KTH Royal Institute of Technology

Mechatronics, Advanced Course Spring Semester
MF2058

PalleTron

Spring term report

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May 20, 2024

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EPAL European Pallet Association 4

HITS Hållbara och Integrerade Urbana Transportsystem 1

LIDAR Light Detection And Ranging 7, 16

1 Introduction

Automation and robotics are becoming a bigger part of our lives, and companies are looking to integrate them wherever they see fit. In this spirit, Scania has set out to automate urban delivery of goods to stores. With this goal in mind, Scania started a project for both an autonomous truck and an autonomous last-meter delivery robot that will transport goods from a truck to an actual vendor. This last-meter delivery robot is the focus of this project, and the goal of it is to design and construct an entirely new prototype that can demonstrate this capability. This project is a part of Hållbara och Integrerade Urbana Transportsystem (HITS) which is a bigger project with the same goal of automating urban transportation where Scania is taking part.

While there are concepts similar to this project for warehouse use, the urban aspect makes this project unique. Because of this uniqueness, an entirely new solution needs to be designed. However, the concepts of lifting pallets and autonomous navigation as well as other related topics are well known. Therefore, there is still a lot of valuable information that could be useful for the project when deciding on how to go about building The Prototype. This pre-study was conducted with this purpose in mind. From here on out, the robot that will be produced during this project, will be referred to as "The Prototype".

This chapter also provides a general overview and background of the project, the general scope, and the way the team was organized. An introduction to the stakeholders is also included where a description of the stakeholder (Scania) and their requirements are stated in detail.

1.1 Background

Cities are constantly growing as urbanisation and population are increasing around the world. The projected population growth in Stockholm region will be approximately one million people by the year 2050. As the population grows and e-commerce continues to thrive, so will the demand for sustainable and efficient deliveries [1].

Last-meter delivery has been performed manually for many years, but this process involves very inefficient and potentially dangerous manual operations by the truck drivers as well as operators. Also there is currently a shortage of delivery drivers which will eventually continue to increase over time[1]. Hence, there is a need for autonomous last meter delivery robots to ease the overall delivery operation. Using an autonomous robot can improve efficiency of delivery operations and reduce the risks and accidents associated with manual operations.

By automating the whole transport chain from warehouse to end customer, the need for delivery drivers will decrease and the demand from the customers can be met. Team PalleTron aims to assist in solving the last step in urban deliveries, the last-meter delivery. The Prototype is a robot that can perform a last-meter delivery operation and deliver the package to the end customer. The Prototype is supposed to pick up loaded EUR-pallets from a delivery truck and deliver the package to the end customer.

This project is part of HITS 2024 which is a collaboration project started by Scania Research & Innovation in 2020 which includes fifteen partners that each conduct research internally to contribute to a common goal. The project aims to accelerate the development of sustainable and efficient transportation systems in urban cities[2].

1.2 Scope

The scope of this project encompasses the design and development of a hardware prototype for an autonomous last meter pallet delivery robot. This includes creating a comprehensive hardware design for both the lifting mechanism and the robot platform, aimed at facilitating the automated handling and transportation of EUR-pallets in urban environments. The Prototype will focus on the mechanical components necessary for autonomous operation, such as mobility and lifting capabilities, without delving into the software development or integration of control systems. Given the project's time frame, the emphasis will be on constructing a physical model that demonstrates the core functionalities required for future software integration and full autonomous operation. The scope is limited to these hardware aspects, excluding software development, extensive field testing, and full-scale deployment.

1.3 Organisation

During the spring term, the project team consisted of eight members, including one designated team manager. Initially, each member researched various aspects essential for The Prototype's upcoming design phase. The information gathered was crucial for brainstorming and concept sketching activities throughout the term.

From the initial research, two main concepts were decided on, for which the team was divided into two subgroups of four members each. These groups worked to refine each concept to determine the most suitable one for construction in the fall term.

Additionally, the team was divided into four smaller groups of two members each, focusing on specific research areas: pallet jacks, last mile delivery robots, lifting mechanisms, and terrain traversal. This research was vital for acquiring the information needed to further develop The Prototype.

Meetings with the stakeholders were held bi-weekly as well as meetings with the teams coach Gustav every week to discuss the recent work and progress. To facilitate easy and fast communication with the stakeholders in between the meetings, a Slack channel was created.

1.4 Stakeholders

The primary stakeholder for this project is Scania. The student team is supported by Raphael Andreolli and Ewa Sondell, who serve as industrial supervisors, along with Viktor Florian, who provides expertise related to the driverless vehicle concept, and Beatrice Svedberg, who offers support regarding Scania's network and activities.

Additionally, the Integrated Transport Research Lab (ITRL) at KTH, which is sponsored by Scania, contributes by providing access to a variety of hardware components. The main contact at ITRL is Professor Mikael Nybacka, who also addresses any questions the student team may have about the available hardware.

1.5 Requirements

This section provides an overview of the requirements obtained from stakeholders, as well as additional requirements that emerged as the project scope was refined. These requirements will serve as fundamental guidelines for the project and will be used for validation upon project completion. The requirements that begin with "Shall" are mandatory and requirements that begin with "Should" are desirable.

- Shall lift standard EUR-pallets (L120 cm x W80 cm x H14.4 cm) with payload of 200 kg.
- Shall avoid tipping while lifting EUR-pallets with a payload of 200 kg.
- Shall lift EUR-pallets from both long and short sides.
- Shall be designed with safety measures such as emergency stops.
- Shall fit within boundary volume (L120 cm x W80 cm x H80 cm).
- Shall be able to move and lift using remote control.
- Shall be designed with further development in mind.
- Should be able to drive on the test track around the M building at KTH.

1.5.1 Test track

The test track can be seen in Figure 1. The area surrounding the KTH M building was deemed to have a terrain that can represent some of the worst conditions that The Prototype should be able to handle in the real world. It includes cobblestone, gravel and slopes up to 7°which was deemed enough for validation purposes. The idea is for the prototype to drive to a pallet with a payload, lift and transport it, and place it in another location.

