Abstract

This End of Bachelor Degree Project report describes the mechanical design of an automatic dispenser. In such a way, the special design of the dispenser is focused for storing medicament boxes in a pharmacy. The main objective is to create a solution which reduces waiting time as well as the storage space.

To perform the solution, a CAD program has been used for assembling all components required and guarantee physical layout of them. Also, several studies have been made to know further features from materials concerned. The result is a first prototype which best combines storage capacity, price and ease of assembly. Therefore, the developed system is a significant alternative to traditional pharmacies for invest in technology and increase sales capacity.

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1. Purpose

The project involves designing a first prototype of an automatic dispenser of packed medicaments for a pharmacy. The project consists in the conceptual and detailed design of a storage and automatic dispensing system of medicaments for a pharmacy. The main objective is to reduce waiting time as well as the storage space.

2. Scope

Due to lack of economic resources and limited time to complete the whole solution, the scope on this project has been mainly focused on developing a detailed mechanical dispensation system for a pharmacy. The other systems, which are part of the whole solution (computer control, electronic control and the transport system), have also been included in the scope but developed as a general overview. In this way it was possible to fully complete one system of the overall project.

2.1. In scope

- Overall project specification:

In this point it has been defined all systems required for the whole project.

- Mechanical system detailed design:

One module of the mechanical dispensation system prototype has been studied in detail: the cabinet where medicines are stored and the automatic extraction system from it.

In order to get a very accurate prototype of the mechanical system, it has been developed through a 3D CAD file. This 3D definition includes all the components of the system.

A 2D drawing of one piece (finger) and a 3D sample video of the mechanical dispensation system are also part of the scope.

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- Budget:

An overall project budget has been done splitting the whole cost into three main categories.

- Planning:

The project planning has been attached to the report.

- Environmental impact assessment:

An environmental impact assessment has been performed concerning all components required for the assembly. Potential operating time issues are also included and discussed in this point.

2.2. Out of scope

Although all systems which are part of the whole solution have been identified, the following systems have not been fully developed due to the constraints mentioned in point 2 (Scope).

- Computer control system:

A computer control system is essential to define accurately and implement. The central point is the creation of a database and the connection with an internal server computer.

- Electronic control system:

Is necessary to program a PLC for receiving information from the server and manage the mechanical system hardware.

- Transport system:

The transport of medicaments (from the cabinet to the cash register) has not been taken into account in the project scope since this system is fully dependent on the pharmacy layout.

3. Justification

3.1. Technical

In general, this project meant for me the opportunity for changing the way we usually are used to do things or accept how things are done. My challenge was to build a system able to do jobs which are currently carried out by people. At the end of the day, automation is one of the most simplest and effective way to reduce our work cycle.

Regarding this project, the presented solution will bring a lot of benefits like reducing delivery time, shorting customers waiting time and making more efficient the work of pharmacy employees. All those benefits will, at the end, improve the customer satisfaction and save money due to efficiency increase.

3.2. Personal

Personally, the industrial organization is a world which strikes me and it is very probably I will work in it in a future. However, before leaving mechanics I wanted to rise to that challenge. Specifically in this project, the presented solution allows increasing sales by implementing new technology (to pharmacies). In this way, as a result the whole time process will shorten.

4. Specification

The project specifications have been established according to the solutions offered by main manufacturers. Therefore, the solution must fit properly into the market so it can store approximately the same order of magnitude.

First, an internet research of main manufacturers was made for knowing the overall concept. Additionally, a pharmacy with one of those solutions was visited to learn more about the system.

4.1. State of the Art

4.1.1. Main manufacturers

The automatic dispensing systems are an expanding industry. In general, people do not know companies and enterprises that provide these kind of products or services. An exhaustive search was needed to find some commercial rivalries.

Three big multinational companies have been found on internet. Those corporations are outstanding on delivering this type of automation solutions:

- Gollmann:

- Willach:

- Apostore:

Vending snack machines are the base of the actual large automated medicament dispensers in pharmacies. So in a minor degree, these machines are part of the State of the Art. Most of them use a rotate system for pulling the product out. This mechanism allows storing snacks with very different shapes, but it is not the best mechanism for compacting packed medicaments.

Image 1 – Standard vending snack machine   *Image 2 – Rotate system and different snack shapes detail*

The following table shows a comparison about the storage capacity for a 2.5 m^2 module:

Company	Vending machines	APOSTORE Leading Technology For Your Success	Willach	Gollmann Kommissioniersysteme
Capacity (boxes)	950	1650	5600	8400

Table 1 – Storage capacity of main manufacturers

4.1.2. "Farmàcia Torreblanca" visit – Apostore

Now a days, few pharmacies have installed any of those systems for automatic dispensation. In order to view how the whole system really works, it was arranged a meeting with Rosa Puig. She is the owner of *"Farmàcia Torreblanca"*, a two floors pharmacy in Sant Joan Despí in which they have recently installed an automatic dispenser from Apostore company. The main objective of the meeting was to understand how the system works and have the opportunity to have a look on it. Due to intellectual property rights I was not allowed to take pictures of the dispensation system either of the pharmacy.

It was learnt the medicament cycle in the pharmacy and how an automatic dispensing system affects this cycle. The first change is the way medicaments are stored. In "Farmàcia Torreblanca" all medicament boxes are left on a conveyor belt (not necessarily well placed) and the robot stores them in the right place. If the barcode of any box is unreadable, the barcode must be introduced manually in the computer system and then a robot stores it in the right place.

Specifically, the mechanical part of the system consists in a cabinet with horizontal glass shelves and a robotic arm, which is responsible for storing and picking the medicaments. Two six meters long cabinets store the pharmacy stock, one in front of the other. Between them, the robotic arm slides to pick the medicament with a gripper (and helped with a suction cup at its end). For safety reasons, both cabinets and the robotic arm are installed inside a locked cabin. The entrance is prohibited when the robot is on movement, so the arm must be disconnected to come in.

To take more advantage of the system, the store is placed on the top floor and all medicaments are dropped into huge plastic pipes when requested. Just with the gravity effect the medicaments are send properly to the cash register.

This is an example of how this type of systems can be adapted/installed to fit with a specific pharmacy layout.

4.2. System Specifications

Quantitative and qualitative specifications have been defined for the automatic dispensing system developed in this project. The following Table 2 shows those specifications:

No. of stored boxes per cabinet	3000 boxes approx.
No. of references per cabinet	200 references approx.
Supply time	Between 5-7 seconds
Installation surface	2.5 m^2 per module
Compaction level	25%
Shape of medicament	Only for prism packed medicines
Dispense several products at once	Up to three products
Modularity	Easy addition of more modules
Load action	Visual help through lights when restocking
Breakage of medicine boxes	System works as usual even when the medicine box is opened or ripped
Reparability of the system	Easy access to all components
Appearance	Compact and rigid

Table 2 – Basic Specifications

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5. Functional decomposition

The automated dispensing system concept is a very useful tool for pharmacies. This can link the pharmacy's stock management and the automatic dispensing system of medicaments. Thus, automatic stock management significantly reduces the time spent on this task and avoids possible accounting errors. Besides that, the dispensing system decreases the customers waiting time and therefore significantly increases the profitability of the pharmacy.

The final concept consists of several point of sales and a modular cabinet that performs the dispensing of medications to the point of sales. All medicaments stored in the dispenser can be ordered from seller computers. These computers are connected to a server with the database, which can also have a program for stocks management or an ERP system. Both computers (sellers and server) are connected to a programmable automaton, which is responsible for all the movements of the different mechanisms that make up the cabinet. Finally, a transport system delivers the packed medicament to the point of sales. In this way, with the automatic dispensing system for pharmacies the seller does not make any unnecessary step or lose time looking for medicines.

Thus, the entire prototype is the interrelationship between the different subsystems shown in the following diagram (Image 3). In following points, those subsystems will be described following the medicament purchase cycle.
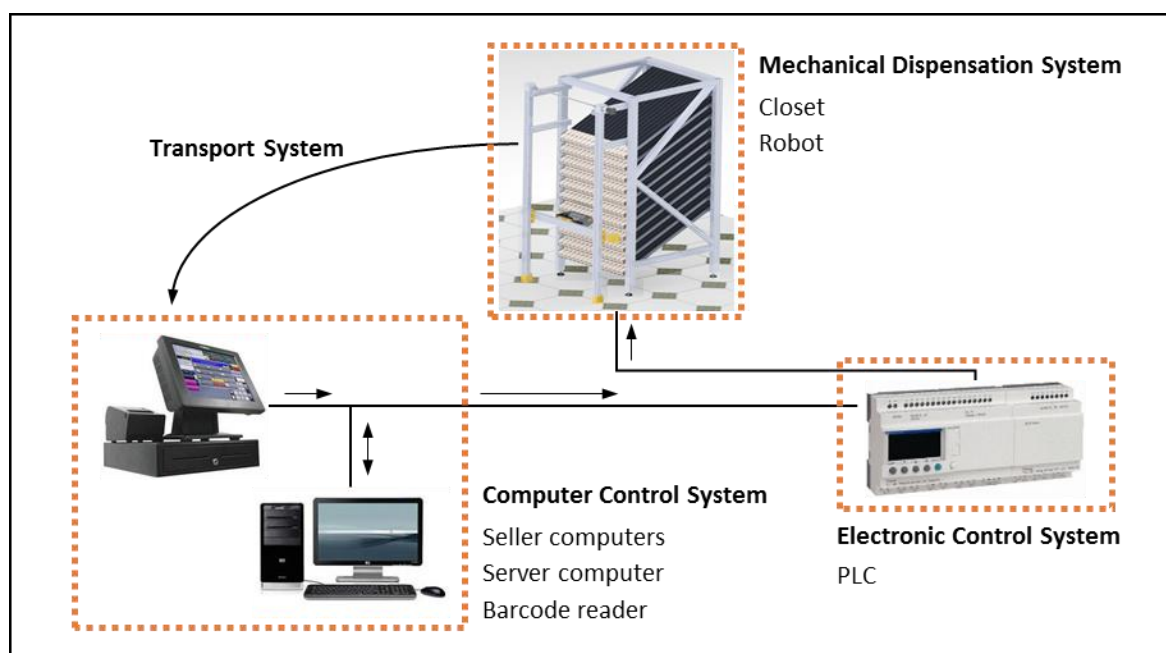

Image 3 – Medicament purchase cycle

5.1. Computer Control System

First of all, each cash register (point of sale) is connected with a computer and from now on each of these sets will be called as seller computer. Additionally, all seller computers are connected to the server computer. The required software will be installed in all of them, so any pharmacist is able to order a medicament by introducing manually the name or by scanning the prescription barcode. Moreover, from seller computers any employee is able to perform all actions related to the cash register; for example charge, refund a product, print a receipt or other cash functions.

The software must contain the database of the pharmacy, updated at any time. This database has all the information about the medicines such as: the full name, internal reference, price, number of units in stock, how many medicaments are going to expire in a certain time, the position in the cabinet matrix, etc. Furthermore should alert in case the actual stock is lower than a minimum level proposed to anticipate a possible break of stock.

In this database the employee can look for a medicament, check their stock, collate any information and finally request a medicament from the store (this action updates the database's stock automatically). All fields of the database must be blocked for not modifying them accidentally in a sale. To modify any field, Administrator rights or access to server computer are required.

On the other hand, the host computer is localized near the dispenser and it is the link between the seller computers and the automat. It also incorporates a reload function for new medicines. The prototype includes a wizard for the automated cabinet load. This wizard indicates on which compartment should be placed, while the stock is automatically updated.

5.2. Electronic Control System

The electronic control system is based on a programmable automat or also called PLC (Programmable Logic Controller). When a medicament is requested from a computer, an order (input) is sent to the PLC already programmed. The PLC reads its control program, makes the corresponding mathematical calculations and, as a result, controls the different actuators of the mechanical dispensation subsystem (outputs).

The software that manages the PLC determines the automat commands. The software indicates which engines should activate and its acceleration. The automat must be programmed with an optimized path function for getting the medicament as fast as it can. The PLC is also responsible for the loading assistance and the stock update when introducing new medicaments into the cabinet.

In this kind of systems, the utilization of PLC's provide lots of extra advantages, some of them are explained below:

- The execution time is extremely fast, order of milliseconds (process understood since the order is given until the servomotors start operating). Then it must be considered the time of performance, which depends on the mechanical servo system.

- Once the PLC is programmed the maintenance cost is extremely low. This is a long-term savings compared to other alternatives.

- It is possible to control more than one device with the same equipment. This provides further precision to the final mechanism and offers the possibility to add extra modules if necessary.

In the following Image 4 is shown an example of a modular PLC from Mitsubishi Electric. A PLC like this would be the suitable option for the electronic control system, as it allows to host a different number of Inputs/Outputs and many of each.

Image 4 – Modular PLC example (from Mitsubishi Electric)

Certainly, the electronic control system is not part of the scope of the project, so it has not been developed in detail. Even so it has been defined the elements that must be connected to the controller to ensure the functioning of the computer control system and the mechanical dispensation system.

