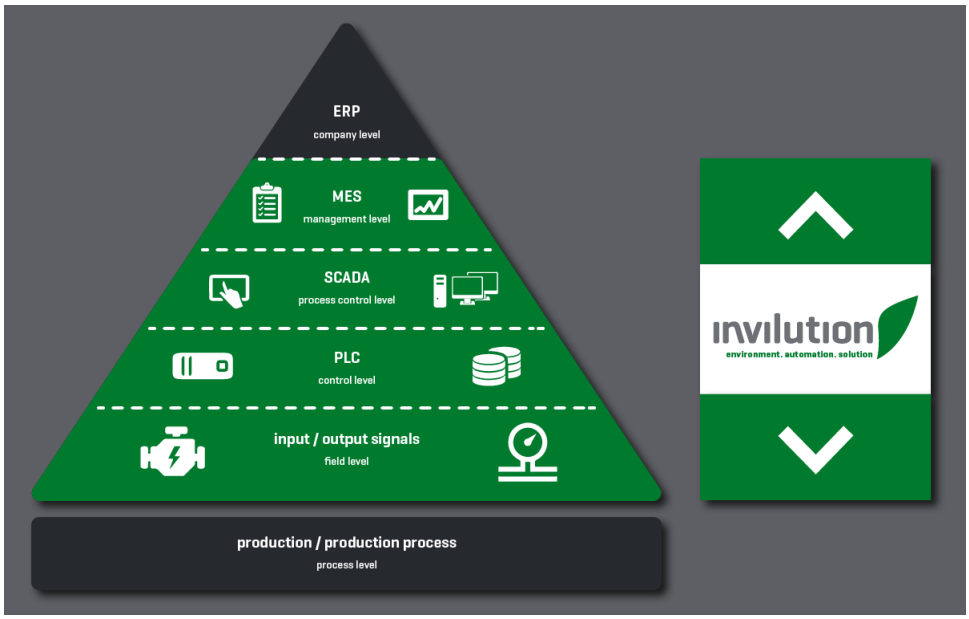

Figure 6: Automation pyramid by Invilution.

Level 1:
The first layer of the automation pyramid concerns sensors and actuators. In an Internet of Things context we would say the 'things and device' layer although here you can imagine other technologies and systems as well.

The first layer in the pyramid is focused on installing sensors and tools on the machines and equipment. On the 3D printers there are already installed sensors in the form of cameras,

temperature and locating sensors.

Level 2:
Built upon that connected layer of sensors, actuators and essentially data sits a layer of services and systems that enables the new ways in which the value chain is organized and managed.

On layer two you need to connect all the sensors and manage them. In the manulab this is done by connecting every printer to a Raspberry Pi which is running Octoprint.

Level 3:
Adding the additional layer of connectivity whereby not just assets are connected but also the data and monitoring systems we then come to IoT and IP service models that enable smarter applications and new capabilities such as preventive/predictive maintenance, asset tracking and so forth whereby there is already a change in business approach for many organizations.

Level three is where we aim to focus our work. On this level you use all the sensors placed in level one and by gathering them, like what is done in level two, you make models that increase the value of you system. In our case this could be in the form of Plug-ins in Octoprint.

Level 4:
The fourth layer, finally, is where you can leverage the capabilities and services and data/intelligence you have to really transform your business model with myriad services, depending on the context.

In level 4 and further you explore how the increased value of your system can change your business. This level is a bit further than we will go, so it is not a relevant as the others.

2.4 Additive manufacturing

As importantly, AM has the potential to become a multifaceted tool, mitigating negative environmental impacts of manufacturing by re- placing many of the casting, moulding and other manufacturing pro- cesses that consume significant amounts of energy and produce ha- zardous industrial waste (Ford, 2014). Furthermore, AM imposes minimal constraints on product design, offering the possibility of manufacturing more efficient lightweight products or the consolidation of previously separate parts into a single object, reducing the amount of energy and natural resources required (Ford, 2014). Finally, other generic benefits such as the ability to print spare parts on demand can significantly reduce the need for holding inventory as well as extending the shelf life of consumer goods. In short, AM's potential impact on the physical environment and sustainability is considerable. Table 3 sum- marises the impact of AM on categories of waste targeted by LM. This table uses the short cases presented above. Examples and arguments presented in next section further support the veracity of Table 3. [6]

