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Transport Carts for Production Lines

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Transport Carts for Production Lines

A Major Qualifying Project Report:
Submitted to the faculty of the
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in partial fulfillment of the requirements for the
Degree of Bachelor of Science By:

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Abstract

This project report discusses the problems with the Kanban Kit Carts that Caterpillar Suzhou Co., Ltd. (CSCL) uses to transport parts around its assembly facility. The carts are inefficiently organized and inadequately surfaced. These issues increase assembly technician fatigue and discomfort, as well as create unnecessary risk to the part finish and overall product quality. The team has redesigned the carts, including a new compartmentalization method and vertical storage area. These new features have been included on a prototype that will be tested by CSCL engineers for possible implementation.

Acknowledgments

We would like to thank Professor Rong for being our advisor throughout the last two months, and for his valuable input and guidance throughout. We would also like to thank Professor He and the other HUST faculty for their help with finding us room to work in, and their input in the project.

The project itself could not have existed without the engineers and managers at Caterpillar Inc.: Paul Watts, Lina Chang, and Jack Liu. In addition to providing us with the project itself, they have also helped throughout by giving us necessary information, drawings, and assisting with our travel arrangements.

Executive Summary

Caterpillar Incorporated is a worldwide leader in industrial machinery design and production. They operate through all phases of their industry, from design to client satisfaction. One of Caterpillar's many world-wide facilities, Caterpillar Suzhou Co., Ltd. (CSCL), has been experiencing some issues with a number of their assembly line transportation carts. The carts are inadequately surfaced, somewhat inefficiently organized, and not as ergonomic as CSCL would like. Our team was tasked with redesigning these carts to better suit the facility's needs.

Our team researched possible solutions to these issues, uncovering several fixes. Once in China, the team acquired samples of surfacing materials, chose a new expansion method, and developed a new compartmentalization method for the design. We then decided to pursue two separate concept designs and began to create them around our chosen methods. One design was non-expandable, with whole compartments for each part, and vertical slots with mating compartments on the bottom for the longer, flat parts. The second was expandable with an opening shelf, compartments made of small tabs, and a full length, vertical storage bin design concept.

Of these two designs offered to the sponsor, one was chosen with some conditional criteria. We were asked to make our tab compartments adaptable in case the parts included on each design were changed at any point. Also, the vertical bin needed to be more ergonomically accessible, so a gate system was added for easier part access. Once the sponsor authorized the new design, we contacted a subcontractor to machine and assemble the necessary parts, and another to surface the prototype.

Due to manufacturing difficulties, our team was unable to test the prototype, so instead Caterpillars engineers were supplied with a list of recommendations. These involved testing and analysis instructions, as well as a general suggestion to start an internal CSCL project. The project would determine the feasibility of either finalizing and implementing a new design, or adapting the original carts to employ the new concepts present on the prototype.

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1. Introduction

Caterpillar Incorporated supplies the global market with a variety of different industrial machines, including backhoes, dump trucks, and even industry specific equipment for tree harvesting and roadway paving. In order to supply the growing economy with these machines, Caterpillar must fabricate, assemble, and ship them according to demand, around the world, as quickly and proficiently as possible. The team worked with Caterpillar Suzhou Co., Ltd. (CSCL) at one of their assembly plants. In order to efficiently assemble the machinery and ship it around the world for sale, CSCL has employed the Kanban methodology of attaining a just in time (JIT) environment.

The methodology calls for a system by which inventory is kept at a minimum, assembly supply as necessary, and speed at a maximum. Part of the Kanban methodology uses Kanban kit carts to achieve this state of efficiency. Each cart is custom designed for each assembly process; however the CSCL carts are inadequate in two aspects. Firstly, the improper surfacing on the carts makes them difficult to clean, which has lead to a waste of packaging material, used in an effort to protect the finished parts they transport. Secondly, it is difficult to access the parts and space is being wasted due to an inefficient organization scheme.

Due to these inadequacies, the team was tasked with redesigning the carts. To help the team accomplish this assignment, several objectives were created. In order to reduce the waste of packaging material, the team found a suitable, cost effective paint protection method. The protection method left the carts pressure washable, and met Caterpillar's contamination requirements. Additionally, the design allowed for easier access to the finished parts, and used space more efficiently, which kept the assembly process running fluidly. With these objectives in mind, the team developed a procedure by which we accomplished this task. The team compared several researched paint protection methods and chose the most effective option. Additionally, the problems associated with the current design were explored to further define the ergonomic design flaws that had lead to these problems. This helped the team design and prototype a possible replacement choice.

2. Background

2.1 Problems

The major problems associated with the current cart design stem from two areas: the ergonomics and the surfacing of the cart. The carts' current shape causes an underutilization of its space, as well as a disorganization of the parts stored on it making them difficult to reach. These problems have resulted in wasted time. The current surfacing of the carts does not provide sufficient protection to the parts they carry, and have also proven difficult to clean. These problems have caused a waste of money and materials for Caterpillar.

2.1.1 Ergonomics and Organization

Figure 2-1 Disorganized Cart

Figure 2-1illustrates a poorly organized cart. The shape of the parts shown above has created a waste of space on the cart. The shape of the parts to be placed on each cart should be more carefully considered; more parts should be able to fit, and should be more easily reachable to save time.

2.1.2 Cart Surface

Figure 2-2 Wasted Packaging Material

The surface of the cart in the above figure does not provide adequate protection from abrasions and impacts. To protect the parts, additional packaging material is being used. The use of this material is wasting time and money for CSCL. The carts should provide enough protection so that money and resources are not wasted.

