TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Electrical Power Engineering and Mechatronics

DEVELOPING MODULAR CASH HANDLING SYSTEM

MODULAARSE SULARAHAKÄITLUSSÜSTEEMI ARENDAMINE

MASTER THESIS

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Tallinn, 2023

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No academic degree has been applied for based on this material. All works, major viewpoints and data of the other authors used in this thesis have been referenced.

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ABSTRACT

Author: Joan Markus Varik

Type of the work: Master Thesis

Title: Developing Modular Cash Handling System

Date: 18.05.2023

56 *pages (the number of thesis pages including appendices)*

University: Tallinn University of Technology

School: School of Engineering

Department: Department of Electrical Power Engineering and Mechatronics

Supervisor(s) of the thesis: Associate Professor Toivo Tähemaa, Early Stage Researcher Viktor Rjabtšikov

Consultant(s):

Abstract:

The objective of this thesis was to design and implement a modular cash management system that could be incorporated into payment kiosks. A key requirement was that the system needed to accommodate multiple currencies while maintaining standardization for ease of manufacturing and management.

The thesis was divided into three main chapters. The first chapter involved a thorough analysis of the existing situation and established the requirements that the new system must fulfill. During this phase, potential device providers that could be integrated into the final system were also identified. The second chapter described the development process of the cash management system, including the creation of 3D drawings which were subsequently used to order the prototype components. While hardware formed the central focus, the software aspect was also addressed due to its vital role in the overall functioning of the cash management system. The third chapter was dedicated to validating the results, providing a detailed overview of the final product, and illustrating the testing process. This was essential to ensure the system would perform effectively and reliably in a live environment.

The outcome of this thesis was a successfully developed modular cash system capable of handling multiple currencies through the same standardized hardware. The system's software configuration could be altered to accommodate different currencies, offering a flexible and adaptable solution. This thesis brought several financial benefits to the company. Firstly, it simplified warehouse management by reducing the variety of configuration devices needed to be kept in stock. Additionally, the new system lowered the ownership costs for the customers and maintenance costs for the company, making the system more profitable for all parties involved. This helped to further reinforce the value and significance of the work carried out in this thesis.

Keywords: cash handling, automated point of sale station, hardware development, software integration

LÕPUTÖÖ LÜHIKOKKUVÕTE

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Töö pealkiri: Modulaarse sularahakäitlussüsteemi arendamine	
Kuupäev: 18.05.2023	56 *lk (lõputöö lehekülgede arv koos lisadega)*
Ülikool: Tallinna Tehnikaülikool *Teaduskond:* Inseneriteaduskond *Instituut:* Elektroenergeetika ja mehhatroonika instituut	
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Lõputöö oli jagatud kolme põhipeatükki. Esimeses peatükis analüüsiti põhjalikult olemasolevat olukorda ja pandi paika nõuded, millele uus süsteem peab vastama. Selles etapis selgitati välja ka potentsiaalsed seadme pakkujad, kelle seadmeid lõplikku süsteemi integreeritakse. Teises peatükis kirjeldati sularahakäitlussüsteemi arendusprotsessi, sealhulgas 3D-jooniste loomist, mida hiljem kasutati prototüübi komponentide tellimisel ja tootmisel. Kui kesksel kohal oli riistvara, siis ka tarkvara aspekti käsitleti selle olulise rolli tõttu sularahakäitlussüsteemi üldises toimimises. Kolmas peatükk oli pühendatud tulemuste valideerimisele, lõpptootest üksikasjaliku ülevaate andmisele ja testimisprotsessi illustreerimisele. See oli oluline süsteemi tõhusa ja usaldusväärse toimimise tagamiseks igapäeva töö keskkonnas.

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Märksõnad: sularaha käitlus, automatiseeritud maksejaam, riistvara arendus, tarkvara integratsioon

THESIS TASK

Thesis title in English:	**DEVELOPING MODULAR CASH HANDLING SYSTEM**
Thesis title in Estonian:	**MODULAARSE SULARAHAKÄITLUSSÜSTEEMI MOODULI ARENDAMINE**
Student:	**Joan Markus Varik, 204811MAHM**
Programme:	**Mechatronics**
Type of the work:	**Master Thesis**
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Validity period of the thesis task:	2022/2023 2022/2023 Autumn
Submission deadline of the thesis:	**18.05.2023**

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Co-supervisor (signature)

1. **Reasons for choosing the topic**

Currently the company that proposed this topic has been developing their own payment station for card payment, but as cash is still relatively widely used in the world and specially common within the older generation, then having a reliable cash handling system is mandatory to keep up with the competition. The cash handling systems are usually developed for a specific application and have very specific needs in terms of functionality, size and integrability, therefore there does not exist a ready built product that can be used. The proposed thesis topic is that the author develops a system that accepts wide range of notes and coins of different currencies and dispenses the return money for up to 6 different nominals, 4 nominals of coins and 2 nominals of bank notes. The system has to be integrated in to the existing software of the payment kiosk. The author needs to choose a partner who's note and coin validators to be used in the cash system, create diagrams of the connection scheme and make 3D models of the housing of the cash system with all the industry standards for security of cash management, this includes security locks, pathways to move the money from one device to another and maintenance covers. From the software side the cash devices need to be collected to one application which will communicate with all of the existing devices and there needs to be a way to manage the devices, tell which device needs to pay out which amount of money and return the amount of money paid in to the system. This kind of software component can be found already on market or programmed, this depends on the analysis results of the first chapter of the thesis.

2. Thesis objective

The aim of this thesis is to build a proof of concept prototype for cash acceptance and return money dispensing system, which is used to validate the compatibility of the developed cash handling system with the existing payment kiosk.

3. List of sub-questions:

First research goal is to find the most reliable method of integrating the devices, this means to minimize the moving parts to extend the lifecycle of the product. Second research goal is to make the system vandal proof so it can be installed on the street inside payment kiosks with enough durability to protect the access to money for at least 5 minutes. Third research goal is to make the device compact enough so it fits inside the existing payment stations without the need for extensive redesign of the payment station. Fourth research question is finding the necessary software components and preparing the system for integrating with the end product, gathering all the documentation and generating the input task for software development company.

4. Basic data:

Basic data will involve the physical parameters of different currencies that the company who proposed the topic is having business relationships with, for example EU, Poland, Switzerland, UAE, Africa. This data is usually found on the Ministry of Finance or local country bank websites, for example Bank of Estonia website has all the information about Euro notes and coins used. Second part will be choosing the note and coin validator partner to be used in the system, first leads for this data will be gained from the company about the partners they have used before. Second part will be visiting an exhibition called Euroshop 2023 to physically meet different manufacturers of the devices and see their capabilities. Third part will be evaluating the price and quality that 3 of the top contenders offer.

5. Research methods

The author plans to collect data from the company that proposed the thesis task about the expectations on the system in forms of interviews with the stakeholders. As there are already some devices existing, reverse engineering will be used to understand exactly what are the key points that should be in the system and how to integrate it with the new system. To support the development process for the physical components the author has been provided access to 3D printer which will be used to generate the first prototypes of the system, this ensures the fast flow of hardware development. An important part of the research will be testing the system with different currencies and studying the physical parameters difference of the currencies to ensure that the system is capable of handling different currencies without interruptions.

6. Graphical material

Most important drawings will be the diagrams to power the system, as not enough power or wrong connection could ruin the system. Second will be the architecture of connecting the devices and where to get the input and output information for the payment kiosk software. And third will be the 3D model drawings of the cash system.

7. Thesis structure

The thesis has three main sections. In the first section the author will analyze the existing situation and based on that, initial requirements for the system will be created. In the second section the main development of the system will be happening with creating the 3D drawings and manufacturing the prototype parts. In the final section the validation of the prototype is carried out, tests with real currencies are done in order to simulare real world situations in order to see how the system reacts.

8. References

Main sources of information will be stakeholder input, 3D Printing prototyping methods, evaluation and comparison of companies, companies internal development plans and legislative acts regarding cash handling in different countries.

9. Thesis consultants

The consultants of this thesis will be the Sales Department of the company who proposed the topic and Service Department, as the company has over 30 years of experience in dealing with cash. There are no specific people as the competences are spread over different people and the information has to be collected from all of them in order to provide the best product.

10. Work stages and schedule

Proposed work phases of the thesis will be following: Finalizing the Extended Thesis Proposal (21.02.2023), Submitting the application for confidentiality agreement (28.02.2023) Collecting basic data (17.03.2023), Testing the chosen devices (24.03.2023), Compiling the architectural and electrical diagram drawings (07.04.2023), Developing the 3D Models for the Cash system (14.04.2023), 3D Printed prototype tests and changes to 3D Models (28.04.2023), Finalizing the product for a proof of concept prototype and forwarding it to production (03.05.2023), Finalizing the theoretical part of the thesis and sending it to approval from supervisor (05.05.2023), final thesis completion, submitting the thesis for evaluation (12.05.2023).

CONTENTS

PREFACE

The subject of the thesis was suggested by Hansab Group OÜ, a pan-Baltic corporation with its headquarters located in Estonia. The company provides a variable list of services across various countries, including cash management, automation, security, and digitalization. Also they are the manufacturers and exporters of a parking system incorporating cash payment kiosks, they identified a need for a more efficient solution to increase their market share and create a new cash payment system.

Hansab Group's extensive experience of over three decades in cash management departments played a crucial role in the development process. This experience has been accumulated through working with a multitude of cash management devices, significantly helped tos et the requirements for the design and development of the new system. Important contributions were made by the company's sales, maintenance, and manufacturing departments, whose inputs were valuable in creating a system that not only met but exceeded their needs. Customer feedback was also taken into account, ensuring that the end result was a product that satisfied the requirements of all stakeholders.

Associate Professor Toivo Tähemaa and Early Stage Researcher Viktor Rjabtšikov supervised the thesis. Their insights and expertise were instrumental in guiding the logical progression of the thesis, providing invaluable direction and feedback throughout the process.

The journey of developing the cash management system was met with challenges and involved substantial costs. Despite these obstacles, the experience was invaluable and led to the creation of an innovative device that everyone involved could benefit from. The author would like to thank to Hansab Group OÜ for the opportunity to contribute to such a project and looks forward to seeing the positive impact of the new system.

