Developing an automated solution for packaging process at Vraa Dampvaskeri A/S

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Abstract

The main objective of this study will be to develop a proof of concept of an automated solution for one of the processes related to Holiday Packages (HPs) in the commercial steam laundry company, Vraa dampvaskeri a/s (Vraa Laundry). The Holiday package consists of 4-6 linen items such as towels, duvets, bed sheets etc. Since there is a remarkable growth in this market, Vraa Laundry needs to increase their capacity to be able to cope with the increasing demand. Although they are buying new machines and will designate a greater space to this service, the company also needs to automise some of the related processes, which are presently handled manually. One of these processes is the packaging of the HPs. Packaging HPs consists of three different processes: manual stacking of the needed contents from the steel cage on the conveyor, automatic plastic wrapping and finally manual stacking of the wrapped packages in the linen sacks for transportation. Manual stacking of the content from the steel cage to the conveyor is the slowest amongst all and consists of a significant potential for automation. An automated solution consists of 6 magazines, one for each item instead of a steel cage. Each magazine has a set of dedicated suction cups at the top to raise a single piece of linen from the stack and a dedicated gripper mechanism to move the linen onto the conveyor. A proof of concept/small prototype will be developed for the chosen automated solution, where the above mentioned mechanism for the stacking of one of the linens in the HP will be developed and after that a discrete event simulator will be used to simulate the whole process. The expected result is that the generated solution will perform the job faster with less dependency on manual labor for packaging of the HP.

Keywords: Textile, Automation, Laundry industry, Discrete event simulation

1 Introduction

Increasing competitiveness and demand to capture the market leader spot has bounded industries to innovate and implement the advancement of technology. Along with the product innovation, process innovation is also playing a vital role for different industries such as automobile and consumer goods to meet customer needs and reach the top paradigm [1]. The laundry industry is also trying to innovate to catch up the fast-changing demands. The automated solutions to handle linen has been a requirement for these industries for decades.

Laundry industry is a well-known industry for repetitive and human extensive jobs, making it suitable platform to implement automation. Vraa Laundry is the third biggest laundry company in Denmark. It has been in the race of innovation since 1991 by the implementation of RFID technology to track material flow through the production line. With nearly 50% of the process being automated, it has a vision to be fully automated along with the implementation of Industry 4.0 platform. It can help to be the environment friendly industry. Danish labour market is highly expensive, and automation can help to reduce dependency on human forces or eventually reduce the working capital cost. One of the processes, which is still carried out manually at Vraa Laundry is the packaging of the linens and forming a Holiday Packages (HP). This process consists of manual stacking of the linens on the conveyor belt which then passes through the wrapping machine to pack the HPs. Textile being non-rigid structure is quite difficult to handle by the machines as it can easily be deformed.

Previously, to execute this task a concept has been developed and tested. The test results showed that the concept didn’t reach the required lead-time, due to which a need for a new design or improved design still exists. The estimated lead time in the previous design was 5 mins/HP instead of 10s/HP. Therefore, the main objective of this study is to develop a concept, which can overcome these challenges and still reach the required lead-time.

2 Process Analysis and Product requirements

2.1 Process Analysis

To design and develop a production process, it's important to understand the process environment and its surroundings.

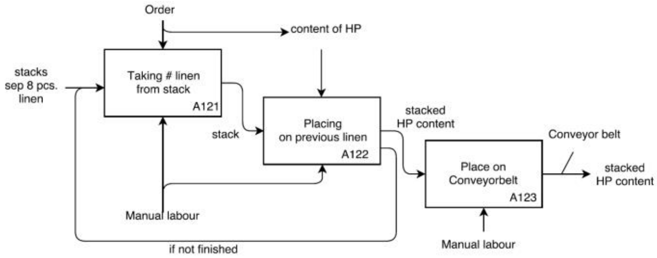

Fig.1. Process box for processing holiday packages

Presently, this assembly process of the HP is a manual process where employee place a stack of 6 different types of linen on the table. Furthermore, the different linens are stacked on each other to form a HP. When a HP is fully assembled it is then moved to the conveyor belt which passes through the wrapping machine. **Fig.1.** illustrates the manual stacking process of the linen. The design and development of a system capable of doing this process is the aim of this study.

