Engineering Education Scheme Wales

Cynllun Addysg Peirianneg Cymru

School

working with

Company

Automated Packing System

School Logo

School Name

Contact Teacher:

Team Engineer:

Company Logo

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Abstract

The Problem Statement

The Company, a large chemical manufacturing company, wants to improve one of their intermediate product packaging processes.

This process currently involves large rubber logs, weighing approximately 25 kg, to be stacked manually on to wooden pallets. These pallets are then removed via forklift to another part of the site where these rubber logs are processed further.

The 'stacking' process is very labour intensive and is required 'round the clock'. Due to the current manual handling nature of the task it has been identified as needing urgent redesign.

Although cost is a factor to be considered in the final design, the primary intent is to find a reliable, long term solution to remove manual handling from the packing process, without adversely affecting the flow of materials throughout the factory.

Executive Summary

The most cost effective solution that satisfies both the brief and the problem statement is to install and configure an industrial robotic arm which will prevent the need for any manual handling of the packing process.

The industrial robotic arms are very reliable machines that can be integrated into virtually any industrial environment, providing they are programmed correctly and most importantly installed with the appropriate "guarding" to prevent anyone working in their vicinity getting injured.

With relatively low installation costs, due to the availability of "off the shelf " robotic arms, plus the existence of power infrastructure at the site, the robotic arm represents a sustainable long term solution to preventing manual handling at The Company.

Introduction

"The School is an 11-18 mixed, English medium, non-denominational Comprehensive School. The School houses some 1100 pupils in Years' 7-13 and is in the Vale of Glamorgan." [1]

The Company was established in 1943 specifically to explore and develop the potential of silicones. It is now a global leader in silicones and silicon-based technology, serving the diverse needs of over 25,000 customers worldwide. The Company is equally owned by The Chemical Company Incorporated.

The Company site covers 160 acres. Here they manufacture silicon based products and intermediates where they chemically react silicon and change it to make silicon based gums, fluids, rubbers and speciality polymers. These products are then sold to the customer and are used as ingredients to their products. These products are found in many household items such as shampoo, deodorant and make-up. The silicon products can also be used to protect, strengthen, lubricate, adhere or conduct materials.

Student Profiles:

Student 1 – Studying Biology, Chemistry, Physics and Maths Mechanics. Enjoys running, playing football and wants to study natural sciences at Cambridge University.

Student 2 – Studying Physics, Chemistry, Biology & Maths Mechanics. Enjoys playing rugby, cross country and wants to become a civil engineer

Student 3 – Studying Physics, Chemistry, Biology & Maths Mechanics. Plays basketball and wants to go to University to study Medicine or biochemistry.

Student 4 – Studying Physics, Chemistry, Biology & Geography. Surfs and likes to play the guitar, is hoping to study biology and become an Environmental Biologist.

Student 5 – Studying Physics, Chemistry, Computing & Maths Mechanics. Plays rugby, enjoys singing and is pursuing a career in computer science.

Student 6 – Studying Physics, Chemistry, Maths Mechanics & Further Maths. Enjoys maths playing football and wants to become a chemical or mechanical engineer.

Student 7 – Studying Chemistry, Biology, Maths Mechanics & French. Enjoys playing piano and does Shotokan Karate. Wants to study Medicine and become a doctor.

The Project Brief

"The project team need to design and configure an automated system that can stack 'rubber logs' from a conveyor belt onto a pallet. It would be of great benefit if the system is flexible in order to be modified to cope with different sized logs and pallets. Hence controlling any hardware via a programmable controller would be advantageous. This will not only prevent manual handling issues, but provide a cost saving due to reduced manpower requirements. The solution must prevent the need for manual handling, so it will require the logs to be automatically picked up from the conveyor belt (when stopped), and stacked on a pallet. During the design process you must assess the risks to employees and consider legal regulations that may apply to the chemical industry."

Analysis of Problem

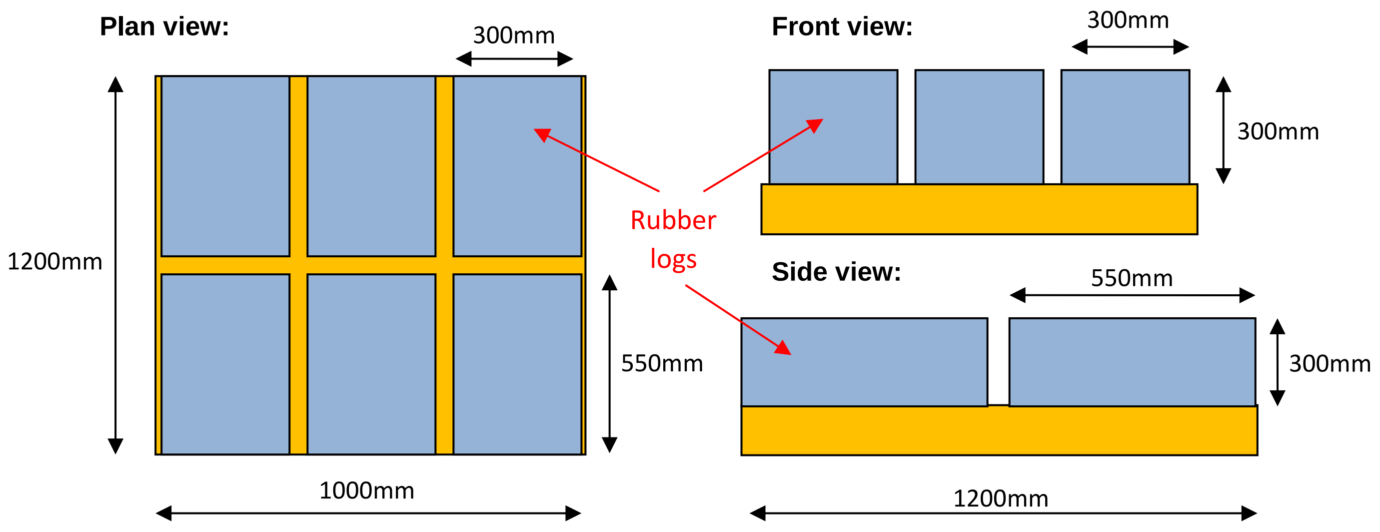
Situation

The Company has identified a manual handling problem with their rubber log stacking process. This process currently required rubber logs, weighing 25kg, to be manually stacked onto a pallet. The logs need to be carried approximately 2m from a conveyor belt, before being stacked onto a pallet located on the floor. This Pallet is then removed from the stacking area via forklift truck.

Standard Pallet dimensions: 1000mm x 1200mm

Log Dimensions: 300mm x 300mm x 550mm (H x W x L). Each Log weighs ~ 25 kg

SIX logs to be stacked on each pallet in format shown below: (Not to scale)



Why this is a Problem

This process presents multiple issues and is therefore in need of urgent redesign. Most importantly the process is highly labour intensive for the workers. It is also a 'round the clock' process and as a result of these two factors there is a high risk of physical damage to the workers due to continuous, intensive labour. These health risks could severely damage both the company and employees. Injuries from manual processes such as musculoskeletal injuries are common throughout the industry due to the repetitive strain of the jobs and can cause workers to be unfit for their jobs.

Another issue is the economic damage caused to company due to this manual process. The use of manual labour, in this instance, **increases the chance of error in the final product** as workers can become tired or strained, or could be facing illness. Workers must also be paid a yearly salary which is economically damaging to the company. In addition to this, humans can fall ill or suffer physical injury so that they cannot be present at work. This would therefore displace the worker from their job and the company would be forced to find additional workers to carry out the task whilst still paying the absent workers. Official government figures show that these injuries like these cost the country upwards of £6 billion per annum. [2]

Solution and Consequences

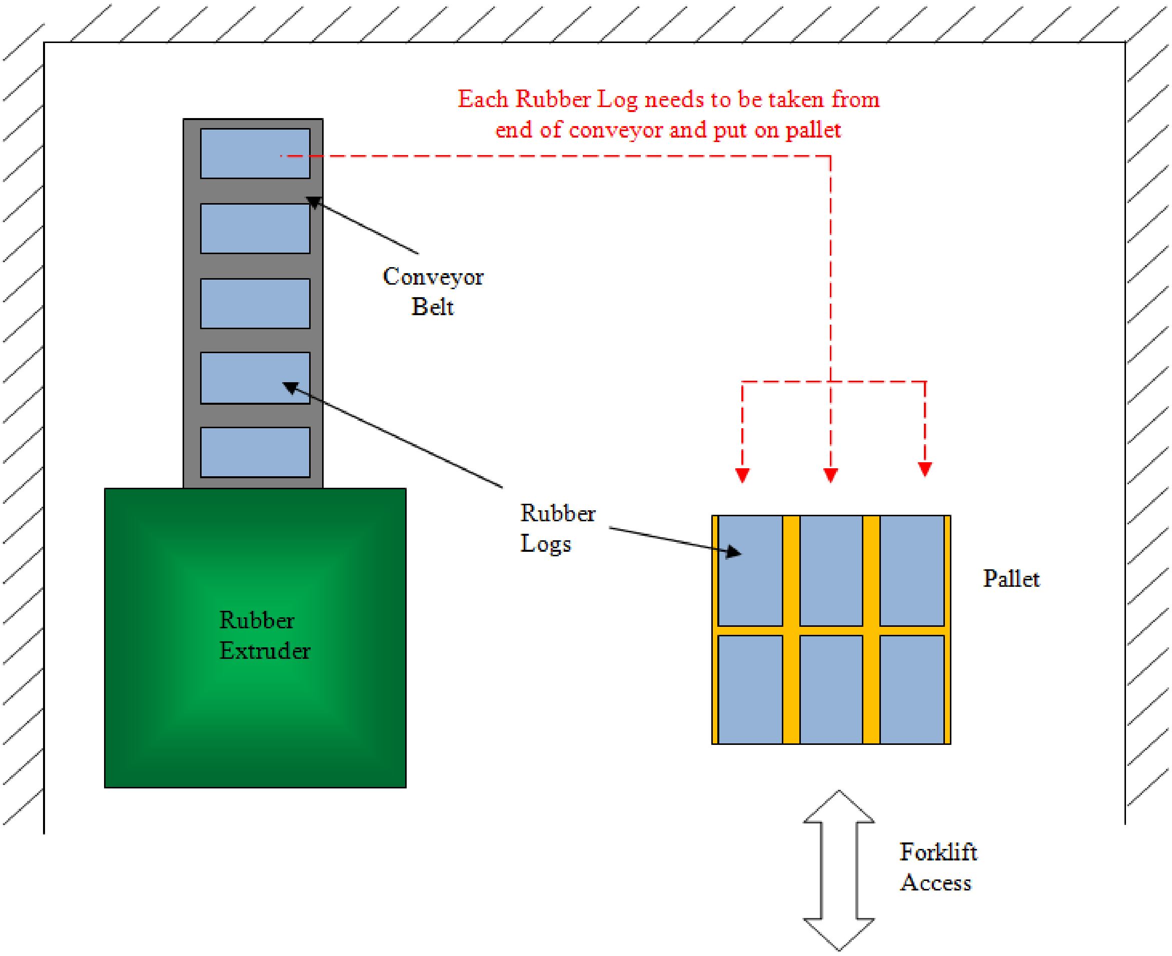
As an engineering team we have been asked to devise a solution to eliminate manual handling from the given situation. The brief also states we need to do this by designing and configuring an automated system to replace the defective manual process currently in place. Following a site visit to The Company it came to our attention that while eradicating repetitive strain injury risks by replacing manual labour with an automated, robotic system, we are in turn **introducing risk of human injury due to a machine**, which can cause more serious injuries to the worker than the manual labour could.

We understand the significance of the dangers of automated machines and will therefore ensure we implement sufficient safety precautions by using effective guarding around the machine and/or using a **Trapped Key Interlocking system**, most likely, 'Castell' due to their significant reputation and arguable market dominance. We will consider the specific health & safety requirements, plus the relevant interlocks and guarding when we analyse our possible solutions. As ultimately, these additional requirements could be instrumental in the overall cost of the projects, and thus play a factor when choosing the final design.