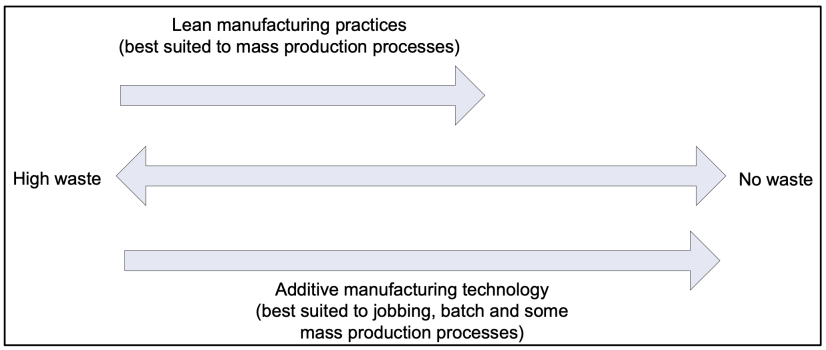

Figure 7: Potential impact of lean and additive manufacturing on waste (muda). [6]

3 Methodology

3.1 Research Method

In this thesis, we will be using an experimental research method. This is done by mapping the current system and by gathering performance data. Later in the research, when potential improvements have been made to the system, we can compare the collected data. When looking at old and new data we can conclude whether the improvements we made affected the performance of the system or no impact at all.

Another part of the 3D printing process we want to impact is accessibility. As mentioned earlier in the Introduction, we aim to make the process easier to use for everyone, independent of the users' technical background. To see if our actions are impacting the simplicity of the manufacturing process we need to look at what happens from the point users enter the Manulab to the point they start their print, not on the result of the end product.

3.2 Process Flowchart

We will be comparing the production processes before the change to the process after the change. To compare the processes we will create process flowcharts. Process flowcharts shows every step and decision involved in the production process. It is important that these charts are detailed so that they can show the change that has been made to the system.

The flowcharts used consists of:

- Start/Stop blocks to show where the process starts/ends.
- Process blocks, show steps taken in the process.
- Decision blocks, indicates where decisions are made. Implements logic to the flowchart.
- Input/Output blocks, shows where elements are added removed from the system.
- Storage blocks to show where storage are placed.

3.3 Octoprint

Every printer in the Manulab is connected to a RaspberryPi where Octoprint is installed. Octoprint is an open-source firmware that lets the printer connect to a network and adds a lot of useful functions to the printer. The main functions we will take advantage off in this thesis is the ability to give the printer network access, and also the plug-in functionality.

Plug-ins are often smaller features that can be added to the printer. We will use the plug-in DiscordRemote [10]. "DiscordRemote is a plugin that allows OctoPrint to be interacted with using a Discord bot". The DiscordRemote plug-in adds features to the printers that they in the current setup lack.

3.4 DiscordRemote in use

DiscordRemote is a powerful plug-in with a lot of useful commands. In the pictures bellow we show some of the functions