2.2 Design and Functionality requirements

The designing of the concept requires some predefined requirements which need to be fulfilled to achieve an efficient functionality system within the production process. The requirements are divided into two categories: Design and Functionality.

Each of these categories contains certain requirements which need to be fulfilled by the final design.

2.2.1 Design requirements

The design requirements mentioned below are based on the present structure of a Holiday package.

1. The designed solution needs to be capable of handling at least six kinds of linen of varying dimensions.
2. It should be capable of handling at least 1 kg of weight.
3. It should be able to handle linen of different material and surface finish.

2.2.2 Functionality requirements

Functionality requirements are established in order to develop an efficient solution.

1. The dimensions of a HP should not vary more than 5 mm in length and width.
2. The handling of linen should be done without deforming other linens. i.e. By picking and placing.
3. The cleanliness of the linen should be maintained by the system.
4. The solution should be able to produce HPs of varying content. Currently, six kinds of HPs are produced at Vraa Laundry.
5. The cycle-time of the process should be 10s/HP.

3 Concept Generation

The primarily aim of the conceptual design is to generate promising concepts [2]. A range of concepts must be generated and then evaluated and selected. In this project, a brainstorm was initiated to generate a range of concepts. During the concept generation, different ideas were discussed, and some concepts has been generated. Some sub-concepts were defined beforehand of the session, which limited the generated concepts. The defined parameters were that the suction cup concepts and the gripper concept were considered good enough to separate and drag the linens. Therefore, it was decided to continue with these concepts and not looking for new solution for this part of the task.

During the concept generation, different concept was evaluated and eliminated. Finally, three concepts were selected to continue with. **Fig:2** illustrates the three concepts. The concepts must be evaluated and screened based on different criterias.