LIST OF ABBREVIATIONS AND SYMBOLS

ATM	Automated Teller Machine
CAD	Computer-aided design
NDA	Non-disclosure agreement
PLA	Polylactic acid
PSU	Power Supply Unit

INTRODUCTION

The phenomenon of urbanization has generated a critical issue of insufficient space on the streets to accommodate the rapidly increasing number of vehicles. This issue presents an unique opportunity for the manufacturers of innovative parking systems. The thesis topic is proposed by Hansab Group OÜ, manufacturer of a ticketless parking system which includes barrier gates, license plate detection cameras, smart payment solutions via applications and physical payment kiosks that support card and cash transactions. The thesis in hand concentrates on cash payment solutions and the development process of the cash payment module as it was absent from the system before. [1]

Nevertheless, cash payment methods typically impose a considerable burden on the parking lot owners, as cash payments impose multiple challenges. For instance, security is a concern that cannot be overlooked. Automated payment kiosks which offer cash payment method must be equipped with robust security measures to prevent theft, vandalism, and fraudulent activities. Additionally efficient cash handling and storage is crucial, processing incoming funds and dispensing change must be done without any margin of error while maintaining the speed and comfort of use. This requires the integration of reliable and precise cash handling mechanisms which have low maintenance requirements, as the system should have minimal downtime to reduce the total cost of ownership. Moreover, as the company is pursuing multiple export markets, the cash handling system must be compatible with numerous currencies while keeping the system as standardized as possible with minimal changes in configuration to maximize the efficiency in manufacturing the system.

This created the basis of the development, with emphasis on the three primary aspects: security, reliability, and modularity. The development process was split in to three stages: 1) Developing the concept of the cash payment module. 2) drafting the architectural and electrical schematics and developing the 3D CAD models 3) constructing the prototype.

The primary tools used during the thesis were SolidWorks 3D CAD Software and 3D printing technology to accelerate the process of prototyping. The outcome of the thesis is a proof-of-concept prototype which serves to validate the proposed ideas and prepare them for large-scale production.

The thesis is split into three different sections. The first section is dedicated to the hardware development for the cash module including the initial market research and prototype construction. Second section describes the software architecture side which is used to Control the hardware. The third section focuses on the final analysis and outcome of the cash handling system development. The appendices mainly consist of graphical materials of the system such as drawings of the prototype hardware.

1. MODULAR CASH SYSTEM ANALYSIS

1.1 Analysis of existing payment station

As the payment station was already existing, the initial step involved conducting an in-depth assessment to identify potential gaps and areas for improvement that could increase the potential of getting a bigger market share for the company while at the same time reducing the costs involved with the maintenance and manufacturing. The assessment was carried out in 2 stages: hardware and software analysis with three different department interests in mind: sales department, service department and manufacturing department.

The first step was to map out the existing functionality list of the 1-st generation payment station. For this the datasheet of the existing device was used which can be found in Appendix 1. Key points from cash management module were:

- Coin acceptance of all nominals in the currency
- Bank notes acceptance of all nominals in the currency
- Dispensing change in 4 different nominals in 1 currency in coins
- Bank notes capacity of 300
- Coins capacity of 1000

To better understand the challenges from the sales department perspective, multiple tender requirements across the markets in which the company operates were examined. The analysis was done based on tenders from Estonia, Latvia, Lithuania, Poland, and Switzerland. The author studied these requirements over a period of two months to find common points between the countries needs and comparing them with the existing functionality of the generation 1 payment station. The requirements were put in a table form to understand the priorities to see which requirements were found most in tenders.

Table 1.1 Requirements from the tenders

Requirement	Estonia	Latvia	Lithuania	Poland	Switzerland
Coin acceptance	x	x	x	x	x
Bank Notes Acceptance	x	x	x	x	X
Dispensing change in 4 different nominal coins	x	x	x	x	X
Dispensing change in bank notes	-	-	x	x	x
3 Lock security system	-	-	x	x	-
Acceptance of 2 currencies	-	-	-	-	x
Bank note capacity of at least 500 notes	-	-	x	x	-
Coin capacity of at least 2000 coins	-	-	x	x	-

After analyzing the results from tender requirements, it was found that the key points which the payment kiosk was missing in the order of priority are:

- Dispensing change in bank notes
- 3 Lock Security system
- Bank note capacity of at least 500 notes
- Coin capacity of at least 2000 coins
- Acceptance of 2 different currencies

This resulted in the system not qualifying for the tenders, and potential market share loss for the company.

In order to create a system which would be easy to manufacture and maintain at the same time, the manufacturing and service departments were approached. As the company has over 30 years of experience in the field of cash handling systems, including ATMs and currency counting systems, then the experience was used in understanding the main challenges of cash handling systems and the issues they are facing mostly. The primary feedback received from the service department was that a considerable portion of the time is spent towards accessing the components inside the devices, if the placement of the devices is not thought through, then a lot of valuable time can get lost in changing a simple component which decreases the service efficiency. Furthermore, an analysis of the service department's maintenance calls was Carried out to understand the types of service calls they receive most frequently. Over a six-month period, a total of 67 service calls were recorded, with 27% of the incidents being related to the cash handling system, while the remaining 73% were related to various other things. On average, each cash handling system call demanded approximately 37 minutes of an engineer's time to resolve the issue. This analysis provided a valuable insight into the potential for significant time savings by enhancing the cash handling system, thus improving overall operational efficiency.

In order to understand the manufacturing departments bottlenecks, an observation of the assembly process was carried out. The key points that were taken from the observation:

- There is room for improvement in device placement as a significant amount of time is spent in accessing and mounting the devices, which could be optimized for greater efficiency.
- Cabling jobs are time-consuming, there are two main reasons behind this. First being the length of the cables as devices are located far away from each other inside the payment station housing and secondly because multiple devices are mounted on a door of the payment station, which upon opening creates friction on the cables which shortens the lifespan of the cables.
- Furthermore, the payment station features multiple locations with sharp edges, presenting potential hazards for individuals who may injure themselves during assembly or maintenance tasks.

By addressing these key findings, the manufacturing process can be enhanced by increasing efficiency and minimizing potential risks to personnel involved in the assembly and maintenance of the payment stations.

For the final evaluation of the current situation, existing customers were approached to hear the feedback from their side which causes the most issues for them. Total of 17 existing customers were approached and the key points from discussions were:

- Difficulty in changing the money for dispensing: Customers reported that the device placement within the payment station makes it challenging to physically change the money. This issue is further amplified by the sharp edges within the payment station, which can cause injury to people attempting to access the money.
- Enhanced security measures are expected, particularly in the form of more robust and strategically placed locks, for example:
  - Enhanced lock quality, utilizing high-quality locks made from durable materials that are resistant against forced entry. To ensure the payment station remains secure against vandals.
  - Strategic lock placement with multiple locks, positioning the locks at important points on the payment station, such as access points to cash.

Multiple locks would also ensure if one lock is accessed, the other lock will still provide protection.

By implementing these improvements in security measures and accessibility for the customers, the payment station will offer a more efficient management of the parking lot reducing the overall costs of ownership by not having to install additional safety measures to protect the payment station.

1.1.1 Hardware requirements

The system requirements were formulated by the thesis author, using the valuable insights of the sales and customer service departments. The primary requirements centered around the hardware as it had to be very robust but yet easy to use in every aspect, the manufacturing process, the maintenance process and also the daily operations could be improved.

Furthermore, the existing payment kiosk housing posed significant constraints on the development of the system hardware, as the goal was to create a retrofittable solution compatible with older payment stations already installed in the field. Alterations to the housing, beyond modifications to the front panel, would have exceeded the budget for the current project. The design had to meet the dimensional requirements of fitting within a 538 x 340 mm housing, ensuring integration with the existing hardware. [2]

Figure 1.1 Overview of the generation 1 payment kiosk 3D model along with its internal dimensions

Based on the information which came from tenders, it was decided that the following will be main requirements inside the system from sales team perspective:

- Acceptance of all nominations of coins in the currency
- Acceptance of all nomination of bank notes in the currency
- Dispensing change in four different coin nominals
- Dispensing change in two different bank note nominals
- Secure system with multiple locks

Secondly the system had to be comfortable to use for the service and manufacturing department. Following things had to be considered as a conclusion from the analysis:

- Ease of Access to devices
- Standardized architecture to keep the servicing and manufacturing time as low as possible
- Standardized components for the stock Management, more configurability for the Customer with the same hardware
- No sharp objects and edges where people could hurt themselves during manufacturing or servicing

Moreover, tax offices in some countries have imposed additional requirements for cash handling systems. According to these requirements, if cash is accessible during maintenance, the entire payment kiosk must be sealed. To avoid having to seal the entire payment kiosk, which would create challenges when maintaining it, as only tax office certified engineers would be able to access it, the cash access must be separated from the overall maintenance part. This was combined with the requirement of secure system with multiple locks as it would allow to complete both requirements with one development. [3]

1.1.2 Software requirements

The primary objective was to maintain ease in stock management and lower the time required for entering new markets. This meant ensuring that all cash management devices could be reprogrammed to a chosen currency. To achieve this goal, the following steps were mapped out:

1. Device Selection, choosing cash management devices, such as note and coin validators, that have the capability to be reprogrammed to a different currency in house, meaning it is possible to generate the programming competences in house. This allows for flexibility in handling various currencies, making it easier to adapt to different markets as only 1 hardware device is needed even for different currencies.

2. Software Integration, develop or integrate software that can communicate with the cash management devices, enabling use of different currency options as needed. It should be user-friendly and clear on how to change currency.

3. Training and documentation: provide necessary training and manuals to the manufacturing department responsible for the initial setup of the payment kiosk, making sure that they have all the knowledge required to handle the reprogrammable currency option.

In addition to the base requirements from management side, the software for the cash handling system also needs to have certain additional features to enhance its functionality and adaptability with different customers.

1. Configurable Accepted Notes, depending on the nominals of change available, the system should be able to accept different notes and coins. This configuration must be easily changeable on site while the system is operational as. This allows the system to adapt to different situations, for example, if the system owner notices that system often runs low on a particular nominal of coins or notes for change, it can be configured to stop accepting certain notes or coins.
2. Use of Greedy Algorithm, the software needs to implement the greedy algorithm when dispensing change. The greedy algorithm is a simple, intuitive algorithm that when dispensing change, always tries to use the largest note or coin possible at each step. The goal is to minimize the total number of notes and coins dispensed. For instance, if the system needs to give €30 in change, the greedy algorithm would first choose to dispense a €20 note, and then a €10 note. This can help to prolongue the devices lifespan on the machine and keep transactions efficient and fast. [4]

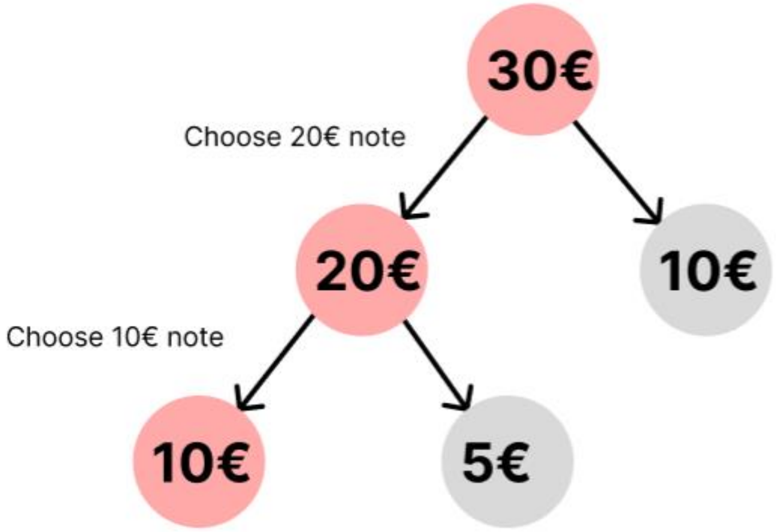


Figure 1.2 Greedy Algorithm example of paying out 30€

Figure 1.2 provides an example of a greedy algorithm usage in the payment station with the slightly darker circles indicating chosen path of dispensing the change according to the algorithm.