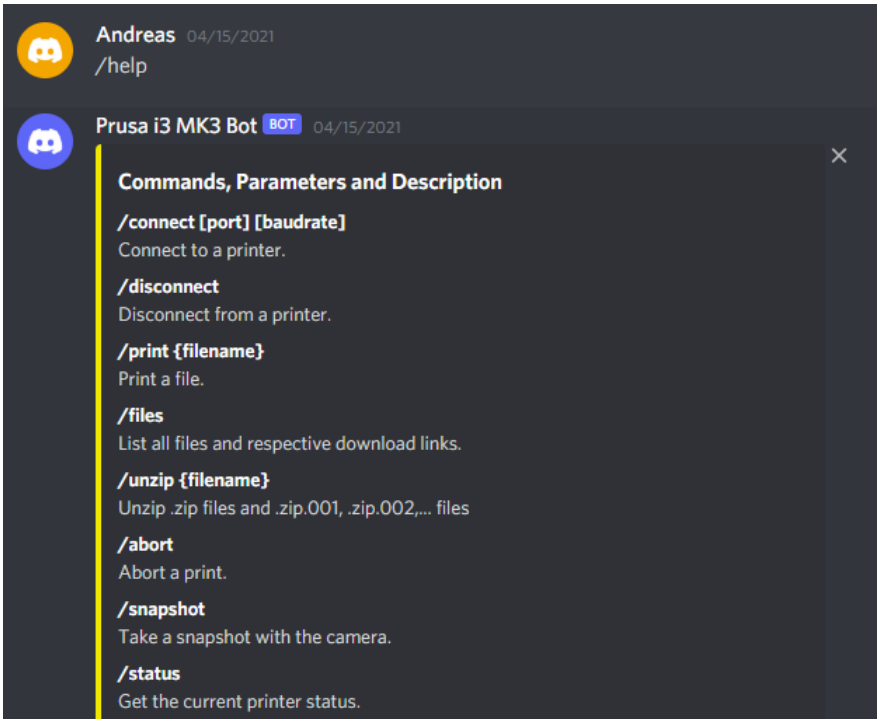

Figure 8: Shows some of the available commands.

The Discord Bot in figure 8 called "Prusa i3MK3 Bot" is a automated bot that listens to a given text-channel. When users enters commands the bot sends the command to the 3D printer and returns the information to the user.

Users can at any given time ask the bot to return the status of a printer. In figure 9 the user gets detailed information about the ongoing print, such as time spent and time remaining, current temperatures and a live picture of the ongoing print.

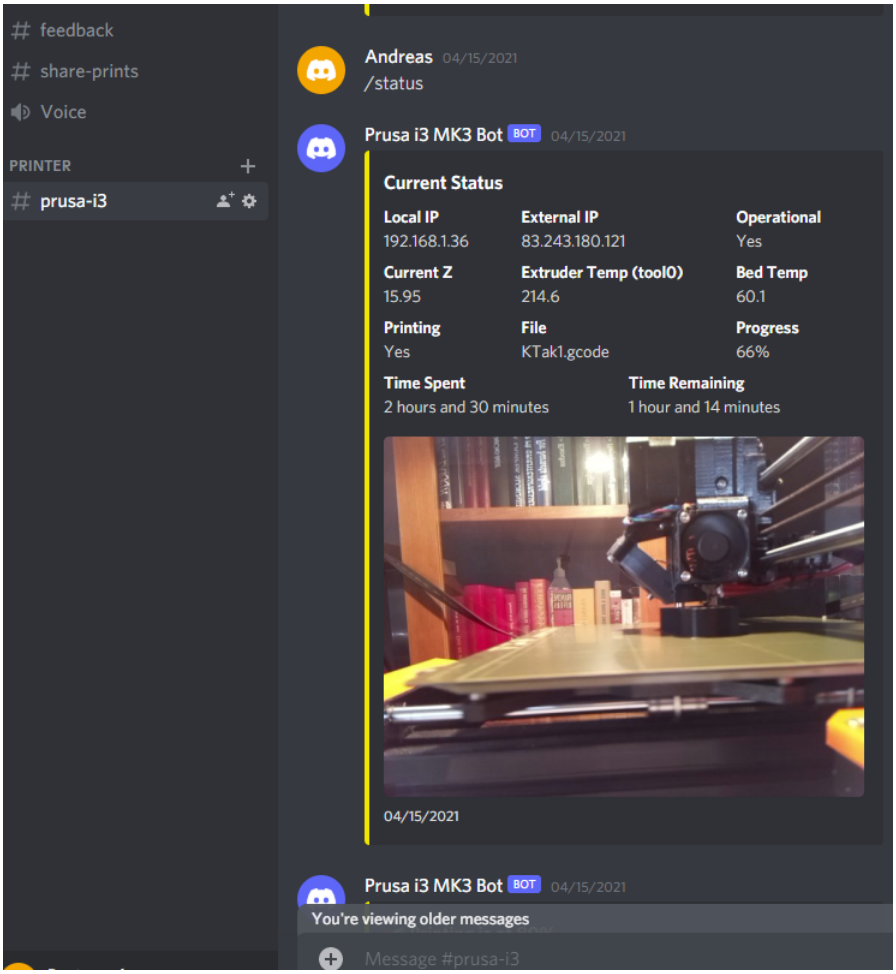

Figure 9: Returns the status of the printer.