Our site visit also made us aware of the importance of flexibility in our automated solution. We understand how advantageous it would be to implement a system that can be modified (occasionally), for example to cope with different sized/shaped rubber logs and/or pallets.

After considering this we decided that it would be of great benefit to control the utilised solution via a programmable controller (a robotic arm).

Warehouse layout (Plan View):

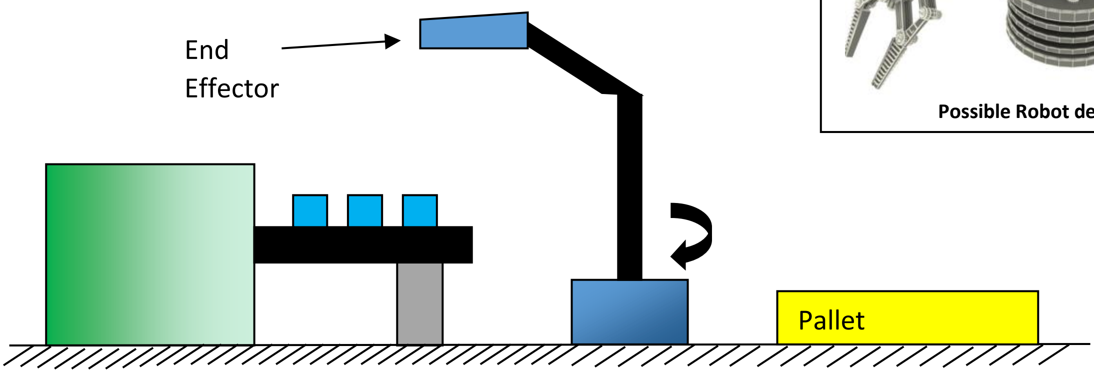


Possible Solutions

Due to the current nature of the system, our design must eradicate the manpower requirements by designing and configuring an automated system to replace the manual labour. Our design must be able to function efficiently within industry. As a team, following extensive research and regular meetings, we have devised three suitable solutions. All of the chosen possible solutions have the advantage of being automated however said advantage causes several possible issues to arise. Due to the need to make the system automated**, all our ideas involved moving mechanics**. As a result, all solutions would require significant guarding consequently the cost of this guarding will be the same for all the possible solutions.

Solution 1: Robotic Arm

One possible solution will be the use of a robotic arm. This solution would comply with our assignment aim in which the function of the process will be automated. This system would perform the task in a far more efficient manner than the manual process and would be able to run twenty four hours a day. The use of a robotic arm would be highly advantageous as it is versatile and can be adapted, with ease, for many applications.

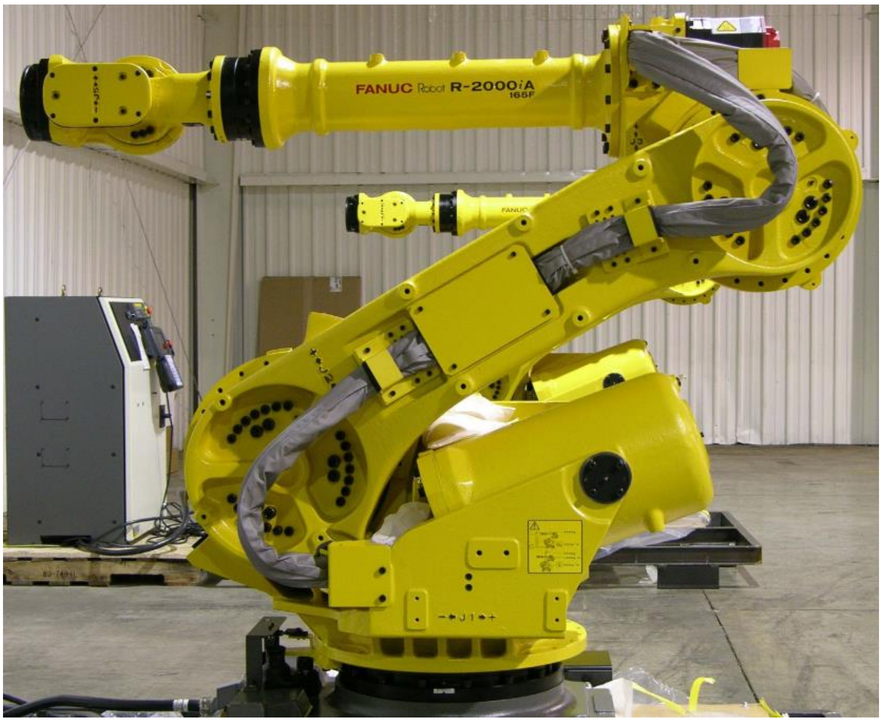


Possible Robot design

This can be done by changing the end effector or ‘claw’ of the robotic arm. For instance, should the industry chose to alter the shape of the product, a different end effector can be utilised. If the industry chooses to alter the mass of the product, the end effector can contain pressure sensors to ensure that the grip of the ‘claw’ is sufficient for the mass of the product. [3] Furthermore, use of a robotic arm will be advantageous to this scenario as the arm is completely reprogrammable. As a result, the arm will still be of value should the industry choose to change the method of production because the sequence of movements can be rewritten. This can be done through a worker. The worker would run the robotic arm through the sequence of motions using a handheld controller and the exact sequence will be stored within the memory of the unit and repeated each time a new product moves along the assembly line. [3] Furthermore the robotic arm can function within all three planes allowing it to function at any point in space within its reach. Therefore, mounted on the floor between the end of the production line and the transport bay, this solution could execute the task perfectly.

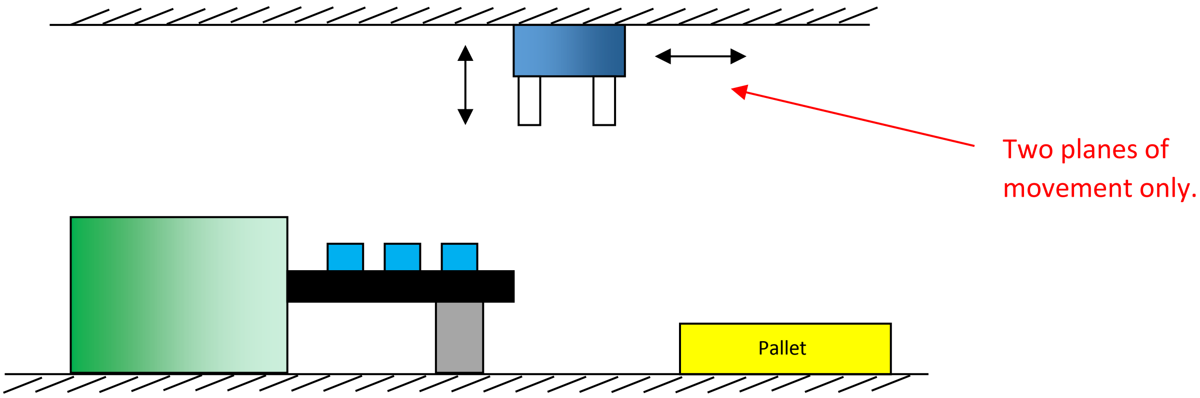
This solution does however cause safety issues to arise with moving mechanical pieces functioning in an area congested with workers. This predicament would be negated by implementing a '**Castell key'** system. This interlock system will ensure the safety of working by isolating the machinery. Should a worker have the need to enter the isolated area a key would be used to allow access. When the key is exchanged the mechanical system will return to its home position and cease to move thus allowing for safe maintenance of the machine. Consequently this implementation would eliminate close proximity between workers and the machine whilst it is functioning. [4]

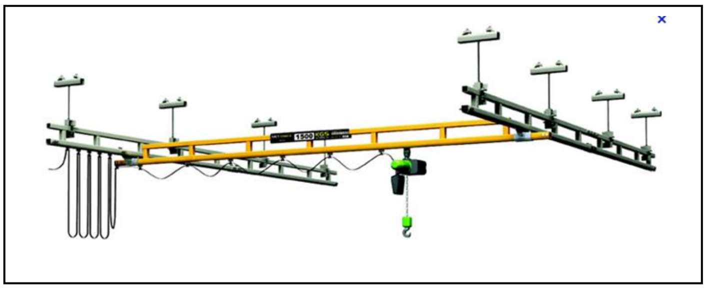
Industrial robots are also common place in many industries, especially the automotive industry. Using an established solution like a robotic arm will be far cheaper than designing a completely new bespoke installation.



Solution 2: Robotic Crane

Furthermore, an alternative solution would be the implementation of a robotic crane operating from the ceiling. The use of a crane would be suitable as it also eradicates manual labour by being able to execute the given task in an automated manner. One advantage of using a robotic crane would be that it too would be highly efficient and also easily reprogrammable. This would allow The Company to make subtle changes to the process and the crane would still be able to execute its command. However, should The Company greatly alter the process, the effectiveness of robotic crane could decrease dramatically. This is because the crane can only function within two planes of movement therefore The Company would be limited in the adaptations it could make to the production line. However, like the robotic arm, the end effector can be altered to allow for small changes in the process such as a development in the shape of the product.





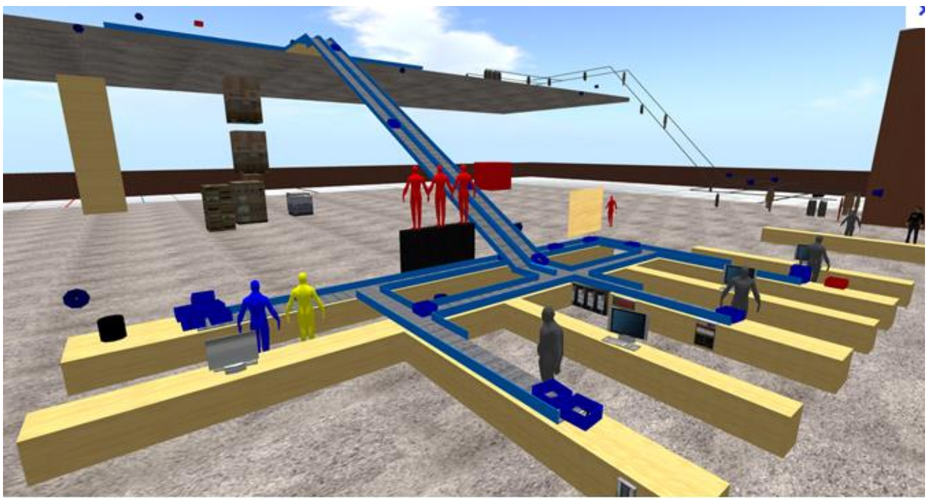
Similar to the robotic arm, the crane would have to be isolated from personnel to avoid injuries involving the moving mechanical objects. It would be difficult to install security parameters around the robotic crane due to its situation on the ceiling. However a ‘Castell’ key system could still be utilised to power down the mechanical objects to allow personnel to access the production line. This solution would however be substantially expensive due to the need to custom design the solution to fit its environment. For instance ceiling height, material and possible slope would be different in different industries and thus a bespoke system may be required which would cause a significant financial cost.

Solution 3: **Multiple Conveyors Belts**

A third alternative solution is to use multiple conveyor belts. Multiple conveyor belts could be installed to eradicate the need for manual labour. This solution will also comply with the assignment aim as the process would become entirely automated. The conveyor belts could carry several rubber logs continuously from the end of the production line to the transport area. Consequently this system would be far more efficient than the current manual system. However we quickly realised that this was easier in theory than in practice, due to the unspecific selection of each log there was no way we could accurately position each log on the pallet. This also meant that the pallet itself would have to move in order for the logs not to be just piled on top of each other but to be laid out specifically. As we were unable to reposition any of the existing equipment we were also stuck with how to move the logs onto the first conveyer belt; a piston was the only idea, which couldn't be used for the whole process.