1.1.3 Choosing the cash components

In order to select the most suitable provider for cash components, an evaluation process was carried out involving four different providers. These companies were found at the Euroshop 2023 exhibition, where they showcased their devices and the companies field of operation. To make a decision in which provider to use, a scoring method was created to assess each company based on different factors. The process of gathering the information involved the following steps:

1. Confidential negotiations: confidential discussions were carried out with each of the four companies to gather information about their products, services and pricing. The negotiations were confidential because they contained information useful to their competitors. Therefore the companies names can not be revealed due to NDA contracts signed.

2. Evaluation criteria’s mapping: worked out a set of evaluation criteria that is necessary to ensure the ease of development for the cash handling system. These criteria include factors like product features, technical support location and options, pricing, physical dimensions, and ease of integration.

3. Scoring method choosing: Assign a score to each company based on value offers compared to their competitors. Companies received points ranging from one to four, with one being the lowest and four being the highest score. Meaning the company that had the highest price was scored one, and the company with the lowest price was scored 4.

4. Overall score calculation and evaluation: calculating the overall score for each company by adding up the points they received in each category. The final score showed the companies overall placement against their competitors as there was not a single company who could offer the best of everything, then a compromise of everything was necessary.

5. Provider selection: choosing the company with the highest overall score as the provider of cash validation devices for the development of system. This decision was based on the belief that the highest scoring company would offer best values for the project, considering their performance across all the factors.

Based on the steps taken above, an anonymous comparison table was generated to evaluate the possible providers, the table can be seen in appendix 2. Not all requirements were equal, meaning pricing for example was more important than ease of integration, therefore scale method was implemented, with the result being scaled up if the requirement was a bigger priority. The number inside the brackets defines the priority for set requirement.

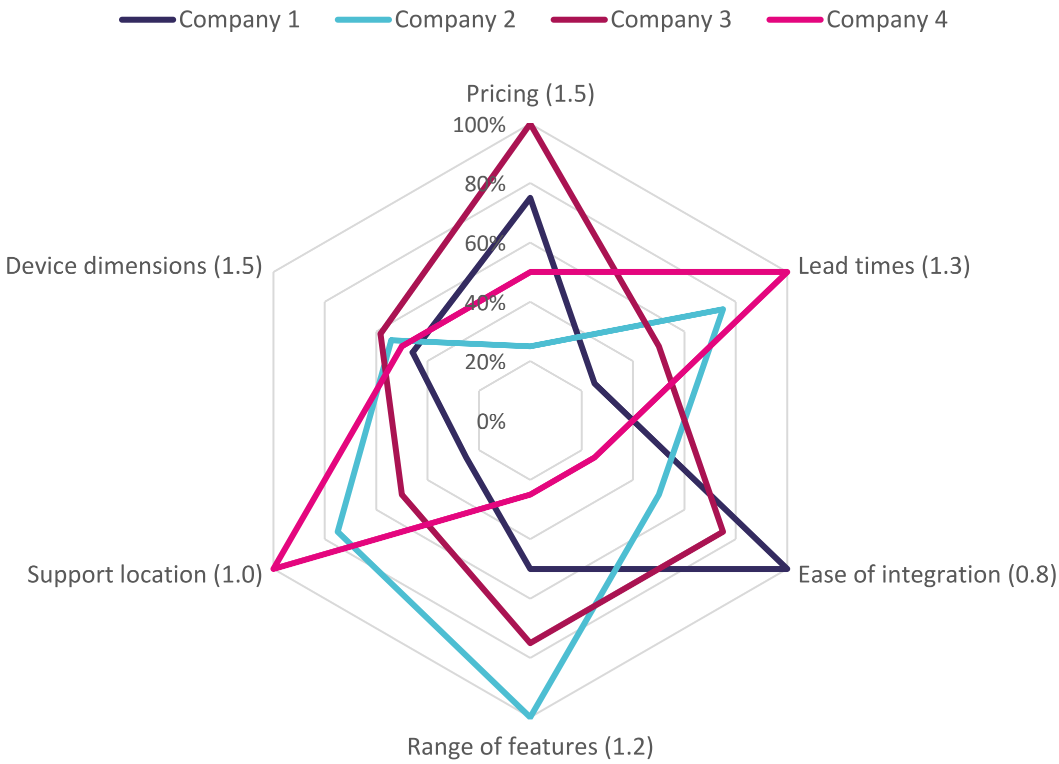


Figure 1.3 Graph of device manufacturer comparison

Based on the total scores calculated from the table, Company 3 stands out as the best choice among the four options. Company 3 has the highest overall score of 20.6, which indicates that it placed well across the factors, such as pricing for the total of all devices needed from their side for the system, lead times, ease of integration, range of features, technical support location and terms, and device dimensions which had to be as small as possible to save the space. The higher total score for Company 3 indicates that it is likely to provide a better overall devices and terms of partnership agreement, making it the most suitable choice for the development of the system.

Total three different devices from the chosen company's portfolio were chosen which fulfilled the requirements of the payment station the best. The first component chosen was the coin validator, capable of accepting a wide range of currencies in which are a target market. This device was selected due to its competitive pricing, relatively easy integration both on the hardware and software side and lead times offered by the supplier.

The second component was the Banknote Recycler, which has a banknote capacity of minimum 600 which is extendable up to 1200 and can also recycle two different nominal banknotes, each with a capacity of 60, with the future option being recycling up to 4 different nominals. This increases the total banknote capacity to 720 for the standard configuration. The banknote recycler was chosen primarily for its ease of integration and long term support among the available options from the supplier.

Lastly, the hopper was selected for dispensing change in coins. Each hopper has a capacity of up to 300 coins depending on the coin size, and since the cash handling system is required to dispense at least four different nominal coins, this results in a total change capacity of 1,200 coins as four compact hoppers will be used. The Compact Hopper was the preferred choice due to its dimensions, as all other coin hoppers were too large to fit inside the specified dimensions of 538 mm x 340 mm alongside the banknote recycler.

These three devices were chosen to meet the necessary requirements and constraints of the cash handling system, ensuring integration possibilities, optimal capacity, and efficient usage of space.

2. MODULAR CASH SYSTEM DEVELOPMENT

2.1 Composing the development plan

To ensure the successful completion of the development and delivery of the project, a development plan was generated. This plan consisted of four main phases.

1. Documentation and initial planning: In this phase, essential documentation, such as 3D STEP files and device user manuals, were collected. This information was crucial for understanding the necessary physical connections between components. An initial plan for the cash handling system was then developed based on this information. Also in this phase the cash devices for prototype were already ordered due to lead times being quite significant.

2. 3D CAD modeling and drafting: Next, the initial 3D CAD file was created, incorporating the necessary components. Sketches and drafts were used to refine the design and generate final 3D drawings. During this phase, various options for moving coins between devices were tested, and various components were 3D printed to determine the best methods for creating coin pathways.

3. Prototype ordering, assembly, and testing: A metal manufacturing company was contacted to produce the prototype, while final components which had to be changed were 3D printed in-house. Once the prototype was assembled, it was tested and validated as a proof-of-concept prototype. Based on the test results, final changes were proposed for the mass-production version of the device.

4. Project outcome analysis: In the final phase, the system development outcomes were analyzed in terms of the accomplishments for the author and the company, as well as lessons learned from the prototyping process which could be used in the future to further enhance the hardware prototyping process inside the company.

This development plan was followed throughout the whole time of the project. It helped to progress the project systematically, ensuring that each stage was completed, and the outcome of the project would be successful.

2.1.1 Documentation and initial planning of development

The development process began with an analysis to determine the most efficient way to connect the devices within the payment kiosk. This helped to ensure that the placement of the devices minimized the complexity of the wiring, and allowed for easy access for maintenance and operation.

The three devices in the cash handling system, the coin validator, hoppers, and the note recycler, each had their own requirements for electrical connections and communication protocols. The coin validator requires a power supply between 10 and 24 VDC and about 0.5 A of current during its operation phase. It communicates over an RS232 communication layer using the CCTALK Protocol, a platform developed by the manufacturer. [5]

The hoppers also use the RS232 layer and the CCTALK Protocol for communication. However, their electrical requirements are slightly higher, requiring a power supply between 12 and 24 VDC and about 1.5 A of current. The hoppers are unidentifiable by the software, meaning that the software cannot differentiate between the hoppers, as they do not have a built-in identifier. [6]

To overcome this challenge, a unique diode is embedded within the cable that connects each hopper. This diode serves as a unique identifier for the hopper it's connected to, allowing the software to understand which hopper is which. As a result, careful management and tracking of these cables is important during system setup and any subsequent maintenance activities. By putting two cables of the same unique identifier to the system, then the system is unable to use either one of the hoppers which it is connected to.

The note recycler requires the most power, demanding 24 VDC and about 6 A during peak power consumption. It communicates over the EBDS protocol on the RS232 communication layer. [7]

To connect the hoppers and the coin validator using a single cable, an additional device, the CCTALK hub, is chosen. This hub takes in 24VDC and RS232 communication and outputs 24 VDC.

The system uses a middle-layer platform known as Paylink to facilitate communication with the cash devices through CCTALK hub. This platform simplifies the integration process by handling basic actions such as the implementation of the greedy algorithm for cash payout and the conversion of communication from the RS232 layer to an XML API.

Designing the coin pathways was one of the most important aspects of the system development. This involves figuring out how coins are routed from the coin validator to the appropriate coin hopper once they are validated, and how coins are dispensed from the hoppers to the customers. The physical space within the payment kiosk is a key constraint in designing these pathways, as the size and position of each device within the system will dictate the layout of the coin pathways, meanwhile still having to fit inside the generation 1 housing space limitations. The pathways must be designed to ensure efficient and reliable movement of coins, while also being easy to access and clean for maintenance. 3D modeling and PLA printing techniques were used to design, test, and refine these pathways, allowing for rapid prototyping and iterative improvements to optimize the design before the mass production of the system. [8]

2.1.2 Creating the architecture for cash devices

One of the part of this phase involved creating a connection scheme for the cash devices. To make the scheme user-friendly and understandable to the service and manufacturing departments, actual images of the devices were used. This way, even people who do not deal with the system daily can easily recognize the devices when opening the payment station for maintenance without having to learn specific names and symbols.