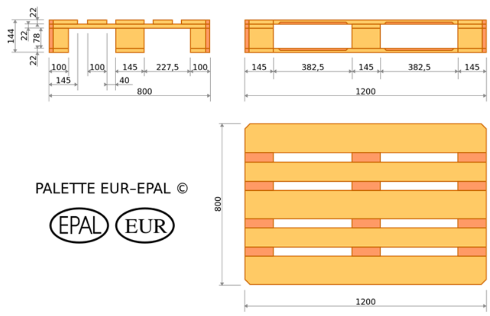
Figure 1: Part of the test track area

2 State of the Art

2.1 EUR-pallets

The EUR-pallet is the most widely used exchange pallet in the logistics world today. They are usually called EUR-pallets or EPAL pallets. European Pallet Association (EPAL) is an international association that is responsible for organizing the EPAL Euro Pallet exchange pool. This pool of EUR-pallets is the largest exchange pool in the world, where one can exchange one pallet for another[3]. Today there are more than 650 million pallets in circulation and most of them are used in Europe [4]. The EUR-pallet can be seen in Figure 2a and its dimensions in Figure 2b. The whole product sheet for the EUR-pallet is found in Appendix A.

(a) The traditional EUR-pallet



(b) Dimensions of an EUR-pallet

2.2 Last Meter/Mile Delivery Robots

Last mile delivery is the final movement of goods from the distribution center to the end customer. Last mile delivery is a crucial part of the distribution of goods to customers but can include complex logistics and transport solutions. The goal is often to improve the ability to provide fast and reliable deliveries to customers which will often lead to further sales along with increased income for companies[5]. Last meter delivery zooms in even further and focuses on the actual delivery of goods from the delivery vehicle to the doorstep or delivery point of the customer. This requires effective communication between the recipient and the delivery personnel to ensure safe and reliable delivery.

2.2.1 Current scenario and associated drawbacks

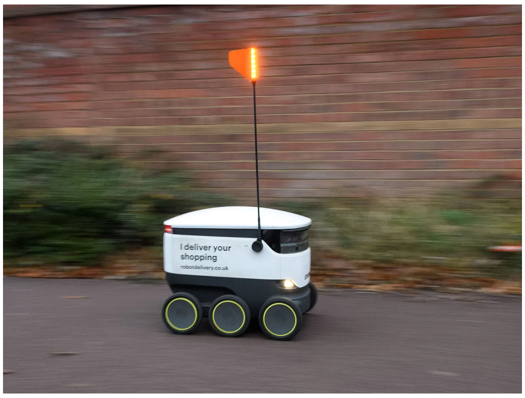
The current last meter delivery operation involves the use of a pallet jack or pallet lifter, which is manually operated by a human operator. This operation is inefficient as it may involve human errors and it is also associated with risks and accidents. This is quite a challenge to overcome and companies are focusing on developing solutions that can offer a more efficient operation as well as ensure safety of operators.

2.2.2 Current Solutions

There are currently no solutions for autonomous last meter delivery robots that are able to lift EUR-pallets. However there are a lot of last mile delivery robots that transport goods from warehouse directly to the end customer.

2.2.3 Starship Technologies

Starship Technologies is a Estonian tech company that has developed a last mile delivery robot that is deployed and operates in urban environments, see Figure 3a. The robot is equipped with nine cameras and eight ultrasonic obstacle detectors that enable it to get a 360° view of its environment[6]. Together with image recognition and machine learning algorithms, the robot calculates the best path to travel at all times[7]. Furthermore, the robot is equipped with 6 large wheels, adapting it for tough urban terrain.



(a) Starship Technologies delivery robot

(b) WAVE: Last mile delivery robot

Figure 3: Existing solutions for last mile delivery

2.2.4 WAVE

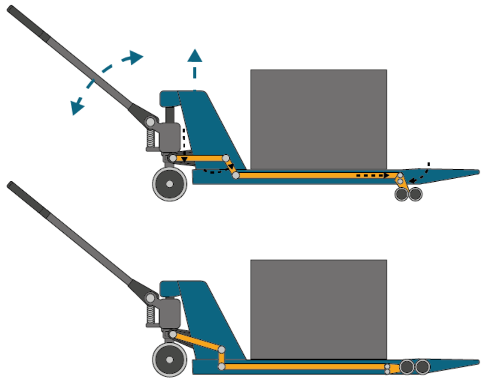
WAVE is a last mile delivery robot that was part of a research project by students at Han yang University in South Korea. The robot was designed to deliver goods on flat ground but is also able to climb stairs with a four-bar linkage design that makes the robot alternate its body with the legs, see Figure 3b. This enables a more flexible delivery that other types of delivery robots aren't able to conduct, providing a solution for customers that have stairs or steps to their door[8].

2.3 Pallet Jacks

A pallet jack is a common tool widely used in factories and logistics to lift and move heavy goods. As a consequence of the standardized form factor of pallets, it is optimized to be able to lift and move them in an easy manner. A standard pallet jack can be seen in Figure 4a.

The pallet lifter comes in many different variations but the general design is the same across the different versions. Consisting of two forks with a lifting mechanism and some kind of handle with wheels enabling the moving and lifting of the pallet.

(a) Regular pallet jack for warehouse use



(b) Typical pallet jack mechanism

Figure 4: Pallet jack and the mechanism it uses

The mechanism of a standard pallet jack which can be seen in Figure 4b consists of the previously mentioned handle which can be moved up and down to pressurize a hydraulic cylinder which in turn lifts the forks. An interesting aspect of this mechanism is the linkage underneath the forks, which also lifts a pair of support wheels located in the front of the forks. Since this mechanism provides points of support throughout the entire lifting operation, it eliminates the need for some kind of counterweight to support the pallet instead.

2.3.1 Typical strength and design constraints

Because of the load-bearing nature of a pallet jack or any kind of pallet lifting mechanism, the structural strength of the construction is essential. There exist many analyses of current pallet lifters, and these can help serve as a guide for how sturdy The Prototype needs to be in order to manage the typical loads that lifting a pallet may induce. One such analysis of a standard pallet lifter was done by [9] Where a Finite element analysis was done for a pair of pallet forks on a pallet lifter. For the development of The Prototype, similar kinds of analyses can be made when dimensioning the forks for the required lifting loads.