Another problem with this process was the fact that the logs may become damaged during movement; as they would either have to slide or drop onto the next belt. This could lead to damage to either the product or the conveyer belts themselves. The process of several conveyer belts for this purpose is also unadoptable preventing it to be used for other tasks, and has a high running cost as the several conveyer belts would all have to be running, requiring many motors and electricity. The other problem with many motors and moving parts is it is likely to need high maintenance and lots of safety guarding to prevent injury to employers. All of these points run the total cost of installation and running up, reducing the viability of this solution.

[5]



Analysis of Solutions

The selection criteria, and the analysis of the different solutions has been summarised in the following table, which ranks the solutions based on specific requirements. These requirements are based on the original project brief. This table shows a numerical analysis, to further complement the written analysis of each solution.

Solution Option:	**Cost**	**Safety** (guarding requirements)	**Reliability** (least amount of errors)	**Flexibility of design** (if spec of logs/pallets changed)	**Prevents all manual handling**	**Suitable for site location**	**Totals**
Robotic Arm	1 (most)	1	9	9	9	9	**38**
Crane	3	1	9	9	9	1	32
Conveyors	9 (least)	1	1	1	3	3	18

The Solution with the highest score will be deemed most suitable.

The value given for each score will be weighted as follows:

- Low/not good: 1
- Medium/average: 3
- High/excellent: 9

Assessing all the solutions on cost, it is assumed that the cost of designing the systems, and purchasing and installing suitable machine guarding will all be similar. The significant differences in cost will be in dependent on the main solution element themselves.

The cost of conveyors is significantly cheaper, but still requires a significant human input, hence this needs to be added to the overall lifecycle cost.

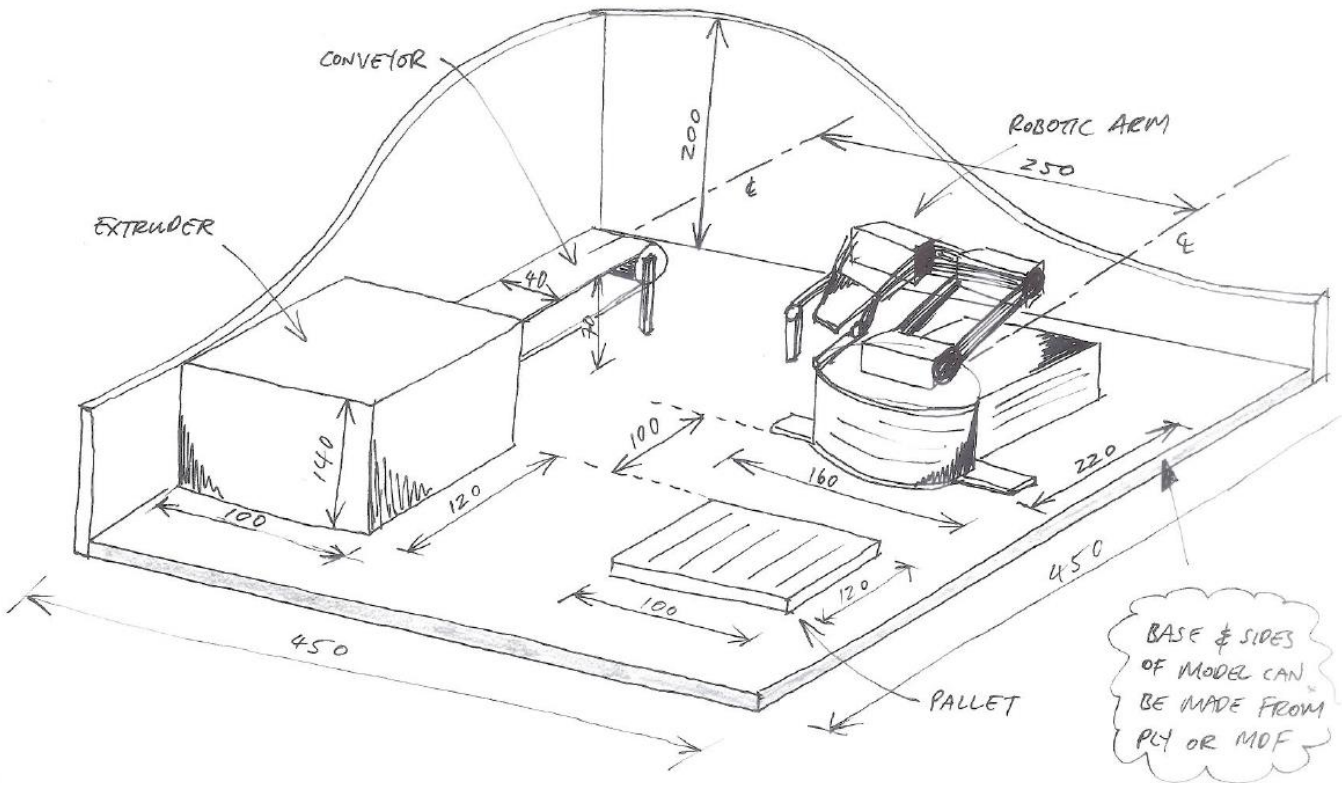
Although the crane came in cheaper than the Robotic arm, the overall benefits of the robotic arm (especially the suitability for the location) means that the Robotic arm is the solution that overall best fulfils the brief.

Chosen Solution - Robotic Arm

Overview

For our chosen solution we all decided that the robotic arm would be best suited to the job. Its adaptability and simplicity made it the better option of the three. There were also off the shelf items which would be ideal as they are a far cheaper solution to purchase and install. The fact that it would be controlled and powered electrically also benefitted the company as they have had past experiences using machines of this type, therefore training of staff would not be necessary and the power source would be the same. The arm was going to be powered electrically with motors, all programmed together, to perform our desired task. Each rubber log would have to have its own program for the robot to carry out in order to transport it to its correct location on the pallet. The robotic arm would consist of a 360 degree rotatory base, a 180 degree "elbow joint", a 360 degree rotatory "wrist joint" and finally the claw/jaw. Each joint would be powered by a small motor that would act in a specific way according to the program we would have written for it using a PIC chip.

Final Solution: Scale model sketch



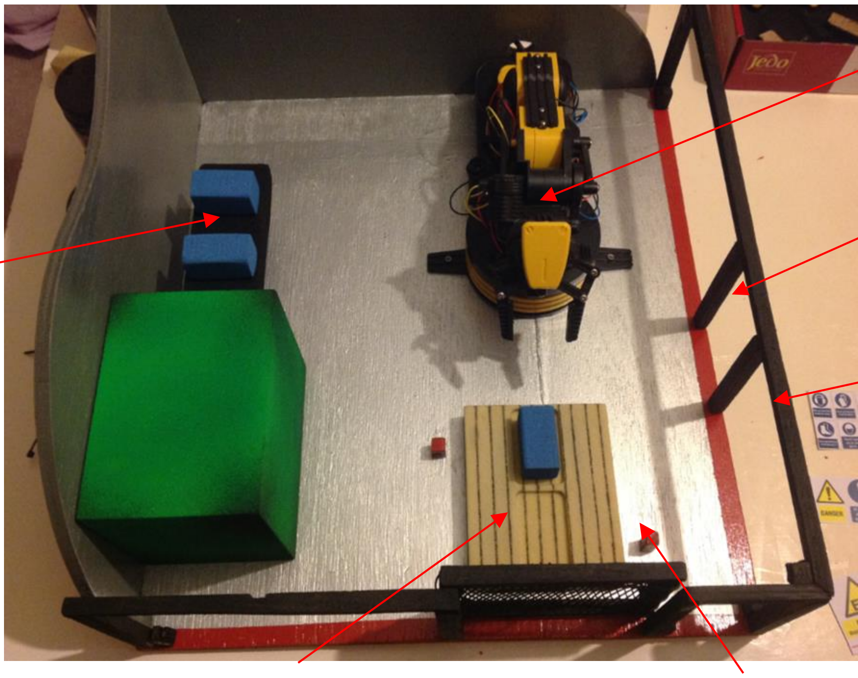
The Claw/Jaw

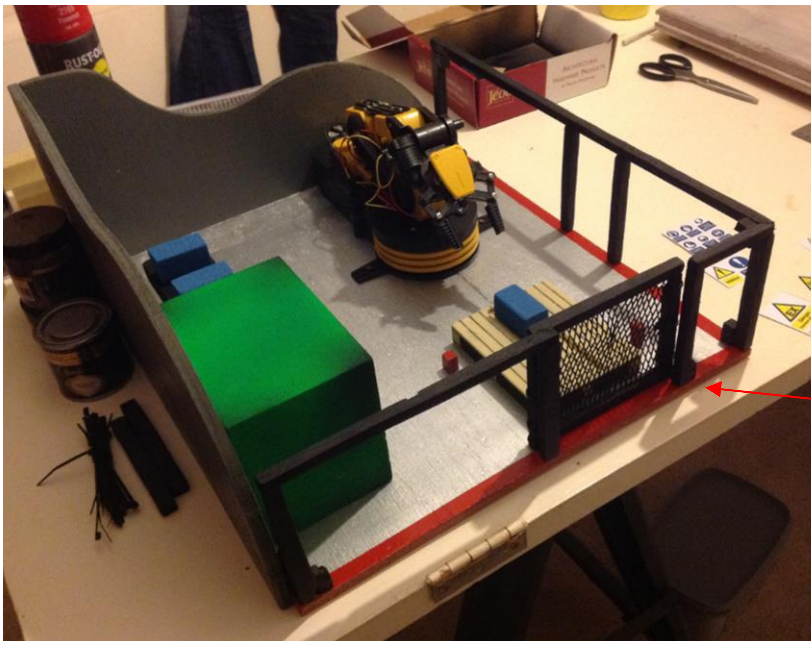
The jaw of the robotic arm is the component that is used to pick up the rubber logs and position it in the right location on the pallet. There was a lot of discussion about what sort of jaw to use. The ideas ranged from suction pads, to a scooping mechanism and then to a claw. The final choice was the claw as the other two methods were less efficient. The suction pads would have to be powered with a complex mechanism which we wanted to avoid, in order to reduce the cost. Although it would have worked effectively it would have meant extra programming that would have been difficult to do without the necessary commands. The scooping method would have been too risky as there would be a chance of the scoop failing to “scoop” it up and so the log may fall on the floor or be placed out of position. There would also have to be a very narrow margin for error as the scoop would have to be at the right height every single time, in order to pick up the log. But due to the sliding of the gears the height of the scoop would vary which, as a result, would either cause the scoop to dig into the conveyor belt or push the log off the belt.

That is therefore why we decided to go for the jaw mechanism instead. The jaw would be able to efficiently pick up the rubber logs and checks could be easily installed to it to benefit the programming and functioning of the robot. Micro switches could be added to the jaw in order to tell it when to stop its motors tuning as the grip may be too tight. The benefit of having this jaw is that it could function on a time delay and would therefore not need to be programmed along with the rest of the robot. This was a helpful aspect as it means that we were able to make the robot more adaptable by being able to offer the buyer their own choice of jaw. They could follow a simple programming guide that we had designed and then attach it to the wrist of the robotic arm.