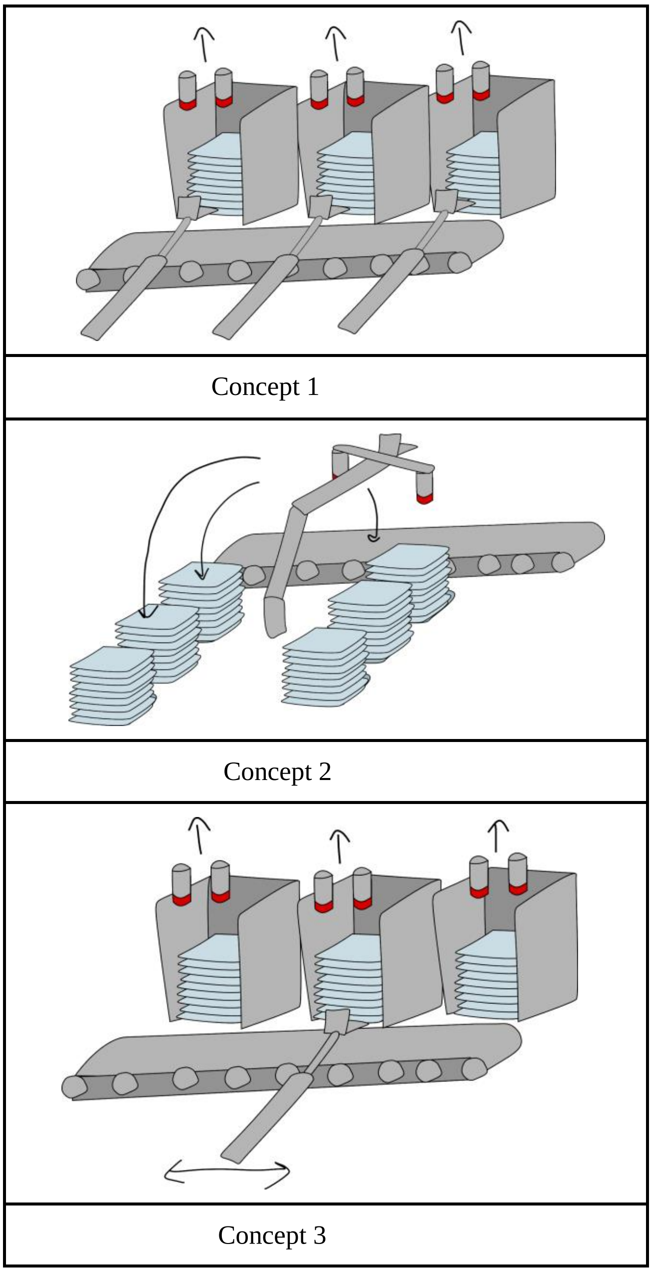

Fig.2. Three selected concepts

The screening of the concepts is a morphological method based on weighted points [1].The points are given based on the features weighted against the requirement by the company. The following features has been considered:

- Flexibility - The ability to make changes in the content of the HP.
- Cost - The initial price of the solution.
- Cycle time - Total time from start to end in a process.
- Scalability - The ability to increase or lower the production capacity.
- Manual labour - How much human interaction does the solution need.
- Complexity - How many parts are used and is there interactions between them.

The weighting can be seen in **table 1**. This score is converted to a weighting to normalize the numbers (W=score/total score). The weighting of the features is used to rate the concepts.

	Score	W
High Flexibility	2	0.10
Low Cost	5	0.24
Low Cycle time	6	0.29
Good Scalability	3	0.14
Least Manual labor	1	0.05
Low Complexity	4	0.19
Total	21	1.00

Table 1: Features and weighting.

The cycle time is considered as the most important feature since this is the initial problem why it gets 6 points. Second is the cost, which is partly coupled to the complexity. The scalability is considered as an important feature to future-proof the concept. The flexibility is less important since the HPs has not changed significantly. The flexibility is still considered since it can open for a new level of service to customize the HPs either on batch size or by single packages. At this level of the screening, reliability is difficult to determine, it is not therefore considered.

After weighting the features against the requirements, the concepts should go through the same process and be weighed against each other in each feature. For the concepts, a scale ranges from 1-3 where 3 is the best score, has been developed. The points will be multiplied by the corresponding weight of the features and then summed up to find the total point of a concept and find its position in general against other concepts. The concept with highest score will be further developed. The scores are illustrated in **table 2**.

	High Flexibility	Low Cost	Low Cycle time	Good Scalability	Least Manual labor	Low Complexity	Total
Factor	0.10	0.24	0.29	0.14	0.05	0.19	
Concept 1	2	2	3	2	3	1	2.14
Concept 2	3	1	1	3	3	3	1.95
Concept 3	1	3	2	1	3	2	2.05

Table 4.2: Table of features and weighting.

Table 2: Features and weighting

Concept one scores highest as it has a shorter cycle time, which is the highest rated feature, and scores second best in the other features despite scoring low on complexity.

4 Design and Development

The automated solution to handle different types of linen was designed and it can be reciprocated multiple times depending on the type of linens to establish the whole production system. The structure of the solution was divided into four sub-parts, and the design can be seen in **Fig 3**. Dividing into sub-parts gives the advantage of modularity while developing a solution. Developing the structure in four different sub-parts and later combining these, helps to ease the assembly and maintenance process. The four sub-parts in the design consists of:

1. Magazine: The lifting plate surrounded by the support plate to store linen and keep the linen at a fixed height with respect to the suction cups.