5.2.1. Inputs

The "must have" PLC inputs are the following ones:

- Seller computers signal: is the main entrance to the system, so server computer must be connected with the automat in a direct way. If a medicine is ordered, actuators must initiate the movement.

- Barcode reader: is used to reload new packed medicaments to the cabinet. When the medicament barcode is scanned, a signal is sent to the PLC and it determines the position of the medicament in the cabinet.

- Stop and start buttons: they are used by the user to interact directly with the system without a computer. The stop button stops the movement of the robot to reach safely to the cabinet. In addition, start button turns the robot on. An example of each are shown in the following image.

Image 5 – Stop button (left) and start button (right)

More PLC entries can be added to the previous inputs to ensure the perfect functioning of the system. For example, stroke end sensors in all actuators, sensors in the drawer compartment to verify the medicine has been successfully taken out, etc.

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5.2.2. Outputs

Engines which require a precise position control cannot be connected directly to the PLC as it is unable to supply the required power. Drivers are the responsible elements for supplying such power to the engines. The PLC sends to the driver the information needed for the engine to do a certain movement. Then the driver processes this information and provides the necessary energy to comply with the order of the controller.

Most of the elements connected to the driver output ports correspond to the robot actuators of the mechanical system, which are all explained in detail in section 7.2 Robot (from page 42). Below are presented the PLC outputs:

- Double axis DLS system: is the main positioning system. Controls both the X axis (rows) and the Z axis (columns).

- Actuator LA 30: this linear actuator provides an extra automated movement to the robot. It opens the drawer box to pass the medicament to the transport system.

- Stepper motor: is the responsible for moving the finger outwards and take the medicament out from the cabinet.

- LEDs: they are located under each compartment in the rear of the cabinet. The corresponding LED will turn on to indicate the position where the box has to be inserted when restocking.

- Stoplight: indicates when the system is in stop condition. It turns off when the button is actuated resume operation.

- Conveyor belt motor (exceptionally): in case the transport system requires conveyor belts, the PLC is responsible for driving its motor.

5.2.3. Location

Usually, a standard PLC (including the CPU, power supply unit and the input and output units) does not exceed 500 mm long. The automat must be located in an accessible area and close to the mechanical system to be operational and available. In this way, it ensures easier installation and future maintenance tasks.

For cabinet geometrical properties, at the bottom there is an unused space that is excellent for installing the PLC. This area is simply accessible from the back of the structure.

5.3. **Mechanical Dispensation System**

The medicament dispenser, where the stock is stored in, is divided in two main parts: the cabinet and the robot.

Medicament boxes will be deposited in a passive cabinet and they will be there until requested. Each medicament reference has a specific channel-shaped compartment registered in the computer control system. Depending on the medicament, it will be located in one zone or in another. For example, the heavier medicaments will be located at the bottom (to avoid a possible structure deformation and to reduce potential energy of that objects). Moreover, the common and more sold medicaments will be located near the exit to the transport system (to reduce the path of the drawer).

The robot is the assembly of the moving parts from PLC (outputs). The main purpose of this part is to remove properly the medicament box from the cabinet. As said in the electronic control system, the robot parts are clearly distinguished in two groups depending on its functionality:

- The first group (and the first that puts into action) is the linear transmission and positioning module, which places the picking drawer in front of the correct compartment.

- The second group of outputs provide two extra movements to the picking drawer in order to take the medicament box from the cabinet and to take the box out from the drawer.

The mechanical dispensation system design has been developed in depth in the 7th point, consequently more specific features and functionalities are detailed there.

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5.4. Transport System

Once a medicament is ordered and already picked from its place, the drawer moves to a corner and leaves the medicament in the transport system. This is the way the medicament can go to the cash register. Obviously that system depends entirely on the pharmacy layout (where the cabinet and the cash register are positioned).

In order to reduce maintenance costs, the best option are inclined planes or roller guides (if possible due to gravity effect). To transport the box upstairs the most effective way is with a conveyor belt which will be powered on with the PLC (it would be considered as another actuator).

6. Mechanical System conceptual design

To design the first prototype module of the mechanical dispensation system, several alternatives for all the main components have been studied in order to select to the best option for each case. It was decided to define the cabinet structure first and all remaining systems, such as the cabinet shelves, the picking robot, etc., after.

6.1. Cabinet structure

6.1.1. Alternatives

The main structure could adopt many different forms depending on its usability, but they have been summarized in four (see Image 6). Essentially they are distinguished in two aspects: the way the user interacts with the structure in order to load new medicament boxes, and secondly the way the medicament is dispensed. In all alternatives, medicaments would be stored in the cabinet shelves.
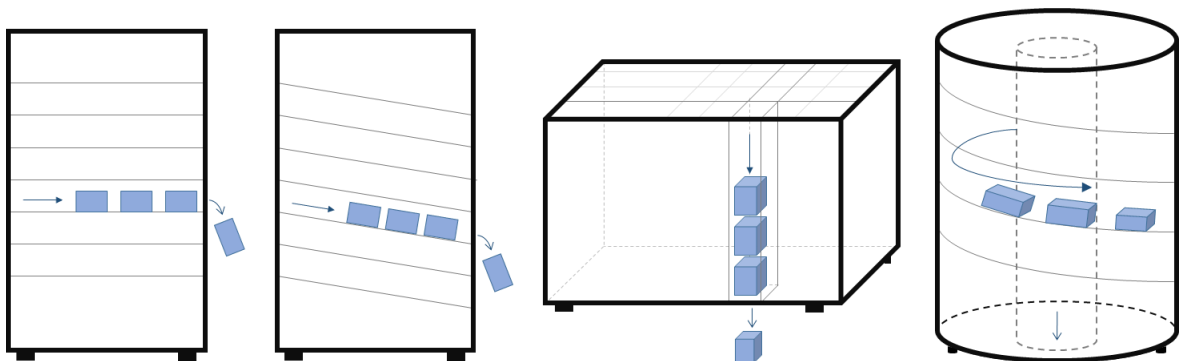

Image 6 – Sketches of the four alternatives (from left to right: alternative 1, 2, 3 and 4)

1- Typical cabinet with horizontal shelves

This option is based on the common vending machines, in which an automat gives the selected product. To push the medicament out would be used a rotate system similar to the snack machines or conveyor belts. Both push out systems have quite a few disadvantages:

- Not easy and uncomfortable load new medicaments.
- Low compaction of medicaments.
- High maintenance costs.
- Sometimes fails and the products get stuck.

2- Cabinet with inclined shelves

This alternative is a variant of the first one for fixing some issues; for instance the loading action, avoid stuck products and reduce maintenance costs. Instead of laid the shelves horizontally, place them quite inclined so all medicament boxes slide down by its own weight. Even so this option has some disadvantages originated for the inclined planes:

- Dead zones with no stored medicaments.
- Need a system for picking just one box so the rest do not be dispensed.
- Possibility boxes get stuck due to friction.

3- Cabinet with vertical shelves

This option is the previous case led to the extreme. The medicament channels would be placed completely vertical so load action becomes dropping the boxes on the correct channel. Although appears difficulties to carry on with that idea:

- Need an accurate system for picking just one box so the rest do not be dispensed.
- Medicament boxes deformation by upper ones weight.

4- Cylinder cabinet with slide shaped pipes

In that last alternative, the cabinet would be a cylinder with a hole on its axis. Inside this cylindrical hole would be installed the picking system. To control it would be necessary to use polar coordinates (move up/down and rotate on the same axis). In addition, channels would be snail slide-shaped for conserving the same width along the pipe. This new concept provides many complications to the system:

- Difficult method to load new medicaments.
- Difficult method to perform maintenance operations.
- Very low compaction of medicaments.
- Lot of space unused.

6.1.2. Selection

One of the most important aspects when making the final choice is how easy is for employees to carry out maintenance operations on the system, such as reload new medicaments, unblocking the system if a box has been stuck, fix possible breakdowns... Furthermore, the simplicity of the overall system lies in the cabinet structure, so as simpler to assemble, fewer mistakes will be made for carelessness.

As a result, the alternative with best features is the second one (inclined shelves). If the load of medicaments is performed from the back (into the corresponding channel), they slide at the end of the channel and get ready to be picked. As there are no belts or rotate systems, there are no maintenance costs associated.

One point to consider is the possibility that the medicine boxes get stuck in ducts and do not reach the end of it, therefore it has been done a study to overcome this problem (explained on 7.1.3 Channels / shelves).

Moreover, it has been decided to design only one module of the cabinet and it can be upgraded with additional modules, if necessary. It has been chosen a pattern for one module size: 1.5 meters wide, 3.0 meters high and 1.65 meters deep. With these fixed measures, it can be installed up to 11 shelves with an average of 16 channels each. It accommodates up to 18 units in each channel, so the storage capacity is about 3170 boxes (similar to rivalry company systems).

If user wants to increase the storage capacity, only needs to add a second module (identical to the first one) attached to it. The new system's width is 3 meters; and stores up to 6340 units. All other dimensions are the same.

6.2. Cabinet components

Once selected the main structure of the cabinet, the rest of the required components are easy to select. There are necessary the follow elements:

- Structural profiles for keep rigidly the cabinet and its components.
- Some kind of shelves in which all medicaments will be stored.
- A robot that will push the medicament out form the shelves.

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7. Mechanical System detailed design

In this section is explained in detail how the mechanical system design has been developed for the first automatic dispenser prototype. Also is clarified how to assemble all the required components.

Below, Image 7 presents the mechanical system design made with SolidWorks 2013. The main advantage of this is that it can be sent (with its drawings attached) to the distributor company (specified later on) and they assemble the components. In the dispenser from the image two packed medicaments are stored on each compartment to show the storage potential. The mechanical system is divided into two main parts:

- The static cabinet where medicaments are stored.
- The robot that picks the medicament out from the cabinet.
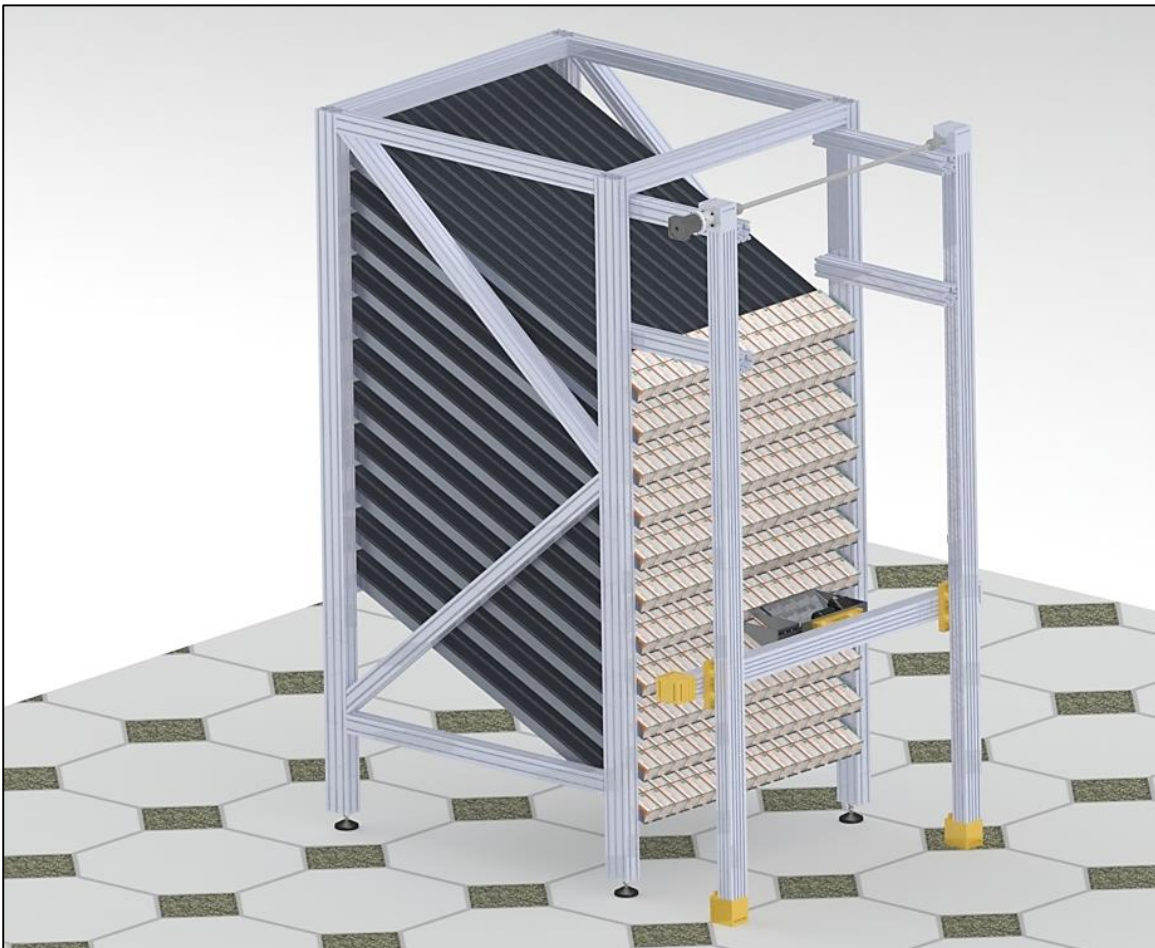
Image 7 – First automatic dispenser prototype