The electrical requirements for the cash handling system were determined by analyzing the operational conditions of the devices within the system. The important part was that the system is designed in such way that only the coin validator and note validator would operate simultaneously during a transaction. Dispensing of change was designed to occur serially, one nominal at a time in order to prevent errors in the amount of change being given, as multiple reasons can happen why change might not be dispensed. This feature greatly reduced the overall power requirements of the system since not all devices need to be powered at the same time.

The note recycler, which has the highest peak power consumption among all the devices, requires 6 A of current. This was the main factor considered when choosing the power supply unit (PSU) for the system.

The chosen PSU is a MeanWell HDR-150-24 single-output DIN rail mountable unit with an input power of 230 VAC and an output power of 24 VDC and 6.25 A. The PSU's output is slightly higher than the peak requirement of the note recycler, ensuring that it can adequately power the device in the system when it is using it's peak power. [9]

The PSU is connected directly to the CCTALK hub, a device that serves as a power distribution unit and communication centre-point. The hub takes the power from the PSU and distributes it to the other cash devices in the system. This setup allows for the effective and efficient powering of the various devices within the cash handling system with relatively easy cabling while minimizing the overall power requirements.

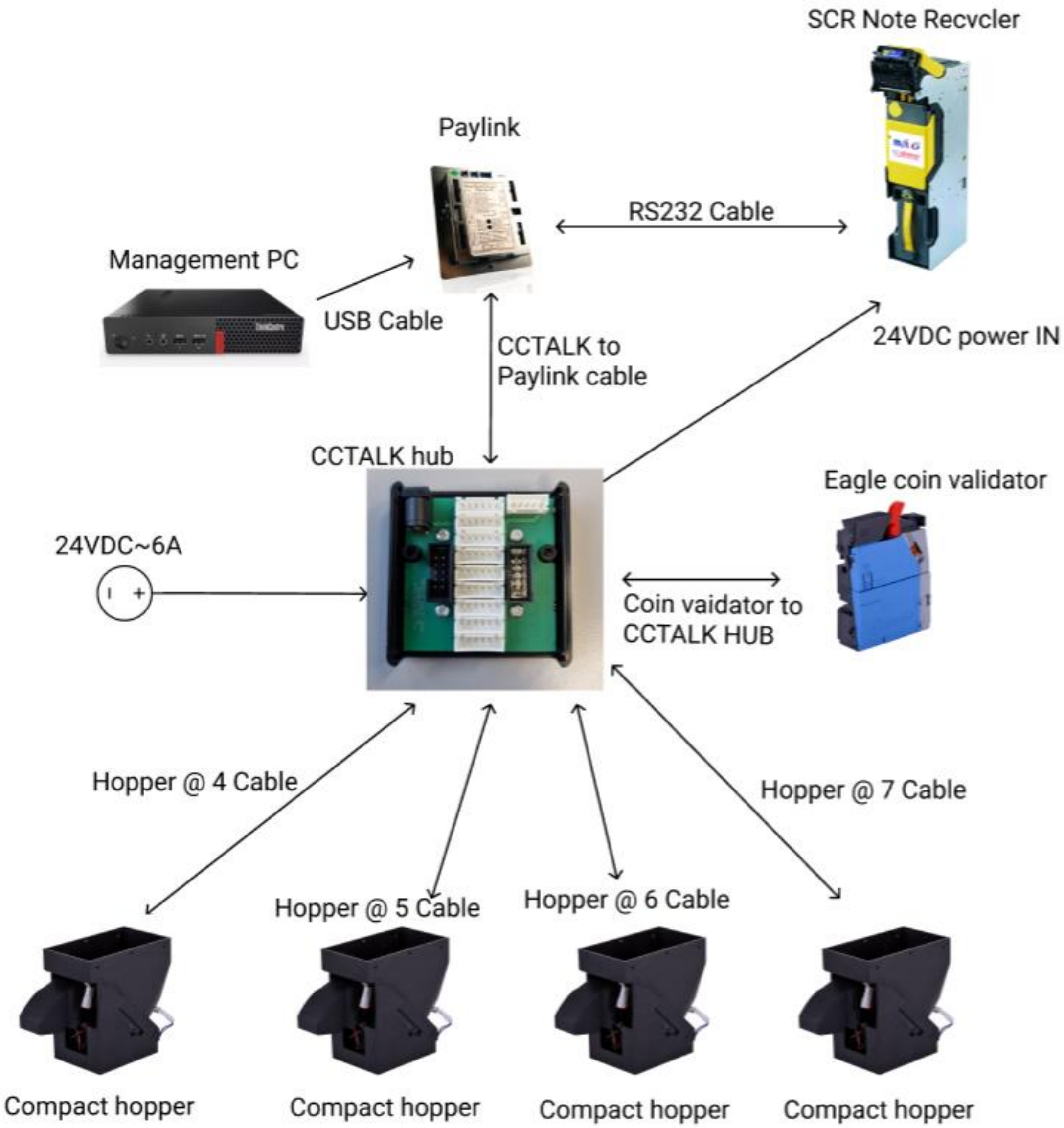


Figure 2.2 Cash system arhitecture

2.1.3 Creating the placement sketch of the cash devices

The design process began with sketching the outlines of a preliminary idea for the placement of the devices within the system. The aim was to make the most efficient use of the available space within the kiosk while ensuring the proper functioning of each device. Two main steps were involved:

1. Device Placement Sketch, the initial idea was to have two coin hoppers placed side by side and two others facing them, forming a square arrangement. The coin collection pathway was planned to be located in the centre of these hoppers, routing coins back to the customer after hoppers have dispensed them. The banknote recycler was planned to be placed on the side of the hoppers.

2. 3D CAD Modeling, after the initial sketch, the next step was to import the devices into a 3D CAD environment SolidWorks, for more detailed examination and placement of the devices. The housing of the previous generation payment station was also imported into SolidWorks. This helped with a more accurate assessment of the space limitations and gave a better understanding of how the devices could be arranged inside the payment station.

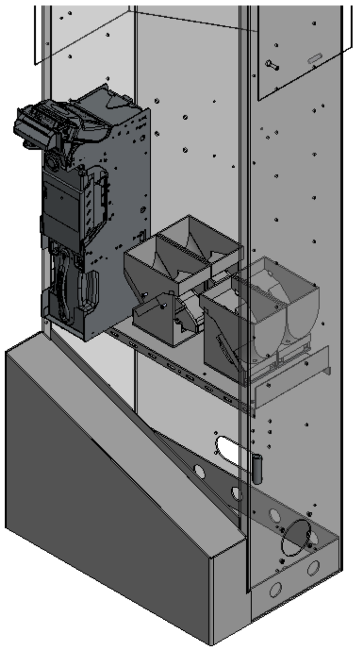


Figure 2.3 View from SolidWorks with cash devices inside the payment station

The Eagle coin validator has the capability to sort coins into five different pathways. Everything was built around this feature in the cash handling system. The usage of these routes is as follows:

1. Four Hopper Paths, four of the coin routes from the Eagle coin validator are directed towards the four different coin hoppers. Each hopper is holding a specific coin. The coin validator, which is able to recognize which coin went inside and route it accordingly to the configuration set by the software, accurately sorts incoming coins based on their value and sends them down the appropriate path to the corresponding hopper. This ensures that each hopper only receives and stores the correct coin type.
2. Overflow Coinbox Path, the fifth path from the Eagle coin validator is directed towards an overflow coinbox. The box serves as a collection point for excess coins during the incassation process. This can be necessary if the hoppers reach their capacity or if the system receives coins of a nominal that it does not have a designated hopper for.

The author decided to place the Eagle coin validator directly above the hoppers. This placement was chosen to have the easiest coin sorting process and make the coin sorting pathways more simple to develop. This not only simplifies the design but also improves the reliability of the system by minimizing the chance of coin jams or misrouting due to the coin pathways being fully closed.

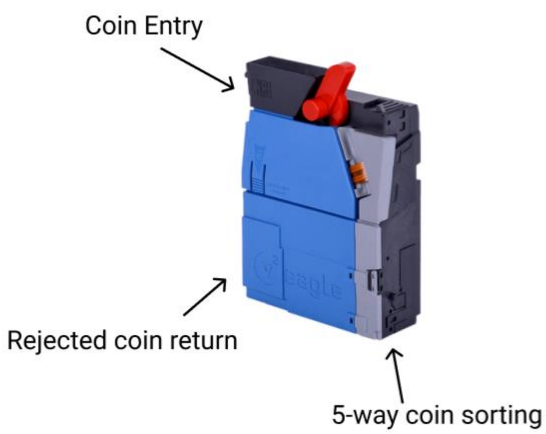


Figure 2.4 Coin Validator with explanation on coin movements

The arrangement of the devices within the kiosk is the most important part, as it directly impacts the reliability of the cash handling process, the ease of maintenance, and ultimately, the price of the system. Therefore, careful thought and planning were necessary in this phase.

2.2 Executing the development phase

2.2.1 Note recycler placement

The SCR Note Recycler, designed as a front-serviceable and rear-mounted unit, allows for easy maintenance and access from the front of the kiosk. In order to ensure the system's functionality in various weather conditions, it is necessary to integrate weatherproofing features into the design and installation processes, in this project case seals on the connection points were used to prevent the rainwater from entering the payment station housing. Aligning the note recycler within the kiosk door requires precise positioning. But this is more complicated as the kiosk door is being constructed with welded hinges, which has larger tolerances on manufacturing. Therefore, the recycler must have alignment options within the kiosk. When the kiosk door is closed, the note input/output slot of the recycler should align perfectly with a corresponding hole in the kiosk's front panel.

The final mounting design for the SCR Advance is a shelf-mounted panel, the panel has cut-outs to enable the sliding of the panel on the shelf, which is attached to the note recycler. This design allows the recycler to be moved back and forward to achieve the optimal fit with the door. Seals were put on the note recycler acceptor head, as this went directly against the door and proved to be the most aesthetically pleasing and functionally working solution.