Figure 2-3 Ineffective Rubber Adhesive

The protective materials currently on the cart are not able to withstand the pressure washers being used. As figure 2-3 above illustrates, the adhesive bonding the rubber mats to the metal cart structure is inadequate and has failed on this specific cart. The carts should be able to be quickly cleaned and put back to use.

2.2 Kanban Method

"Kanban" is a term originating from Japan in the 1980's (Wang, 485). Literally translated to "visual cards", it refers to a system by which the JIT (Just in Time) methodology may be applied. For example, if an assembly line finishes one pallet of supplied parts, a certain card is then attached to the cart. The cart is placed at the empty cart post, wherefrom it is transported to the part supplier with the information attached. The supplier reads the cards attached to the carts, and reloads the carts accordingly. With this methodology, no assembly line runs out of parts, and no line becomes over-encumbered by excess parts, keeping the plant operating at maximum efficiency at all times. This, most importantly, allows the minimum of part inventory to be maintained. This process is visualized in the figure below:

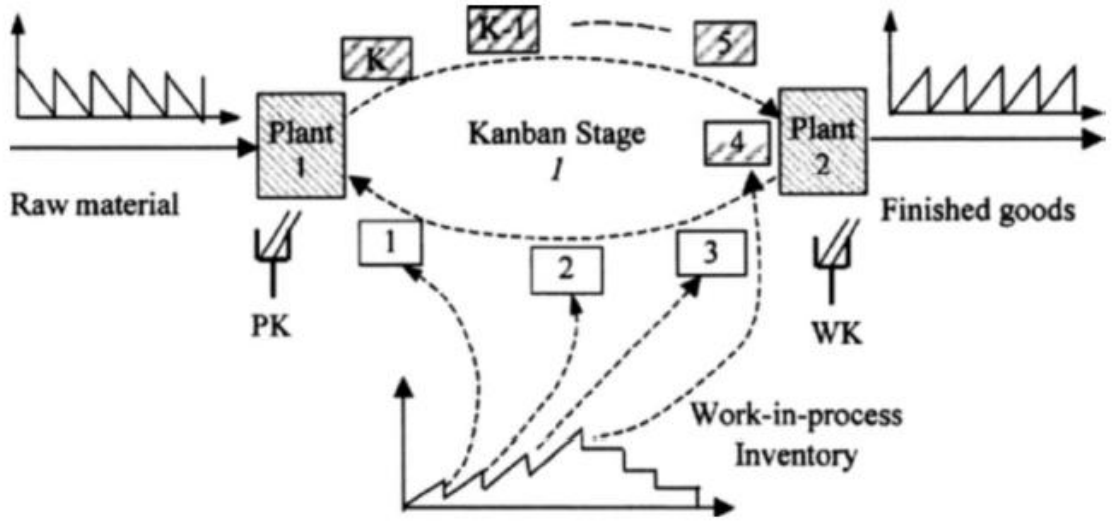


Figure 2-4 Single-stage Kanban Supply Chain System (Wang, 486)

The diagram illustrates the flow of raw materials into the processing plant, through to the assembly plant. The white boxes (1, 2, 3) represent transport devices to be filled with parts, and are called withdrawal Kanbans. The hatched boxes (K, K-1, 5) represent Kanbans that are transporting parts to the assembly lines, and are called production Kanbans. When the Kanbans are emptied, they then become withdrawal Kanbans, and are placed at the withdrawal Kanban post (WK) with a “visual card” requesting certain parts for further production. These are then transported to the production Kanban (PK) post and filled with the appropriate parts according to the "visual card".

2.3 Paint Protection Methods

One of the major issues associated with carts is the ability to protect the surfaces of the parts they carry. At the moment, the parts need to be covered in extra materials, like bubble wrap, to provide appropriate protection. Some surfaces of the cart have rubber pads attached to them to help avoid abrasions. However, the method of adhering the pads to the carts breaks down over time, especially after being washed. To solve these problems, the team came up with several ways of coating the carts.

2.3.1 Elastomer Coatings

The first method the team researched was polyurea elastomer coatings. These coatings are often sprayed onto the beds of pickup trucks as liners. While many businesses providing this sort of coating concentrate on pickup trucks, most of them also offer coatings specifically for industrial environments.

Depending on the formula used, this method can provide impact, abrasion, and chemical resistance, as well as waterproofing. Most of the formulas provide protection to each of these elements, but in different amounts. In order to supply this protection, the appliance is coated in a mixture of polyurethanes and a curing formula, and the substance is allowed to cure. Common durometers (hardness measurement) of this material would be in the area of 60-70.

One of the companies that were contacted informed the team that the cost of their product would be high due to the process of applying the coat. Some suppliers said the solution would have to be applied at one of their locations, others said that it would be possible to apply it without going to them, but it would be necessary to purchase a spraying device. These devices are also expensive. According to Ameron Coatings, the components of the formula itself tend to come in three 55-gallon buckets, and weigh a total of approximately 740 kilograms.

2.3.2 Heat-Shrink Tubing

Another method that was researched is thick-wall heat shrink tubing. These tubes are made from thermoplastic materials like polyolefin, fluoropolymer, PVC, neoprene, and silicon elastomer. This tubing is commonly used in electrical applications. Normally it is applied to insulate, seal, and bundle wires, as well as provide protection from abrasions, moisture, and dust.

To apply heat shrink tubing, a tube is placed over the material to be covered. Then, a heat source, like a heat gun or oven, is placed near the tubing. This heat can make the tube shrink up to one sixth of its original diameter. The friction between the tubing and the material it is being attached to keeps it in place. If heated close enough to its melting temperature, the tubing can fuse to the underlying material, providing a better seal. Some tubes include an adhesive surface on their interiors, which allows for a good seal to be made without heating the tubing as much.