7.1. Cabinet

7.1.1. Aluminium structural profiles

For the main structure of the cabinet and other support systems it has been decided to use structural aluminium profiles. The assembly of this structural sections saves a lot of time versus welded steel structures. A distinct feature is the ease in which two profiles are linked together by profile connections. Image 8 shows an example of two structural sections:
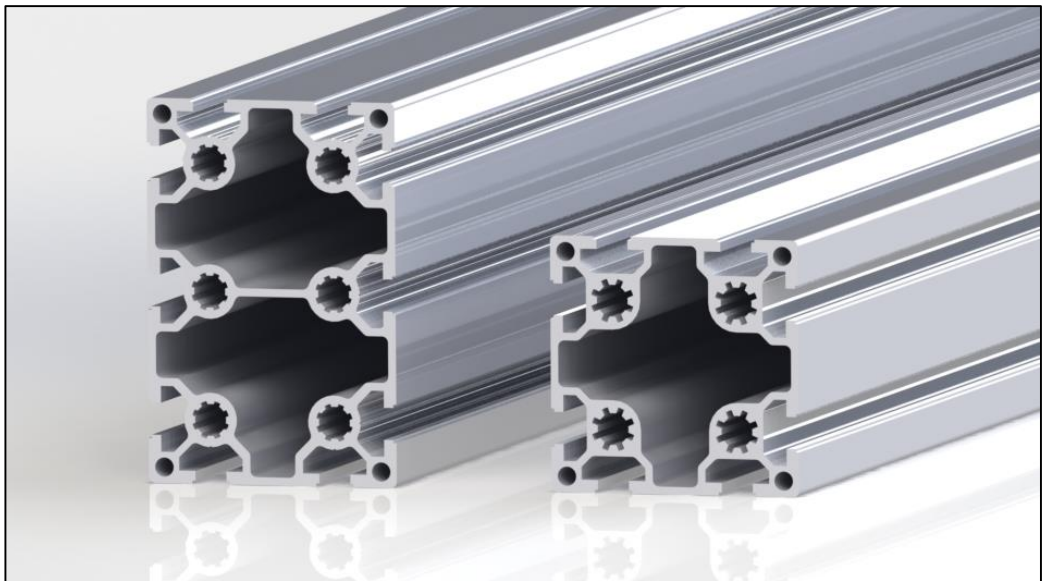

Image 8 – 80 x 120 and 80 x 80 mm Hepco's structural sections

A few providers have been found which supply this kind of aluminium profiles, among them: Hepco, Profi-team and Bosch Rexroth.

Hepco was the distributor selected. As the selling price of the profiles is very similar in all three companies, Hepco was chose according to the extra services offered:

- Referring to Hepco's Catalogue "Aluminium Frame and Machine Construction System" (MCS) (page 5): *"[Hepco] Provides cutting, drilling and tapping service to any structural profile and includes the complete frame assembly to customer's drawings with fast*

deliveries. […] All profiles include T-slots along their length, allowing simple insertion of T-nuts and T-bolts to attach connection brackets or accessories."

- Website and Catalogues are clear and understandable.

- CAD files and technical data is provided for all profiles, connection brackets and accessories.

All Part No. listed in sections 7.1.1.1 and 7.1.1.2 come from the Machine Construction System (MCS) Catalogue.

7.1.1.1. Main structure profiles

It has been decided to use two different structural sections for the assembly of the main structure. This structure supports the major loads and holds its own weight. Consequently, for the four pillars will be used a high inertia profile. In addition, a lower inertia (but also high) and a lower mass profile will be used to improve structure rigidity.

On the other hand, both sections must have the same T-slot size for a suitable connection. The way how all profiles are joined and the T-slot concept is explained in detail on 7.1.2 Structural profile connections.

The structural sections chosen are Part No. 0-132-80120 and No. 0-132-8080 from the Catalogue, which correspond to 80 x 120 and 80 x 80 millimeters aluminium profiles. These ones are some of the profiles with grater moment of inertia and less mass from all Catalogue. In previous Image 8 are illustrated both structural sections, 80 x 120 mm profile at left and 80 x 80 mm profile at right.

Specifically the profile of 80 x 120 mm has an X axis inertia of 362 cm^4, which makes it the second profile with more inertia from the whole Catalogue (among 40 structural sections); ideal for the structure pillars (ID number 1 from Image 9). These ones measure 3.0 meters long, as this size represents a typical measure for roofs of warehouses and other businesses where the dispenser can be installed in. In addition, this profile is used too for fixing the opposite top pillar each other (ID number 2 from Image 9). Both measure 1340 mm, and adding the pillars width (2 x 80 mm) sum a module width: 1.5 m.
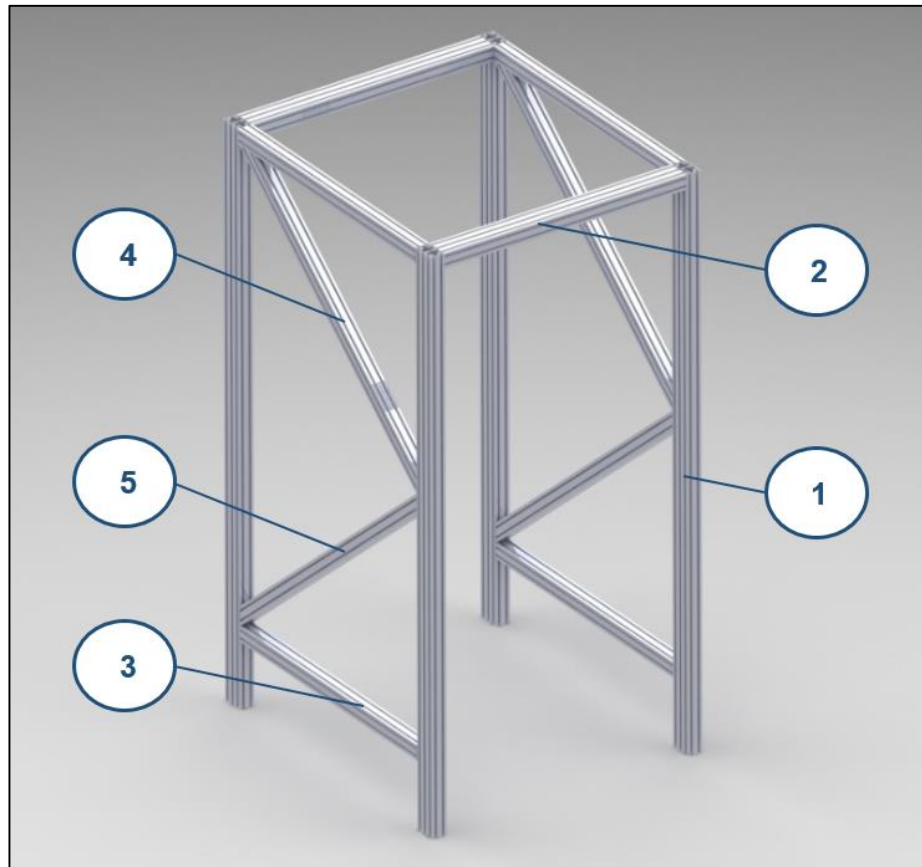
Image 9 – Assembly of the main structure (see ID numbers in Table 3)

Furthermore, the 80 x 80 mm structure profile has been placed crossed on both sides of the structure to increase the rigidity and avoid buckling action (ID number 4 and 5 from Image 9). It has a 124.4 cm^4 inertia in both axis and it represents the sixth profile with more inertia (among 40 structural sections). The above cross-sections are inclined an angle of 45° to the horizontal and the following represent a 50° angle. This profile has also been used for securing the front pillar with the rear one of the structure (both, top and bottom) (ID number 3 from Image 9).

Both profiles have a 10 mm T-slot size along their length as well (see all technical data of each structural section in Annex A - *Structural Sections & Profile Connections*).

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To assemble the main structure the following profiles are required:

ID	Units	Part No.	Name	Material	Length (mm)	Extra
1	4	0-132-80120	80 x 120 profile	Aluminium	3000	
2	2	0-132-80120	80 x 120 profile	Aluminium	1340	
3	4	0-132-8080	80 x 80 profile	Aluminium	1420	
4	2	0-132-8080	80 x 80 profile	Aluminium	1850	45º cut *
5	2	0-132-8080	80 x 80 profile	Aluminium	1920	50º cut **

Table 3 – Required profiles for main structure assembly

* In the two ID 4 profiles a cutting extra service is required: 45º cut in both faces (non-parallel faces)

** In the two ID 5 profiles a cutting extra service is required: 50º cut in both faces (parallel faces)

7.1.1.2. Shelf support profiles

It has been made a calculation to choose the right profile to clamp each shelf (set of channels). The deflection formula (Eq. 1) has been applied for a profile rigidly fixed at both ends under static loading:

$$d = \frac{F \cdot L^3}{192 \cdot E \cdot I_{xx} \cdot 10^4}$$

F = 500 N (top approximation)

L = 1340 mm

E = 70000 N/mm² (provided in Hepco's Catalogue)

I_{xx} = different for each structural section (cm⁴)

Eq. 1 (Provided on Catalogue page 46)

The deflection value has been determined for every profile provided in the Catalogue with a T-slot size of 10 mm. To make the final selection has been valued that the deflection value cannot exceed 0.2 mm and with the minimum beam weight. The structural section selected is Hepco's Part No. 0-132-6060, a 60 x 60 mm aluminium profile (see all technical data in Annex A - *Structural Sections & Profile Connections)*. The arrow's value in the center of this structural section is 0.1905 mm. The rest of results are listed in Table D. 1 in Annex D - *Calculation Results.*
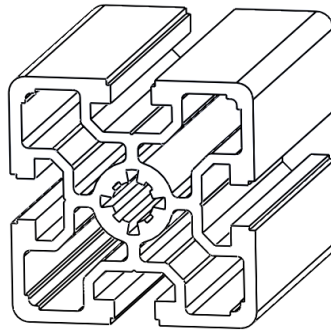
Image 10 – 60 x 60 mm aluminium profile

For supporting a set of channels, two 60 x 60 mm profiles of 1340 mm length each are required. One in the middle of the front pillars and the other one between the back pillars; but the back profile is placed little higher up that the front support. Placing the back profile higher than the front profiles, a slope is achieved and shelves will be placed on (the angle is explained in 7.1.3 Channels / shelves (page 31)).

With a 3 meters high structure, up to 11 shelf support profiles can be fitted with 180 mm distance between them.   Image 11 shows all shelf support profiles assembled to the main structure.

Image 12 – Shelf support profiles detail

Image 11 – Assembly of the shelf support profiles

7.1.2. Structural profile connections

One of the reasons for choosing this kind of profiles is the simplicity for clamping profiles each other. As Hepco says in MCS Catalogue *"all profiles include T-slots along their length, allowing simple insertion of T-nuts and T-bolts to attach connection brackets or accessories"*.
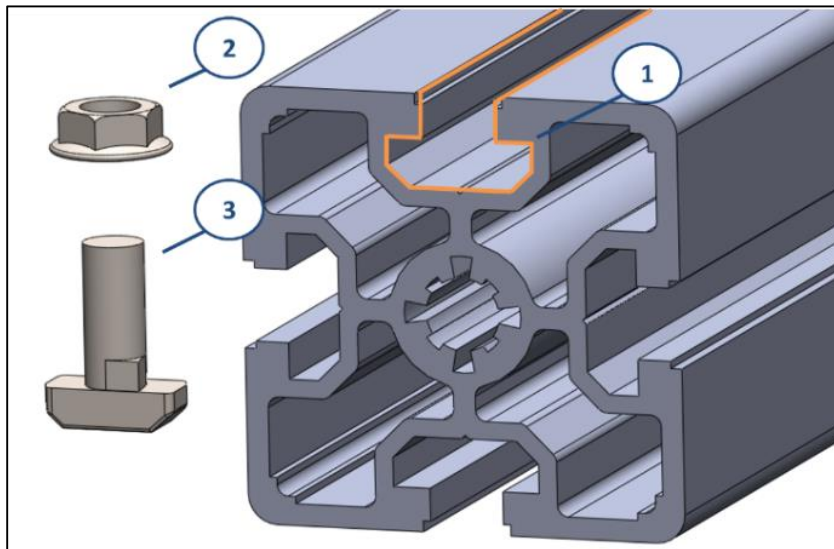

Image 13 – 1.T-slot, 2.Flange nut and 3.T-bolt

Image 13 shows a T-slot in a 60 x 60 mm aluminium profile (ID number 1; represented in orange), a M8 Flange nut (ID number 2) and a M8 T-bolt (ID number 3). To correctly fit the T-bolt, it has to pass inside the T-slot and turn it 90º, then screw the nut.