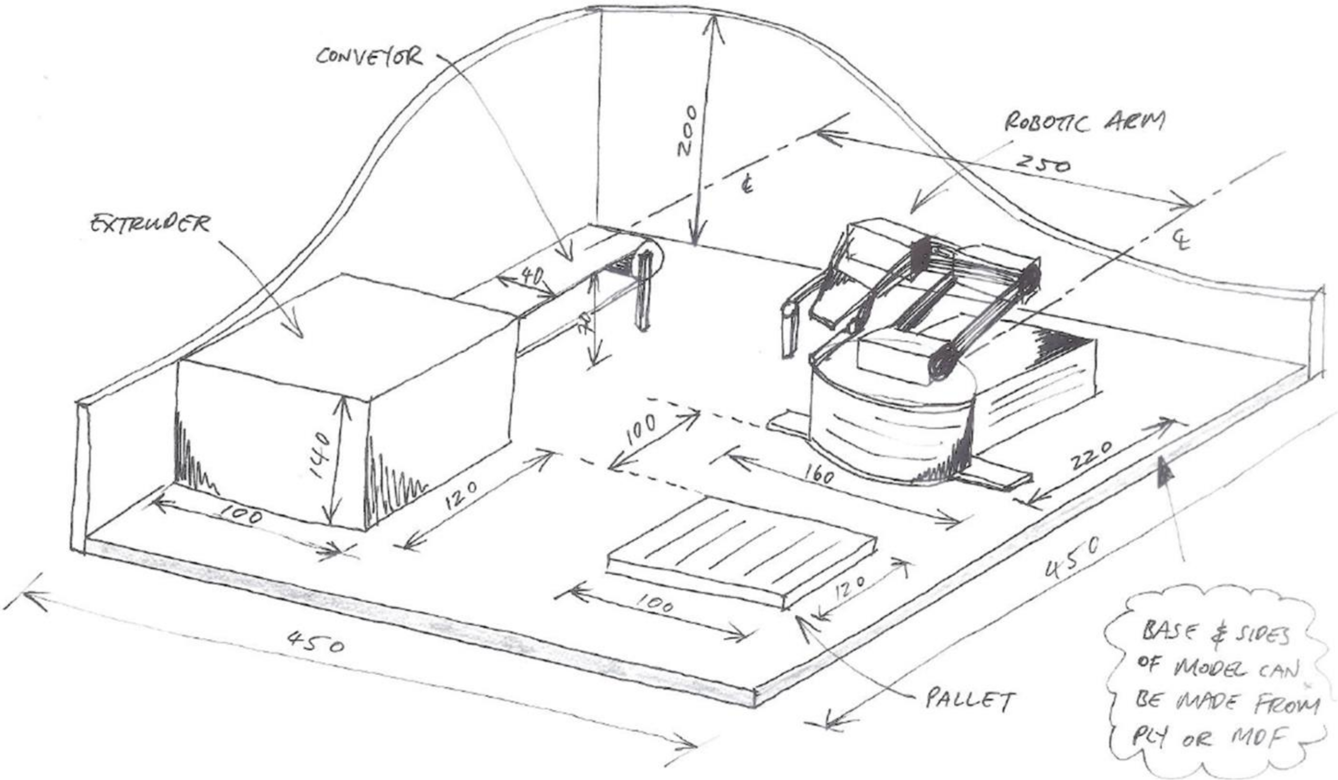
Prototype and Model Development

As a team we were keen from the onset to have a **working** prototype. We considered multiple options, and after discussions and online research we decided that the best way to demonstrate the benefits of our robotic arm solution was to purchase a kit and then to programme the robotic arm using a Raspberry Pi. After going out and purchasing our model, two team members spent one day of the December workshop assembling it, whilst three others began production of the scale model. The prototype/model not only show the functions of the robotic arm itself, but also the overall working of the guarding, and how, along with photoelectric sensors, induction loops and a forklift operator, the stacking of the rubber logs can be done without the need for manual handling.

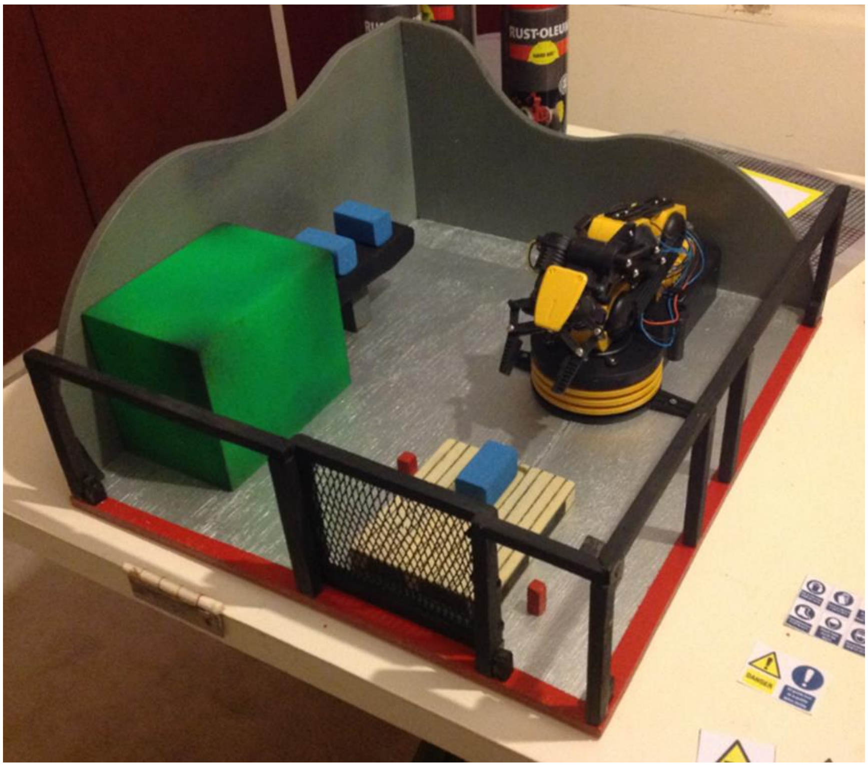




The prototype developed from a drawing of the general arrangement



To the building of a working model, which shows the working of the robotic arm, and shows the interaction protection required in order to operate the arm safely:



Project Management

In order to manage our project effectively we began by allocating roles to clearly identify the responsibilities of each group member. As a team we analysed the strengths and weaknesses of each group member and allocated roles and responsibilities accordingly. One responsibility was the creation of a Gantt chart to clearly illustrate the tasks to be completed and the dates in which the tasks were due for comletetion. We set up a mobile group messaging system to allow all members of the group to commmunicate and share problems and motivation. This was suggested as we would not have to worry about every team member's timetable in order to find time for feedback. Initially this seemed like a good idea as it could allow contact between the group twenty four hours a day from anywhere. However it quickly became clear that this method would not suffice for feedback that needed to be given following quieres and problems. We therefore arranged weekly progress meetings around everyones cramped timetable. This was highly successful as not only could feedback and queries be dealt with first person, it was a much better method of motivation for the team to work more efficiently.

"Forming, storming, norming, performing"

As a group we went through a series of stages vital to allow the team to grow, tackle problems and plan work effectively. The first of the stages involved **"forming"** the group itself. This team building stage introduced the group members to one another and also introduced the task itself. At this early stage we worked and behaved quite independently allowing us to see each group member's individual qualities. We then progressed into a **"storming"** stage in which work had to be done collectively as a group. How the given problem was going to be resolved came into question in this stage and also the roles of each member. Each group member had the opportunity to voice their perspective on the problem and any ideas they had to resolve it. In order to develop past this stage the maturity and patience of all group members was tested as conflicts in ideas were resolved. Progressing further we entered a stage of **"norming"** in which, collectively, a plan and a goal was devised. Some group members had to comprimise their ideas and agree with the other team members in order for the team to function effectively. Following all of this progression our team had developed to a point at which we could begin a **"performing"** stage. Here we had progressed as a unit capable of effectively carrying out tasks with no conflict. We were all highly motivated and competant to carry out all tasks with no external input required. [6]

Responsibilities of group members:

Student 1 was allocated as team leader following a speech and a team vote. Having explored his strengths and weaknesses he was tasked to be one of the main report writers and editors due to his grammatical ability. Furthermore, as team leader, it was his responsibility to ensure that all team members were on task at the engineering workshop and that all of each member's responsibilities were carried out on schedule.

Student 2 was also tasked to be one of the main report writers and editors due to her flair in writing. In addition to this, it was decided that she would have the responsibility of coordinating communication between the team and also with our link engineer. Finally due to her design technology experience she was allocated the role of constructing the robotic arm prototype and initial production of the scale model.

Student 3 was agreed, by the team, to be methodical and good at research. As a result he had the responsibility of researching the health and safety parameters required by automated systems and also took notes at meetings. Following this vital research he was also tasked to help write and edit the final report. In addition to this he collated the report together following multiple drafts.

As a team we agreed that **Student 4** has mechanical knowledge and design technology experience. As a result it was he who researched the scientific and engineering concepts surrounding our project and applied this knowledge within the report. In addition to this he has some previous programming experience and therefore assisted the team at the engineering workshop in learning about the use of Python (Raspberry Pi Programming language).

Both **Student 5** and **Student 6** have good IT skills and both also said that they are experienced in producing research notes. Consequently, we decided that they will research environmental sustainability and commercial and social implications of the solution to the project. Student 5 also played a key role in the production of the scale warehouse model at the December workshop.

Student 7 was allocated to make and design visual aids for our presentation due to his design technology ability. In addition to this it was also decided that he would research background information and look after all the research due to his organisational skills.

Student 8 has extensive programming knowledge and experience and thus it was decided that he would have the responsibility of programming the prototype for the presentation. In addition to this he had to learn the programming 'language' to be able to program and reprogram a specific automated system.

Our project mangement abilities were called into question when a highly influencial team member left the team. Shortly after Christmas, Student 8 left the project due to matters outside of his control. As a result we had lost our programming expert and at first glance, appeared to be in a situation of great discomfort. With the programming of our prototype still to be completed we had to alter the responsibilities of all of the group members to accommodate a loss in personnel. Immediately after discovering this departure we held a team meeting to discuss our options. It was decided that Student 4, being the most experienced, would undertake the role of main programmer. We also sought the guidance and experience of fellow school member Student 9, whom we knew had good knowledge and a passion for programming.

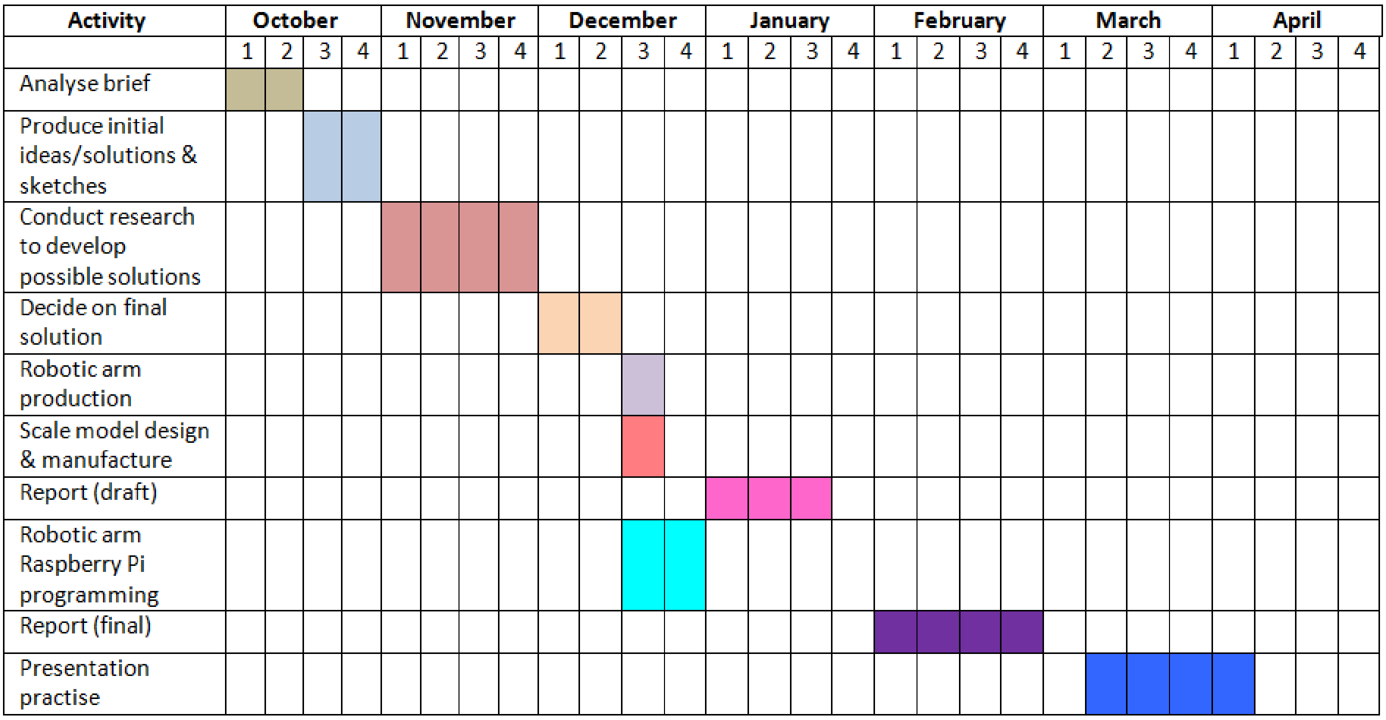
How the Project has benefited the Team

Over the six month period our team has not only developed into a fully functioning unit but has also gained vital benefits individually. For instance the EESW project has provided several experiences with professionals in an industrial setting. This has given our team an insight into the nature of engineering careers. Furthermore the project has benefited our report writing and presentation skills that will prove to be of great use in our later careers. Tasks within the project have also allowed our time management skills to profit as we applied ourselves to meet deadlines. In addition to this the project as a whole has led to immense development in our key skills which has been of great effect in other areas of our education.