2. Linear Movement: This is used to move the linen from the magazine to the conveyor belt.

3. End Effector: Tool to hold the linen while moving.

4. Conveyor belt: It serves the purpose of moving the linen from the assembly area to a wrapping machine.

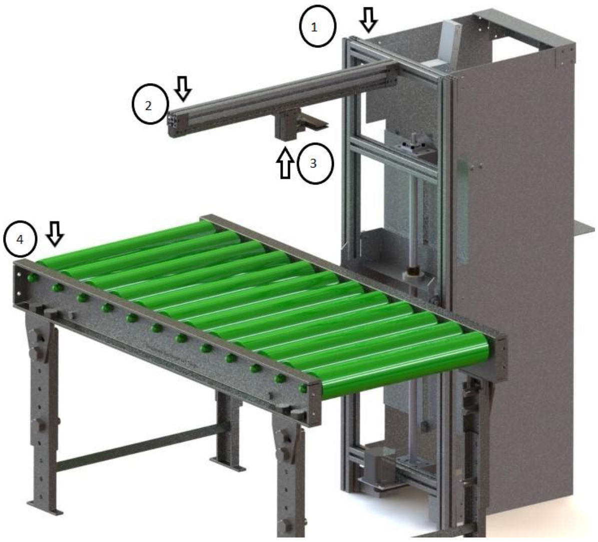

Fig.3. A CAD model of the solution.

The conveyor model was developed only for the dimensional purpose as the magazine structure need to be mounted on it. It was not the part of the development process.

4.1 Magazine

The magazine is designated to lift the linen and maintain its position with respect to the suction cups and the end effector. The magazine consists of two parts: A lifting plate which serves the purpose to store the linen, and a suction system to lift and separate the linen from the stack, as can be seen in **Fig 5**. Process parameters influencing the design of the magazine is drafted in **Fig 4**.

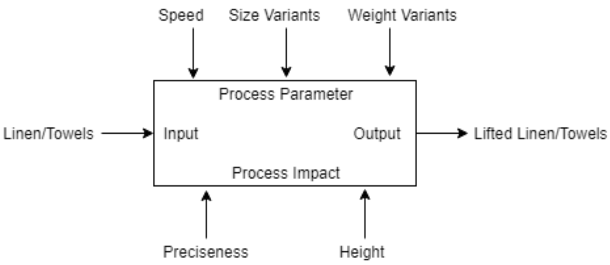

Fig.4. Process box for magazine

Since the dimensions and weight of the linen varies, it is quite important for the magazine to lift the linen at a desired height. Also, the position of the suction cups with respect to the end effector and dropping height over the conveyor belt need to be fixed. These dimensions are derived from the test performed on the proof of the concept. Experiments result can be found in the **Appendix 1a.**

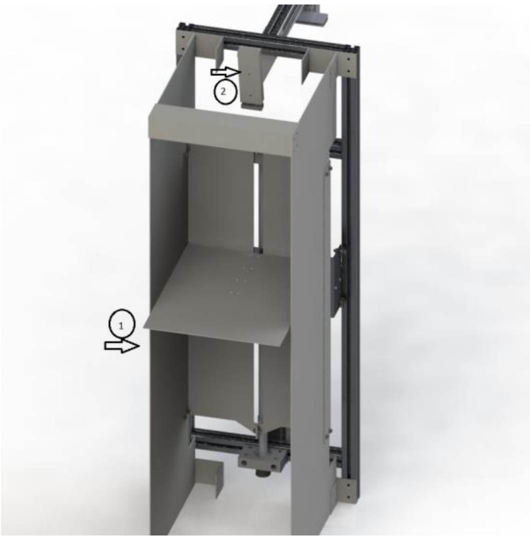

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Fig.5. Designed magazine with lifting plate (1) and suction cup (2)

4.1.1 Lifting Plate

An aluminium plate with dimensions dependent on the width of the linen is mounted to a spindle. This plate has three roller bearings on each side which helps to glide the plate over the frame freely. A motor is attached to the spindle which corresponds to the translational movement of the plate. The side plates limit the position of the linen with respect to the suction cups.

4.1.2 Suction System

Two suction cups along with a vacuum ejector is mounted on a pneumatic piston. The piston provides the back and forth motion of the suction cup to lift and separate the linen from the stack. The stroke length was the prime factor based on which piston that was chosen.