To select the best profile connection from Hepco's range, a number of factors, which are considered essential for assembly, have been prioritized. Table 4, taken from Hepco's Catalogue, shows all connectors offered by the company (in columns) and some interesting factors (in rows). From the table it has been prioritized the factors detailed below:

1. Cost effectiveness
2. Frame stiffness
3. Tolerance of inaccuracy
4. Adjustability
5. Aesthetic finish

	Flexi Connector	Angle Brackets	Interior Bracket	Bolt Connector	Connection Screw
Flexibility of Usage	★ ★ ★ ★ ★	★ ★ ★ ★ ★	★ ★	★ ★	★ ★ ★
Adjustability	★ ★ ★ ★ ★	★ ★ ★ ★ ★	★ ★ ★	★	★
Frame Stiffness	★ ★ ★ ★	★ ★ ★ ★	★ ★	★ ★ ★ ★ ★	★ ★ ★ ★ ★
Vibration Resistance	★ ★ ★ ★	★ ★	★	★ ★ ★ ★ ★	★ ★ ★ ★ ★
Space Requirement	★ ★ ★ ★ ★	★ ★	★ ★ ★ ★ ★	★ ★ ★ ★	★ ★ ★ ★ ★
Tolerance of Inaccuracy[1]	★ ★ ★ ★ ★	★ ★ ★ ★ ★	★ ★ ★ ★	★	★ ★ ★ ★
Cost Effectiveness[2]	★ ★ ★ ★	★ ★ ★ ★ ★	★ ★ ★ ★	★ ★	★ ★ ★ ★
Aesthetic Finish	★ ★ ★ ★ ★	★	★ ★ ★ ★ ★	★ ★ ★ ★ ★	★ ★ ★ ★ ★

★ ★ ★ ★ ★   = Highest/Best

★   = Lowest/Worst

Table 4 – Connection Cross-Reference Chart (from Hepco's MCS Catalogue - page 52 -)

[1] 'Tolerance of Inaccuracy' refers to the time and care needed when building MCS System frames with the various connections methods. For example, Angle Brackets will tolerate low build accuracy, which is quickly and cheaply achieved, whereas Bolt Connectors will not.

[2] 'Cost effectiveness' is a measure not only of component costs, but also takes into account the time required to build various methods into MCS System frames.

Among all product range, two components were chose since they are the most suitable for assembling: Flexi Connectors and Interior Brackets.

Additionally we need to take in account that all profile connections are assembled by pairs; one connection is required at the head of the profile and another one at the end. In this way the load is symmetrically distributed.

7.1.2.1. Main structure profile connections

For the main structure profiles flexi connectors have been chosen since they have the best combination of frame stiffness and cost effectiveness. Specifically it is used the Flexi T Connector (A) (Part No. 1-242-4549) for all 90º angle unions and particularly the Flexi Angle Connector (Part No. 1-242-4553) for non-right angle unions. In Image 14 and Image 15 is shown an example of each.

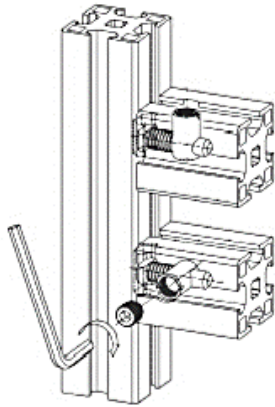UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH
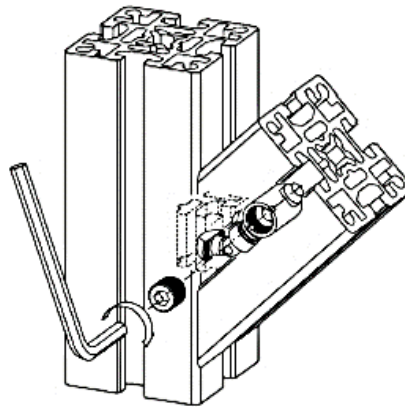
Image 14 – Flexi T Connector (A)

Image 15 – Flexi Angle Connector

For assembling both connectors it is necessary to drill dimension 'C' (shown in its datasheet in Annex A - *Structural Sections & Profile Connections*) to suit the relevant profile with a 15.1 mm diameter drill. Then screw with an Allen Key to fix the connector.

7.1.2.2. Shelf support profile connections

For the shelf support profiles, Interior Bracket (B) (Part No. 1-242-1040) has been chosen. Image 16 shows an example of how to assemble an Interior Bracket (B) (the M8 set screws are supplied) but the right joint position is the detailed in Image 17. This joint position increases the maximum offset load per ten.
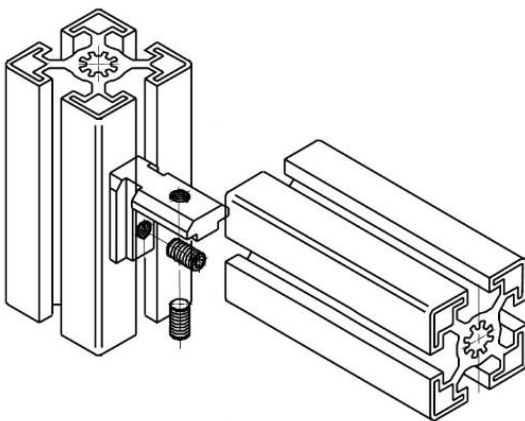
Image 16 – Interior Bracket (B)
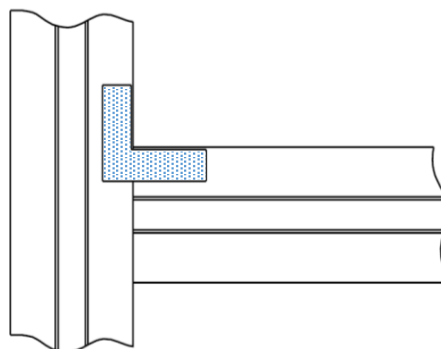
Image 17 – Interior Bracket joint position

In this sort of connectors not extra manufacturing actions are required, just tighten the screws on its correct position. In this way, the location of the profiles can be changed easily if necessary.

7.1.3. Channels / shelves

Medicaments are stored on the shelves of the cabinet. To save space and compact boxes in an easy and standard way, U-shaped channels were designed. The width of these profiles is based on the most common medicament boxes measures, thereby ensure a minimum clearance for the product to slide smoothly through the channel. This issue is treated in 7.1.3.2 Channel design.

This idea is more efficient than the idea of making a shelf and place arbitrary divisions on it, because there would not be a clearance guarantee. Even more, divisions would need time and precision while channels only have to be fixed to a support.

7.1.3.1. Alternatives

As channels are inclined, the predisposition of medicines is to slide down. Therefore, a system needs to be designed to hold the box at the end and let pass just one when requested. To make a good selection a brainstorming with sketches of different mechanisms was made:
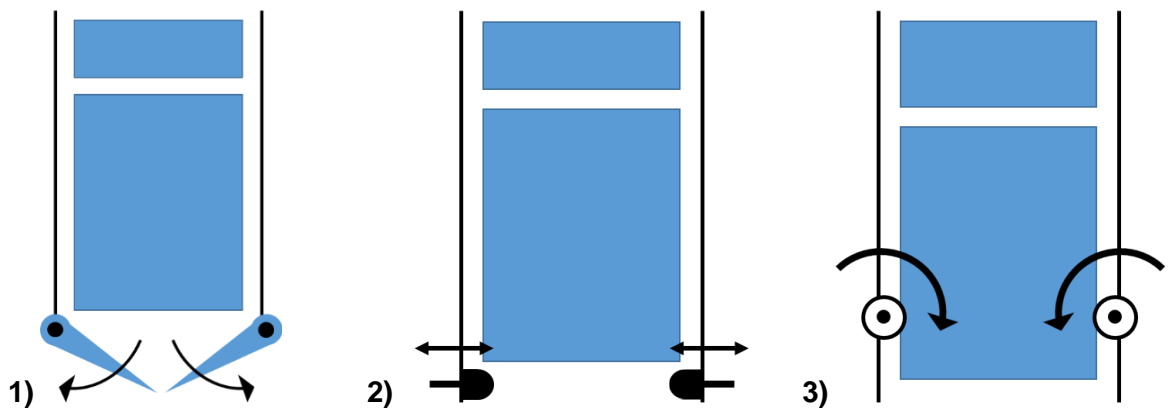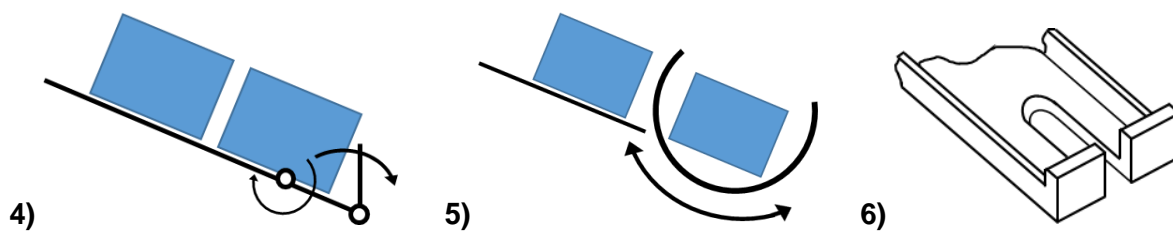
Image 18 – Sketches of the alternatives for channels

(1, 2, 3 plan views; 4, 5 left side views; 6 isometric view)

The main handicap for most of the mechanisms is to be able to pick just one product, because when opening gates all boxes slide at the same time. Mechanism shown in sketch number 5 can get just one box: just by turning the compartment to the left (reload compartment) and then to the right (empty compartment). Despite that, almost all suggested solutions (from 1 to 5) increase a lot the manufacturing cost, as is needed to customize and automate all the ducts one by one.

The only alternative which does not need either automation or actuators is number 6, in which a notch is mechanized at the end of each channel. The medicine can be removed from the cabinet with the suitable combination of robot algorithms: the medicament box must be lifted in parallel with the channel inclination. Once the plastic tops have been overcome, the first box slides into the robot (and the second one is stopped by the tops).

7.1.3.2. Channel design

The final design is a 1.5 mm thick U-shaped profile, 50 mm high, and variable effective width (it can be 65, 80, 100 or 140 mm) according to the box to be stored (Image 19 shows the front plane with its measures). The length of all profiles is 2 meters.

To specify the different channel widths, 46 medicament measures has been placed in a column chart (see Graphic 1). In a large majority of the medicament sizes corresponds to "Farmàcia Torreblanca" sizes, so that this measures exemplify a significant sample. Once sizes are classified, they have been divided in three large groups. The fourth group is for exceptional big boxes.
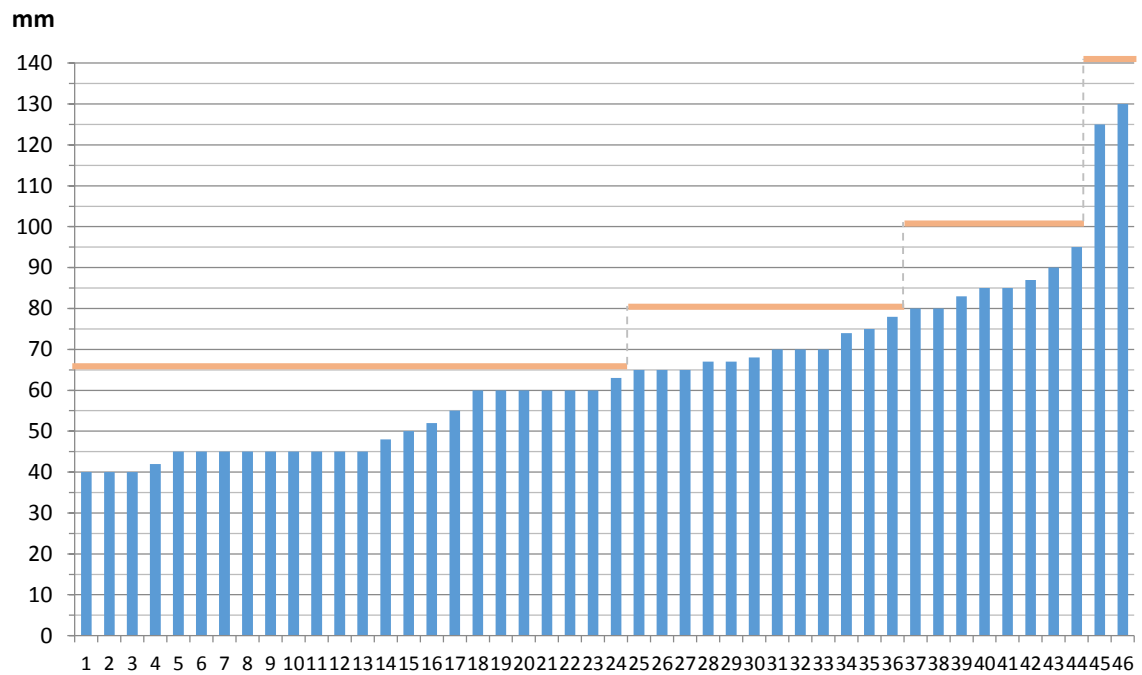
Graphic 1 – Column chart for 46 medicaments width (blue) and variable effective channels width (orange).
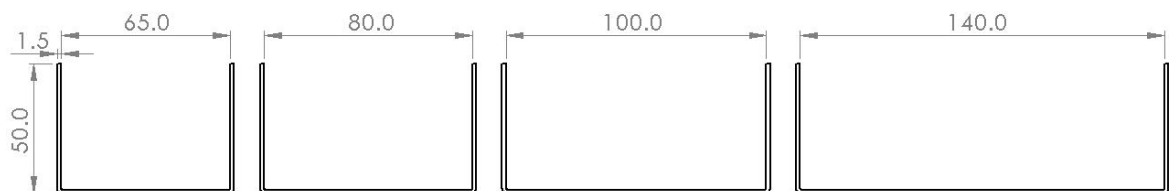