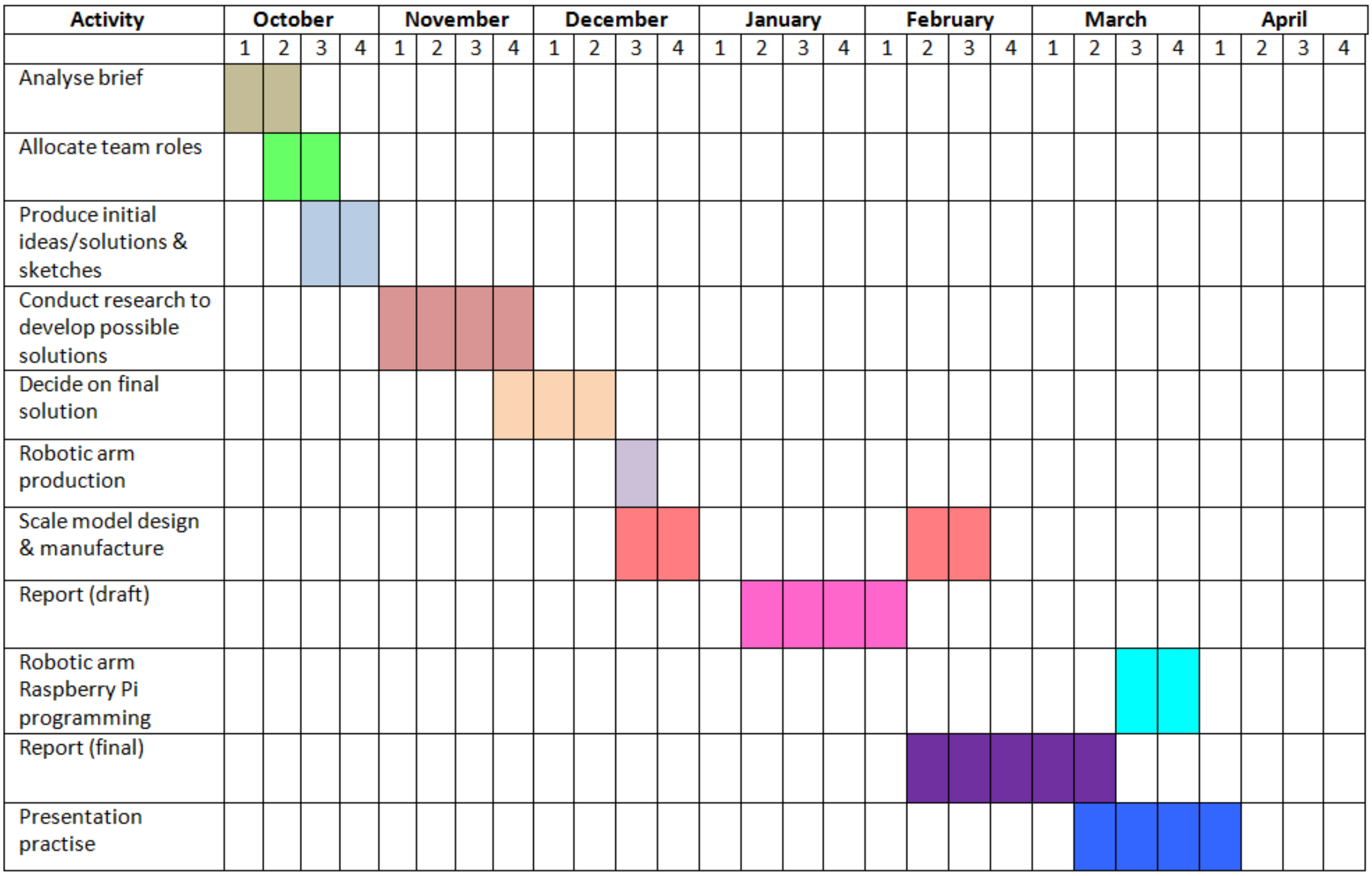
Division of Time

The (below) Gantt charts attached illustrate signinficant changes and hence show how we had to manage the project. For instance, initially there were fewer tasks shown however as the project developed it became clear that we had more to acomplish than at first thought. Furthermore, The charts also show that both drafting and completing the fianalised report took longer than expected. This is because of a loss in personell and also over expectations as to the rate at which each group member could work. Initially we had not scheduled in an increase in personal work due to mock examinations during December, as a result we had less time to spend on our project, and several tasks had to be delayed. We also believed that the programming of the raspberry pi could be accomplished at the december workshop. However, due to a lack of equipment, the unexpected departure of a group member and insufficient technical knoweldge/experience the task of programming had to be pushed back until we had the required support.

Gantt chart 1: Original Project Plan



Gantt chart 2: How the project plan changed to cope with unexpected project issues



Health and Safety

The issue of Manual Labour

According to the UK national scheme for health and safety, over a third of injuries in the workplace are caused by manual labour. Most of the injuries are musculoskeletal disorders – repetitive strain injuries. It is estimated that these injuries cost the Government over £6 billion per annum [1]. A musculoskeletal disorder is any injury, damage or disorder of the joints or other tissues in the upper/lower limbs or the back [7]. Although workers could be trained in the prevention of these injuries, this clearly cannot be a 100% efficient method of avoiding these injuries.

The use of manual labour to transport the 25kg rubber logs can result in further safety risks due to the risk of slipping and tripping whilst carrying the logs. Although The Company have already minimised these risks by ensuring a clear workspace is provided (this is in accordance with the companies Code of Conduct) the risks have not been eliminated.

Our Solution

We have developed an automated system of moving rubber blocks which eradicates the use of manual labour. As manual labour is minimised, in turn the risks of musculoskeletal disorders due to repetitive lifting and carrying of the 15kg logs are also **eliminated.** Subsequently the number of days missed by workers in this process is also eliminated, thus saving The Company money. This is in accordance with The Company's code of conduct for a safe working environment. They believe that the best way to reduce injuries in the work place is to eliminate the root causes. [8] Our proposed solution of the robotic arm will eliminate the root cause of the problem and so falls in line with The Company's code of conduct.

On the other hand, implementing a robotic arm in turn introduces new and different health and safety risks. Operating mechanical (robotic) arms pose a serious threat to any humans who come into contact with them. They could cause a serious injury such as paralysis and broken bones, or even fatalities, therefore it was paramount we addressed this issue.

Overcoming Risks posed by Our Solution

To minimise the occurrence of these risks, we have implemented machine guarding around the entire operating unit. The machine guarding will cover the conveyor/the conveyor belt will have a separate guarding system to prevent contact between workers and the moving belt. We have also chosen to use a Trapped Key Interlocking system, such as the Castell system. The Castell Trapped Key Interlocks are highly renowned as being of superior quality to many others in the same field. The access gate will have a trapped key interlock system in place, this works by preventing access unless the power to the robotic arm is shut off using the **same key** required to open the gate.

Trapped Key Interlocking ensures that a process is followed and cannot be circumvented or short cut. "A key is used to start the process and remains trapped whilst the machine is running. The only way to remove the key is to isolate the hazard." [4] The same key is then required to gain access to the dangerous area and remains trapped whilst the gate or door is open. The key can only be removed from the lock when the gate or door is shut. "In this way, the key is either trapped when the machine is running and access cannot be gained, or trapped while access is gained and the machine cannot be running." [4] This, effectively, eliminates the risk of a person coming into contact with live machinery preventing injury, saving the company money and also preventing a possible lapse in the process.

[4]

Machine guards will be used to further prevent contact between workers and live machinery. A stainless steel cage will guard the majority of the functioning units within the room. This can only be accessed when the machines are not running due to the Trapped Key Interlock system. For example, the conveyor belt poses a moderate health and safety risk as workers could potentially, if no machine guarding is used, trap their hand/arm inside the conveyor causing injury. This would damage The Company's reputation as a company with extremely high health and safety standards and of course injure its workforce causing a possible lapse in production and a violation of The Company's code of conduct. Therefore measures must be taken to safeguard against these potential risks. Machine guards are required by law to prevent injury and so will obviously be incorporated in our design. Certain health and safety standards as outlined by the Provision and Use of Work Equipment Regulations 1998.

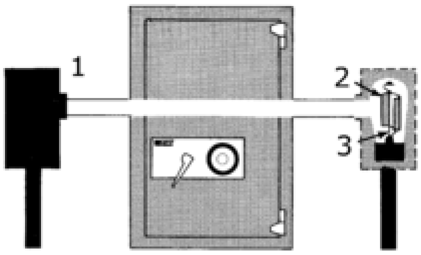
Safeguarding of hazardous parts of conveyors may be by design (e.g. lift-out rollers that prevent finger trapping), fixed guarding (requiring a hand tool such as a spanner to remove) or hinged or removable interlocked guards (e.g. guards fitted with coded, magnetic interlock switches to prevent the machine running with the guard removed). Such interlock switches are designed and produced by Castell, which has a very high standard of health and safety, in accordance with The Company's code of conduct for a safe working environment.

Satech perimeter guards could be installed containing the entire process, thus eliminating any need for contact between worker and machinery and combined with a Castell Key System practically eliminates the risk of a worker coming into contact with live machinery.

Satech perimeter machine guards offer a cost effective method of modular machine guarding. They are very simple to install so are versatile and suitable for use with the setup required by The Company. [9] They are therefore a vital, if not the most vital, component of the reducing of health and safety risks posed by the current and proposed solutions.

[10]

The forklift access/ loading gate will also need to be interlocked. This means that the robotic arm cannot be in operation whilst the pallets of rubber blocks are removed. To overcome this problem, limit switches may be utilised on the forklift access gate. This is so the Robotic arm cannot start; unless the limit switches are closed (i.e. the gate is closed). Likewise, the gate will only open, if the Robotic arm is in its “home” position and a pallet is present within the designated stacking area. This can be achieved by the use of photoelectric sensors. A photoelectric sensor detects the presence/absence of light, often infrared by using a light transmitter and a photoelectric receiver. [11]



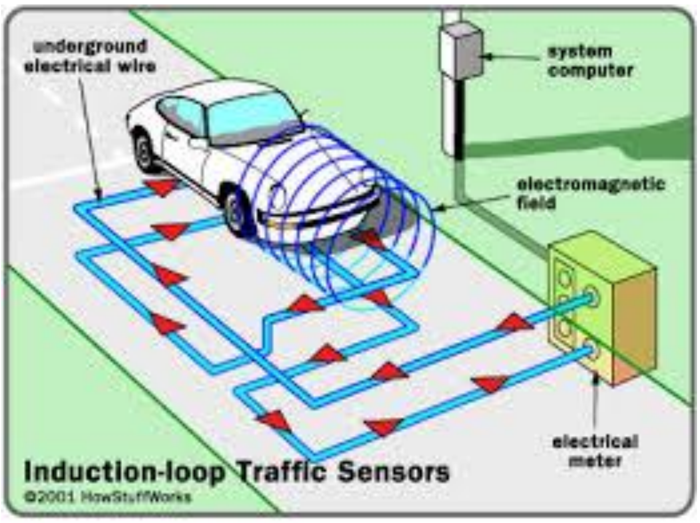
[12]

When the beam is broken, by a pallet, the arm will know that the process can begin/must end so the pallet can be removed by forklift.