In figure 10 the bot automatically posts updates about the ongoing print. These alerts can be sent to the user to monitor the print.

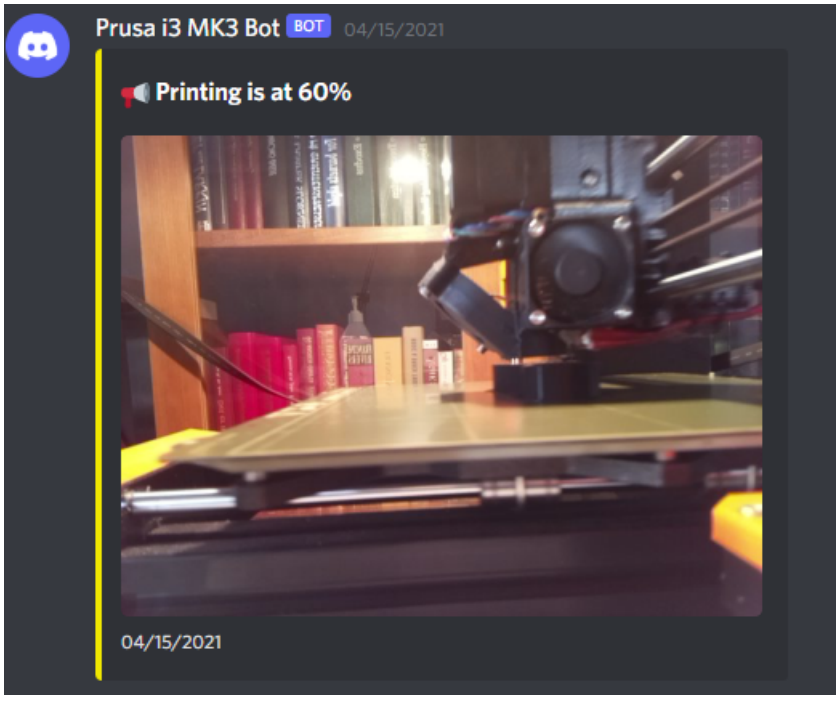

Figure 10: Updates are sent at given intervals.

4 Results

The way the 3D printers are used in the Manulab is now in two different ways. One where the file is transferred with an SD-card and the other where the user connects to the printer over the a local network and uploads and operates the printer online. Below the different processes are shown in detailed flowcharts.

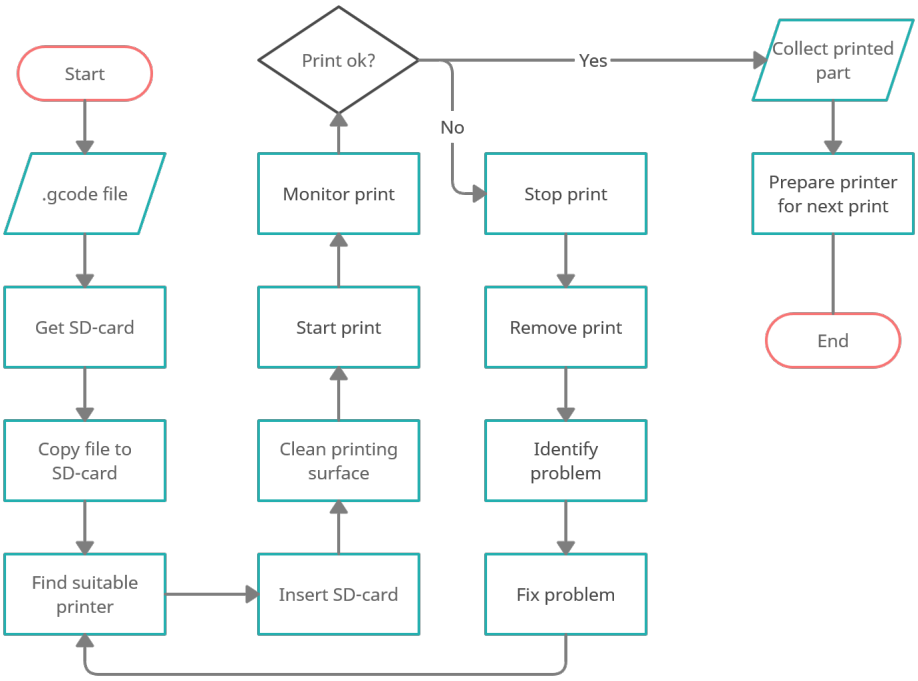

Figure 11: Process flowchart when using SD card.