4.2 Linear Actuator

The designing of actuator requires consideration of process parameter and process impact. These parameters will help to choose a specific actuator dedicated for the given process. Velocity, length and acceleration is the parameters that determine which actuator that will fit the solution. **Fig 6** shows the parameters which need to be considered. In the market, various types of actuators are available such as pneumatic, hydraulic and electrical actuators which can further be divided into piston based, spindle based or belt driven actuators.

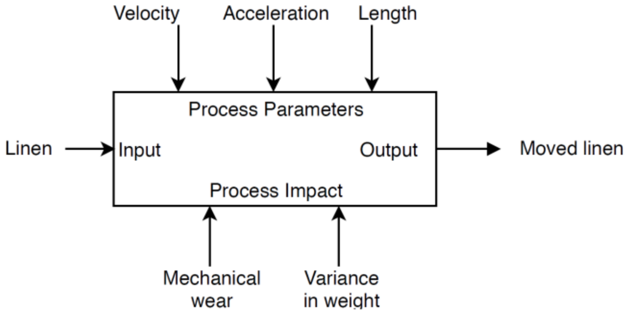

Fig.6. Process box for linear actuator

Based on the experiments performed on the proof of concept design, the linear actuator for optimal speed was chosen. Experimental results can be found in the **Appendix 1b**. The linear actuator used in the solution is shown in **Fig 7**.

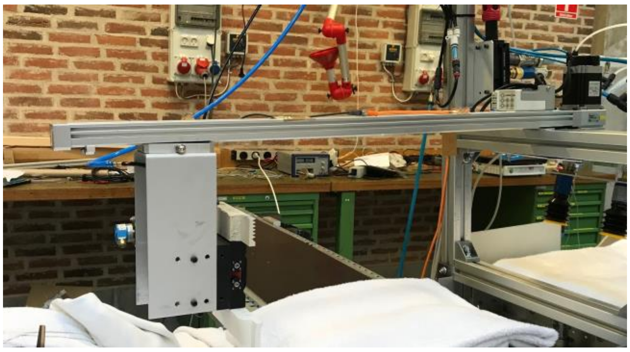

Fig.7. Linear actuator used in the setup

4.3 End Effector

A designated tool is designed to hold the linen while the linen is being handled. **Fig 8** shows the process parameters and process impact factors which are taken into account for designing purpose.

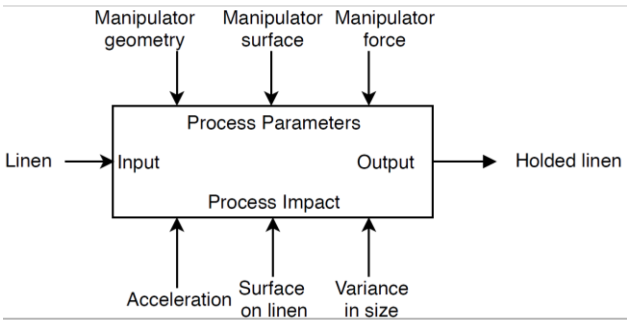

Fig.8. Process box for end effector

The width and thickness of the linen is varying along with the surface finish. Linen with smooth surface finish requires a better gripper to hold on to the linen without slipping it of while moving over the conveyor.

Fig 9 shows the 3D printed gripper design that is used as the end effector. The gripper is designed with a longer length in the bottom to give a larger surface area to connect with the linen.

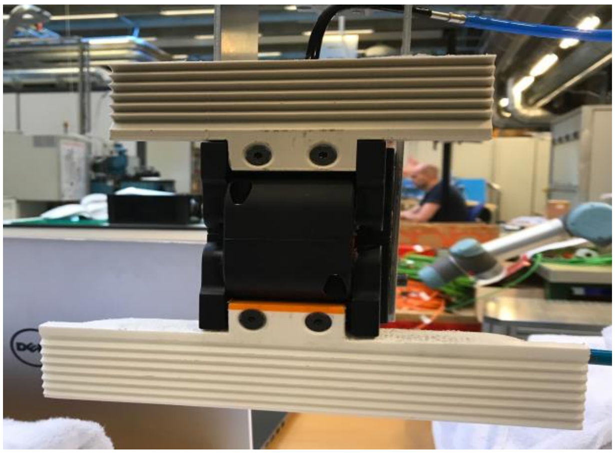

Fig.9. Gripper design

The gripper is mounted on a rotary actuator which controls the opening and closing of the gripper. The rotary gripper is chosen based on the force it exerts when the gripper is closed. This ensure no slippage of the linen.