A limit switch is a mechanical switch that operates in such a fashion as to halt further mechanical motion of the object which operated the switch. A **flow diagram** has been produced to further explain the process (See next page).

There will be an induction coil buried in the floor in front of the gate. This induction coil can detect the large metal object of the fork lift truck and open the gate. Inductive loops work by detecting a change of inductance (i.e. a metal object). It constantly tests the inductance of the loop in the floor, and when the inductance rises, it knows there is a forklift waiting to remove the palletised rubber blocks. Obviously, this will also need to be interlocked. Therefore, the forklift access gate will only open when the arm is in its home position and a forklift is above the induction coil. The Flow diagram explains further:

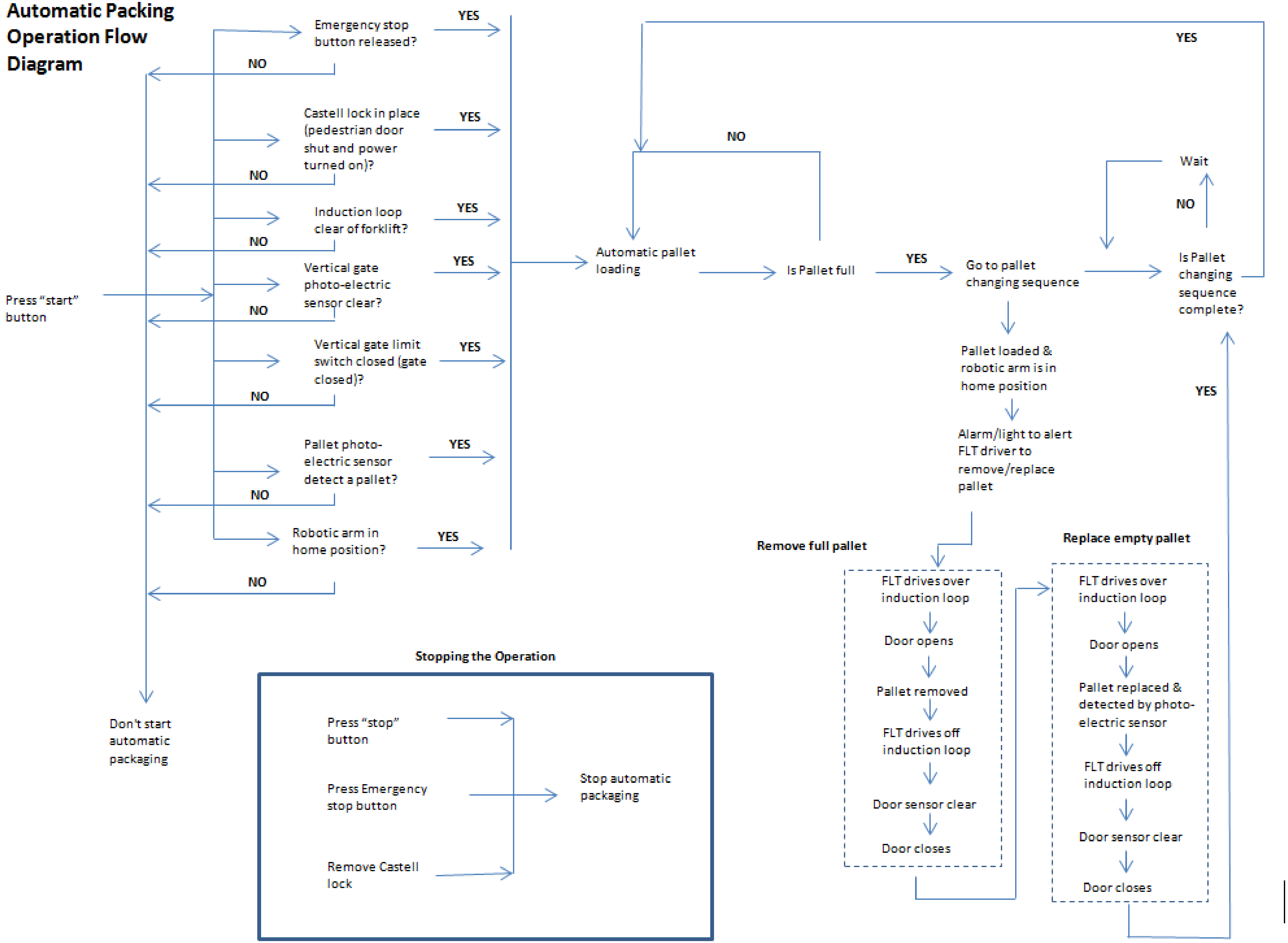
[13]



The car represents the forklift, and the disturbance in the field by the large metal object opens the gate for access.

The complete **Automatic Operation** of the packing system is shown in the following flow diagram. And describes how the protection layers interact with the moving parts (arm) plus how the pallets will be changed via forklift truck.

Automatic Packing Operation Flow Diagram



Sustainability

Economic Sustainability

The economic implications of this solution will contribute in its success. If the costs of procurement, running and maintenance of the machinery are less than the amount spent on the current process, then it will be **financially** worth the investment. However, whilst the solution must be economically viable, due to the focus of the project safety will prevail in criteria over economic benefits.

The Company has to be careful in selecting the correct machine in terms of operating and maintenance cost. If the robotic arm's acquisition and running costs are too high, then it may not be worth installing the machine, and an alternative approach will then have to be found.

The robotic arm will be too expensive to manufacture in-house at The Company, so the intention is to purchase one from a specialist robotic solutions firm. In order to build it in-house, The Company will need resources, materials and expertise in robotics. [20] As robotics is not The Company's speciality, it is far more economically viable to purchase a customised and fully functional robotic arm instead of commissioning a bespoke system, which of course would also cost the company a larger sum of money.

Using an automated process can improve the efficiency of the project, resulting in projects finishing within a shorter window of time due. This increased rate of work can help The Company to increase output, which will result in a higher volume of products, increasing revenue for the company.

Improved efficiency of the process can also reduce manual workload on workers. This will directly lead to a reduction in injuries. A third of all injuries at work happen due to manual handling of, or lifting, heavy objects [15]. It is estimated by Health and Safety Executives that in 2012/13 there were 231,000 injuries that led to over 3 days of absence at work [14]. These injuries can have a major implication on the employer, workers and the working environment. Importantly, injuries resulting in absence will cause delays in completion of the project, directly affecting employers. For any injury sustained at work, the employee is entitled to financial compensation from the employer, which can affect the budget and expenditure of the project.

Some injuries can have a long term negative effect on the health and well-being of employees. It can, in some cases, lead to long-term unemployment. Not only will this affect the employee directly, but it will also negatively impact on the socioeconomics of the employee's city or country. All employers, therefore, strive to reduce any source of injuries. Installing a robotic arm will remove the need to manually lift heavy objects, reducing the chances of having an injury which in turn will save money.

Environmental Sustainability

As we decided to use a robotic arm for our project, there were many environmental factors that we needed to take into account. The Company have a high standard and strive to be as efficient and sustainable as possible. The robotic machinery that will be selected to use for this purpose will be considered based on the following criteria:

- The size of the machinery allows the workers to easily install or move it for storage
- The machinery is efficient in consumption of electricity which in turn will produce less greenhouse gases
- Replacement parts are readily available either in the factory or the local area
- Faulty parts can be recycled easily, reducing the waste in landfills

Selection of a supplier has to be considered carefully. A supplier that has a good track record of providing reliable and efficient machines should be selected. A supplier with a good environmental record should be considered. This can include factors such as the materials used in the machinery, the handling/recycling of defected parts, manufactures equipment in an environmental friendly factory [16][17].

The biggest effect of the machinery on the environment comes from its electricity use. The more electricity it uses, the more it will cost to run and this in turn might increase the greenhouse gases if the electricity is supplied from a fossil fuel power station.

As the consumption of electricity will be the main environmental factor, we can roughly estimate how much electricity will be consumed by the machine and how much CO_2 will be produced. From the project specifications we know that the weight of each log is 25 kg. The extract from the specification is shown below:

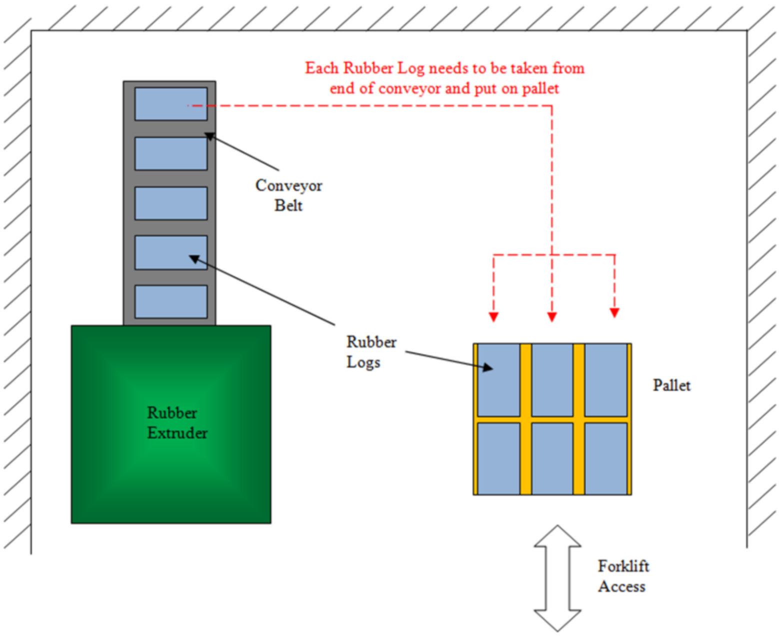


Figure 1: Pallet and conveyor belt position

From the diagram we can estimate the total distance the log has to be moved is 2 m + 1 m. We can add another 1m from vertical lifting and placing it on the pallet.

$$Work\ done = Force \times Distance$$

$$Distance = 4m, Force = 25kg$$

$$Force = mass \times acceleration$$

$$\therefore F = 25kg \times 9.81ms^{-2} = 245.25N$$

$$\therefore Work\ done = 245.25N \times 4m = 981J$$

This is theoretical work done, in practical due to inefficiency and the design of the machine we can estimate the work done to move the pallet will be about double, around 2000 J

To calculate Energy in Kilo Watt Hour we can use:

$$Energy_{(kwh)} = \frac{Energy_{(J)}}{3{,}600{,}000}[8]$$

$$Energy_{(kwh)} = \frac{2000J}{3{,}600{,}000} = 5.5 \times 10^{-4}kWh$$

If assume that in one minute, two logs are moved from conveyor belt to the pallet and the machinery works for 15 hours a day. Hence in 15 hours, the machine can move:

$$15hrs \times 60 \min = 900minutes$$

Pallets moved in 900 minutes= $900 \min \times 2\ logs.per.min$ = 1800 logs moved in 15 hours

$$\therefore Power\ consumed = 1800 \times (5.5 \times 10^{-4}) = 1kWh\ daily\ consumption$$

As a rough estimate it costs around 20 p/kWh by Swalec [9]

So in total 15 kWh consumed / day. If the machine runs for 300 days a year, it will cost:

$$300days \times 15kWh = 4500kWh \times £0.20 = £900, cost\ a\ year\ to\ run\ tis\ machine$$

We can see that the CO_2 emissions per kWh. 2.331kg is the conversion for kWh used, which is calculated by the carbon trust. [10]

$$4500kWh \times 2.331kgCO_2 = 10{,}500kgCO_2$$

With this number The Company can decide if this machine will be environmental friendly.

Social Sustainability

The Company displays a lot of thought towards social factors their company can affect. It states that "*technology is at its very best when it benefits somebody. So people are at the heart of everything we do…. In addition to looking after our own employees, we're also committed to helping people in the developing world…improve their lives in any way we can, and making this technology affordable to everyone, everywhere.* [19] This brings us to the social impacts of our solution.

The Company has decided to reduce the workload on their employees. They have considered their needs and the need to make their working life easier.