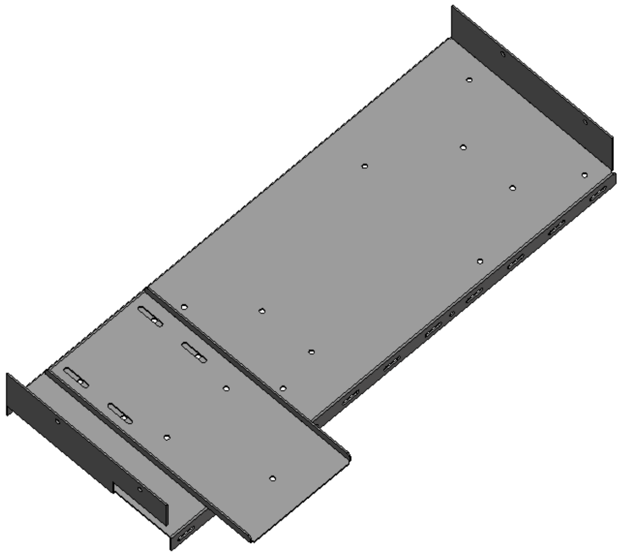


Figure 2.5 Shelf with the attachment panel for note recycler

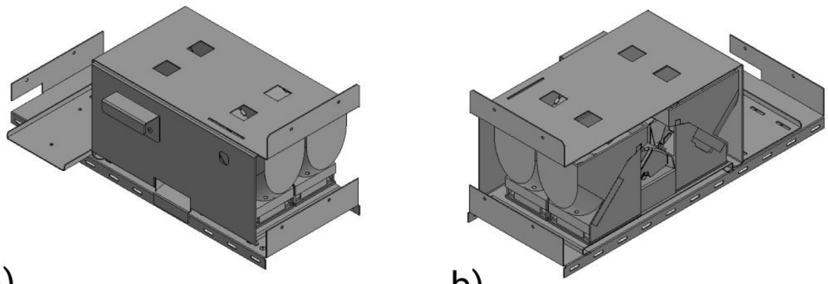
2.2.2 Hopper system development

The design process began with the main requirement to ensure easy access to the hoppers. However, given the decision to install the coin validator in a fixed position directly above the hoppers then the convenient access to the hoppers would be lost. The idea to overcome this challenge and maintain the easy accessibility was to develop a drawer mechanism that is integrated into the payment station.

The drawer function meant placing the hoppers on a movable shelf. The top roof of this drawer was designed to mount the coin validator together with the coin sorting pathways, 33 x 33 mm holes were cut inside the roof of the drawer, to have the place for coins to fall through to the hoppers from the coin validator via routing pathways. This design allowed for the hoppers to be easily accessed by simply sliding out the drawer when required, this meant that the coin validator would be fixed to the pathways and less issues could arise when constantly opening the payment station.

This drawer design helped to solve additional issue, the drawer mechanism could be secured with a lock, adding an extra layer of security to the system. This means that during a regular maintenance routine, a technician would not have unrestricted access to the hoppers containing the coins or if vandals could access the main part of the kiosk, then there would still be additional lock before the money. This physical security measure can significantly enhance customer trust towards the service department, as it ensures that the coins are securely stored and only accessible to authorized personnel making changes in the dispensers.

In conclusion, the drawer function not only improved the ease of maintenance access to the hoppers but also contributed to the overall security and reliability of the system.



a) b)

Figure 2.6 Hopper shelf corner views a) Front corner view b) Rear corner view

The development of the coin return pathway from the hoppers to customer, was a critical point in the cash handling system. The goal was to ensure a smooth passage for coins without any obstructions, as the main requirement was that the system must be completely jam-proof. Any malfunction that might prevent customers from receiving their change could severely affect user confidence and the overall performance of the system which creates bad marketing for both the parking lot owner and also the manufacturer of the system.

The coin return pathway was constructed using metal, chosen for its durability and compatibility with the rest of the shelf. The metal surface was then covered with a matte paint to further reduce friction between the coins and the pathway, it was important that the paint quality was as good as possible, otherwise the coins could get stuck on the pathway.

Multiple design options were considered for this pathway. One initial idea was to guide the coins in an upright position, which would mean that they roll on their edges down the pathway. It would significantly reduce friction as coins rolling on their edges have less friction with the metal pathway than when sliding flat. However, this idea was later scrapped due to the coins dispensing in an uncontrolled manner from the hoppers. Factors such as the speed, angle, and rotation of the coins as they are dispensed are variable and difficult to control without possible risks of coin jams.

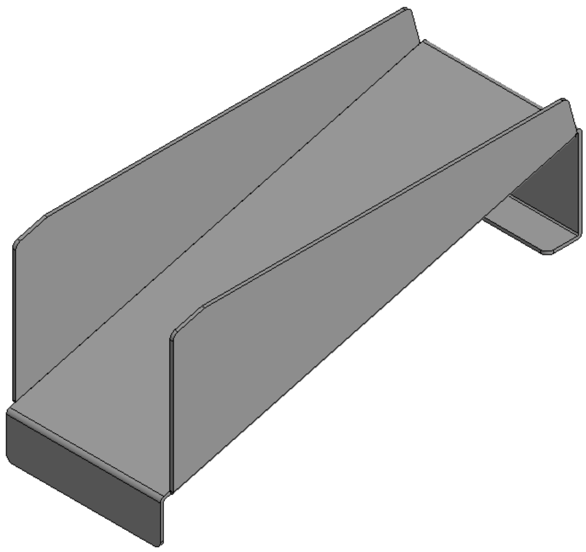


Figure 2.7 Dispensed coins routing to customer pathway

The final design for the coin return pathway was a regular flat surface where coins could simply fall and slide down to the customer. The main requirement for this design was to create a pathway as enclosed or sealed as possible to prevent the coins from bouncing off and causing jams or miscounts.

2.2.3 Coin validator and routing pathways

Given the previous decision to fix the coin validator on top of the hoppers drawer, on the pathways for coin routing, the design of these pathways had to be perfect in order to ensure smooth functioning of the system. As the coins were released from the validator in a controlled, always upright, manner it was determined that keeping the coins in an upright position would be the most space-efficient option as in total there was 100 mm of height to fit the pathways to. This approach also required smaller angles for the coin pathways, which further helped with the compact design of the pathways.

One of the main topics in designing these coin pathways was determining the appropriate dimensions to be able to use a wide range of coin sizes in different markets. To establish these dimensions, an analysis of coin sizes in the target markets was conducted.

Table 2.1 Coin sizes in different currencies [10 – 15]

Currency	Minimum diameter	Maximum diameter
EUR	16.25 mm	25.75 mm
USD	17.91 mm	30.61 mm
GBP	18.0 mm	27.3 mm
CHF	17.15 mm	31.45 mm
PLN	15.5 mm	24 mm
AED	15 mm	28.5 mm
UAH	16.3 mm	23.5 mm

From the table it turned out that the smallest coin diameter found was 15 mm, and the largest was 31.45 mm. However, to ensure that the system would work with a wider range of potential coins, the author decided to design the pathways to handle coins as small as 12 mm and as large as 33 mm in diameter. This decision was made to introduce some tolerance into the system and to future-proof it, considering the possibility that coins from different markets which are not in focus right now could be used in the future, and the system should not be redesigned later.

The development process started with identifying the optimal angles for the pathways that would allow coins to keep rolling, even from a stationary position. The purpose of this was to ensure a smooth and jam-free operation of the coin handling system. Four different coins were selected for these tests: 2.00 EUR, 5.00 UAH, 5.00 CHF, and 1.00 PLN. These coins were selected because they represent a wide range of sizes and weights in use in the target markets.

Using 3D printing technology, the author created a model of a single coin pathway with a flat surface. The 3D printed pathway served as a physical prototype for testing how the coins roll under different conditions.

The main objective of these tests was to ensure that a coin would start rolling on the pathway even when its initial speed was zero. This was critical requirement because it was important to prevent any potential jams that could occur if a coin were to become stationary in the pathway. If a coin can start moving from a standstill, it significantly reduces the chances of a coin jam happening.

The testing procedure involved placing each coin at various points of the pathway and observing their motion and reaction to different angles. The angle of the pathway was incrementally increased until the coins consistently started rolling from a stationary position, the angle was then measured. The angle of 8 degrees provided the optimal slope for the pathways, ensuring that coins would reliably move through the system regardless of their initial speed or position. In the end, a minimum incline of 12 degrees was selected for the coin pathways to prevent jams, even in situations where a coin's rolling resistance might be increased due to dirt or damage to the coin's rim on which it is rolling on.

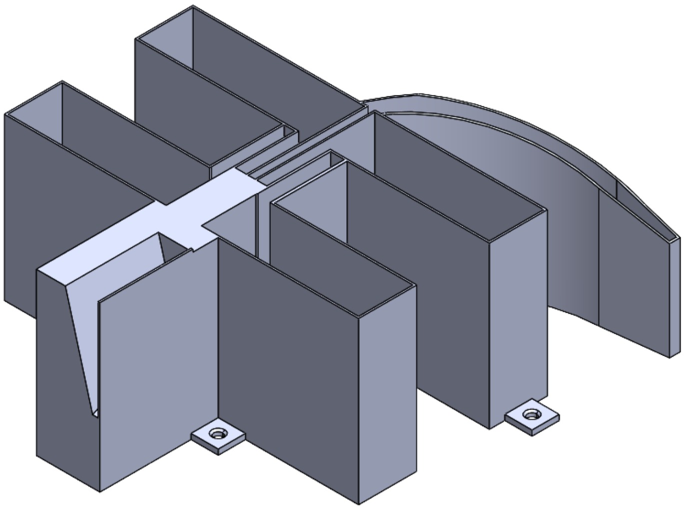


Figure 2.8 Final pathways of the system in SolidWorks environment

The coin validator's option to route coins to five different pathways was fully used in this development process. Four pathways were designed to lead to the individual hoppers, two on the right and two on the left side of the hopper system, and a fifth pathway was created to route the coins to the overflow coinbox. Each pathway required a unique design to forward the coins to the correct positions of the hoppers and overflow coinbox, as well as to ensure smooth and reliable coin routing. The result of the development was one component, which featured 5 different pathways inside, and coin rejection pathway which routed rejected coins back to the customers.

The complex shape of these pathways presented a challenge for both prototyping and mass-production. Previously used methods of manufacturing, such as machining or sheet metal bending, would have been too complex and costly due to the difficulties of the pathway shapes. The decision was done to use 3D printing for both the prototype and later for the mass-production of these pathways. 3D printing technology offered the option to create these small and difficult shapes with a high tolerance, while also providing the option to produce these parts once quickly and cost-effectively in mass-production phase.

The material chosen for the 3D printing was Polylactic Acid (PLA) plastic. PLA was chosen due to its many benefits: it is biodegradable therefore environmentally friendly, has a relatively low melting point making the printer required for printing PLA relatively cheap, is easy to print with, and has good strength and durability, which are crucial for the pathways that need to withstand the continuous movement and impact of coins.

With this method, the pathways could be printed and tested if they are functioning in the prototype. Any necessary adjustments could be made quickly by altering the 3D model and printing a new part, as the author had access to 3D printer then all the usual queues of waiting in line for production were non-existent. Once the designs were finalized, these 3D printed pathways could be produced in larger quantities for the mass-production units by a 3D printing company. 3D Printing was chosen due to being the cheapest option currently, as around 40 components are estimated to be produced per year. To compare against injection moulding, then estimated offers for manufacturing two moulds were taken, one for the main part of the pathways was estimated for around 25000 € and the mould for the lid of the main pathways was estimated to cost around 20000€. Therefore injection moulding was excluded from choice as of this point.