4.4 Sensors and controls

The system can be controlled based on the pseudocode in **Fig 10**. The flow charts contain the task performed based on the input decision from different sensors.

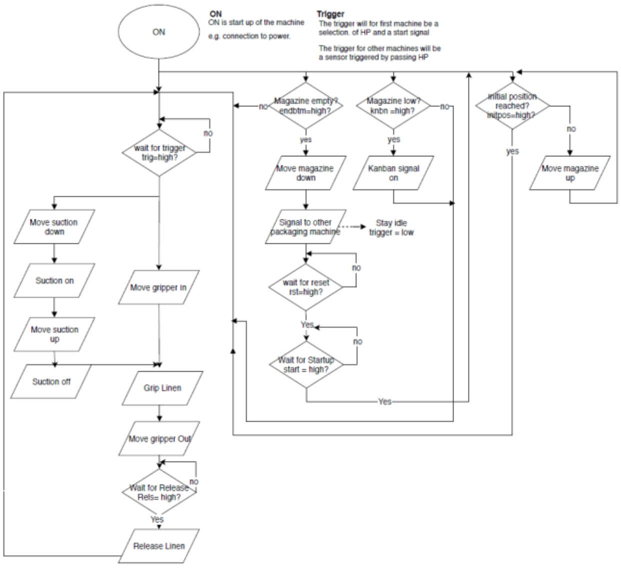

Fig.10. Pseudocode logic

Several sensors are mounted on the system to control the functionality of the system and make it more industrial ready and autonomous. Sensors such as photoelectric and inductive sensors can be used for the input signal which controls the actuators movement.

All the sensors and actuators relate to a Programmable Logic Controller (PLC). The logic from the pseudocode is used for the programming purpose.

5 Testing and Results.

5.1 Testing Methods

80 trials were performed to test the functionality of the system in the real world. Each trial process is divided into two processes. Process 1 is the lifting of the linen by the suction cup and Process 2 is grasping and placing of the linen by the gripper on the conveyor belt. The trial is failed even if one of these two processes failed in a trial.

5.2 Testing Results

Out of 80 trials, only 10 trials are presented in **Fig 11.**

	Small Towels		Big Towels		Duvet	
Iterations	Process 1	Process 2	Process 1	Process 2	Process 1	Process 2
1	Approved	Approved	Approved	Approved	Approved	Approved
2	Approved	Approved	Approved	Approved	Approved	Failed(2)
3	Approved	Approved	Approved	Approved	Approved	Approved
4	Approved	Approved	Approved	Approved	Approved	Approved
5	Approved	Approved	Failed (1)	Approved	Approved	Approved
6	Approved	Approved	Approved	Approved	Approved	Approved
7	Approved	Approved	Approved	Approved	Approved	Approved
8	Approved	Approved	Approved	Approved	Approved	Approved
9	Approved	Approved	Approved	Approved	Approved	Approved
10	Approved	Approved	Approved	Approved	Approved	Approved

Fig.11. Test results

As it can be seen in **Fig.11**, in case of small towels 100% process efficiency was achieved. But in case of big towels and duvets, out of every 20 trials, one trial failed. The process efficiency of total HP process sums up to be 85.7% for a HP consisting of two big towels, one duvet and one small towel. This failure was not due to the system failure but due to limitations by linen. Fail (1) denotes failure due to non-lifting of linen by the suction cup which was due to improper folding of the linen. Fail (2) was failure due to non-grasping of linen by the gripper. This was due to a short distance between suction cups and the edge of the linen facing towards the gripper. A sufficient surface area is required for the gripper to grasp the linen failing for which the process may fail as it happened in this case.