One of the original ways of operating the 3D printers is by transferring the file with an SD-card from the computer to the printer. The detailed procedure of this process is presented in figure 11. To perform this process it requires the user to be at the physical location of the printer.

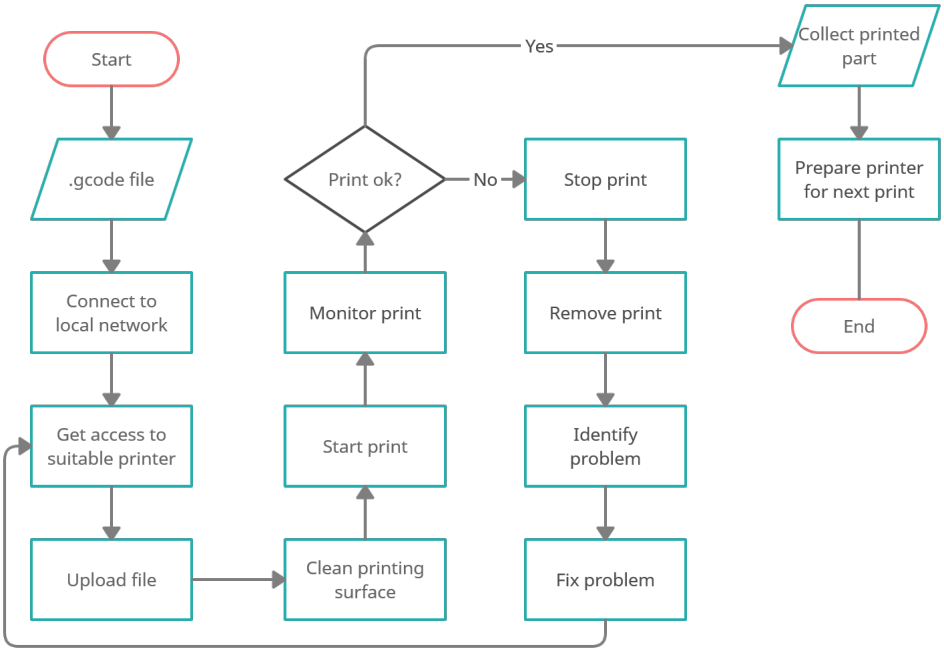

Figure 12: Process flowchart when using local network.

The other way of using the 3D printers in the original setup is to connect to them via the local network, shown in figure 12. When connecting this way you interact with the printer with the installed firmware, Octoprint. Octoprint lets you upload your file and start the printing process. However, this local network can only be connected to if the user is in close proximity to the printer. So this alternative also requires the user to be at the physical location of the printer.