Since there will be differences in the mechanical structure of The Prototype and a traditional pallet jack, it could be worth looking at more general research regarding structural analysis. A case study from the University of Waterloo [10] has been conducted to look at failure modes and structural integrity in a more general sense. This is a great starting point for analyzing the fork design and identifying failure points across the whole design.

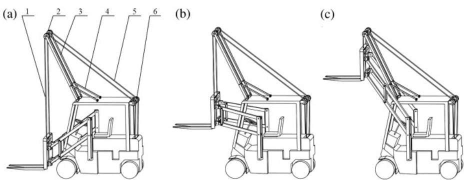
2.3.2 Automated Pallet Jacks

Automated pallet jacks are automated cargo handling devices designed to move and carry cargo autonomously without the need for manual pushing or maneuvering. These devices are typically battery-operated and equipped with a variety of sensors and control systems to automatically navigate and perform specific tasks, such as lifting and stacking goods.

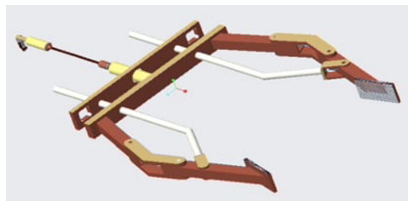
Automated pallet jacks utilize a combination of sensors such as proximity sensors, ultrasonic sensors, and Light Detection And Ranging (LIDAR) for navigation and obstacle avoidance. Control systems, including microcontrollers and onboard computers, process sensor data to make real-time decisions.

2.4 Lifting Mechanisms

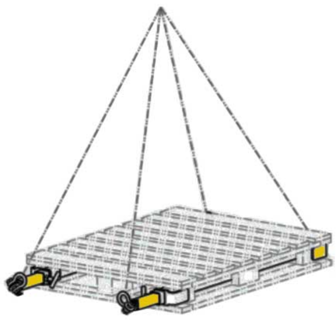
There are several lifting mechanisms that can be utilized to facilitate the lifting of pallets. This section briefly explains different existing lifting mechanisms that could be used in the project.



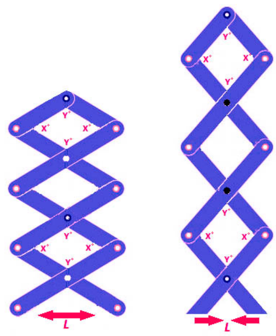
(a) Lifting using forks mechanism example



(b) Pallet gripping mechanism



(c) Illustrations of pallet hoist mechanism



(d) Scissor mechanism

Figure 5: Lifting mechanisms

2.4.1 Forks

Forks, as seen in Figure 5a, are metal beams commonly attached to forklifts and pallet jacks, designed to work with pallets. These beams have specific length and spacing that match standard pallet dimensions, enabling efficient lifting and transportation. The movement of the forks is typically powered by hydraulic systems, which vary in configuration depending on the machine. Hydraulics enable smooth and controlled lifting and lowering of the forks, allowing the operator to easily position the forks beneath the pallet from either side, facilitating secure and stable lifting.

2.4.2 Gripper Mechanism

The gripper mechanism, though not as prevalent in the industry, offers unique advantages for specific scenarios. This method uses gripping arms or claws to grasp the pallet from the sides. It is particularly useful for handling items that are robust and not easily damaged. However, gripper mechanisms require clearance space around the pallets for the arms to engage, which can lead to less efficient storage configurations. Despite this limitation, grippers can be advantageous in environments where precise handling and positioning of pallets are necessary. A gripper mechanism can be seen in Figure 5b.

2.4.3 Using Hoist or Winches

Hoists and winches are effective lifting methods when workspace height is not restricted. These systems use cables, chains, or ropes wound around a drum to lift and lower loads. In some cases, a counterweight may be required to balance the load and ensure efficient operation. Hoists and winches are particularly useful in applications requiring vertical lifting over considerable heights, such as in warehouses with high storage racks. They offer precise control over lifting and lowering, making them suitable for handling heavy and bulky pallets. An example of such a mechanism can be seen in Figure 5c.

2.4.4 Scissor Mechanism

The scissor mechanism, as seen in Figure 5d, is a widely-used lifting method in the industry, especially for applications where counterweights are impractical. This mechanism consists of interconnected metal arms that form a crisscross (scissor) pattern, which extends and contracts to raise and lower the load. Scissor lifts can be actuated using electrical motors, hydraulic systems, lead screws or pneumatic cylinders. The choice of actuation depends on the specific application and required lifting capacity. Scissor mechanisms provide stable vertical movement, making them ideal for lifting pallets to various heights without needing additional support structures.

2.4.5 Lifting with Wheels Mechanism

This mechanism is used in traditional pallet jacks. It involves lifting the entire body of the pallet jack by using a hydraulic jack located near the large wheels. When the hydraulic jack is activated, it extends the small wheels at the end of the forks, elevating the entire pallet jack and its load. This dual-wheel system, with both large and small wheels lifting simultaneously, allows the operator to easily maneuver the pallet jack and its cargo over various surfaces and into tight spaces.

2.5 Terrain traversal

As mentioned in previous sections, there are already existing autonomous pallet lifters. The challenge that is unique to this project however, is the operating environment of the lifter. Since it is supposed to operate in urban environments it has to be adapted to function there. Urban environments introduce some problems, with the main issue being the terrain. Urban terrain means that unlike factory floors there will be objects obstructing the way and uneven ground as well as slopes. There are some different ways to handle this terrain but the main thing that needs to be considered are the wheels of the operating vehicle. In this section, different kinds of solutions for wheels and wheel deployment will be discussed.

2.5.1 Wheels attached to the forks

Regular pallet jacks that are used today have small hard wheels attached to the forks, as seen in Figure 4a. This is a major issue since these are not constructed for the terrain in urban environments. To be able to enter underneath an EUR-pallet from both sides the wheels cannot have a diameter that is larger than 10 cm. This is seen in Figure 2b which showcases the dimensions of an EUR-pallet. The typical solution for wheels to handle worse terrain is to increase the diameter so they can traverse over larger obstacles.