Even thick-wall tubing is thin compared to the other abrasion-resistive surfaces that were looked at. Among heat shrink tubing's disadvantages is the minimal impact resistance it provides. Since the parts to be carried on the carts are still unknown, the thin covering may not provide adequate abrasion protection. As the tubing needs to wrap around the object it covers, it would be impossible to cover flat planes on the cart. Testing would be necessary to determine if it is possible to power wash the heat shrink tubing as well.

2.3.3 Adhesive Rubbers and Polyurethanes

Another simple product that was researched was adhesive-backed rubbers and polyurethane products. Unlike the elastomer coatings mentioned before, this application comes in strips, and can be placed on surfaces like tape. 3M Bumpon Rollstock and Continuous Strips are among the brand names of this product.

Products similar to these appear to be used on the current versions of the carts. The adhesive on the rubber is wearing down, due to age and water. Among the adhesives that are available for these products are acrylic, natural rubber, and synthetic rubber. Some of these adhesives may have better resistances to elements like water, but testing would be necessary to determine if they are better than what is currently being used.

2.4 Caterpillar Contamination Requirements

The final design for this project must adhere to a set of contamination requirements. These are detailed in the Benchmarking Guide for Contamination Control – Reference Guidelines. Many of the requirements are concerned with keeping surfaces clean. All surfaces should be kept clear of dust, debris, and other contaminants. Other sections concern themselves with ensuring that components are stored correctly, and that parts are properly protected.

3. Methodology

The team has developed a general methodology for our approach to solving the issues associated with the original carts. Our efforts focused on addressing the main problems with the current carts by: 1) Developing a new organizational and ergonomic methodology with a suitable scheme, 2) Assessing the researched surfacing methods to find an applicable choice which will sufficiently protect the finished parts and meet Caterpillars contamination requirements, and 3) Producing a new cart design and a prototype which met the following specifications:

- Carts must be 30 percent more space efficient
- Ergonomics of the cart must meet CPS standards
- Wheels must not slip into the assembly line tracks or jostle when going over them
- Carts should be surfaced to prevent damage to finished parts
- Carts must meet Caterpillar's contamination requirements
- Carts must be pressure washable
- Carts must be roughly the same footprint as the original
- Carts must be made from the same 2mm steel sheet as the original

Developing an organizational methodology involved considering the currently used method, our researched methods, our examinations of the carts, and input obtained from the assembly technicians. The team combined the results from the work performed in association with cart ergonomics to produce an organizational scheme reduced technician access time and difficulties. This helped the team meet several of our specifications.

A sufficient protection method was selected by inspecting the currently applied rubber and its inadequacies. These inadequacies were checked against those of the researched methods, and the best option was selected for testing. Once the method successfully completed testing, it was integrated into the final prototype design.

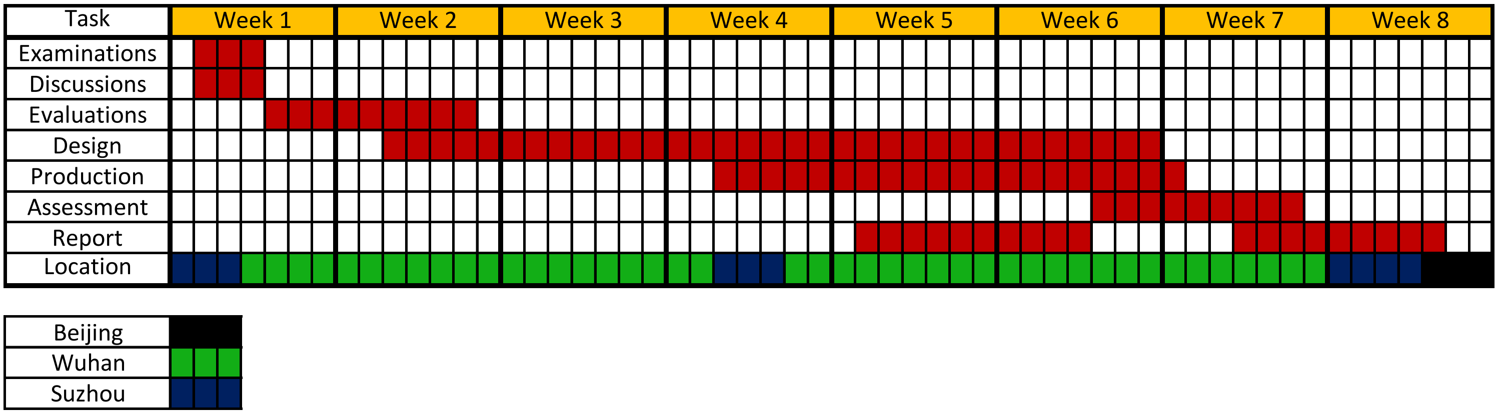
Once the organizational scheme was created, and a surfacing method had been chosen, both were tested and the team began to design the physical structure of the cart, and all necessary accessories, around the selected methods. This entailed giving due attention to all of the short comings of the chosen solutions.

Once the necessary designs were created, the team presented them to the sponsor. Given authorization, a contractor was hired to construct a prototype; which was then tested and compared to the teams developed specifications as listed above and the results obtained from the original carts. The test results were then analyzed and presented to the sponsor, as well as included in the Results and Conclusions sections of this report as a way of measuring the success of the project.