The utilization of 3D printing technology in this context helped to keep the prototyping efficient and effective solution to a complex design and manufacturing challenge, ensuring that the coin pathways worked effectively within the full cash handling system.

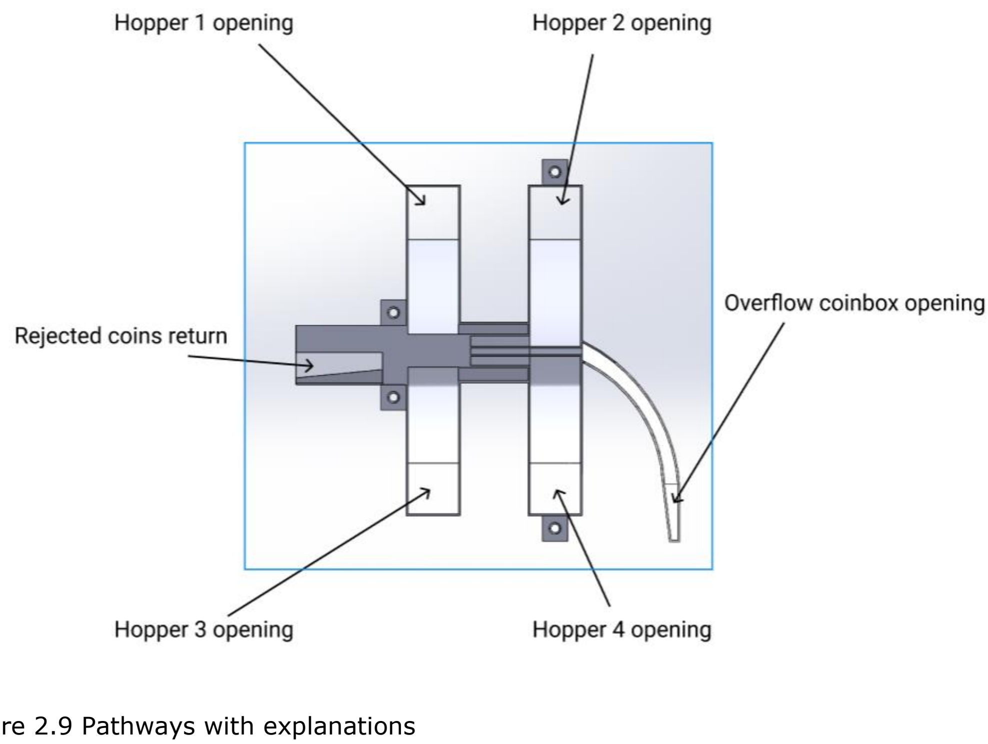


Figure 2.9 Pathways with explanations

As the coin validator needed to be securely attached on top of the coin pathways then to accomplish this, a specially designed lid was created that covered the pathways and also provided the necessary mounting points for the coin validator.

The lid and the pathways were joined together using an interference fit method, a type of fastening between two parts which is achieved by friction after the parts are pushed together, rather than by any other means of fastening, this allowed for a tool-less installation of the lid. In the current case, the lid was designed to be slightly wider than the pathways. When it was pressed onto the pathways, the resulting friction between the two components held them securely together. This method was chosen because the pathways did not have many options in generating screw holes or snap hooks. [16]

For the attachment of the coin validator to the lid, two points of attachment were built on the lid. Both of these points made use of existing mounting options on the coin validator to facilitate easy assembly and secure attachment. The first point of attachment was designed as an interference fit hole that matched an existing point on the coin validator. The validator was simply inserted into this hole, and the friction between the two components held it securely in place from the rear side.

The second point of attachment was designed to be secured with a screw. A hole was made in the lid that aligned with a corresponding hole in the coin validator. A screw was inserted through both holes and tightened attaching the validator to the lid. Using these mounting points allowed for a secure, cost-efficient, and reliable way of attaching the coin validator to the pathways, ensuring that it remained firmly in place during operation, while also simplifying the assembly process.

The decision was made to engrave the pathway number and the corresponding hopper number directly onto the plastic lid of the coin pathway which are used in the software to reference a specific pathway or hopper. It creates a clear identification of each pathway and its corresponding hopper. This engraving ensures that there is no confusion about the configuration of the payment station, as each pathway number and hopper number is part of a standardized hopper and pathway numbering system. By having these numbers permanently engraved directly on to the component, it also helps to prevent any errors in installation or maintenance that could happen from the manufacturing department side or confusion about which pathway should align with which hopper.

Secondly, by engraving these numbers at the 3D printing factory itself, it ensures that no device can leave the manufacturing without the proper markings. This helps maintain quality control standards, as every component will have its pathway and hopper numbers already clearly marked when it arrives from the factory.

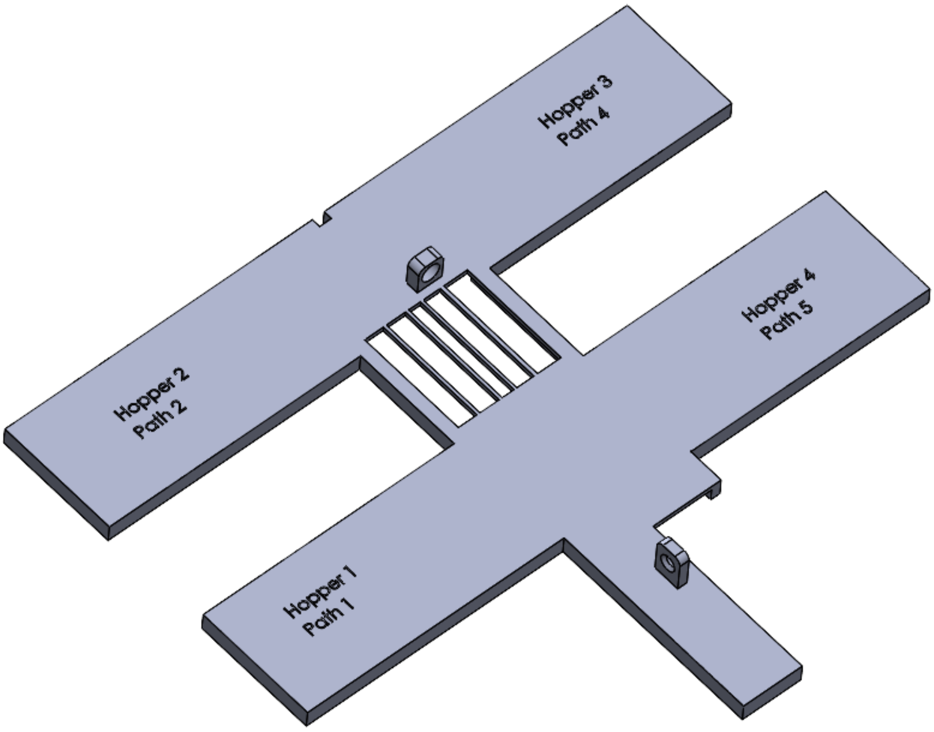


Figure 2.10 Pathway lid with data engravings and mounting points for coin validator

Once the prototype coin pathways were 3D printed and assembled, they were put through intensive testing to ensure that no coin jams would occur, regardless of the coin size being used. The testing phase involved using a variety of different coin sizes, reflecting the range of sizes that the payment station would need to be working with in a normal scenario.

When a coin jam did occur during the testing process, the author carefully examined the location and circumstances of the jam to understand its cause. Factors considered during this analysis would include the size and orientation of the coin at the time of the jam, the speed of the coin, and the specific location within the pathway where the jam occurred.

Based on this analysis, adjustments were made to the design of the coin pathway in the area where the jam had occurred. This involved changes to the size, shape, and angle of the pathway. The goal of these adjustments was to eliminate the factors that had caused the jam, while maintaining the functionality of the coin pathway. Once the adjustments had been made, the revised coin pathways were 3D printed once again.

The testing process was then repeated with the new prototypes, using the same range of coin sizes to ensure a comprehensive assessment of their performance. This process of testing, analysis, design adjustments, and re-testing was repeated a total of three times. After the third round of modifications, no further coin jams occurred during testing. This suggested that the final design of the coin pathways was successful in preventing coin jams, and the design was compatible with the hopper system developed.

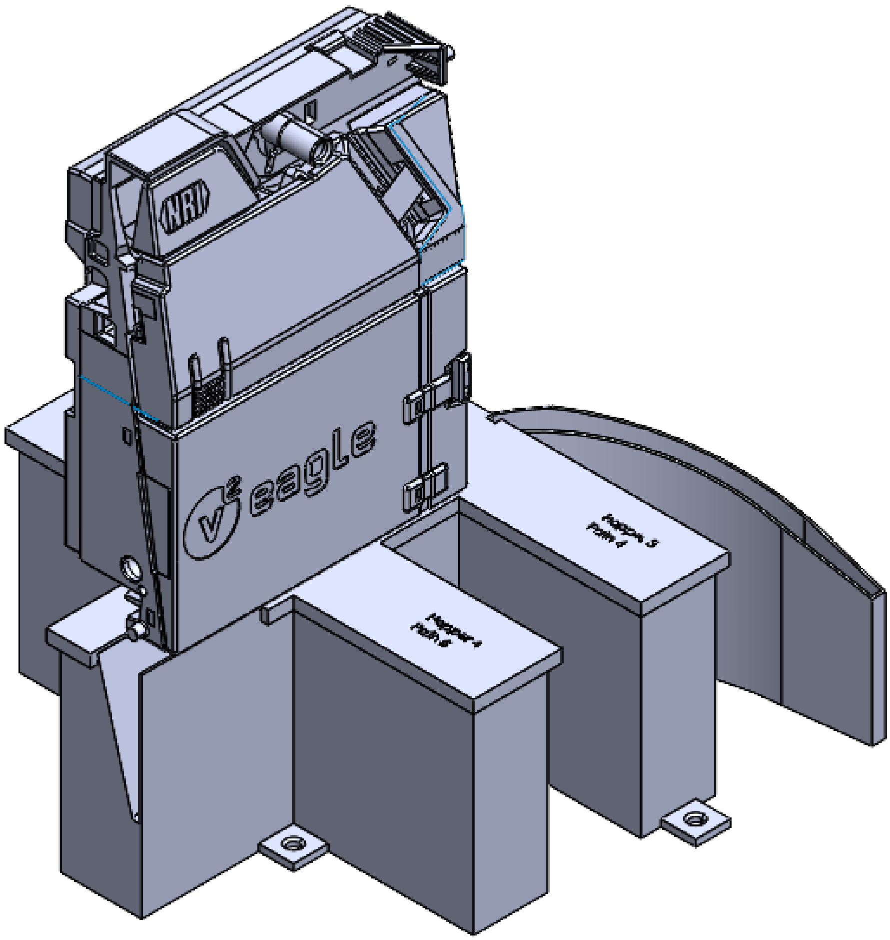


Figure 2.11 Full assembly of coin pathways with coin validator

Figure 2.11 provides an overview of the assembled coin pathway system, designed to be mounted on top of the hopper drawer. The system is made up of three main parts: the coin validator, the lid of the pathways, and main primary pathways. The coin validator sits on top of all the components. Then the coin validator is mounted to the lid and the lid is further on mounted on top of the main pathways.