One interesting solution for The Prototype to handle driving over larger obstacles is to fit smaller sized wheels in a triangle like shown in Figure 6. Fitting wheels in a triangular pattern like this is usually called "Tri-star wheel system". This will make the mechanism function like a wheel with larger diameter since it elevates its center point and can therefore roll/climb over larger obstacles.

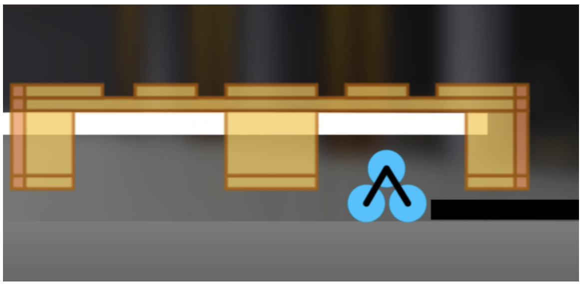


Figure 6: Smaller wheels arranged like a triangle to make them function as a larger wheel

A robot that was constructed using six of these tri-star wheels called "Tribot" proved to be very good at climbing vertical obstacles. Despite its wheel diameter of 220 mm it could climb obstacles up to 450 mm[11]. Tribot can be seen in Figure 7. However, The Prototype most likely cannot have six wheels and will therefore not be able to climb as high. This tri-wheel concept could however still enable traversal up pavements or other obstacles.

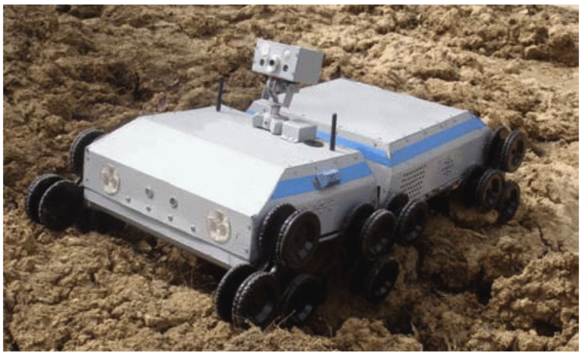


Figure 7: Tribot concept vehicle

Another possible solution could be to have wheels with a larger diameter that are folded up into the forks initially during the phase when the pallet lifter is entering the pallet, and exiting the pallet. This however would require some sort of smaller support wheels similar to the normal pallet jack fork wheels to prevent the pallet lifter from tipping. Some sort of lifting mechanism would be needed to elevate the EUR-pallet enough to deploy the larger wheels.

2.5.2 Mechanisms for adjustable ride height

Regular pallet jacks like the one in Figure 4a use hydraulics to lift pallets, as described under section 2.3. To solve the challenge of both lifting the pallets and elevating The Prototype from the ground to gain higher ground clearance, and thereby, better all-terrain capabilities, an idea could be to have some sort of mechanism to facilitate adjustable height of the wheels. One solution could be the wheel being attached to a rotating shaft, and the shaft being driven by a DC-motor, once such design was proposed by Zhao et al. for an "All-Terrain Wheel-Legged Robot"[12]. The mechanism at work is illustrated in Figure 8 and the robot is illustrated in Figure 9. A potential issue with this mechanism is that it is too weak to support the weight of a pallet.

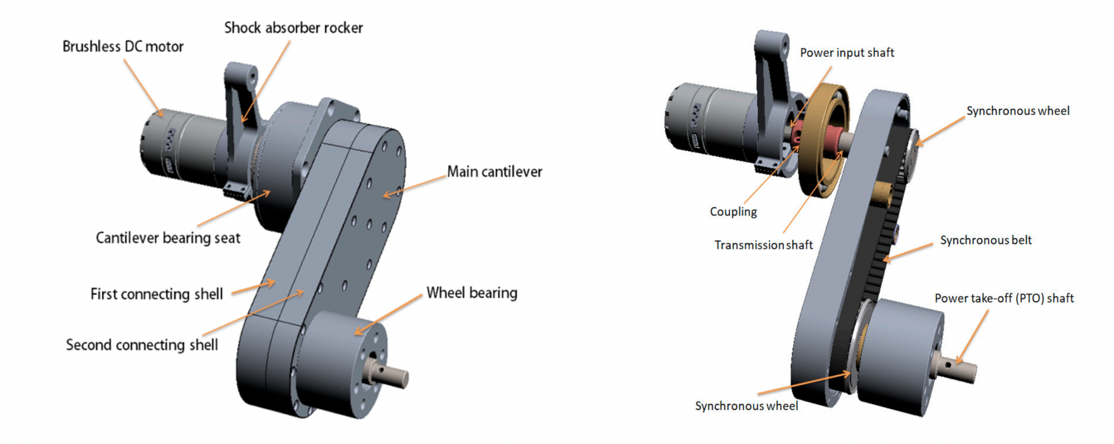


Figure 8: Suspension device for adjustable ride height

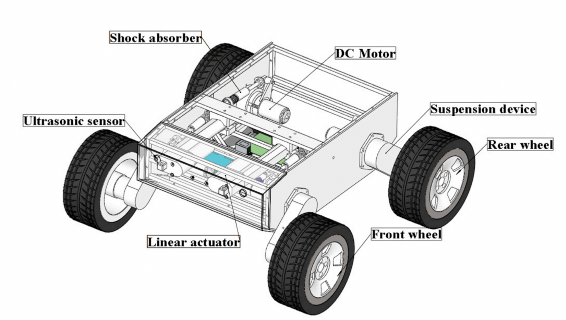


Figure 9: Robot with adjustable ride height

Another solution could be a so-called Ride Height System. One such solution that is mainly sold to car enthusiasts comes from JRi Shocks and uses a combination of hydraulics and mechanical springs in order to facilitate both ride height adjustment and suspension. This system in particular promises a maximum of 12.7 cm change in height, with the adjustment taking 5-7 seconds [13].