4. Procedure

The following procedure was created to achieve the general project objectives with the above discussed methodology. This was accomplished through the five main processes listed below, according to the timeline listed below:

1. Discussion of the original design inadequacies with the assembly technicians.
2. Ordering of samples of researched paint-protection methods for testing.
3. Evaluate the obtained technician responses and testing results to select or develop the best methods.
4. Design a new cart, unifying the chosen solutions.
5. Create a prototype for testing and project assessment.



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Discussions		🟥	🟥	🟥																																																				
Evaluations					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥																																											
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Beijing	⬛⬛⬛
Wuhan	🟩🟩🟩
Suzhou	🟦🟦🟦

Figure 4-1 Project Timeline

4.1 Discussion with Assembly Technicians

Being that the assembly technicians are the people who use the carts, and will be the ones using the new carts (should they be adopted), the team gathered as much information from them as possible. This was done with one main method: informal interviews/discussions.

The team had discussions with several assembly technicians. The sessions were conducted as structured conversations that focused on the problems described in the background section of this report. The team attempted to glean as much information as possible about what might have been the underlying causes for the organizational difficulties being experienced with the original carts. This information was then used, with the information obtained from the examinations and research, to help the team develop a suitable organizational methodology.

4.2 Examining the Current Carts

In order to fully understand the design flaws with the current carts, the team determined all of the issues that are creating the existing problems on the assembly lines. To do this, we first selected a number of the more problematic carts: G03A, G13A, L10A, L04D, L06A, L13A, L17A, and L21A. We then inspected these carts closely and obtained their part lists. This effort uncovered useful information that aided us in deciding which methods to use in our designs.

4.2.1 Ergonomic and Organizational Issues

The team examined the problems concerning ergonomics. Determining why some parts were difficult to remove was explored first. The unfinished surfaces of the cart were noted, as well as varying heights and weights of some of the more problematic parts. This assured that the new design would not experience the same difficulties with part loading and unloading.

The team then explored why the parts were difficult to organize on the cart. Similar to the problem outlined above, the size and shape of the cart were considered with respect to the organizational issues. The team considered adding new structures to compartmentalize the cart. This was seen as a viable option for possibly improving the carts safety and space efficiency, and it was decided to employ this in our designs.

4.2.2 Rubber Surfacing Method

The surfacing method employed on the original carts was inspected, and the rubber's ability to protect the parts from scratches and dents was determined. We did this by examining the surfaces roughness and cleanliness.

The team also inspected the exposed metal areas of the cart and determined that this is one of the reasons that it has proven to be an ineffective method of protection. This was done by comparing the parts being placed on and removed from the cart, and whether or not it was likely for them to come into contact with the exposed metal. Notes were taken when potential problems were identified. Knowing this allowed the team to prevent the reproduction of similar issues within our own designs.

4.3 Evaluating Surfacing and Organizational Methodologies

The team organized, analyzed, and documented the obtained information from the inspections, as well as that from the assembly technicians. This was then used in choosing a final paint protection method, and designing an organizational methodology. These choices were then tested and presented to the sponsor.

4.3.1 Ergonomic and Organizational Methodology

Some possible solutions were brainstormed and entered into the decision matrix shown below, which helped the team analyze and quantify each methods advantages and disadvantages.

	Building Simplicity 10%	Maintenance 20%	Ease of Use 30%	Expense 20%	Ease of Ergonomic Design 10%	Space 10%	Weighted Average
Swinging Top	9	8	8	9	6	8	8.1

Raising Levels	6	6	6	7	8	9	6.7
Drawers	6	5	8	8	5	6	6.7
Split levels	7	5	6	8	5	6	6.2
Non Expandable	10	10	4	10	10	9	8.1

4-1 Ergonomic Decision Matrix

Since ergonomics and organization are top priorities at Caterpillar, and are the focus of the redesign, the ease of use category was given a thirty percent weight. Because any maintenance performed on the cart would cause downtime and additional cost, it was weighted with twenty percent; and vice versa for the cost column, since it is a concern to Caterpillar, but will only be a one-time expense; it was given a twenty percent weight. The ease of ergonomic design and building simplicity criteria were of little concern and would only one-time issues, so they were each given a ten percent weight in the decision. The space change when expanded was also, comparably, of little concern and only received a ten percent weight.

Several of the better options were chosen for presentation to the sponsor prior to the beginning of the design phase. With the sponsors feedback on the methods, the team then decided to proceed with two separate designs; one expandable, and one non-expandable. Both designs were incorporated with their own method of compartmentalization; full or tabbed, as illustrated below:

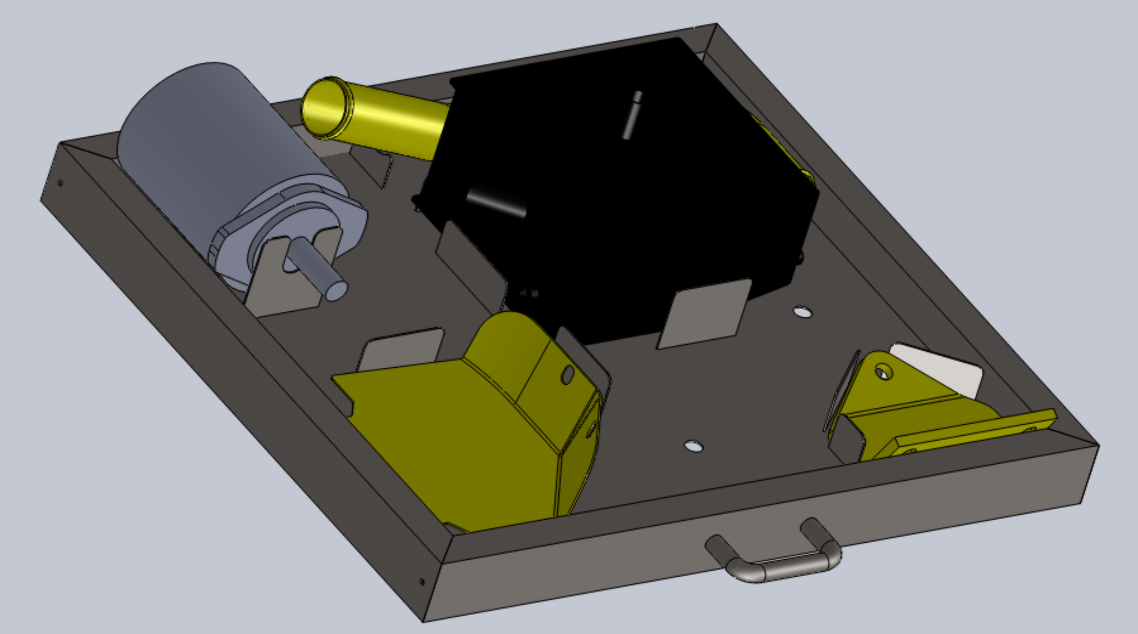

Figure 4-2 Tabbed Compartments

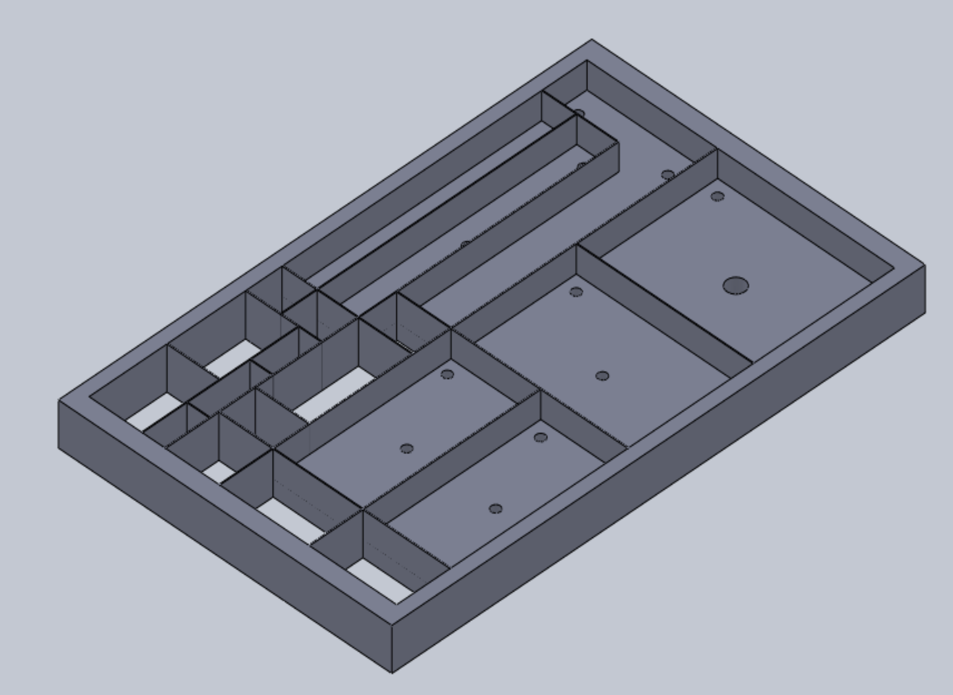

Figure 4-3 Full Compartments

4.3.2 Surfacing Method

Using criteria obtained from the team's examinations and research, the different surfacing methods were also put into a decision matrix. The decision matrix (listed below as table 4-2) contains all of the criteria that CSCL had expressed to us as necessary to them when considering the implementation of a new method.

	Application Difficulty (10%)	Cost (20%)	Abrasion Protection (40%)	Impact Protection (40%)	Lifespan (20%)	Weighted Average
Polyurea Elastomer	10	4	9	9	9	8.31
Heat-shrink Tubing	2	9	6	6	6	6.15
Polyurethane Pads	9	7	8	7	8	7.62

Table 4-2 Surfacing Decision Matrix

Since the function of the surfacing material is to protect the parts from being damaged, abrasion protection and impact protection received a forty percent weight. The application difficulty is a one-time issue, so it only received a ten percent weight. Though cost is important, it is also only a one time issue and was given a twenty percent weight. The lifespan of the material was also important, as it must last long enough to warrant its use; it was given a twenty percent weight as well. The decision matrix yielded one clear choice – polyurea elastomer, the spray-on rubber option.

The team contacted the suppliers (obtained prior to arrival) to order samples of the chosen protective method. The samples obtained were of varying hardness, and were from several different suppliers. The sponsor was presented the samples and specifications of the polyurea elastomer and a specific hardness was selected. The assorted samples are pictured below:

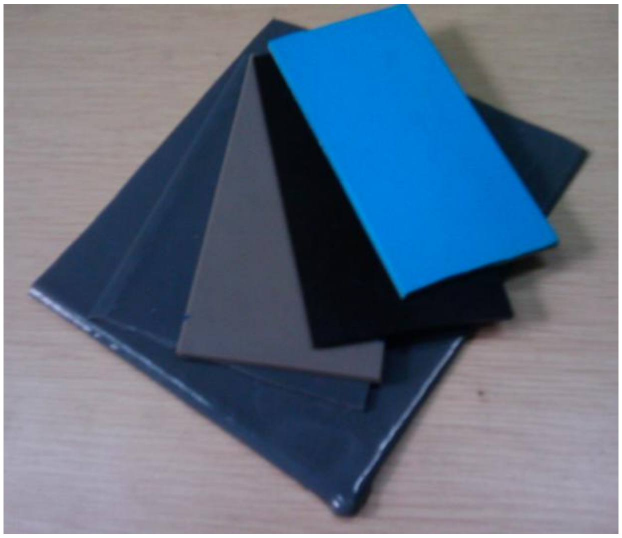

Figure 4-4 Surfacing Samples

4.4 Cart Design

The team decided to initially concentrate on redesigning one cart for prototyping. We selected L06A due to its relatively high number of parts to carry, as well as their variation of size and shape. The team then chose to create one expandable and one non-expandable design, each with one of the two compartmentalization methods discussed above.