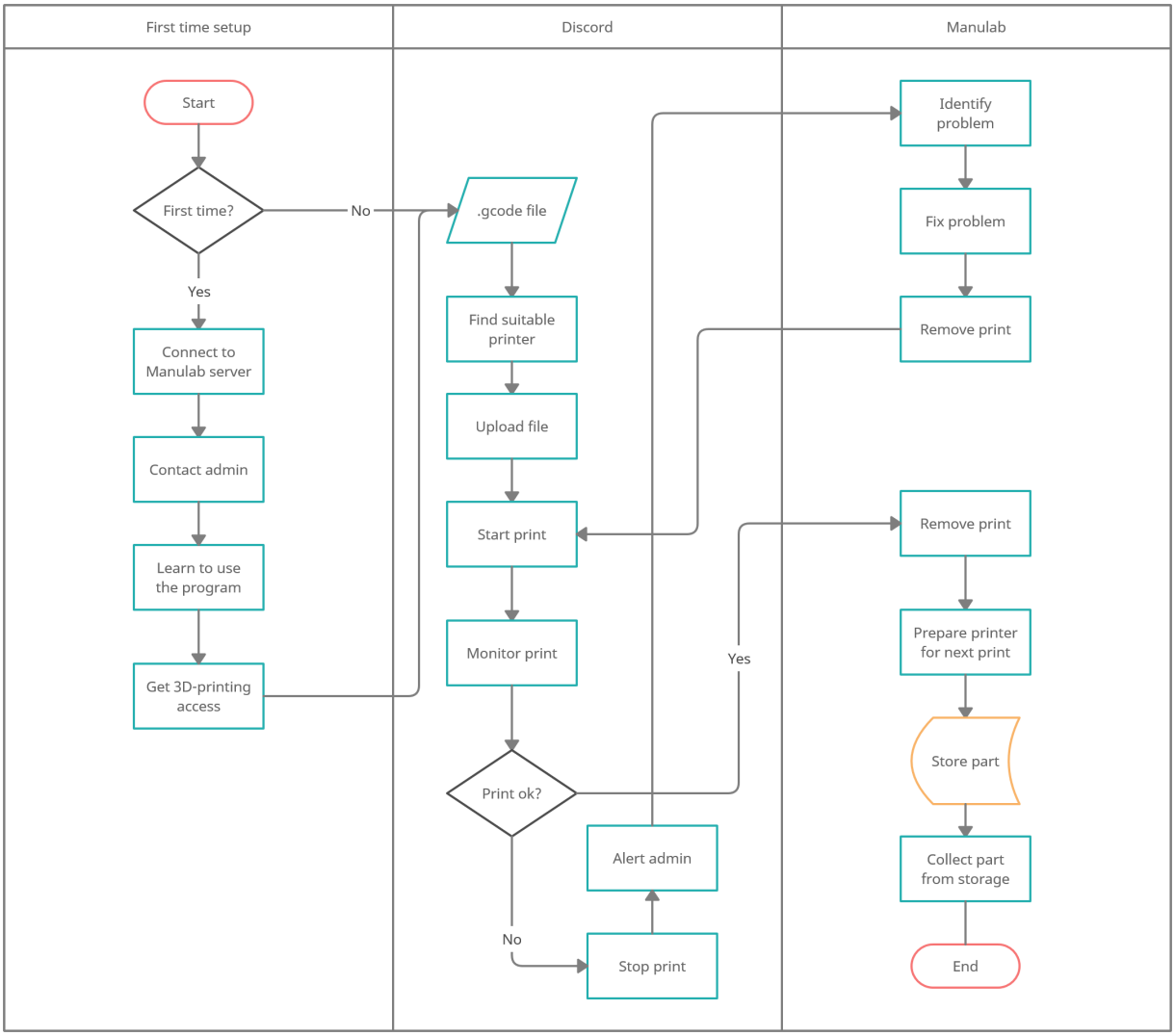

Figure 13: Process flowchart when using Discord.

The process flowchart when using Discord is divided into three different columns, the first column shows the process of the first time setup. This is only required the first time the user wants to start a print and can be skipped at later cases. The first time setup is in place to connect the user to the server and learn how to use Discord to 3D print. The next step is to get printing access by an admin, for security reasons. This way the responsible personnel can control who has printing access.

The next parts of the process flowchart is very similar to the original setups, the main differences is where the process steps take place. The second column contain the steps that is done on the Discord platform, and the third column contains the steps that is done in the 3D printing factory.

5 Discussion

To help with the discussion, the Lean Production concepts shown i figure 14 will be used to compare the production process before and after. And also to answer the research questions.