2.5.3 Fork wheel lifting

Lifting a pallet without a counterweight requires both lifting of the front and fork wheels in a simultaneous manner. The lifting of the front wheels is quite simple as it has a lot of space to move and to fit lifting actuators. The main problem therefore becomes the lifting of the fork wheels which are required to fit in between the space of the planks of a pallet as well as handle the previously mentioned terrain and also incorporate a strong lifting mechanism.

There are many ways to lift with the fork wheel, but fulfilling the requirements mentioned is what makes it more challenging. Therefore, this section will cover some possible solutions for the fork wheel.

One simple solution to lifting a wheel in a tight space is to simply pivot it around a point so that it moves downward as it rotates and therefore lifts up. This solution however requires more space lengthwise and the rotation mechanism has to be very strong. One way of incorporating the rotation could be through a simple pulling mechanism, such as a winch that drags the wheel around the pivot. This mechanism is similar to how airplanes fold out their wheels, and an example of such a mechanism can be seen in Figure 10.

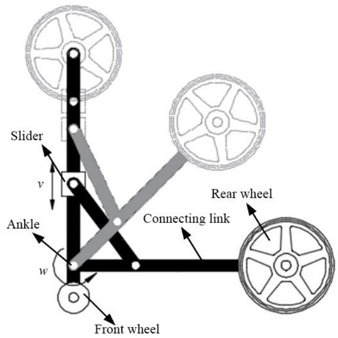
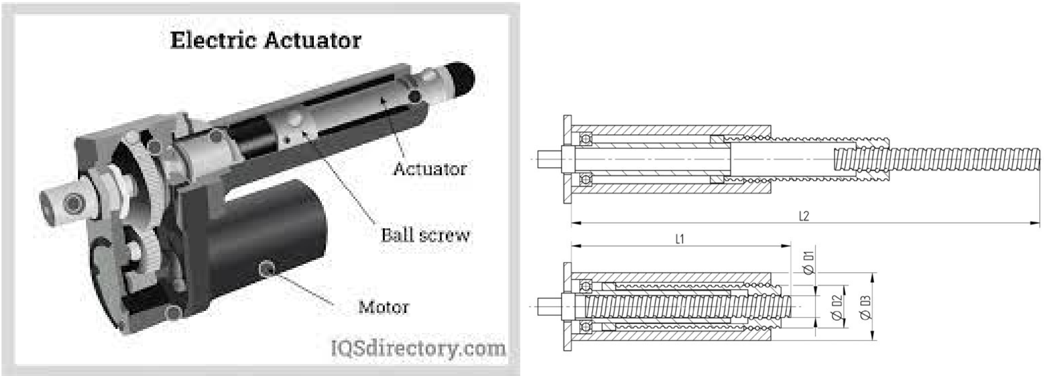


Figure 10: Pivoting wheel example mechanism

Considering that current pallet lifters face the same problems with lifting the fork wheel, a good solution could be to simply copy them and use the same or at least a similar lifting solution. The most common solution for current pallet lifters is also a sort of pivot mechanism that uses linkages from the front wheel to also lift the fork wheels through pivoting downward. A more detailed description of a standard pallet lifter mechanism can also be found in 2.3

Yet another solution is instead to use a more direct approach of linear actuators. They work as electrical actuators that simply extend in one direction. If a small and powerful enough linear actuator could be found, it could directly attach to the front wheel to extend it downward, lifting the payload. An image of one such actuator can be seen in Figure 11a



(a) Linear actuator **(b)** Telescopic screw mechanism

Figure 11: Linear actuators

A different kind of linear actuator called a telescopic screw could also work with some additional possible advantages. This actuator is more complex and uses a set of screws that are located inside each other and extend simultaneously. A drawing of this mechanism can be seen in Figure 11b. This mechanism can lead to a more compact form factor while maximizing the extension range. Dyno Robotics [14] uses a similar mechanism in one of their concept last meter delivery robots and, while complex, it has many benefits. One consideration with this approach is however that the telescoping feature might lead to reduced load capacity as the telescoping elements decrease in diameter, as well as a more complex design.

Hydraulics can also be a compelling and precise way to lift and move things and could be integrated into the fork wheel mechanism. As described by Awe Robotics, hydraulics are a good, flexible way to enable strong movement in robots[15]. However, the main design constraint with hydraulics is the amount of supporting equipment needed, such as pumps and controllers. The cylinder itself may also be hard to integrate into the pallet forks.

3 Concept Development

The concept development was initiated by a brainstorming phase where all team members were asked to draw sketches of design ideas. This was done before discussing possible solutions to avoid bias towards ideas that had been discussed. The result of this process was a large number of concept sketches that could be discussed and compared. Features and ideas from these were merged into two main concepts that were to be developed further. These both featured different ways of accomplishing the projects largest hurdle; lifting pallets from both sides while being compatible with urban terrain. The two concepts and their respective advantages and drawbacks are featured in the sections below.

3.1 Lifting on top

This concept involves the use of a scissor lift mechanism for lifting the pallets from both sides. The lifting mechanism consists of scissor lifts, lead screws, forks and a driving motor, as illustrated by the concept sketch in Figure 12. The forks, along with the scissor mechanism, are semi-connected to the main body, and the lead screw along with the nut is mounted just beneath the forks. The scissor lifts are attached to the lead screw through a nut. The driving motor can be either mounted on the main body of the concept or on the lifting mechanism where the drive shaft of the motor is connected to the lead screw.

The basic idea is that the concept will drive towards the pallet on which the package is placed and as it reaches the pallet, the forks extend themselves beneath the pallet. The forks will be positioned in such a way that the scissor lifts do not collide or interfere with the EUR-pallet. The driving motor is used to rotate the lead screws on which the scissor lifts are mounted through a nut. The linear motion of the nut will lead to contraction or elongation of scissor lifts, the elongation of the scissor lift will result in lifting the pallet upwards and then the concept vehicle will move beneath as well as align with the pallet. Finally, the scissors will contract and place the pallet with the package on top of the main body enabling the concept to freely transport the package.