2.2.4 Managing the cash system with Software

The Paylink hardware, produced by the same manufacturer as the note and coin validators, functions as an middle layer of communication in the payment station's cash handling system. It assists with the efficient communication between the cash devices and the payment station's central system, exchanging information about cash types and values being accepted, validator and hopper statuses, error messages, and commands for the cash devices.

However, while the Paylink hardware is necessary for communication, it does not fully manage the cash devices. This task is left to the in-house software, which utilizes the API from the Paylink to make decisions and send commands to the cash devices. This software also allows for customizability, updates, and improvements based on the specific needs and requirements of the payment stations while maintaining full control over the cash handling process. This control is necessary for ensuring the reliability and security of the payment stations, and for compliance with regulations from the tax offices related to cash handling and payment systems.

The software is also responsible for setting the acceptor config, which dictates the cash nominals the system will accept, and for assigning each hopper to hold a specific coin. The system continuously monitors the status of each hopper and reroutes the corresponding coin to an overflow coinbox when a hopper is full, ensuring that the payment station continues to accept cash and preventing jams or other problems that might occur due to overfilling. This also means that the hoppers are self-filling, and require no manual interference from the system owner during normal operation and only the overflow coinbox should be managed on a daily basis.

The software uses a polling mechanism to continuously check the status of the validators every 500 milliseconds. When a change in status is detected, the software updates the payment station database, which keeps a record of all transactions, including the type and amount of currency accepted with exact time of acceptance. This record-keeping is necessary for financial auditing done by the tax offices, providing real-time transaction information, and managing the cash devices. After receiving a coin, the hopper contents are checked, if the hopper is full, rest of the coins that the hopper contained are sent to the overflow coinbox.

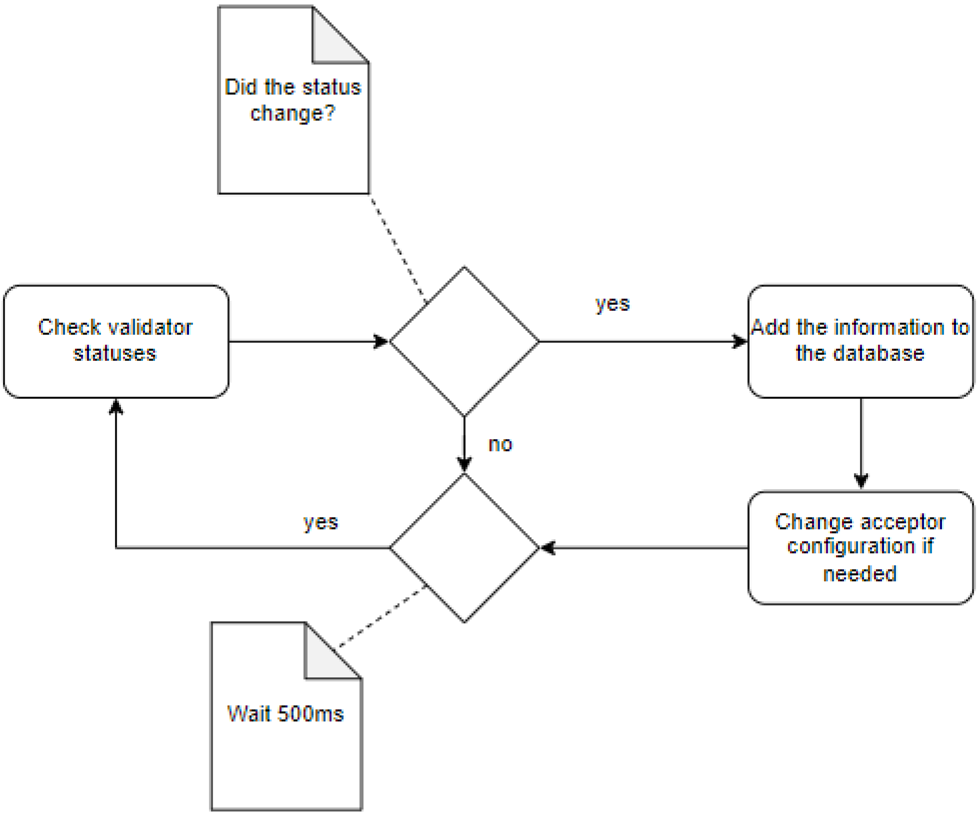


Figure 2.12 Logic diagram of checking what has been paid in the system

The cash handling system has a separate algorithm to manage change dispensing. When a customer requires change, the system initiates a process where it checks its internal database to determine which nominals it currently has available. It then proceeds to dispense the change, starting from the highest nominal value. For example, if it needs to dispense 1.00 EUR, it would start by trying to dispense a 1.00 EUR coin. However, the system is also designed to handle issues that may arise, such as a hopper failing to dispense a coin in case of a jam or other malfunction. If such an event should occur, it would automatically switch to a lower nominal to complete the transaction. To continue the previous example, if the system failed to dispense a 1.00 EUR coin, it would instead attempt to dispense two 0.50€ coins which in the end provides the same amount of change for the customer. If the dispensing of change fails entirely, the customer will receive a receipt indicating the unsuccessful return of change, which can be presented to the operator of the payment kiosk, who can then manually return the owed change.

Additionally, the payment station is equipped with remote monitoring capabilities. This feature aids in proactive issue detection and resolution, preventing minor glitches from escalating into significant malfunctions. In the event of a system malfunction, the remote monitoring system promptly notifies the relevant personnel. This quick response system allows for the issue to be resolved promptly, minimizing the downtime of the payment station and ensuring continued, reliable service for customers which generates revenue for the system owner.

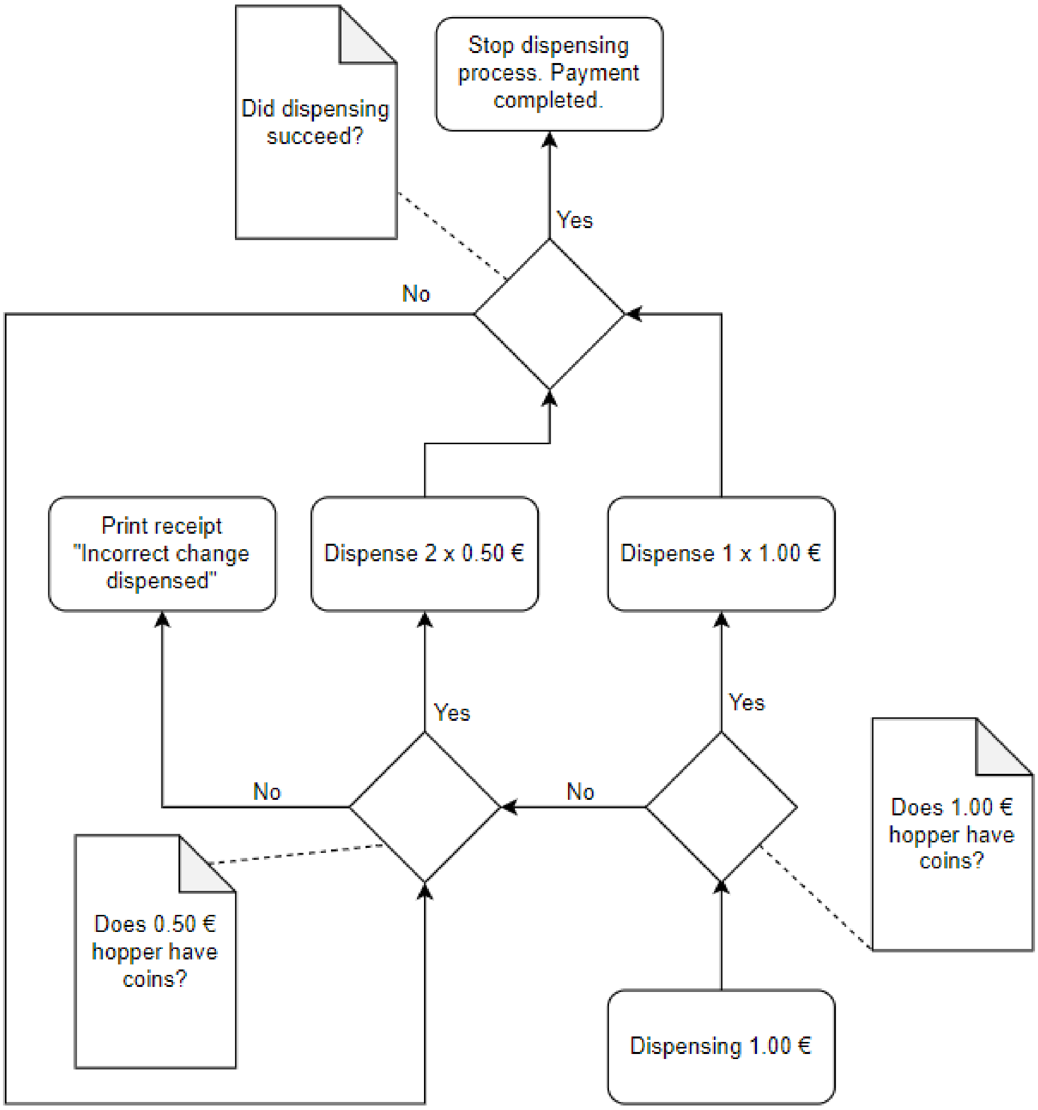


Figure 2.13 Flowchart of dispensing the change to the customer

Figure 2.13 describes the flow of dispensing the change, in this case with the example of dispensing 1.00 €, including the failure of managing to dispense the change.

3.PROOF-OF-CONCEPT PROTOTYPE VALIDATION

3.1 Finalized product

The finalized product was a fully functioning, enhanced cash handling system that offered many improvements over previous generation. These improvements mainly consisted of ease of assembly, reliability, security, and user-friendliness, making the system more attractive end customers and helping the company to get a bigger market share.

The ease of assembly was addressed by focusing on a modular design with easy fixing methods and clear assembly instructions. The modular design allowed for individual components to be assembled separately and to create a more configurable option regarding the customer needs. Clear assembly instructions were also documented, ensuring that each step of the assembly process was easy to understand and follow for everyone.

Secondly, the reliability of the system was improved through a lot of testing and quality control. Each component of the system, including the coin validator, the hoppers, and the coin pathways, were thoroughly tested to ensure it met the standards of performance and jam-free operation.

Security was also a key focus in the development of this cash handling system. Additional locks were added to protect the system from tampering. For example, the system was designed to securely store cash and to save information about each coin and transaction in the system.