The fails give a limitation of the system with respect to the linen, as the orientation and position of the linen need to be accurate to achieve the optimal result. It is assumed that this won't be the problem in the designed magazine presented in section **4.1**. The magazine used in the testing differ from the main design as the side plates mentioned in sub-section 4.1.1 was not used in the tested design.

6 Simulation

The proposed solution is deemed to be less dependent on the employees and may increase the HP production capacity. To verify if this solution will increase the production capacity, a discrete event simulation with Arena software was performed. The developed model replicates the process from the refilling of the machine until the wrapping process. The Arena model has been developed for HP which is the most popular HP. As each machine is capable to handle one kind of linen, a setup of four machines are established for this model. This HP is the most critical HP since this has the highest demand and it can therefore be deemed that if the solution is functioning for this solution, it can function for all other HPs.

With the aim to find the optimal number of items in each magazine in the proposed solution, three scenarios were developed with varying quantity of linen in the magazine. **Table 3** shows the three developed scenarios.

	Scenarios		
Content	1	2	3
Towel (T)	40	40	30
Bed Sheet (BS)	40	40	30
Pillow case (PC)	40	240	200
Duvet (Du)	40	40	30

Table 3: Stacked number of items in assigned magazine in different scenarios

In all three scenarios mentioned above, following factors remains constant:

- The cycle time of each process module is set to be 10 s.
- The refilling time is 20 s, based on observations.
- The transportation time between the magazines is estimated to be 5 s.
- One working day in the model is considered as 12 hr.

The results of the simulation reveals that the second scenario requires minimum number of refill repetition i.e. 2216 refills to produce 14000 HPs. The second scenario requires 6.16 hours of manual labour to refill the magazines. The results also reveal that the minimum time to produce 14.000 HPs belongs to the second scenario.

Each large stack of towels/linens contains 200 items which is used to refill the magazine based on the required quantity. Once the magazine is empty, a worker needs to fetch a new stack to continue the refilling the magazine. Fetching a stack is observed to take 45 s, which means that the worker is spending 3.5 hours to fetch steel-cages.

When summing up the total required manual labour, 9.66 hours is needed to produce 14.000 HPs. Currently, 70 manual labour hours is needed to produce the same number of HPs. This means a cost reduction in term of using the manual labour. Based on this, the company can remarkably reduce the production cost of the HPs. It may be argued that the manual labour is still required for the setup. It is a true argument but there is another nearby non-automated process where manual labour can be employed along with this proposed solution. Therefore, the manual labour will not be wasted.

It can be considered that the cycle time of the proposed solution is same as the cycle time of the manual labour process. However, the current cycle time of the manual labour will not remain constant and the proposed solution can work even faster. Therefore, the company can easily speed up the production or increase the production capacity by adjusting the cycle time.

7 Conclusion

In this paper, a design for automated solution for the packaging process at Vraa Laundry has been presented. The design can handle various linens which can be picked and placed on the conveyor belt. The knowledge was collected by analyzing the present manual process. The analysis was divided to form design and functionality requirements. Based on this, concepts were generated and compared to choose the most suitable concept to be further developed.

The four sub-parts in the final design was developed and assembled to test the functionality behaviour in the real world. Each process parameters were analysed to design a compact structure. The final design was tested for several trials to check the process efficiency of the proposed solution. With 85.7% process efficiency, the solution shows that it has the capability to be improved to attain a better result. It can be considered that the failure during the test was not due to the system error but due to the limitation raised by the linens. Even the simulation model of the HP process gave a significant decrement of required manual labour despite keeping the cycle time same as the present manual process. The only process where manual labour is required in the proposed solution is for transportation of folded linens to the HP packaging process and to refill the magazine.

Acknowledgement

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References

[1] K.T. Ulrich, S.D. Eppinger. "*Product design and development*". 5th edition, Mc Graw Hill, 2004.

[2] Y.C. Liu, A. Chakrabarti and T. Bligh "*Towards an "ideal" approach for concept generation.*". *Elsevier*, Vol. 24, No. 4, pp 341-355, 2003.