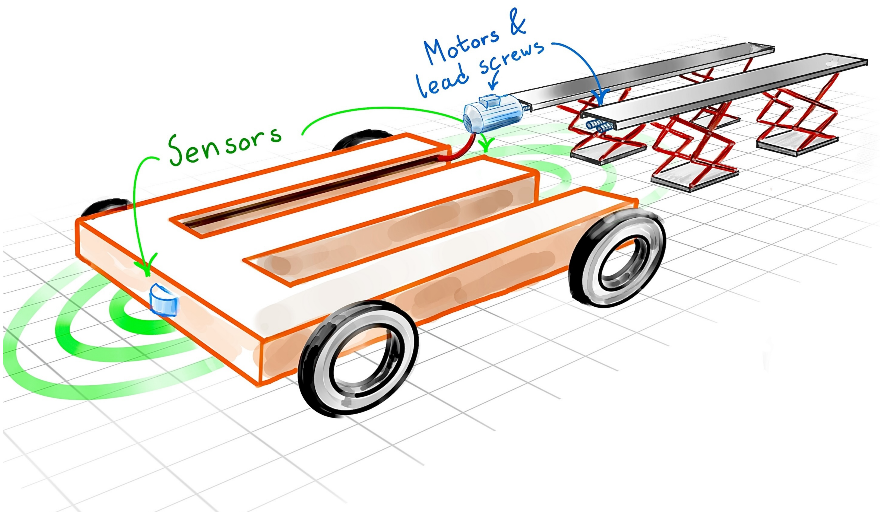


Figure 12: Lift on top concept sketch

With this design, the wheels for The Prototype can be freely chosen, which leads to high terrain compatibility and maneuverability. It is also capable of handling slopes. An additional benefit of the design is that it makes sensor integration quite simple because sensors can be placed on the front and back for 360°coverage.

However, there are plenty of disadvantages which are associated with this design concept. One significant issue with this design is that the forks may cause damage to the pallet during scissor contraction if they interfere with the bottom plank when the pallet is lifted from the long side. Apart from this, the concept involves a considerable number of moving parts, which increases design complexity and makes maintenance a difficult task. Also, there are a lot of "unknowns" associated with this design, which leads to high uncertainty. Moreover, the concept has lower margin for error when it comes to lifting, which could be a major issue.

3.2 Lifting using wheels

Another approach proposed by the team was lifting using wheels. The basic idea of this concept is similar to a general pallet jack. A potential design of the concept can be see in Figure 13. As shown in the Figure, the concept features a sensor in front of the machine to detect the surroundings. The most important part of this concept lies in the wheel part. When entering the pallet, the wheels are lined up and tucked away in the forklift's racks (to save as much space as possible). When the forks are placed in the proper position, the wheels hidden in the frame will extend, together with the front wheel to lift up the EUR-pallet.

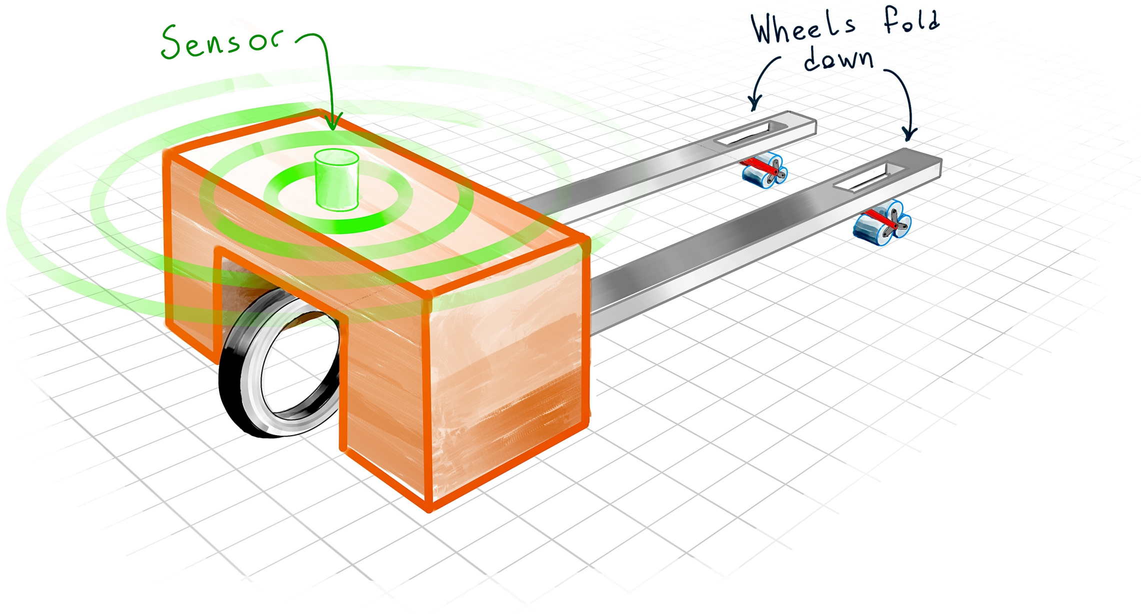


Figure 13: Lifting using wheels concept sketch

This concept has some advantages over the other concept, at the same time, this has some disadvantages as well. The advantage of this concept is that it has less amount of unknowns compared to the other concept. In this design concept, each component is already prototyped in reality, which means that the design is much less difficult. Moreover, ease of design, ease of handling and simplicity of the lifting mechanism makes this concept a better one than the other.

At the same time, as mentioned in section 2.5.1, the wheels at the end of the forks makes it difficult to handle the long side of the pallet due to the clearance of the hole in the pallet and the bottom wooden plank in the pallet. This is one of the main constraint in this concept.

3.3 Concept Evaluation

In order to evaluate the two concepts in a fair way, a Weighted Decision Matrix[16] was utilized. The idea of the evaluation method, firstly, is to determine all the different criteria that will be evaluated. Secondly, these criteria are weighed according to their respective importance. Thirdly, each concept is scored on the different criteria, a higher score is better. The scores are then multiplied with the weights for the respective criteria. The products are then summed up to produce the final result. The criteria which the group determined were categorized in six different categories; Ease of design, Component integration, Lifting, Logistical, Movement and Risk management.