The structure of the concept designs was the same as the original carts: a 2mm thick steel sheet. Also, the shape of the shelves and load bearing structure was kept from the original carts: 40mm square cross-section vertical pillars and horizontal crossbars for the structural supports and 40mm by 80mm cross-sections for the shelf rims. The shelves were mounted onto the vertical pillars with 8mm bolts that would thread directly into the shelf. The bottoms of the vertical pillars were welded to the bottom assembly (which had the same rim cross section as the shelves). This is illustrated for the expandable and non-expandable proposals in appendices A & B.

4.4.1 Concept A: Non-Expandable with Full Compartments and Vertical Slots

Since it was a non-expandable design concept, the first design was more similar to the original carts. This was a major advantage of the design; since there were no moving parts, there were fewer parts to wear out giving it a lower lifetime cost and need for maintenance. By creating the new design for its specific assembly task, the team was able to form compartments for the each specific part, allowing all of the parts to be stored on the top level in a more efficient and organized manner. The design also stores the heavier parts on the perimeter of the cart, in order to reduce technician fatigue further.

Many of the parts were held vertically in their own individual slots. Since there was no second level on the cart, there was also no need to bend over or reach to remove parts. Despite these advantages, the design was more crowded than the second design, which made placement of parts an issue. Another problem with this concept was placing the parts vertically. The open slots left an opportunity for parts to come into contact with other parts as they were placed in their footings on the bottom shelf. This would damage the parts and make the jobs of the technicians and warehouse workers more difficult, but would save on the cost and cleaning time of each cart.

4.4.2 Concept B: Expandable with Tabbed Compartments and Vertical Bin

The expansion method that the decision matrix had shown to be the most viable was the opening top concept. The parts on this design would be at roughly the same height as the parts in the original carts. However, since the cart can be opened up, there would be less need for the workers to lean, bend over, squat, or get into otherwise uncomfortable positions that reduce technician productivity and safety. This concept is illustrated below:

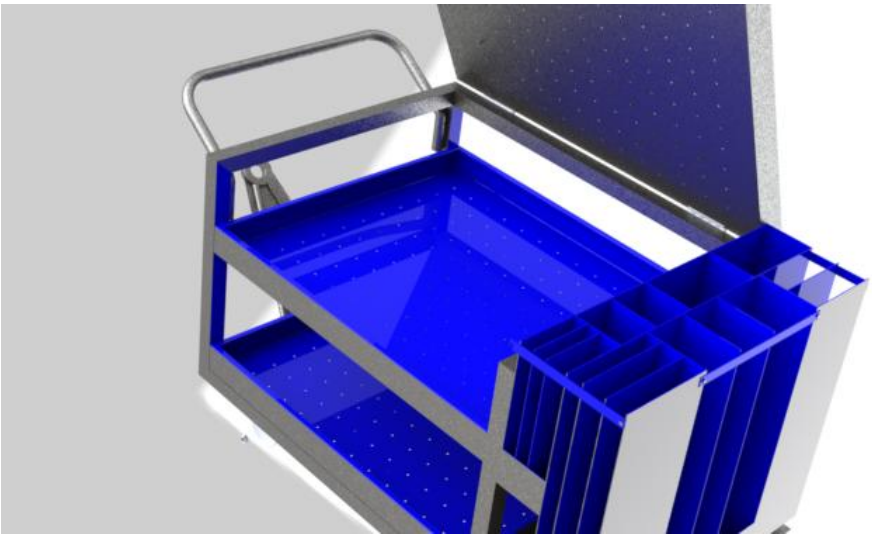

Figure 4-5 Rotating Shelf

The long, flat parts would be placed vertically in a separate section. The vertical compartments on this design would run from the top shelf of the cart to the bottom of each part, allowing for no interference between parts below the top shelf. Though this would not experience the same part interference issues as Concept A, it would be more complicated and expensive to machine, surface, and clean. Another innovation included in this design was the use of tabbed compartments, these were welded into place on each shelf, designed to hold its specific part only. This offered a very tight fit, and would solve the issue of the parts jostling around and the possibility of them falling off of the carts.