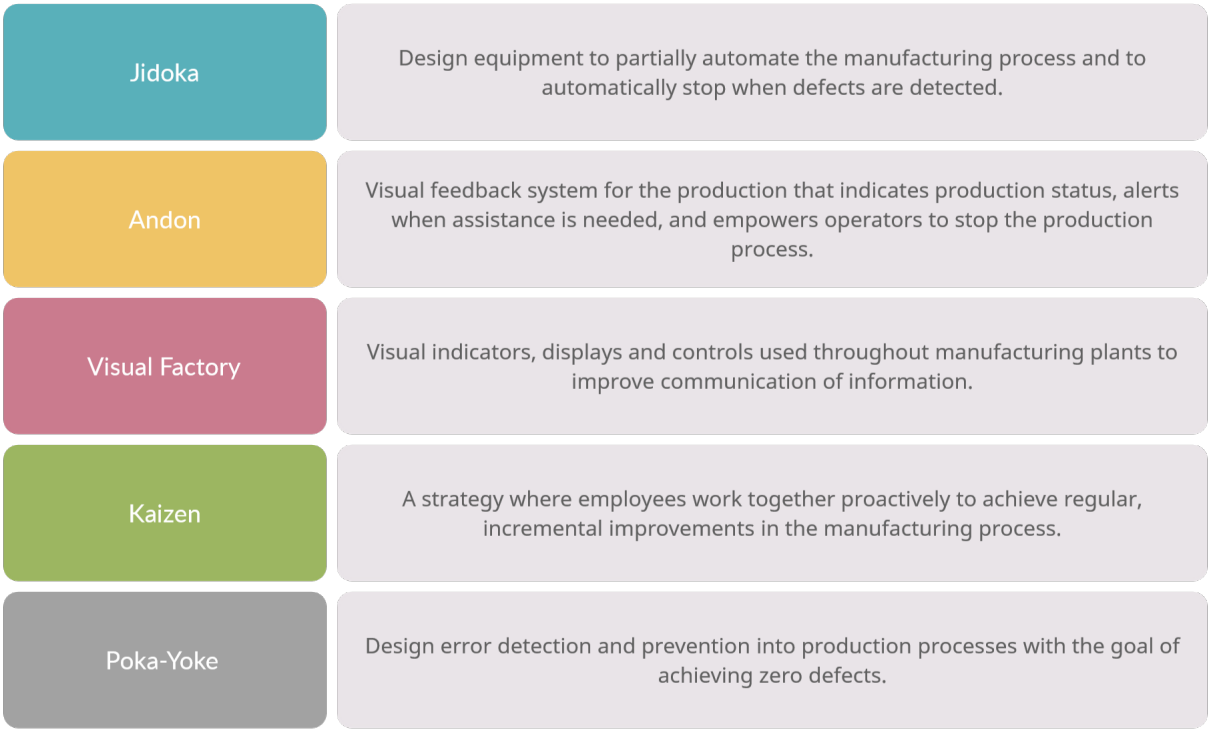

Figure 14: Lean Production that is relevant to the production process.

5.1 How does the printing process work as it is?

Looking back on the process flowcharts in figure 11 and 12 the main takeaway is that the processes as it is, is very linear and have zero automation. Another central takeaway is that for users to use and monitor the production process they need to be there in person.

- **Jidoka:** There are no partial automation taking place in the printing process as it is, the printing procedure is linear and done manually by the user, step by step. One might argue that when using the local network connection to the printer the file transfer is partially automated versus the SD-card process flow. "Automatically stop when defects are detected", the printers does have some defect detection built in for a few scenarios. In the majority of cases the print is stopped manually if there are defects in the print.
- **Andon:** A visual feedback system for the prints is not present other than observing the print in person. Operators does have the option to stop the production process, but again the operator need to be in the area to stop the process. Either by connecting to the local network or by physically stopping the print on the printer.
- **Visual Factor:** The 3D printing factory does not have any visual signals that improve the communication of information.
- **Kaizen:** Since the Manulab is a place for people to meet and work, experiences is often shared between students in the Manulab. However, since the physical work in the Manulab has been greatly reduced there is no official medium for students to share and learn about the production processes in the Manulab.

- **Poka-Yoke:** Similar to the points made about Kaizen, the error detection and prevention takes place in the Manulab by sharing experiences and tips between students.

5.2 How does Discord change the printing process?

To answer this research question the figure 13 will be used as a reference. Discord brings another dimension and structure to the 3D printing factory in the Manulab. Functions that before was only accessible to people in the Manulab can now be accessed wherever you are, given that you have access and permission to use them.