Through extensive discussions within the group, the criteria were decided and the concepts were scored. The resulting Weighted Decision Matrix can be seen in figure 14.

Categories and criteria	Weight(1-3)	Lift on head (score 1-5)	Lift using wheels (score 1-5)
Ease of design			
Ease of mechanichal design	**3**	1	**3**
Ease of electrical design	**2**	3	3
Ease of software design	**2**	4	4
Component integration			
Ease of sensor integration	**2**	**4**	2
Space for component integration	**3**	3	3
Lifting			
Side-lift capability	**3**	2	**3**
Capacity for strong lifting	**2**	3	**4**
Pallet flexibility	**1**	4	**5**
Movement			
Maneuverability	**2**	**4**	2
High stability (not tipping)	**3**	3	3
Terrain capability	**3**	**4**	2
Ability to handle slopes	**2**	**4**	3
Small footprint	**2**	2	2
Risk management			
Low amount of moving parts	**2**	2	**4**
Ease of maintenance	**2**	3	**4**
Margin for error when lifting	**2**	2	**3**
Amount of "knowns"	**2**	2	**4**
Weather resistance	**1**	2	**3**
Safety measure integration	**1**	2	**3**
Logistical			
Affordability	**2**	2	**3**
Availability of components	**3**	1	1
Ease of building	**3**	1	**2**
Result:		123	**138**

Figure 14: Weighted Decision Matrix for concept evaluation

3.4 Selected concept

As evident from the weigthed decision matrix (Figure 14), the Lifting using wheels concept was scored higher and therefore chosen to be developed further. To summarize the team's discussion, the Lifting using wheels concept was found to have a simpler and safer mechanical design than Lifting on top. The Lifting on top scored higher in the Movement and Component integration categories, because of its ability to have four motor-driven wheels and 360° LIDAR coverage. However, this was not enough to compensate for the amount of question marks and risks related to the deployment and operation of the scissor mechanism. As discussed in 3.2, the main issues that have to be resolved with the chosen concept, Lifting using wheels, are the ability of the wheels on the fork to be able to handle harsh terrain and the elevation of all the wheels, especially elevating the large motor-driven front wheels(s).

4 Discussion and Conclusions

A key topic of discussion during concept development was the ability to lift a pallet from both sides. For the lift-on-top concept, the group concluded that it was the most complex to design and build, as it requires both a mechanism for deploying the scissor lift under the pallet and the scissor lift mechanism itself. The lift using wheels has more "knowns", meaning it requires fewer complex parts to be designed. The group prioritized ease of design, recognizing that the lift using wheels was the simpler and more effective option due to its fewer moving parts, providing a more robust and safe design. Additionally, the project's duration is an important consideration. A simpler design requires less time for both design and manufacturing, thus avoiding delays associated with complexity. Another consideration was how accurately the lifting mechanism needs to be deployed and whether differences in pallet conditions would affect the lifting mechanism. It was concluded that the lift using wheels was less sensitive to needing precise accuracy, as the pallet doesn't have to be perfectly aligned with the lifting mechanism to be lifted.

The most concerning aspect of the lift using wheels is the ability to fit large enough wheels in the small gap on the longer side of the pallet. Since it should be able to operate in an urban environment, larger wheels enhance its ability to navigate urban terrains filled with obstacles like potholes, uneven pavements, and debris. The main focus will be to find a mechanism capable of deploying large enough wheels without interfering with the pallet. Another focus is to find a mechanism that can lift the front wheel and fork wheels simultaneous while avoiding tipping.

After conducting comprehensive state-of-the-art research, it has been concluded that no existing solutions perfectly align with the concept. However, there is a lot of research in related fields. This allows inspiration to be drawn from current solutions during the development of The Prototype. These existing solutions can be adapted to meet specific needs, using previous knowledge to create something new and tailored to the requirements.

4.1 Risk analysis

When developing and designing new concepts there are always risks involved as there are a lot of unknowns. Risk comes in the form of not only physical risk with operating a machine but also in the development process where risk can be in the form on hindering development. An example of this is if one part can not be finished because of an external factor such as other parts missing or interfering, which leads to delays or design problems.

Below, in Tables 1 and 2, are safety matrices identifying various risks categorized as either physical or organizational. The risks also have mitigating actions which will be implemented or considered to prevent any accidents or delays during the project.

Organizational Risks

Risk	Severity	Likelihood	Mitigating Actions
Project Delays	High	Medium	Use agile project management, regular progress checks.
Insufficient Resources	Medium	Medium	Pre-project resource assessment, Ask for more funding, order cheapest parts.
Coordination Failures	High	Medium	Regular team meetings, clear communication channels, assigned roles.
Technical Misunderstandings	Medium	Medium	Regular technical reviews, involve all team members in design decisions.
Documentation Errors	Medium	Low	Discuss report structure and divide subjects, peer reviews for all documentation.

Table 1: Organizational Risks

Physical Risks

Risk	Severity	Likelihood	Mitigating Actions
Injury during Operation	High	Low	Safety planning, emergency protocols, follow safety protocols
Prototype Failure	High	High	Thorough testing phases, use of quality components, prototype redundancy.
Damage during Testing	Medium	High	Structured testing protocols, consider testing dangers.
Electrical Hazards	High	Medium	Safety planning, proper grounding practices, be aware of risks.
Mechanical Failure	High	Medium	Use of robust design principles, pre-test all mechanical parts or at least calculate their strength with redundancy.

Table 2: Physical Risks

5 Fall semester planning

This section outlines the plans for the fall semester, divided into two subsections: team organization and time planning. The team organization subsection will detail the management and structure of the team, while the time planning subsection will cover the scheduling of various tasks.