Image 19 – Front view of the four possible effective width for channels (measures in mm)

The target of this piece is that boxes slide down themselves along the profile stopping at the end. To achieve that, the static friction coefficient between the box and the channel must be overcame. It has been made an Excel table to find this coefficient and the slope angle to overcome this coefficient. Different surface materials (first column) and medicaments (second column) of diverse weight, roughness and surface contact were considered:

Surface	**Medicine**	**Medicine feature**
Steel	Paracetamol	Two surfaces (smooth and Braille)
Polished steel	Strepsils	Light / two surfaces (smooth and Braille)
Glass	Almax	Large contact surface
Painted wood	Primperan	Heavyweight
Teflon coating		

To perform the study, each medicine is placed on each surface (for all possible combinations), as shown in Image 20 and Image 21. Carefully a car jack mechanism is rotated to lift the surface in a continuous and non-stop way. When the static friction coefficient is exceeded, the medicine initiates the movement. It has been noted the height (h) in which that happens for all surfaces and all medicines ($b = \sqrt{L^2 - h^2}$).
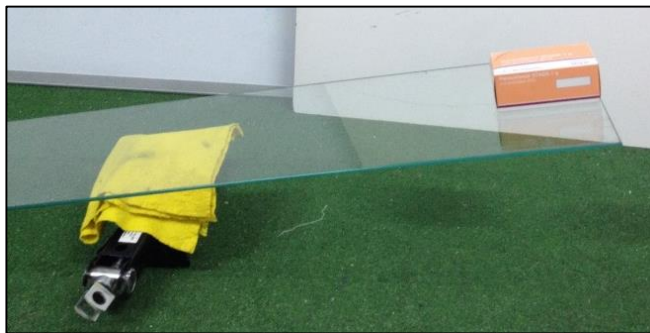

Image 20 – Paracetamol on glass surface

Image 21 – Almax on polished steel surface

To solve this exercise of slope it has been made a sketch of the limit position and it has been developed the equation system, as represented in Image 22:
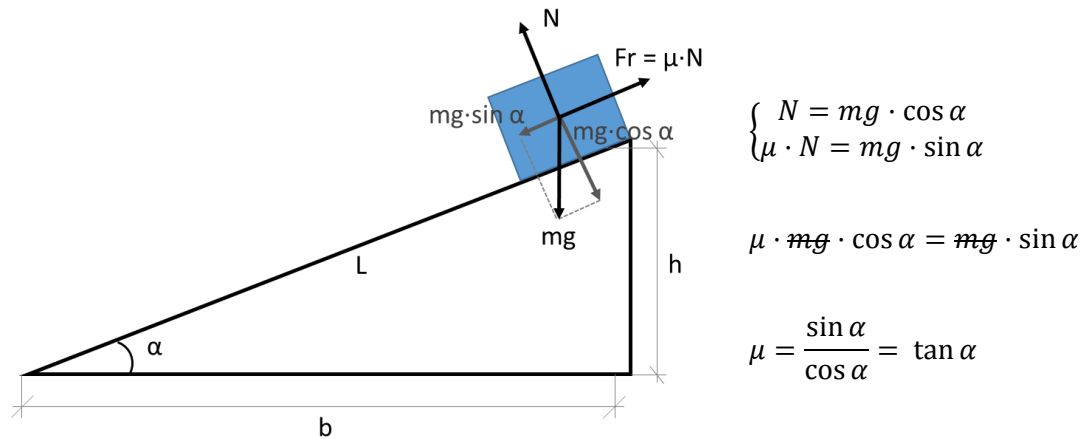

$$\begin{cases} N = mg \cdot \cos \alpha \\ \mu \cdot N = mg \cdot \sin \alpha \end{cases}$$

$$\mu \cdot \cancel{mg} \cdot \cos \alpha = \cancel{mg} \cdot \sin \alpha$$

$$\mu = \frac{\sin \alpha}{\cos \alpha} = \tan \alpha$$

Image 22 – Drawing of the slope and its equations

With Eq. 2 and Eq. 3 has been found the friction coefficient (μ) and the slope angle (α) respectively.

$$\mu = \tan(\alpha) = {}^h\!/_b \qquad \alpha = \mathrm{atan}({}^h\!/_b)$$

Eq. 2 and Eq. 3

Analyzing results, the lowest coefficient was obtained with the glass surface but for safety reasons no glass surfaces will be used (high fragility). The second surface with the lowest friction coefficient is a surface on which Teflon coating was applied. Usually, this technique is used to reduce the friction coefficient between two surfaces.

According to the study, the average of the static friction coefficient is 0.339 for the Teflon coating surface. The maximum detachment angle registered for this plane is about 22.05º, with a light medicament and a rough surface (Braille inscriptions). The maximum angle was taken to ensure all medicines will slide through the duct without stopping. The rest of results are listed in Table D. 2 in Annex D - *Calculation Results*.

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In this way, and adding a small safety margin, the same slope (25.0º from horizontal) was taken for all shelves.

7.1.3.3. Fabrication

The ideal material to manufacture this kind of profiles is aluminium because it is an easily machined material and with low density. Extrusion process is used to make aluminium profiles. This method reduces the section of a semi-finished aluminium product (bloom) by passing it through a mold. It is performed at high temperatures (500ºC) to minimize pressure (annealing state material).

If the profile obtained after extrusion does not satisfy geometric requirements a profiling operation is performed. The whole structure is passed through a machine with rollers which profiles the product. Once ready, cut to correct length (2 meters).

The notch in the front (Image 23) must be done with a milling operation. More specifically, with a vertical high step milling machine (for roughing) and a low step (for finishing). Both milling cutter diameters should be 20 mm, so that the cut is generated in a single pass; and an 80 mm length cut. A horizontal mill is enough for the 20 mm recess of the front (Image 24).

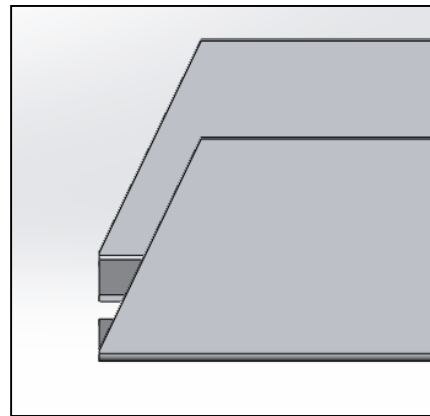*Image 23 – Notch detail (w. vertical mill)*

Image 24 – Recess detail (w. horizontal mill)

The following operation is a Teflon coating treatment in the three inner faces of each channel for reducing friction. Later on, two 1.4 mm holes must be done with a drill. Finally, tops should

be screwed in that small holes next to the notch with M1.4 micro-screws as represented in Image 25. These plastic tops are 5.5 mm high pieces, which can be found in any hardware store.
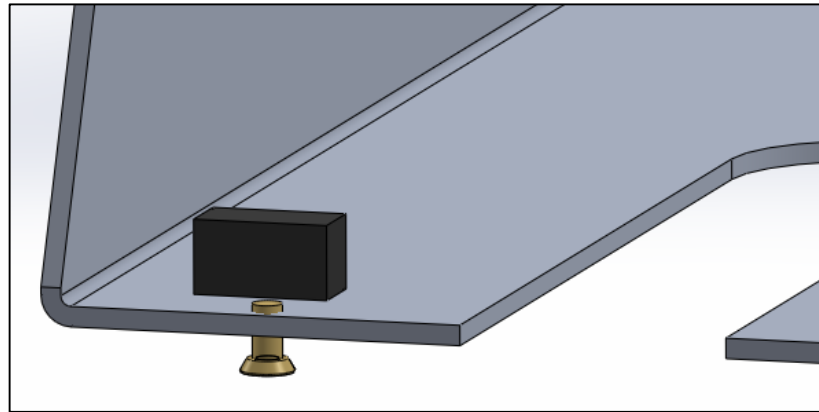

Image 25 – Micro-screw and top detail (exploded view)

7.1.4. Brackets

In order to find a profile connector to hold all designed channels to the horizontal supports forming a non-right angle, a market search was carried out. Unfortunately no suitable connector was founded, either in Hepco's range or in the rest of the market. So it was decided to design a new bracket, similar to the ones supplied by Hepco but with an angle of 25°.

7.1.4.1. Fabrication and assembly

As shown in the following images (Image 26 and Image 27), the geometry of the piece is quite complex. It has two special faces for joining to a structural section with profile connectors and a smooth side for attaching a flat plane.

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Image 26 – Bracket front view

Image 27 – Bracket rear view

Although manufacturability has not been worked out in depth the bracket could be obtained from a folded aluminium sheet (with all holds made) and then weld the top surface. Surely cheaper current techniques exists for the same purpose but they are unknown.

Once obtained, the bracket must be welded to the channels for a perfect fit. Welding is the best way to join these two components. Otherwise if any other process (such as glue or screws) is used there is the risk of not securing enough strength or to alter the channels roughness (the first case would be a system breakage and the second one a component jam). To make a good bond both bracket longitudinal sides must be welded to the profile as exemplified in orange in Image 28.
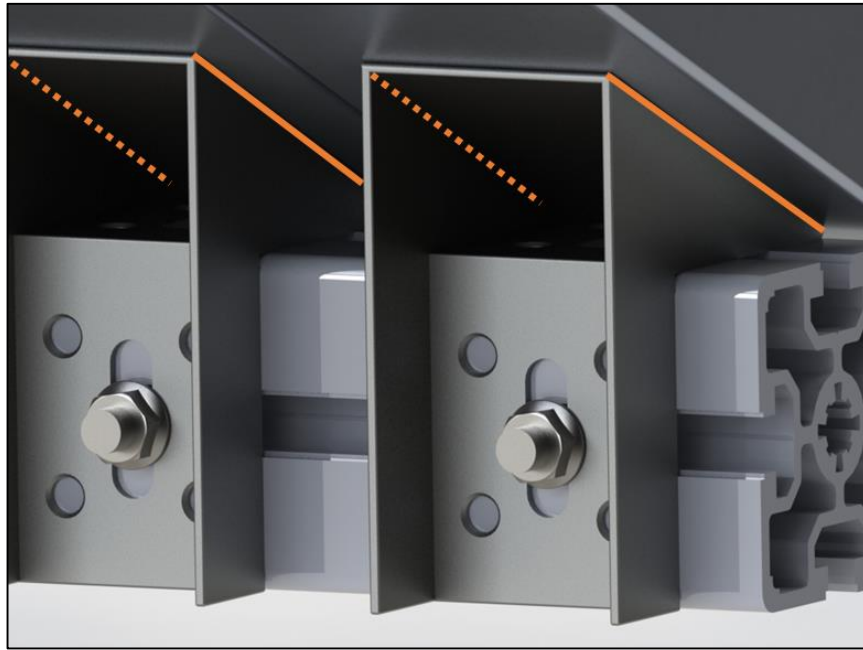
Image 28 – Union bracket detail

As shown in the following Image 29, the distance between the brackets in a channel must be 1560 mm so that the channel is clamped tightly to the supporting structure.
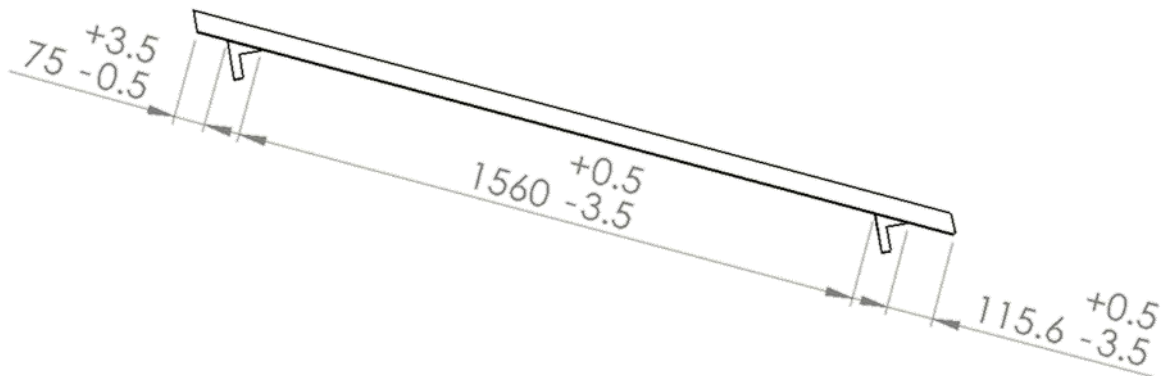

Image 29 – Channel side view (all dimensions are in mm)

The way for assembling the channel to the structure is to fasten with T-bolts and 10 mm flange nuts in the support T-slots as shown in the previous Image 28 (one T-bolt and one flange nut on each bracket).