- **Jidoka:** The manufacturing process is still mainly consists of manual steps. Discord does partial automate the monitoring process by giving the user alerts with the status of the print. And the process of removing finished prints could be done by personnel at the Manulab, this leads to the printer being available to new users quicker. The users are also able to control the print wherever they are.
- **Andon:** Discord gives the user the ability to check the status and get notifications if something happens. Discord also gives the user the ability to interact with the print with powerful commands such as start/stop print. These functions are available on all devices with Discord installed.
- **Visual Factor:** The Manulab Discord server gives users the ability to look up the status and information of every printing unit in the factory. The information however is not always given to the user without some digging. Users has voiced the need of a status page that summarizes the state of every printer. An implementation of such feature would improve the communication of relevant information to users of the factory. The physical factory is still lacking visual feedback features.
- **Kaizen:** Discord is a great tool to connect users. With this foundation it is easy to share both areas that can be improved and also solutions to fix the problem.
- **Poka-Yoke:** With the use of Discord as a platform for 3D printing, Discord keeps a backlog of every event and command that is performed. This gives us an valuable tool to identify errors and where thay occur in the production process. When the potential fix is implemented the same log could show if the fix is sufficient.

5.3 What are the functionalities Discord bring to the printing process?

First and foremost, Discord adds another level of accessibility to the 3D printing factory in the Manulab. The core features in the 3D printing factory are still the same, it’s a place where curious users can test possibilities of 3D-printing, but the ways of accessing and using the printers has increased. Even tho the way to access to the 3D printers has changed there are still sufficient security measures available to ensure the printers are used correctly.

Discord is a very popular communication software and is used by over 140 million users monthly [9], so it will be reasonable to assume that many of the potential users of the facilities at the Manulab will be familiar with Discord. This may lower the bar for potential users to learn about 3D printing and facilities at Manulab. It’s also a way to for new users to get a "non formal" visit to the Manulab.

Discord also creates a platform for new users of the Manulab to connect with "established" users and exchange experiences. With such a platform in place there will always be people to ask and everyone can contribute.

5.4 What other areas does Discord affect?

Discord servers are highly customizeable, so if the need to include an area for "Laser Cutters" arises this is very easy to do. This also means that if the project of implementing Discord server for the Manulab is a success, it is easy to use the experience and make new servers for other labs or communities.

Similarly, Discord could also be utilized as a teaching platform. It's quick and easy to create groups for classes and courses. Also Discord could be used by smaller teams to share work and collaborate with projects. Showing users the possibilities and benefits of using Discord gives them the possibility to utilize it in other areas.

6 Conclusion

The experimental methodology used in this research work, contributes to open up a new mindset for how the Discord platform and Lean Automation insights can be applied in development of manufacturing performance, knowledge sharing and innovation.

This research work analyzes the lean performance of a 3D Printer Factory, with the original technical setup. The 3D Printer Factory is not aligned with lean principles, and this limits the efficiency and the usability. The 3D Printer Factory can only be operated from the physical location, and the knowledge of how to design for 3D printing and the development of the manufacturing process is not documented or systematically shared within the users.

This research work analyzes also the lean performance of the same 3D Printer Factory, with a new technical setup, where a Discord communication platform is integrated into the technical setup. The results show that the 3D printer Factory now to a large extent is aligned with lean principles, and this raises the efficiency and the usability. The 3D Printer Factory can now be operated from the Discord platform, which is web – based, with access to millions of users of the Discord platform. The Discord platform is easy to use, and becomes a foundation for establishing a resourceful open community, creating an accessible and adaptable 3D printing control center, creating a platform for learning and sharing of knowledge, and gathering of data that be used for further improvements of lean principles.

This research work introduces a new perspective and opportunity for knowledge creation and open innovation of 3D printing Factories.The setup of the Discord platform done here in this research work, can also be connected to laser cutters, robots, and other automated production equipment. Application of the Discord platform can open up new opportunities for Universities for how education can be done.

7 Future Work

The idea of implementing Discord as a communication platform, as is done for the 3D printing factory, could be explored for other production units in the factory. The units could be laser cutters, production robots and logistics robots.

The development of direct system improvements based on the data collected within the server could be explored. Improvements such as a queue system for prints and an overview page for the factory could directly improve the Lean Performance of the 3D printing Factory.

Discord could also be used as a link in the process of exploring the uses of new technology in conjunction with the production processes at the Factory. Bin picking, augmented reality and digital twins are technologies that could be exiting to explore.

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