5.1 Team organization

For the fall semester, the team will continue working in specialized sub-teams. This approach allows small groups to focus on specific areas such as mechanical, electrical, or software design. During the manufacturing phase, these sub-teams will also divide tasks into the manufacturing of parts, assembly of parts and components, and testing. To ensure comprehensive skill development, members will rotate between sub-teams, giving everyone the opportunity to gain experience in all areas. Additionally, regular meetings with stakeholders and the coach will be scheduled to keep them informed of the latest progress and to facilitate feedback and assistance.

5.2 Preliminary time planning

Below, in Figure 15, a preliminary plan for the fall period is showcased.

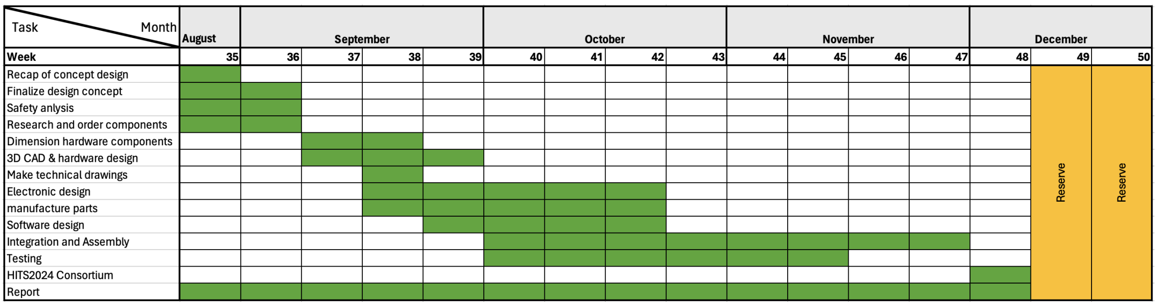


Figure 15: Preliminary plan for the fall

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Appendix A EUR-pallet Product Sheet

EPAL EURO PALLET

800 x 1,200 mm

EPAL®

The work of the European Pallet Association, its National Committees and licensees forms the stable basis for the successful, open pallet pool and enables the global exchange of EPAL load carriers. There are more than 650 million EPAL pallets in circulation around the globe that are used throughout the sector and it would be impossible to imagine industry and logistics without them. Their meticulous adaption to the needs of the market has enabled the alignment of nearly all warehouse and transport systems throughout Europe to the standard dimensions. Constant quality assurance and high quality materials ensure trouble-free, safe performance for users and loading. Their multiple use saves a considerable amount of environmental and economic resources.

FACTS & FIGURES

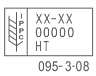
Materials: 11 boards of quality timber, 9 woodchip or solid wood blocks, 78 nails. Produced according to the EPAL Technical Regulations.

Length	800 mm
Width	1,200 mm
Height	144 mm
Weight	Approx. 25 kg
Safe working load	1,500 kg

When stacking laden pallets on a solid, even surface, the bottommost pallet must not exceed a load of max. 5,500 kg.

MARKINGS

"EPAL in oval" on the left and right corner block (since 08/2013).

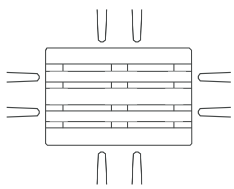


IPPC symbol, country code, registration number of the national plant protection authority, heat treatment, licence number-year-month on the central block.

EPAL control staples

HANDLING

4-sided accessibility with chamfered lower edge boards on both sides enables highly efficient handling during production, storage and transportation all the way along the supply chain. Compatible with all (conventional) standard load carriers, industrial trucks and warehouse systems.



QUALITY CONTROL

The international pool of EPAL load carriers is the only load carrier pool in the world subject to independent quality assurance by external inspection companies. This is the only way for EPAL load carriers to guarantee the consistently high quality that they offer the markets.

BUREAU VERITAS 1828

ISPM 15

Compliance with the ISPM 15 standard is the most essential condition for the unrestricted use of load carriers in the international movement of goods. All EPAL Euro pallets are therefore produced according to the stringent specifications of the IPPC and can thus be deployed around the globe. Local plant protection agencies will provide information on the countries that recognise the IPPC standard.

REPAIR

Damaged EPAL Euro pallets can be repaired cost effectively and in a climate-friendly manner by all EPAL-licensed pallet repair operations. Following the quality-assured repair, EPAL Euro pallets repaired according to standard receive a repair marking nail bearing the "EPAL" trademark and the licence number of the repair operation.

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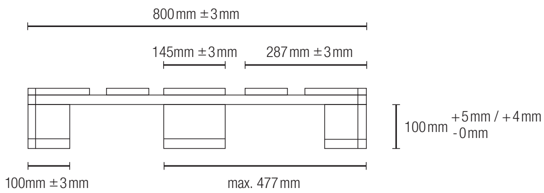
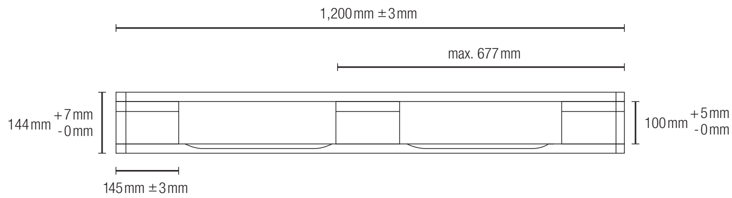
EPAL EURO PALLET

800 x 1,200 mm

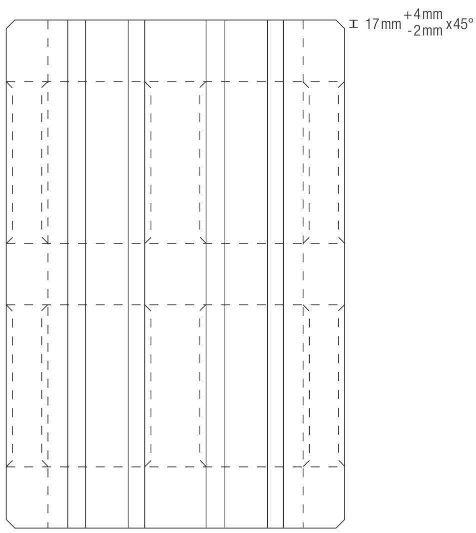
800 mm side



1,200 mm side



Top view



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