User-friendliness from the aspect of ease of access to the devices for maintenance team and end customer was another important aspect of this project. The hoppers were put on a locked drawer to make the access to them very easy for authorized personnel in order to maintain the system or change the cash inside them.

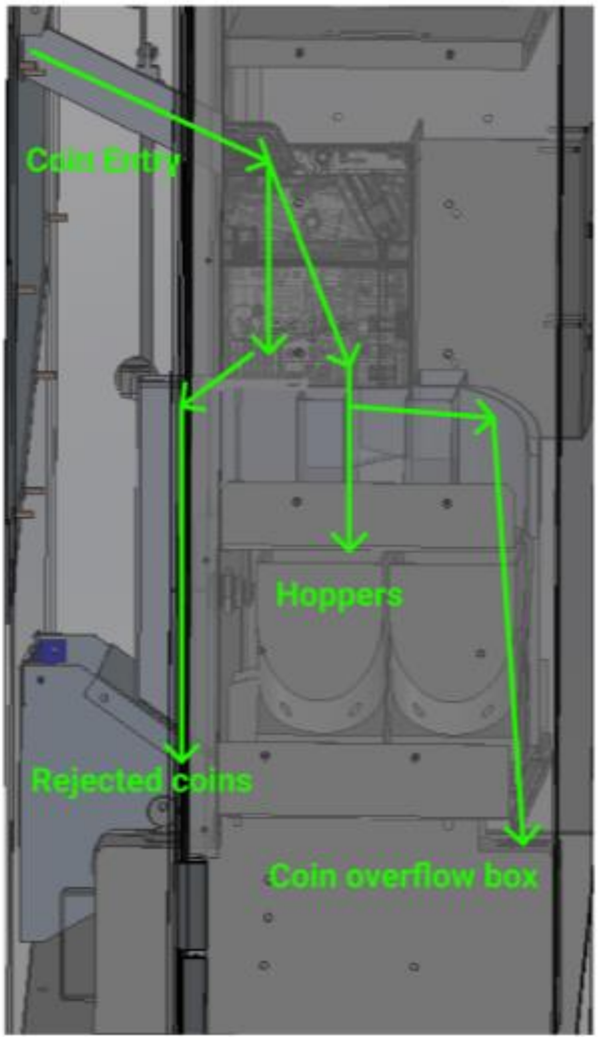


Figure 3.1 Overall schematic of coin movement

The coin system in the cash handling system was designed with a series of pathways that guided coins through the process of validation, storage, and dispensation of change. This began with the pathway to the coin validator, then the validator examined and verified the coins. Validated coins were then split between five different pathways to their designated hoppers or overflow coinbox. When hoppers were full, coins were rerouted along pathways to an overflow coinbox. In case the customer put in a coin of wrong currency or something that is not even a coin, then the coin is rejected and returned to the customer through a special rejected coins trajectory.

3.1.1 Testing the system

The finalized cash handling system was stress tested to verify its compliance with the requirements set in the first chapter and to ensure its reliability. These tests were necessary because the system can potentially be installed in remote locations where on-site maintenance or component replacement can be challenging and costly for the company.

The stress tests involved at least two hours of continuous coin inputs for each of the currencies: Euro, Swiss Francs, Polish Zloty, and Ukrainian Hryvnia. This testing strategy was designed to simulate a real-world, high-demand environment as there are already payment stations installed which have thousands of card payments per day, and to find any potential issues with coin routing that might cause problems down the line. The final system performed well under these stress conditions, successfully processing coins of all the tested currencies. However, there was one exception to the systems universal coin handling capabilities with different currencies.

The system was unable to dispense 5 Swiss Franc coins as change. This limitation was due to the physical properties of the 5 CHF coin itself, as the coins diameter is 31.45 mm, it was simply too large to fit inside the hopper, which is the component responsible for dispensing coins. In theory, this limitation could be avoided by selecting a different model of hopper capable of dispensing larger coins, but using such hopper would have the need to make the payment station with larger overall dimensions, and it would not fit inside the generation one kiosks. In the end it was decided to accept this limitation as the redesign of the kiosk would not be worth it. Therefore, the system was designed with the limitation that while it can accept 5 CHF coins, it cannot dispense them as change.

3.1.2 Benefits for the company

Developing the cash handling system was a significant investment for the company. The associated costs included the prototype device price, the salaries of the people involved in the development phase, and the costs related to 3D printing technology. However, these initial expenses were covered by the benefits the system brought to the company.

One of the key benefits was the enhanced system's ability to fulfill a larger number of tender requirements. An analysis of the company's tender data from the last six months indicated that the new system could meet approximately 40% more tender requirements when cash devices were involved. This percentage was received by comparing the number of tenders that the company was unable to qualify for or lost due to the lack of a modular cash handling system versus all of the tenders the company participated in. With the new system, the company is able to compete more effectively in the marketplace and secure more contracts.

Furthermore, the robustness and reliability of the new system leads to reduced maintenance requirements. Service engineers no longer need to make frequent site visits to clear coin jams, which resulted in substantial cost savings, the reduced need for engineer time, in addition lower fuel and travel costs decreased the company's operational expenses regarding the payment stations of around 17%.

In addition, the system's configurability had a direct impact on the company's warehouse management. The manufacturing department was able to keep warehouse stock levels lower because the same core devices were used in all systems, with only the configuration being different. This meant that less money was tied up in warehouse stock, freeing up resources for use in other operational areas. Additionally, the need for physical warehouse space was reduced, further decreasing the costs.

In sum, the development of the cash handling system, despite its initial costs, brought about considerable benefits for the company. By enhancing competitiveness, reducing maintenance costs, and optimizing inventory management, the system contributed significantly to the company's operational efficiency.

SUMMARY

The objective of this thesis was to design and develop a cash management system with the capacity to handle multiple currencies while minimizing hardware variations. The key challenge was that cash handling systems are typically custom-built by each manufacturer for their own systems, with no off-the-shelf product available in the market that could be integrated into an existing point-of-sale device manufactured by the company.

An extensive process of analysis, planning, and development was undertaken to achieve the goal. This included a thorough examination of the existing system and its limitations, generating a set of requirements to be focused on during the project, and selecting the devices to be integrated into the system.

The central development phase involved creating 3D models, 3D printing their prototypes, and testing the parts with real currencies. Given the distinct characteristics of different countries' currencies, testing was a crucial part of the process. The task was made more complex due to the need for careful space management as the housing in which the system was installed to, was already existing without the possibilities to change the dimensions. Cash management devices, particularly those handling coin acceptance and dispensing, are typically quite large in their size. One of the unique selling points of the developed system was its compact size compared to competitor systems.

The physics of coin movements posed another significant challenge. In some instances, coins were dispensed from devices in an uncontrolled manner. The system had to be designed to reliably handle these situations and ensure a jam-proof operation.

After resolving these obstacles, the result of the thesis was a retro-fittable, multi-currency cash handling system. The system offered the potential to be used in multiple countries, increasing the company's scope for projects and potential to grow in the field of export markets. Moreover, it also reduced operational and manufacturing costs due to its easy assembly and maintenance-free design. This system not only addressed the company's need for a multi-currency solution but also enhanced its competitiveness by offering a compact and reliable cash handling system.

KOKKUVÕTE

Selle lõputöö eesmärk oli kavandada ja arendada sularahahaldussüsteem, mis on võimeline käsitlema mitut valuutat, minimeerides samal ajal riistvaralisi variatsioone. Peamine väljakutse seisnes selles, et sularahakäitlussüsteemid ehitab iga tootja tavaliselt oma süsteemide jaoks eritellimusel ning turul ei ole saadaval ühtegi valmistoodet, mida saaks integreerida ettevõtte toodetud olemasolevasse maksejaama seadmesse. Eesmärgi saavutamiseks viidi läbi ulatuslik analüüsi-, planeerimis- ja arendusprotsess. See hõlmas olemasoleva süsteemi ja selle piirangute põhjalikku uurimist, nõuete kogumi koostamist, millele projekti käigus keskenduda, ja süsteemi integreeritavate seadmete valimist.

Keskne arendusetapp hõlmas 3D-mudelite loomist, nende prototüüpide 3D-printimist ja prototüüpide testimist eri riikide valuutaga. Arvestades eri riikide valuutade erilisi omadusi, oli testimine protsessi oluline osa. Ülesande muutis keerulisemaks vajadus hoolika ruumihalduse järele, kuna korpus, kuhu süsteem paigaldati, oli juba olemas ilma mõõtmete muutmise võimaluseta. Sularahahaldusseadmed, eriti need, mis käitlevad müntide vastuvõtmist ja väljastamist, on tavaliselt üsna suured. Väljatöötatud süsteemi üheks unikaalseks müügiargumendiks oli selle kompaktne suurus võrreldes konkurentide süsteemidega.

Müntide liikumise füüsika esitas veel ühe olulise väljakutse. Mõnel juhul väljastati münte seadmetest kontrollimatult. Süsteem pidi olema konstrueeritud nii, et see suudab selliste olukordadega usaldusväärselt hakkama saada ja tagada ummistusekindel töö.

Pärast nende takistuste lahendamist oli lõputöö tulemuseks tagantjärele paigaldatav mitme valuuta sularahakäitlussüsteem. Süsteem pakkus potentsiaali kasutamiseks mitmes riigis, suurendades ettevõtte projektide ulatust ja potentsiaali kasvada eksporditurgudel. Lisaks vähendas see tänu lihtsale kokkupanemisele ja hooldusvabale disainile ka kasutus- ja tootmiskulusid. See süsteem ei vastanud mitte ainult ettevõtte vajadusele mitme valuuta lahenduse järele, vaid suurendas ka ettevõtte konkurentsivõimet, pakkudes kompaktset ja usaldusväärset sularahakäitlussüsteemi.

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APPENDICES

Appendix 1 – Payment station datasheet information

List A1.1 – Features of the payment station

- Modular metal housing w. 2-point locking mechanism
- PC based architecture
- 19‟ touchscreen UI
- Cash management
- Bill validator, 300 note capacity
- Coin acceptor w. 5 way sorting, 1000 coin capacity
- 4 hoppers
- Removable coin box
- Card payment (chip + cless)
- Receipt printer
- Barcode scanner (optional)
- LED ambient light

Appendix 2 – Table comparing device providers

Table A2.1 Comparison between device providers

	Company 1	**Company 2**	**Company 3**	**Company 4**
Pricing (1.5)	4,5	1,5	6	3
Lead times (1.3)	1,3	3,9	2,6	5,2
Ease of integration (0.8)	3,2	1,6	2,4	0,8
Range of features (1.2)	2,4	4,8	3,6	1,2
Support location (1.0)	4	1	3	2
Device dimensions (1.5)	1,5	4,5	3	6
Total score	**16,9**	**17,3**	**20,6**	**18,2**