7.1.5. Feet

A feet below the four pillars has been added to avoid damage to the structure or to the warehouse floor. The chosen foot is part of the range of Hepco available accessories and it is supplied in the same way that the structural sections and the profile connections.

Specifically, the selected model has the largest support surface with the ground (particularly the base has a 100 mm diameter). The stem tap size is M12 metric and it fits perfectly with the profile end tapping size from the 80 x 120 mm structural section (used in pillars). In Image 30 is shown the used foot for the assembly. It is the Part No. 1-243-0051 from Hepco's Catalogue.
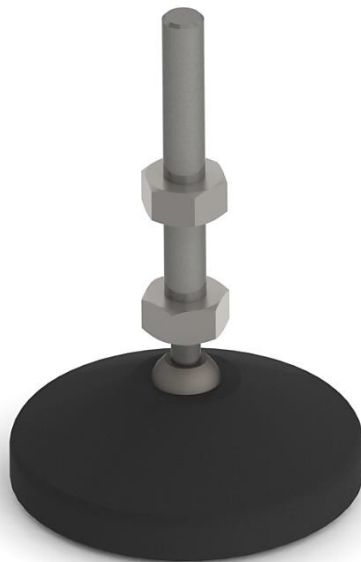

Image 30 – M12 stem foot

To join the component to the main structure is only necessary to fit the stem of the foot in the structural section tap hole. Later M12 nut (included) has to be tighten to the structural section with a spanner. This increases the structure high in 75 mm, making a final high of 3075 mm.

7.1.6. LED boards

An aluminium board was designed for supporting LED rows. These LEDs will be a visual help for the pharmacist when loading new medicaments (this use case is explained in depth in 8.2

Load new medicaments). As shown in Image 31 the board is 1450 mm long per 80 mm high and 5 mm thick with many 11 mm diameter holes.
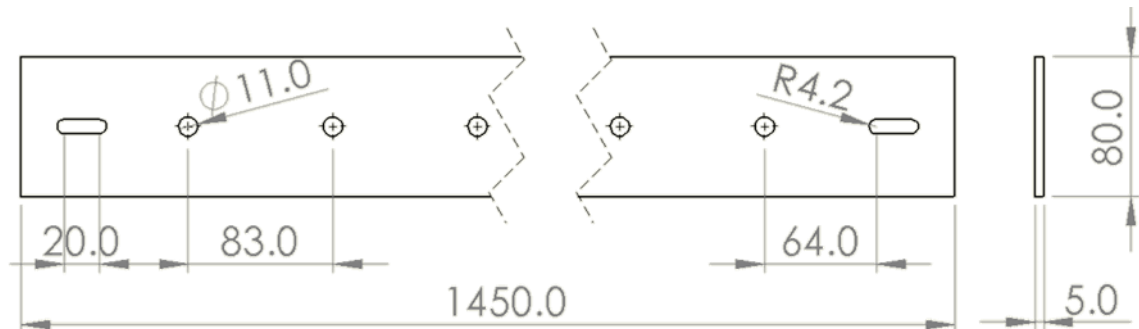

Image 31 – Front and side views of the LED board (all dimensions are in mm)

Inside each hole red LEDs will be installed. The dimensions of that boards were designed to fit perfectly in the back of the cabinet, each one under a channel row. For that reason, eleven boards are necessary for the first prototype. Image 32 shows some LED boards already assembled, each one under a shelf.

Image 32 – LED boards assembled in the cabinet (rear side of the cabinet)

All holes should roughly coincide vertically with channels, so it is necessary to know what kind of channels (width) are used. To fix boards to the structure it is only necessary to enter M8 T-bolt (10 mm T size) into the structural T-slots (10 mm T-slot size), pass it through the elliptical holes of the board and tighten them with M8 T-nuts.
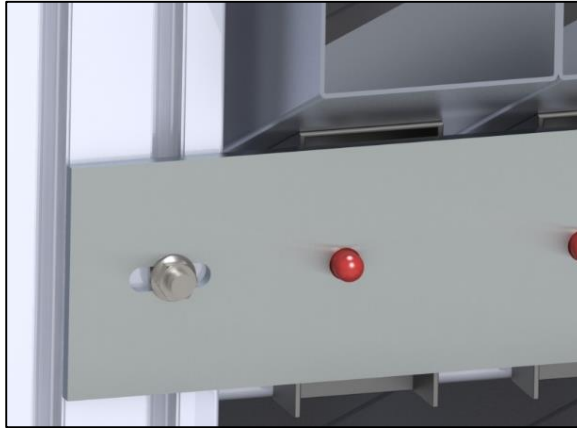
Image 33 – LED board fixing detail

7.2. Robot

7.2.1. Positioning actuators

As previously mentioned, a robot will be positioned in front of the medicine that is going to be picked. The automaton must be able to move across the front of the cabinet; that means vertical movement (Z axis) and horizontal movement (X axis). For compatibility reasons between components and to make easy the assembly, a linear transmission and positioning system was chose form the same company than the structural profiles (Hepco).

On the first page of Hepco's Catalogue "Linear Transmission and Positioning System" (DLS) are detailed some facilities such as: "the unit can *be linked together with a costumer's PLC to provide more complex point-to-point control. […] [DLS] can link with servo or stepper motor systems and controls. Using this method, the DLS can address even the most demanding and dynamic multi-axis positioning requirements."* Furthermore, if it is necessary the company provides *"mechanical and electrical components to complete a full-function unit, including switches, couplings, gearboxes, motors, drives, brakes, […]."*

7.2.1.1. System choice

The linear system has been chosen according to physical and geometric requirements. For physical reasons, any of DLS3…L, DLS4…S or DLS4…L are good candidate systems (M_{max} = 70 Nm and Ms_{max} = 20 Nm; both moment loads exemplified in Image 34). Besides, for

geometry limitations a 250 mm B minimum size is required (B dimensions showed in Table 6); thereby the DLS4…L system was the selected one.

Table 5 below shows the maximum slide loads for each system and in Image 34 are represented those loads (taken from Hepco's DLS Catalogue page 22):

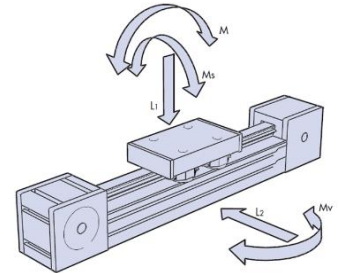| System	Max Moment Load (Nm)			Max Direct Load (N)	
	M	Ms	Mv	L1	L2
DLS3...S	56	24	105	1600	3000
DLS3...L	120	24	225	1600	3000
DLS3C...	108	24	200	1600	3000
DLS4...S	165	70	280	3500	6000
DLS4...L	300	70	510	3500	6000

Table 5 – Maximum load capacities for each size of DLS   *Image 34 – DLS load drawing*

Below, Table 6 shows the main dimensions for each system and in Image 35 are represented those dimensions in a general DLS drawing (taken from Hepco's DLS Catalogue page 8):

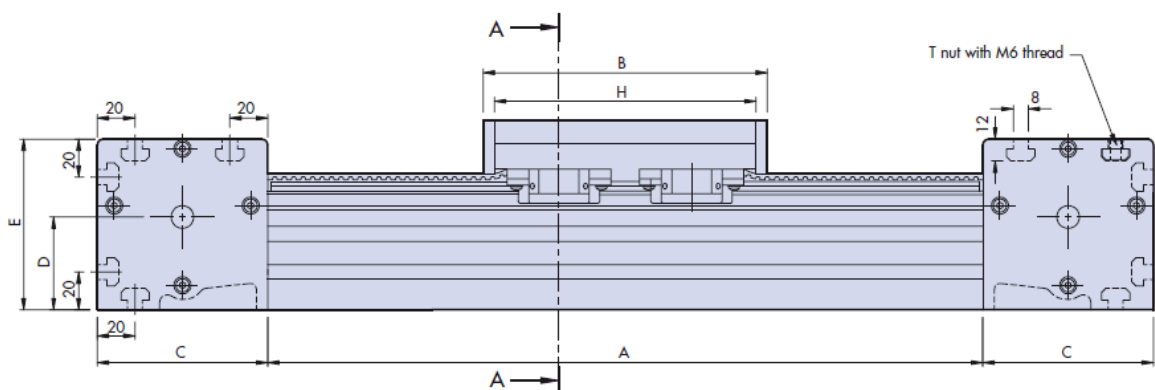| System	A	B	C	D	E	F	G*	H
DLS3...S	to	150	91	49	91	62	9	138
DLS3...L	order	230	91	49	91	62	9	218
DLS4...S	to	200	111	63.5	120	76	12	184
DLS4...L	order	280	111	63.5	120	76	12	264

Table 6 – Main dimensions for each size of DLS

Image 35 – DLS front view with dimensions

In detail, two DLS4 2850 L are needed for vertical displacement and one DLS4 1600 L for horizontal displacement (they are the same system but with different lengths). So the positioning system is very similar to the application example showed on page 7 from DLS Catalogue (Image 36).
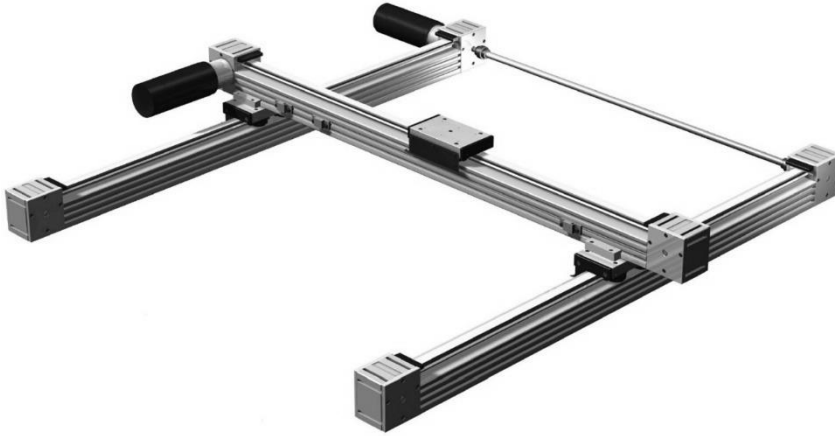

Image 36 – DLS application example: X-Y System

As shown in Image 38, four additional short aluminium profiles have been introduced to the main structure to withstand the DLS system. The 80 x 80 mm structural section has been chosen as it has the same T-slot size than main profiles and DLS system. All four sections are 715 mm long, the suitable dimension for the picking component. The upper ones are placed in contact with the horizontal top profile and the lower ones are positioned 480 mm below.

This last aluminium profiles are attached to the front main columns and to the vertical DLS guides with Flexi T Connectors (B), which corresponds to Hepco's Part No. 1-242-4551. A scheme of how this profile connector works is shown in next Image 37.
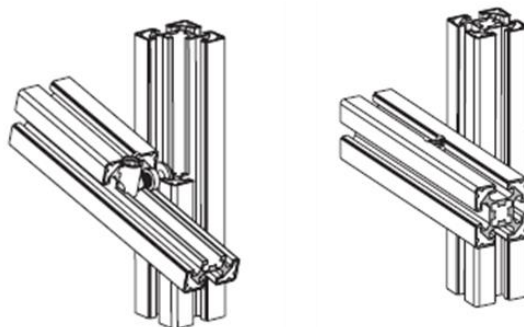

Image 37 – Flexi T Connectors (B)

Image 38 – Double axis DLS system attached to the main structure

7.2.1.2. Ancillary components

Furthermore, the following ancillary components are also required for a perfect function of the positioning system unit. All those components are supplied by Hepco as well:

- AC geared motor:
  The AC geared motor DLSPGB80-0 is the Hepco's recommendation for DLS4 systems with a 50 Nm medium output torque.

- Drive shaft and support bearings (GX 2 - D4 – L 1340):
  Connects between the output shaft and the input shaft of the two vertical parallel DLS axes. In this way both motors rotate together.

- Servo:
  With that controller is possible to manage several axes at time, coordinating movement between X and Z axes. Therefore, reduces traced path.