The robotic arm replaces the need for the current manual workers. However this would simply result in the employee which manually handles the logs being re-assigned to a different role in the company. The workers displaced by the automated system could be trained to complete other jobs such as piloting the forklifts and so could still be employed within the same working environment. Although in the same environment these workers would no longer be at high risk of musculoskeletal disorders due to continuous and intensive labour.

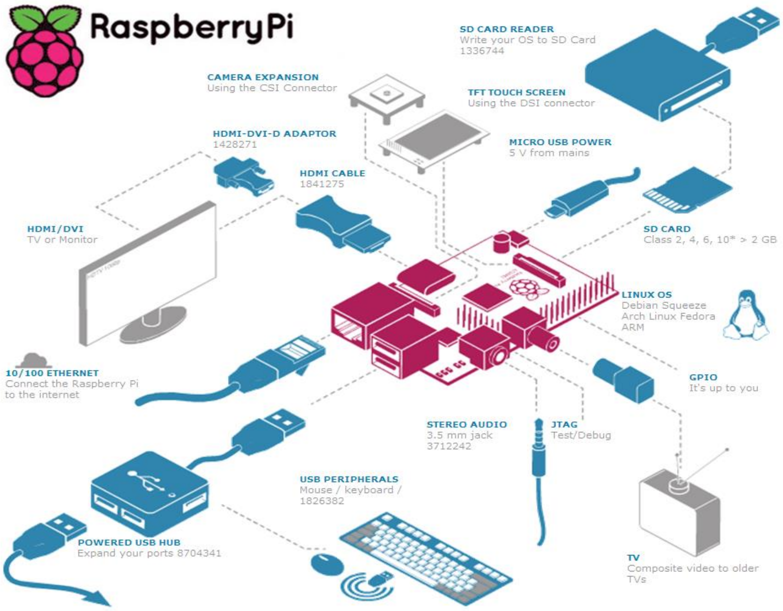
In the current economic climate, this may allow a cost-effective management of The Company's finances. Furthermore, as we aim to source locally it is expected that a boost will be experienced by other sectors in the area, creating further jobs. This is in addition to the essential improvement in health and safety created by the addition of the robotic arm. As stated by The Company,

> "*Health and safety of employees, customers and suppliers is the most important driver of environmental and sustainability decisions in all countries"* [18]

Whilst the utilisation of a robotic arm does raise health and safety issues, it also negates the use of manual handling (in accordance with the brief) which in turn removes the possibility of inuring workers via musculoskeletal disorders. The health and safety issues raised by the proposed system have been dealt with previously in the report. Therefore, our proposed system is socially sustainable.

Programming (Raspberry Pi)

Initially we had many ideas about how we would remove manual labor from within the handling process, so we decided to utilize a robotic arm for which we had many ideas how it would work, ultimately we chose a design but had no operating system. Our first decision was to use a **Raspberry Pi** so there would be a visual representation of the coding and so that it would be relatively easy to install, operate and adapt. Also, Raspberry Pi's are becoming an increasingly popular option in programming; and it would not be too difficult to make it correspond with the robotic arm.



Our initial challenge was a limited level of coding/programming experience, as only two group members had any coding knowledge it was a clear problem for the group. So, to rectify this problem, we attended a Python lecture during Django Weekend at the University. This was very beneficial in developing our understanding of Python and its application in STEM subjects. Attending the December workshop in the University was largely beneficial as a computer scientist with knowledge of both Raspberry Pi and the python programming language (as well as general coding) taught us how to properly utilize the Raspberry Pi and simple coding technique. However one of our primary programmers left the group, due to uncontrollable events, which was a loss, so in turn Student 3, with help from Student 5, had to put in more effort and bring in the help of a school friend who is a semi-experienced programmer which made the task of programming the robotic arm a more achievable target, he understands the language and explained it to us so that we would understand what we were doing and thus be able to program the arm.

We used the programming language Python as it is a relatively simple language and the new up and coming way of coding. It was recommended as it is very flexible so if the measurements and placements of the logs should ever change, then we simply have to slightly alter the coding so that it would follow the new placing and measurements. We also used the Raspberry Pi as it was an easy way to get a visual representation of the coding and it does not require extensive experience or training.

The Coding:

Usb.core - the module which lets us communicate with the USB port. This is part of the pyUSB package which we needed to install.

sys - imports some basic commands that allowed us to communicate with the system, e.g. command line, inputs-outputs, etc.

time - imports "time" functions - which not surprisingly, measure time, introduce delays etc.

Optparse - A module which parses (gathers, chops up and allocates) the command line options and values.

pickle - Another module from python's inbuilt libraries which lets you move specific large data around easily – we used this for loading and dumping variables to a file as the arm had many moving pieces.

csv - A module specifically for importing and exporting comma separated value files such as our instructions for the machine from the coding which we might have to transfer.

ROBOT ARM CONTROL PROGRAM

```
#import the USB and Time library into Python

import usb.core, usb.util, time


#Allocate the name 'RoboArm' to the USB device

RoboArm = usb.core.find(idVendor=0x1267, idProduct=0x000)


#Check if the arm is detected and warn if not

if RoboArm is None:

   raise ValueError("Arm not found")

#Create a variable for duration
```

```
Duration=1
#Define a procedure to execute each movement
def MoveArm(Duration, ArmCmd):

#Start the movement
   RoboArm.ctrl_transfer(0x40,6,0x100,0,ArmCmd,3)

#Stop the movement after waiting a specified duration      time.sleep(Duration)
ArmCmd=[0,0,0]
RoboArm.ctrl_transfer(0x40,6,0x100,0,ArmCmd,3)

}}
```

Now we needed to give the arm some movements, this is just a demo of the coding.

```
{{CodeBox| \
<source lang="python">

MoveArm(1,[0,1,0]) #Rotate base anti-clockwise
MoveArm(1,[0,2,0]) #Rotate base clockwise
MoveArm(1,[64,0,0]) #Shoulder up
MoveArm(1,[128,0,0]) #Shoulder down
MoveArm(1,[16,0,0]) #Elbow up
MoveArm(1,[32,0,0]) #Elbow down
MoveArm(1,[4,0,0]) #Wrist up
MoveArm(1,[8,0,0]) # Wrist down
MoveArm(1,[2,0,0]) #Grip open
MoveArm(1,[1,0,0]) #Grip close
MoveArm(1,[0,0,1]) #Light on
MoveArm(1,[0,0,0]) #Light off      }}
```

Evaluation of Solution against Original Brief

Our brief was to design a system that could automatically, without any human labour, transport 25kg rubber logs onto a pallet. With six logs per pallet the system would have to be designed in order to put each log into the correct place on the pallet so that they could all fit on.

The main criteria for the design were:

1. It had to replace the manual handling task that would normally have required from a production operator.
2. It had to work automatically without anyone being there to provide constant supervision.
3. Be programmable
4. Be strong enough to move loads of at least 25kg.
5. Be simple enough to be easily maintained & fixed.
6. Be in accordance with The Company's code of conduct for health and safety.
7. To be adaptable to different tasks.

Our design meets all of the requirements stated in the brief. The robotic arm has been designed to function automatically with a set program that repeats itself so that the outcome is always the same. It therefore meets two of the requirements; replacing the manual labourer and also being able to work automatically.

Although we were not able to build the actual robotic arm we would have used motors with high torque as these would be able to lift heavier loads. The base of the arm would also be secured in place so that it wouldn't fall over due to its weight, or the logs weight. This would therefore meet the requirement of being able to lift objects exceeding a mass of 25kg. Note, an industrial robotic arm would have a load capacity far exceeding our requirements.

The design would meet the fifth specification by purchasing an off the shelf robotic arm, that had a low maintenance design. We would ensure the robotic arm was installed such that there was ample access to allow for maintenance tasks to be carried out easily.

Our solution abides by The Company's code of conduct for a safe working environment as we have included extensive safety precautions to be implemented. These are all covered in our Health and Safety section.

Finally, we have met the adaptability aspect as the arm will be able to be moved around and does not have to be fixed in one specific place. The jaw of the arm is also detachable so wider jaws or different types could be fitted by simply removing the jaw beforehand. The jaws would have specific mounts that could be bought along with the arm so that jaws, manufactured by different companies, could be attached to our arm.

Conclusion

As a team we feel that our chosen solution of a robotic arm would be truly beneficial and advantageous to The Company if implemented. Not only does it fulfil the design brief by removing the need for manual labour, but this removal would also provide a more reliable and efficient option than currently in place. We are also satisfied that although our chosen solution introduces new safety risks to humans, we have combatted these risks and the solution is in accordance with The Company's strict health and safety guidelines.

How successful was the Prototype?

Our prototype was greatly advantageous as the robotic arm and scale model demonstrate both the robotic arm's functions; and also the safety parameters we have suggested to be implemented. Our prototype has not been, however, completely successful. Our robotic arm is moved by 5 motors operating 5 gearboxes. These gearboxes have "slack" in them, meaning when you want to create movement in the opposite direction, there is a delay as the gears rotate and mesh in the opposite direction. This is an additional technical challenge we have to overcome in getting our model to work effectively, as we need to take this delayed movement into consideration. This challenge **does not** present itself on the full scale industrial robotic arms as they use a different type of motor for their movement. They use Stepper Motors, and they typically have about 7 of them per arm. Stepper motors are very easy to control, and allow you to have very accurate movements - ideal for robotic arms.

Recommendations

After conducting this project, the project team are satisfied that that solution identified will meet the Project Brief as given by The Company. The chosen solution will resolve the issues identified in the original problem statement and will prevent manual handling injuries by eliminating repetitive manual labour. The chosen solution is economically and environmentally viable and in accordance with the company's strict health and safety guidelines.

We recommend The Company should install a robotic arm stacking solution. Due to the pre-existing setup, all that will need to be purchased is the robotic arm itself and the health and the safety features such as the Trapped Key Interlock system, most likely from Castell, a leader in the field. Typical robotic arm with payloads of 25kg cost approximately [21] £50,000. This is a large upfront fee, but in the long term will cost less than paying workers to do the same job, even when factoring in the maintenance of the machine. The robotic arm itself can be purchased from a specialist manufacturer, but further project work will be required to program the robotic arm to perform the specific functions required in the unique location at The Company.

The project design can be further developed by designing the guarding requirements specific to the manufacturing location. The guarding forms an integral part of the design and needs to work seamlessly with the robotic arm in order to keep the plant and people separate, plus allow efficient movement of materials through the factory.

The final recommendation will be to create and implement a training program for the staff that will be operating and maintaining the robotic arm.

- There will need to be an Engineer training program, so they have the necessary knowledge to modify the program controlling the robotics. They will need to do this if the size of the rubber blocks change, or if the company decide to use different sorts of wooden pallets.
- There will need to be a training program to ensure the operators of the robotic arm are fully aware of its safe operation and how to trouble shoot any day to day operating issues
- Finally, there will need to be a maintenance regime setup with training for the technicians who will carry out this maintenance.

Acknowledgements

As a team we would like to express our great appreciation for our link engineer, Engineer 1, for his constructive and experienced guidance throughout the project. We are extremely grateful for his willingness to give us so much of his time and his ongoing, enthusiastic encouragement. He has helped us work efficiently as a team, overcome the problem of an unanticipated loss of a team member, build an aesthetically pleasing and functioning prototype and has provided us with a basic programming technique.

We would like to acknowledge our former team member Student 8 for his input and knowledge that aided us with our project, the depth of his technical knowledge was essential for us when making decisions regarding the programming. He helped to set out the initial coding of our arm during the December workshops in the University.

We would also like to acknowledge Student 9 for his guidance with the programming of the robotic arm after the loss of team member Student 8, who was supposed to be the primary programmer of the arm. He helped to further educate team members on how to program using Python.

We are particularly grateful to the University for their facilities and enthusiastic help and guidance during the December Workshop; and finally to EESW for this invaluable opportunity.

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Appendices

Process:

We began generating ideas way back in the induction day, almost immediately after meeting our link engineer and receiving our brief, as we were all enthusiastic and excited to start. However, our lack of technical knowledge and understanding of the brief quickly became apparent, and so we decided that extensive initial research had to be carried out by all team members on designated topics before any realistic decisions had been made. Here are some extracts from our research.