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7.2.2. **Drawer**

The drawer is one of the most important moving parts in the mechanical system. It is responsible for pulling the medicament out form the channel with the last set of actuators.
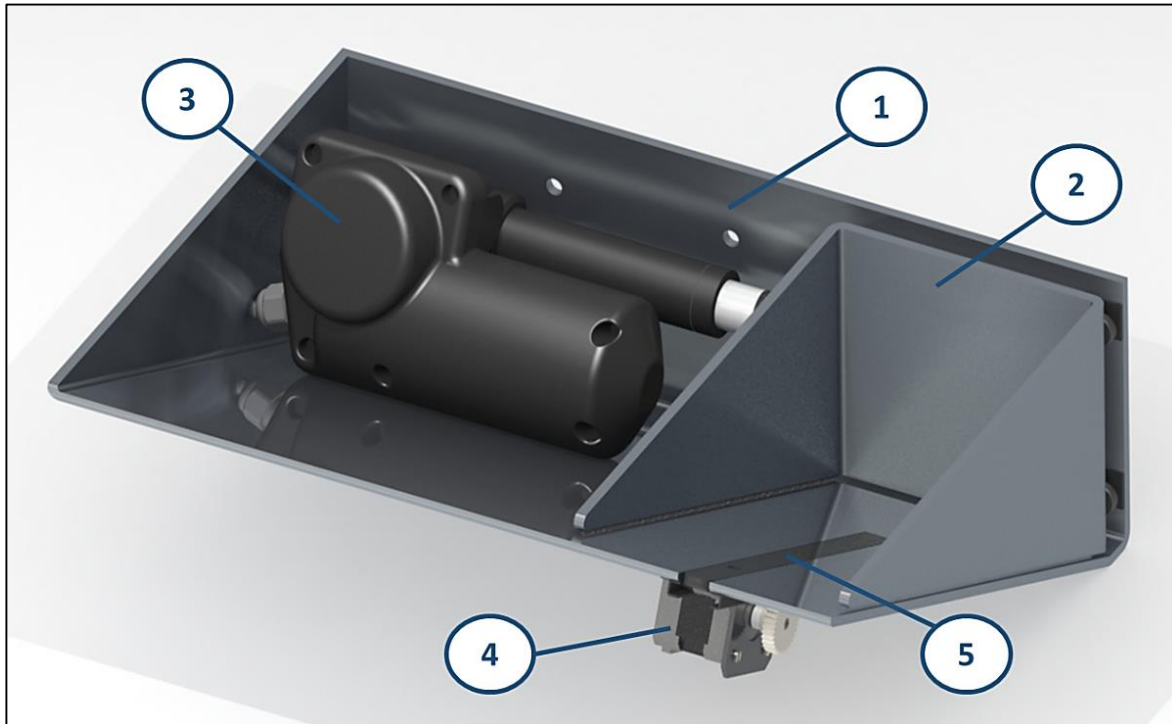

Image 39 – Drawer components assembly

The whole drawer assembly is attached to the horizontal DLS4 device with 6 M8 screws on its base structure. As shown in Image 39, the drawer is the assembly of 5 pieces: two aluminium pieces (ID numbers 1 and 2), two actuators (ID numbers 3 and 4) and one plastic piece (ID number 5). Simple slides and clamps are used for joining all pieces.

The following points describe all components and connectors that make up the drawer assembly.

7.2.2.1. Aluminium parts

Drawer's base is a 5 mm thick folded aluminium sheet (ID number 1 in Image 39). As shown, it only has three faces; top surface is not essential, and right wall is movable. The special shape of this piece makes easy the medicament withdrawal action from the cabinet and from itself. Specifically its ground is 25º to the horizontal, therefore all boxes slide down to the end. In addition, it has a 200 mm long slot where a plastic movable part will be installed. A rigidity issue has been discussed because of this slot. Although medicament weight is very low, a small rivet could be added to the sheet to guarantee a sufficient stiffness.

The movable aluminium part (ID number 2) is also a 5 mm thick folded aluminium sheet but simpler than the first one; in particular this piece does not have ground surface. When a medicine box is pulled out from the cabinet, it falls inside the movable piece. This part is the responsible of taking the boxes out from the drawer. So, in order to sweep all boxes out a weather-strip was fitted with.

Image 40 – Base aluminium slide and holder

Image 41 – Movable aluminium piece slide

A two-piece 135 mm long metallic slide was used for assembly both aluminium parts. The little wheels from the movable aluminium piece slides (see Image 41) are introduced into the base aluminium base slide (Image 40).

7.2.2.2. Actuator LA 30

The relative movement between the aluminium parts (base and drawer) is effectuated by an electric linear actuator that pushes the movable piece out. For joining both elements (the actuator and the aluminium piece) a metallic holder is screwed. In previous Image 40 is shown this system.

The linear actuator supplier enterprise is LINAK, this company is specialized in actuator systems development. From all LINAK's product range, possible actuators were studied paying attention on stroke length, maximum speed and thrust (push) & pull force. All these alternatives are listed in Table 7:

Name	Stroke length (mm)	Max. speed (mm/s)	Thrust max. push / pull (N)	Length dimension (mm) (w. stroke length = 0 mm)
LA 12	130	40	750 / 750	245
LA 22	200	37	300 / -	198
LA 27	300	13	6000 / 4000	170
LA 28	600	46	3500 / 2000	160
LA 30	400	65	6000 / 3000	156
LA 31	290	32	6000 / 4000	230
LA 36	999	160	10000 / 10000	300
LA 44	290	14	12000 / 0	290

Table 7 – Technical specifications of linear actuators from LINAK

All actuators satisfy the minimum stroke length (140 mm) and almost all with push and pull minimum force. The final decision was the actuator which best combines size and speed, it was the LA 30. Additional features of LA 30 not mentioned in last table:

- Can be supplied with potentiometer for servo operations.
- Can be supplied with extra powerful motor for increased speed and strength.
- Ideal for Industrial Automation applications.

Image 42 – LA 30 actuator from LINAK

Image 42 shows a picture of the actuator used for the assembly. For more information see Annex B - *Component Datasheets*, where the LA 30 Datasheet has been attached. Two handles keep the actuator attached to the drawer. Also short M3 screws were used to fix them to the structure. Like the double axis DLS system, this actuator is connected and powered by the PLC.

7.2.2.3. Stepper motor

On the external side of the aluminium base a stepper motor is placed (ID number 4 in Image 39) attached to a steel square support. This kind of motors were chose for its high value for money. As explained in the National Instruments stepper motors datasheet: *"Stepper motors provide very precise, extremely cost-effective motion control. The motors move in small, precise, 1.8 degree increments at 200 steps/revolution and are brushless and maintenance-free. Stepping action is simple to control and does not require complicated, expensive feedback devices"*.

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The NEMA 17 stepper motor was selected because is the best choice in terms of dimensions. It also has the appropriate torque versus speed relationship required for its use. In Annex B - *Component Datasheets* has been attached the National Instruments NEMA 17 Motor specifications.

A special bracket support for NEMA 17 steppers was used for fixing the motor to the assembly. Four M3 and 6 mm long screws are needed to ensure the support to the aluminium base and four more (10 mm long) to fix the stepper motor. This bracket helps to focus and set the right position of the motor shaft.
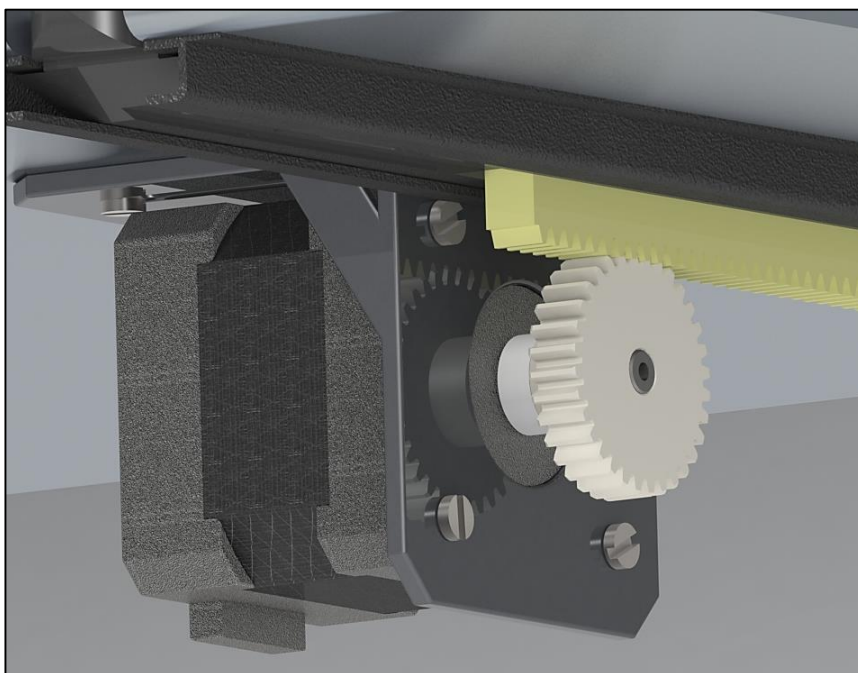
Image 43 – Stepper motor and bracket support detail

A nylon washer was placed first in the stepper shaft, then a 0.8 module gear. It is necessary to use the Part No. A-1M-2MYHF08032 pinion gear form SDP/SI Company. Geometrically fits perfect in the stepper shaft and in the hole between them. Also the material which is made of (acetal) allows an easy assembly into the shaft (just pushing it till the nylon washer stopper). In Annex B - *Component Datasheets* has been attached the pinion gear Datasheet with all dimensions of the piece.

As well as the double axis DLS system and the LA 30 actuator, the stepper motor is powered by the PLC.

7.2.2.4. Finger

An extruded plastic piece (ID number 5) is attached in the slot of the aluminum basis. This is fitted in the rails placed under the platform. Properly lubricated the piece should not assume friction at all on its movement. The best way to manufacture this piece is the mold extrusion since high geometric precision is required. Afterwards the three screw holes are made with a 3 mm diameter drill.

All dimensions required for finger manufacturing are detailed in the 2D drawing attached in Annex C - *2D Drawing*. The piece's shape has been designed to facilitate penetration into all channel notches, as its function is to extract the medicine box. As it is aligned with the aluminium basis, the angle from horizontal is 25º so the manufacturing material must overcome the friction coefficient with that specifics. Thus, molten plastic has been chosen as the ideal material for its development. For protecting the external surface it has been applied a PTFE coating treatment.
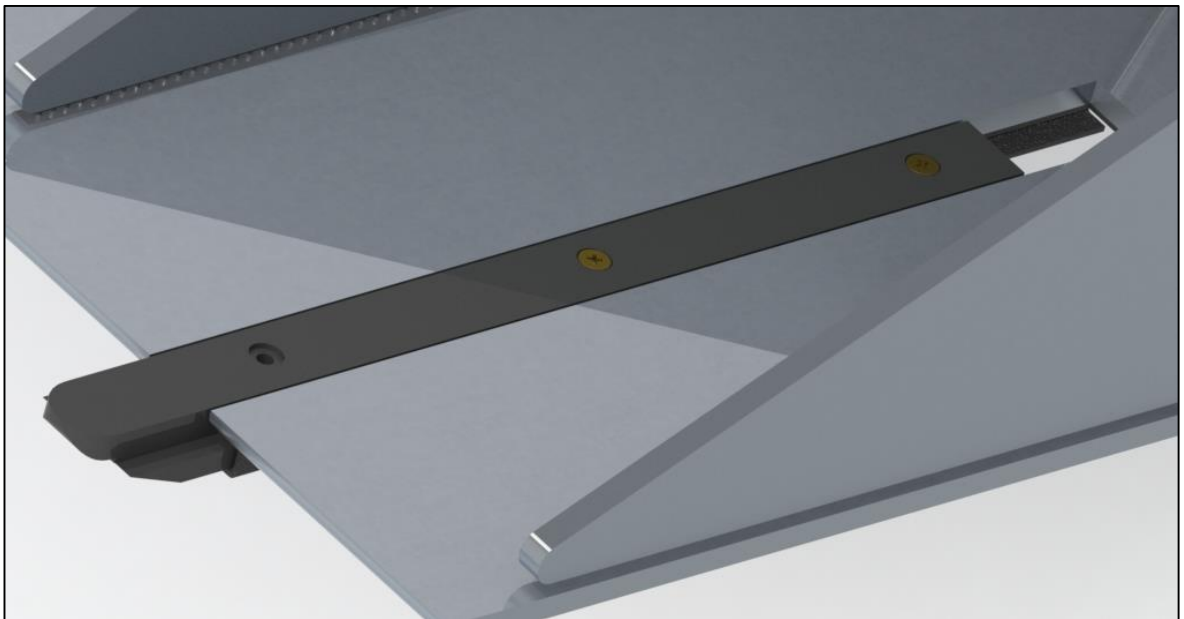

Image 44 – Top finger detail

At the bottom of the finger, a rack is attached with 3 mm diameter and 12 mm length micro-screws. These screws are introduced from the top of the finger as Image 44 shows.

The 0.8 module rack was chose from the same company as the pinion gear (SDP/SI) in order to get entirely precision (Part No. A-1P12MY08B300). A 112 mm minimum length rack is needed to ensure the complete path of the piece. With this last element (rack), the stepper motor rotary motion is converted into linear motion. In Annex B - *Component Datasheets* has been attached the rack Datasheet with all dimensions of the piece.