(1) Robotic Arms – What's out there?

There are many industrial robot brands. The largest ones will have a complete range of robots for different applications and at different sizes. The smallest companies usually target a specific size or application range. Examples of industrial robot brands are:

- Fanuc
- Motoman
- ABB
- Kuka
- Denso
- Adept
- Comau
- Kawasaki
- OTC Daihen {5}

Adept Technology – SCARA:

The robot shown at right is made by an American company, Adept Technology. Adept is America's largest robot company and the world's leading producer of SCARA robots. This is actually the most common industrial robot. SCARA stands for Selective Compliance Articulated (though some folks use Assembly here) Robot Arm. The robot has three joints in the horizontal plane that give it x-y positioning and orientation parallel to the plane. There is one linear joint that supplies the z positioning. This is the typical "pick and place" robot. When combined with a vision system it can move product from conveyor belt to package at a very high rate of speed

The robot's joint structure allows it to be compliant (or soft) to forces in the horizontal plane. This is important for "peg in hole" type applications where the robot will actually flex to make up for inaccuracies and allow very tight part fits. {1}

This type of configuration features two horizontal joints and a cylindrical work area. It is not intended for work in multiple planes, but rather precision within one plane. {4}

{2} Small SCARA video clip

Fanuc:

This is pretty much the typical machine people think of when they think of industrial robots. Fanuc makes this particular robot. Fanuc is the largest maker of these type of robots in the world and they are almost always yellow. This robot has six independent joints, also called six degrees of freedom. The reason for this is that arbitrarily placing a solid body in space requires six parameters; three to specify the location (x, y, z for example) and three to specify the orientation (roll, yaw, pitch for example).

If you look closely you will see two cylindrical pistons on the side of the robot. These cylinders contain "anti-gravity" springs that are a big part of the reason robots like these can carry such heavy loads. These springs counter-balance against gravity similar to the way the springs on the garage door make it much easier for a person to lift.

You will see robots like these welding, painting and handling materials. {3}

{1} http://www.learnaboutrobots.com/industrial.htm

{2} http://www.youtube.com/watch?v=aqOuaYxXRa4

{3} http://www.learnaboutrobots.com/industrial.htm

{4} http://www.thomasnet.com/articles/automation-electronics/industrial-robot-basics

{5} http://blog.robotiq.com/bid/63528/What-are-the-different-types-of-industrial-robots

(1) Why choose a robotic arm?

An industrial robot is defined by ISO as an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes. (3)

The use of a robotic arm would comply with our assignment aims in which the job must be made completely automated. A robotic arm would be a good choice as it is extremely versatile in the jobs that it can carry out and is therefore adaptable for many uses. The robotic arm will give the company a competitive edge in their manufacturing as it is a far more efficient means of transporting the goods to the loading bay and will increase the rate of which this process is carried out in the workplace. I addition to this The robotic arm will easily integrate into most spaces and will save the company money as labourers will not have to be paid to carry out the task.

How it functions.

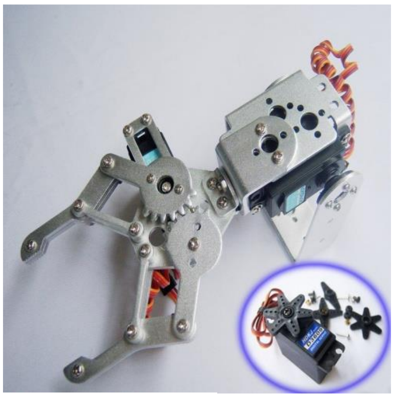
A typical robotic arm is made up of seven metal segments, joined by six joints. The computer controls the robot by rotating individual **step motors** connected to each joint (some larger arms use hydraulics or pneumatics). Unlike ordinary motors, step motors move in exact increments (check out Anaheim Automation to find out how). This allows the computer to move the arm very precisely, repeating exactly the same movement over and over again. The robot uses motion sensors to make sure it moves just the right amount. (4)

How effectively it is programmed

To teach a robot how to do its job, the programme guides the arm through the motions using a handheld controller. The robot stores the exact sequence of movements in its memory, and does it again and again every time a new unit comes down the assembly line. (4)

Research Claw ideas.

This style of claw has been used countless times by major industries due to its versatility and efficiency. Companies like KUKA have produced arms similar to these which provide 360^{o} rotation at base and extra rotations at the two other sections. In addition to this the grip or claw is completely interchangeable allowing for the transport of goods of varying shapes and sizes. The robotic jointed arms are also changeable to allow for the handling of payloads ranging from 5kg with a smaller scale device up to 1300kg with the use of heavy duty joints that would be perfect for palletising. (2)



Robotic hands often have built-in **pressure sensors** that tell the computer how hard the robot is gripping a particular object. This keeps the robot from dropping or breaking whatever it's carrying. (4)

The end effector, or robotic hand, can be designed to perform any desired task such as welding, gripping, spinning etc., depending on the application. For example robot arms in automotive assembly lines perform a variety of tasks such as welding and parts rotation and placement during assembly. In some circumstances, close emulation of the human hand is desired. (1)

(1) http://en.wikipedia.org/wiki/Robotic_arm

(2) http://www.kuka-robotics.com/united_kingdom/en/

(3) http://en.wikipedia.org/wiki/Industrial_robot

(4) http://science.howstuffworks.com/robot2.htm

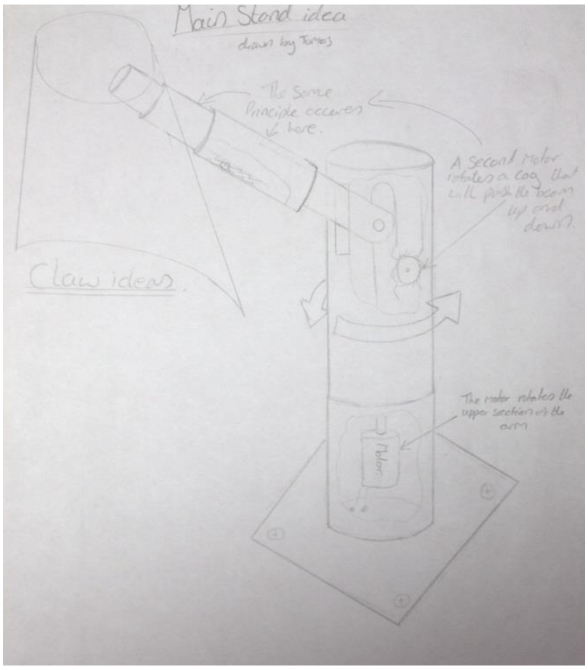
(2) Cost of Possible Solutions:

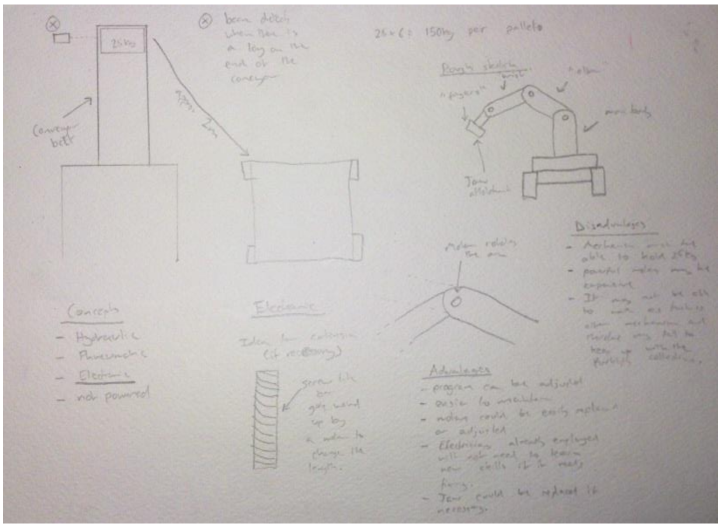
The size and type of conveyer belt that is required to fulfil to required job starts at approx £1030, however we must also add accessories such as emergency break/ stop, and adaptability to change speed which all add up to another, approx, £500 which needs to be added onto the original price. These prices are for each conveyer belt so the whole system is around £3060.These prices also don't include VAT or installation. (1)

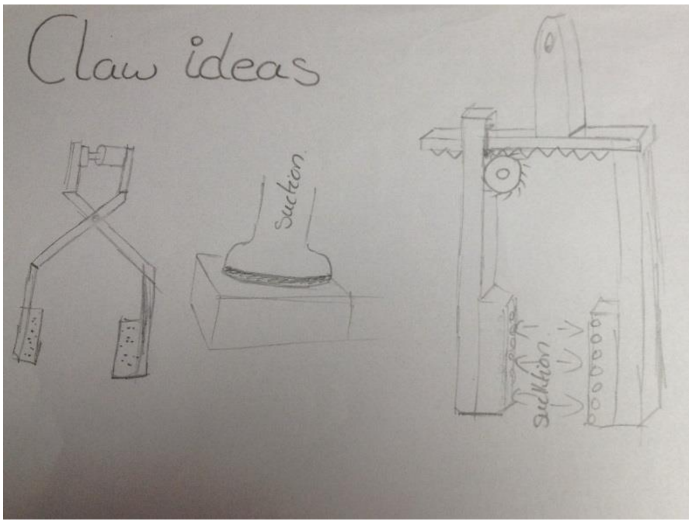
Small overhead cranes such as the image start from £5000 and can range up to and in access of £20,000. However some supplies are open to deals and discounts for installation and large deals. (2)

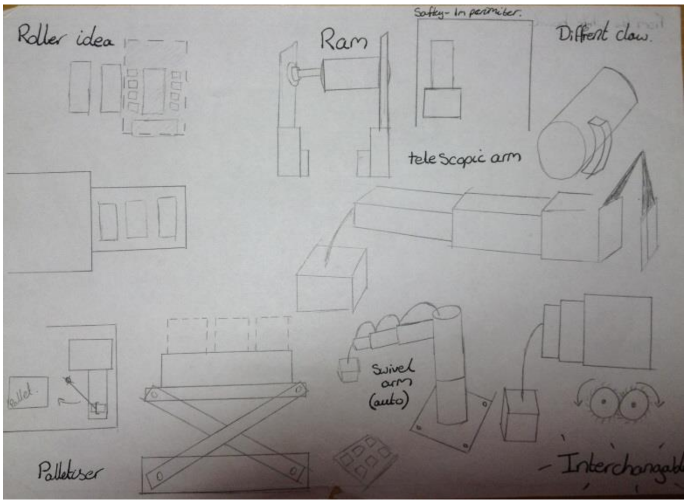
1. http://www.conveyorsdirect.co.uk/beltconveyor_prices.htm
2. http://www.alibaba.com/product-detail/new-product-LDA-single-beam-overhead_1119059143.html

We decided on holding regular team meetings to ensure that everyone was on-task and that we had a chosen solution in time for the December workshop. Early on meetings could be rather hectic; beginning as a large team of eight extremely enthusiastic members it could be difficult to maintain order with new ideas being rapidly generated by all members simultaneously. However once specific roles were allocated, each member had a specific focus and therefore sense of purpose in the team. Below are some minutes and initial ideas/sketches from some of our team meetings.









Meeting 3 Minutes – 06/11/13

Present:

Student 1	Student 4
Student 3	Student 6
Student 5	Student 7
Student 2	Student 8

Agenda:

>Develop initial ideas

>Explore realistic, possible solution options

>Discard certain ideas = closer to final solution

>Allocate team roles

Solution #1 (ROBOT)

>Needs to be fully programmable

>360 base swivel

>Multiple degrees of movement

>Base movement needed to reach pallet?

>Grabber arm undecided – very useful if this could be adapted (see spec)

Solution #2 (CRANE)

>Base moves in x plane

>Arm/crane moves in y plane

Claw Ideas:

>Suction pads or cups – this could be unnecessary for relatively low weight – could require high amount of energy = we want to be as sustainable/eco as/when possible

>Claw with rubber pads to increase friction and reduce slipping

>See sketches

Action points:

>More specific research needs to be done

>Allocate specific research tasks to team members