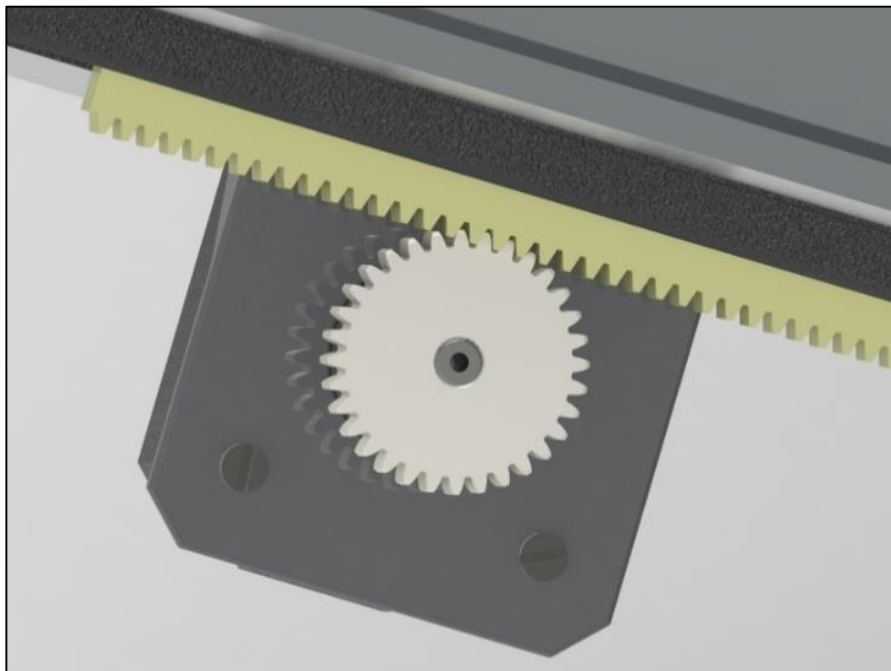The following Image 45 shows the gear unit already assembled.

Image 45 – 0.8 module rack and gear detail

8. Use cases

This section explains the two main use cases of the complete system. The first of them is dispensing a medicament stored in the cabinet and the other one is how to load properly new medicaments into the cabinet.

8.1. Dispensing a packed medicament

This point details the actions pharmaceuticals should do and which motors and actuators are involved in the process of dispensing a medicament. Furthermore, if an actuator moves a fixed distance, this will be specified.

First of all, the pharmacist must select the required medicine from the computer database and order it. The work of the pharmacist ends here, he just need to wait for the medicine. The computer communicates with the PLC and this translates the order information to the position (row and column) where the medicine is in the cabinet.

The double axis DLS system is the first engine set to initiate the movement. As it has a servomotor, it allows to combine the X axis movement with the Z axis movement. The function of the DLS system is to place the drawer in front of the medicament compartment; specifically to situate the plastic finger in front of the right channel notch.

The next actuator being on is the stepper motor. This actuator has to make one counterclockwise turn (turn 360 degrees). Thanks to rack pinion mechanism the finger slides out the drawer and passes under the shelf's notch. When the finger reaches the final position, the DLS system proceeds. Only the Z axis (vertical) moves and it has to rise 10 mm to exceed the stops located at the end of the channel. At this time, the medicine slides over the black finger and gets into the drawer. Once inside (3 seconds later) the stepper motor must rotate the 360 degrees again but this time in clockwise direction to collect the rack inside the drawer.

Later on, the double axis DLS system restarts the movement to place the drawer on a left side corner (depending where the transport system is installed on).

Then the actuator LA 30 stroke is extended 141 mm length, thereby removing the medicament from the drawer. At that time the medicine is already on the transport system and once arrived it can be delivered to the customer.

Finally, while the actuator LA 30 shrinks completely, the double axis DLS system is positioned on its starting position ready to collect a new medicament.

The main actuators movements have been exemplified in a sample video attached to the CD. In particular, the video shows the double axis DLS system, the stepper motor and the gear unit.

8.2. Load new medicaments

At the moment of loading new medicaments users only need to scan its barcode. The barcode reader is connected to a computer located at the rear of the cabinet. The Computer Control System and the Electronic Control System interconnected will switch the right LED on. Then the employee is the responsible to visually identify the channel and introduce the medicament in it.

Restocking is carried out with the help of a barcode reader connected to a computer. To proceed, the employee must read the medicine barcode with the barcode reader. The barcode signal is sent to the computer, which using the installed database, associates the medicine reference with a position in the dispenser. This new information is sent to the PLC, which turns the corresponding LED on. These LEDs are placed on the boards of the rear of the cabinet as explained in paragraph 7.1.6 LED boards.

9. Budget

An overall project budget is made splitting the overall cost in three categories. Budget includes the required hours for the first prototype development as well as an assumption of wage.

9.1. Engineering costs

Engineering costs are all costs associated with the intellectual work performed to define the first prototype. Approximately 290 hours were needed for the performance, of which 15 hours correspond to the learning process. These are not quoted in the following task table:

Tasks	Wage	Effort hours	Total
Conceptual design	45 €/h	65 h	2925 €
Calculations	40 €/h	20 h	800 €
Search and selection of components	35 €/h	30 h	1050 €
CAD	25 €/h	85 h	2125 €
Report writing	25 €/h	75 h	1875 €
CUMULATIVE TOTAL			**8775 €**

9.2. Software cost

Software cost is the CAD software licenses cost used to define the first prototype. The license pricing has been divided by eight hundred assuming it is a year working hours for one junior.

Software used	License Pricing	Conversion	Total
SolidWorks Premium 2013	4800 €/year	6 €/h	510 €
PhotoView 360 2013	(incorporated in SolidWorks Premium 2013)		--
CUMULATIVE TOTAL			**510 €**

9.3. First prototype cost

The last category of costs are associated with the manufacture of the first prototype. This cost has been divided into two phases: an estimate cost of all mechanical components and the labor cost required to assemble it.

Components from the Computer Control System and Electronic Control System (and equipment installation) are not accounted for the first prototype cost. This equipment would be principally the seller computers, the PLC and the software development.

9.3.1. Mechanical

All components price has been looked for all over the market, webpages and even has been asked for a quote to Hepco. Although the selling price of the main components from the mechanical dispensation system (structural profiles and positioning system) was not found, it has been made an estimate cost compared with the competition. The mechanical cost estimation is 20000 € for all mechanical components.

9.3.2. Assembly

There are two ways for performing assembly task:

- To contract Hepco the mounting service (mechanical components company supplier).
- To contract another external company, cheaper than Hepco, for the same service.

|	Wage	Effort hours	TOTAL
Hepco assembly service	30 €/h	14 h	420 €
External company assembly	20 €/h	18 h	360 €

10. Planning

At the very beginning of the project, an overall project planning was realized for distributing all tasks in four months' time. Below, in Graphic 2 is shown a Gantt chart in which are detailed all general chores. The time line is represented in the horizontal axis by the week number (corresponding the week 0 to the last February's week).

It was necessary to adapt the project's planning to the personal agenda in two certain points. The fifth project's week overlapped with a half-term exam and in week number fifteen happened the same but with the final exam. Therefore, in those weeks the project's burden must be reduced.

The Gantt chart shows two different plans:

- The original planning is represented in green, which was made before starting the project itself. It was agreed the second week of July as the delivery date. In particular, full green bars corresponds to completed tasks on time and the crossed green ones to delayed tasks.

- The delayed tasks timing is represented in blue bars. Consequently the delivery date was modified to September (week 28).
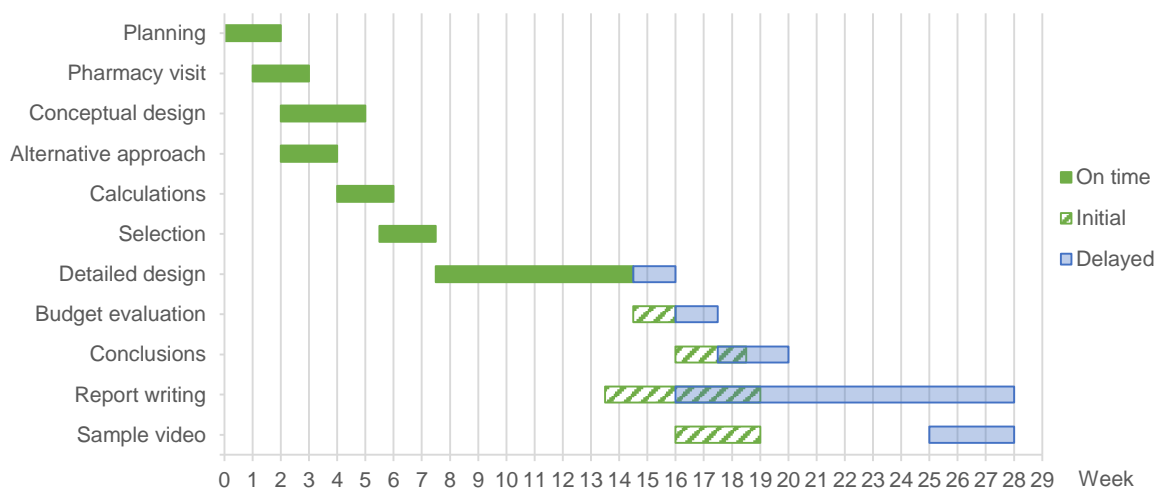
Graphic 2 – Gantt chart

11. Environmental impact assessment

The construction of the first prototype is out of the scope of the project. Despite this, an environmental impact assessment of the presented solution has been made for anticipating potential problems.

In a first step, all structural components selected for the design are able to reuse or to recycle; such as aluminium and plastic pieces. Furthermore, all electric and electronic equipment fulfill the RoHS European Union directive. As said in a Lindquist & Vennum article: *"This directive restricts the use of six hazardous materials in the manufacture of various types of electronic and electrical equipment: Lead (Pb), Mercury (Hg), Cadmium (Cd), Hexavalent chromium (Cr^{6+}), Polybrominated biphenyls (PBB) and Polybrominated diphenyl ether (PBDE) "*, so that all used components are hazard-free.

In reference to operating time, the system engines have a low electricity consumption so there is no negative environmental effect. The critical point is the noise level. Both, pharmacist and pharmacy neighbors would be affected by the robots operating noise when acting or either in stand-by mode. As the noise level of such engines is unknown, it is recommended to soundproof the room where the mechanical system is placed.

12. Conclusions

Once project completed two set of conclusions can be taken. The two sets are presented below.

First set of conclusions: Conclusions concerning the product development.

- The following table show the level of fulfillment between the initial specifications and the prototype of the automatic dispensing system.

No. of stored boxes per cabinet	3000 boxes approx.	🟢	
No. of references per cabinet	200 references approx.	🟢	
Supply time	Between 5-7 seconds	🔵	
Installation surface	2.5 m^2 per module	🟢	
Compaction level	25%	🟢	
Shape of medicament	Only for prism packed medicines	🟢	
Dispense several products at once	Up to three products	🟠	Depends on which three products
Modularity	Easy addition of more modules	🟢	
Load action	Visual help through lights when restocking	🟢	
Breakage of medicine boxes	System works as usual even when medicine box is opened or ripped	🟢	
Reparability of the system	Easy access to all components	🟢	
Appearance	Compact and rigid	🟢	

Table 8 – Compliance verification of specifications

Table's legend:

⬤ Unfulfilled specification

⬤ Mostly fulfilled specification

⬤ Fulfilled specification

⬤ Not enough information available

- As observed, teen out of twelve of the initial specifications have been hundred per cent achieved.

  Regarding the two non-hundred per cent specifications:

  For the supply time specification there is not enough information to measure the supply time and therefore achievement cannot be guaranteed. Regarding the specification of dispensing several product at once is not hundred per cent achieved since it depends on the dispensed medicaments: if the size of those medicaments is a standard size (up to 90 mm each) the system will do it; but if exceptionally all three requested medicaments are larger than 90 mm, the system is not capable.

- Additionally, the project scope has been fully accomplished.

The second set of conclusions are my personal conclusions:

- The main objective of the End of Bachelor Degree Project is to develop an accurate solution for a specific problem/challenge taking into consideration all different aspects involved. Personally I found it a real personal challenge to overcome, as many systems depend on each other and the best solution is always driven by the right combination/ interaction between them.

- One of the major complications when carrying out a project like that for the first time is to know the solutions/materials that the market is already supplying to develop a specific system. Another handicap to deal with was the fact of expressing all ideas in a non-native language.

- A part from all technical knowledge, I also learned how to approach a real problem from scratch and I have improved my skills on project management.

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LÖDIGE INDUSTRIES. < http://www.lodige.com >

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GOLLMANN Kommissioniersysteme. < http://www.gollmann.es/ >

WILLACH Pharmacy Solutions. < http://www.willach-pharmacy-solutions.com/es >

APOSTORE. < http://www.apostore.de/es/inicio.html >

RX Medic. < http://www.rxmedic.com/ >

ARX Automaticación de Farmacias. < http://www.arxautomatizacion.es/ >

SCRIPT PRO Perfect Integration. < http://www.scriptpro.com/ >

13.1.3. Structural section manufacturers

HEPCO Motion. < http://www.hepcomotion.com/es/ >

PROFI-TEAM MiniTec. < http://www.profiteam.es/es/ >

BOSCH REXROTH. < http://www.boschrexroth.com/en/us/ >

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LINAK. < http://www.linak.es/ >

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AMMERAL BELTECH. < http://www.ammeraalbeltech.com/ >

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