4.4.3 Prototype Design

The concept designs were presented to the sponsors, who provided the team with feedback that allowed us to generate a final prototype design. The expandable option was selected with the use of air springs on the hinged top for safety purposes, and the tabbed and vertical bin compartment methods were selected with some suggestions. The sponsor expressed concern about parts rubbing along the rubber surfacing as they were lowered into the vertical compartments, and suggested using one open side with a gate to hold the parts in place. This concept is demonstrated by the figure below:

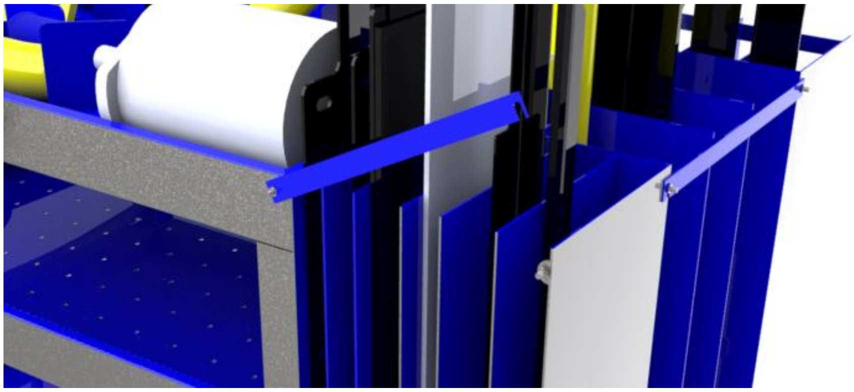

Figure 4-6 Prototype Gates

The sponsor also suggested attempting to make the tabbing adjustable in case the parts transported by the cart were changed at some point. In order to accomplish this, a grid of holes would be drilled into the bottoms of each shelf. Each tab would have several threaded pins on the bottom that would fit into the holes. The tabs can be fixed in place by threading a nut onto the pin, underneath the shelf. To work with the various shapes and sizes of parts, tabs of several lengths and widths were designed, as well as some capable of being placed diagonally. This is shown below in figure 4-7:

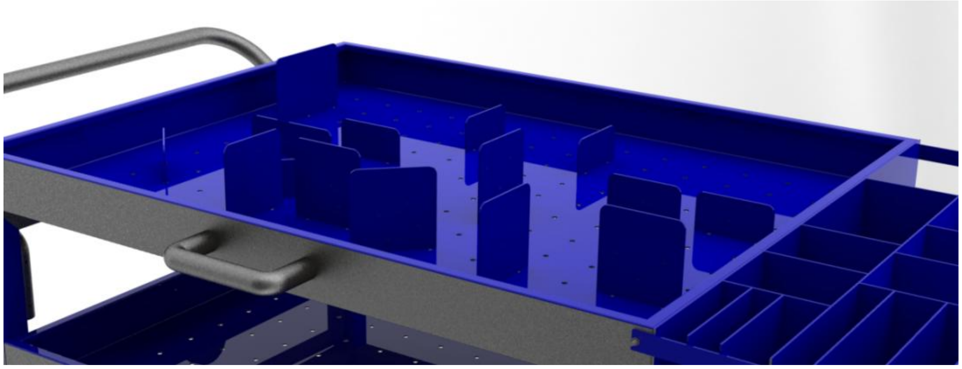

Figure 4-7 Prototype Tab Compartments

4.5 Prototyping

The prototype design was presented to the sponsor, and then forwarded to Suzhou QiHang Precision Machinery Co., Ltd (the manufacturer of the original carts) for machining. Upon completion of its construction, it was shipped to Lumeng Waterproofing and Anti-Corrosive Material Co. Ltd in Shandong Province for surfacing. It was surfaced with 60HA hardness, spray-on polyurea elastomer; Lumeng model number LM-SPUA904. Its specifications are shown below:

Model #	LM-SPUA904
Company	Lumeng
Hardness	60HA
Adhesive Attraction	8MPa
Tensile strength	20MPa
Density	1.02g/cm3
Water resistance	0.3Mpa/0.5h
Recommended thickness	1-3mm
Application method	Spray

Table 4-3 Prototype Surfacing Specifications

5. Results

5.1 Space Efficiency

Originally outlined by the sponsor, a space efficiency improvement of at least thirty percent was necessary. The space efficiency was split into two categories: horizontal and vertical. Since the carts would have to remain roughly the same size, the team has defined the horizontal space efficiency as the ratio of unused space to total space, or $E_H\% = \frac{S_{Unused}}{S_{Total}}$, expressed in a percentage form. The unused space is also equal to the total space minus the used space, or $\frac{S_{Total} - S_{Used}}{S_{Total}} = 1 - \frac{S_{Used}}{S_{Total}}$, which is what the team actually calculated for the carts. The total space, S_{Total}, was defined as being the sum of all of the shelving space available; and the used space, S_{Used}, was defined as the area of each part that was parallel to the surface of the shelves, as the blue shaded area in figure 5-1 illustrates:

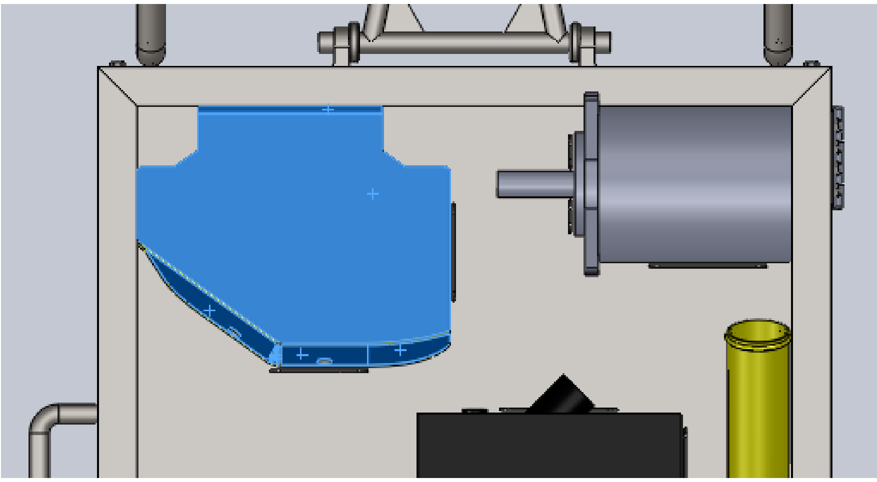

Figure 5-1 Used Space

The improvement in horizontal space efficiency was calculated by dividing the change in space efficiency by the new carts efficiency: $\Delta E_H \% = \frac{\Delta E}{E_N} = \frac{E_N - E_O}{E_N} = 1 - \frac{E_O}{E_N}$. Since the vertical portions of the cart carried more parts, and were decreased in their overall size, we defined the vertical space efficiency improvements as the change in size, divided by the original size: $\Delta E_V \% = \frac{\Delta S}{S_O} = \frac{S_N - S_O}{S_O} = 1 - \frac{S_N}{S_O}$. The team achieved its space efficiency improvement goals for the prototype with a horizontal improvement of 33.23 percent, and a vertical improvement of 55.20 percent. The numbers for these calculations are provided in appendices D through F The figure below shows the space efficiency improvements for Concept A, Concept B, and the prototype respectively:

E_{AH} (%) = 27.90%
E_{AV} (%) = 34.92%
E_{BH} (%) = 26.68%
E_{BV} (%) = 33.69%
E_{PH} (%) = 33.23%
E_{PV} (%) = 55.20%

Table 5-1 Space Efficiency Improvements

5.2 International Experience

In addition to the technical difficulties presented by this project, the team faced many other challenges. The language barrier proved to be an obstacle every day. The two team members from WPI spoke only English. The four team members from HUST spoke Mandarin Chinese as a first language, and while they were proficient with English, some things were lost in translation. Thought exchanges would occasionally take far more time than necessary to complete. When gathering information from technicians and suppliers, the Chinese team members were the only ones who could be part of the discussions. Before a conversation would start, the team would have to meet to make sure that nothing was forgotten during the discussions.

Communication outside of the project was also a problem. Simple tasks, like navigating the city, doing laundry, and getting food were sometimes difficult. Few people that the team interacted with spoke English, and many signs had only Chinese characters on them. Thankfully, the Chinese partners were often able to translate or otherwise help in these situations. In time, many of the tasks became easier, and the partners from WPI could accomplish them by themselves. As a result of these challenges, the team has gained valuable experience working internationally with people that do not necessarily understand common American phrases. This experience has made the team comfortable in an international work environment and is something we would be happy to do again.

The distances between the team, the advisors, and the sponsor also provided a unique challenge. While the team never had to wait very long to get answers to problems, and the requirements of the project were clear, getting answers to questions in real time was a fairly rare occurrence. Meeting with advisors happened every few weeks. In order to meet with the sponsor, the team would take overnight trains, and have to stay in hotels. As a result of this, we spent most of our time on our own, which taught us how to be self motivated.

6. Conclusions

6.1 Technical Conclusions

Without having a finished prototype to evaluate, it is difficult to know whether or not we successfully completed the project. However, all of the specifications that the team outlined were met:

1. Carts must be 30 percent more space efficient. This requirement was met and exceeded. In the horizontal direction, the prototype is a 33.23 percent improvement on space efficiency. In the vertical direction, it is a 55.20 percent improvement on space efficiency.
2. Ergonomics must meet CPS standards. We met this specification by adding the hinged top level of the cart, which allows easier access to the lower levels, and the gates, which make accessing the vertical parts easier.
3. Wheels must not slip into tracks or jostle when going over them. This requirement was met by the new six caster design.
4. Carts must be surfaced to prevent damage to finished parts. This requirement was met by coating the cart with a softer, more easily cleaned material than was used previously.
5. Carts must meet Caterpillar Contamination Requirements. This requirement was met by applying a more easily cleaned surfacing material and drainage holes to remove cleaning fluid.
6. Carts must be pressure washable. This requirement was met by replacing the adhesive rubber pads with a spray-on rubber surfacing material.

7. Carts must be the roughly the same footprint as the original carts. This requirement was met by keeping the cart dimensions at 1.2 meters long by .75 meters wide, not including the handle and trailer hitch. When the cart top swings open, the width increases by a minimal amount.
8. Carts must use the same 2 millimeter steel sheet as the original carts. The same 2 millimeter steel sheet construction was used for the new cart.

6.2 Social Conclusions

The major challenge associated with this project was working with the subcontractors to have the prototype constructed. While there was supposed to be a completed cart at the end of the project for us to test, there was a communication issue when the team met with the manufacturer, which caused the prototype to be completed later than expected. The manufacturer took longer than anticipated to machine and assemble the prototype, and used a shipping company that failed to ship the prototype within the promised timeframe.

There are several places that this disconnect could have occurred. It might have happened when the students from WPI and the students from HUST were discussing what to tell the manufacturers. We might not have completely understood each other, and as a result, the HUST team members did not stress the importance of our time frame to the manufacturer, causing the time delay. If everything was discussed between team members and nothing was forgotten or misunderstood, then the problem might have been that the manufacturer simply did not understand the tight time frame we supplied him with. It is also possible that the manufacturer simply under estimated the time necessary for machining and assembly, or did not know how long it would take to ship the cart.

The manufacturer was contacted on a regular basis to check the status of the cart, but we still don’t know for sure where the problem originated. In the future, the best solution would be to write down everything necessary to be conveyed, and maintain continual communication with the subcontractors to ensure that any problems encountered are dealt with as swiftly as possible.

7. Recommendations

Since the team was unable to test the prototype, there is more work left to be done before creating a final production design. We would suggest that CSCL do two things, 1) test and analyze the prototype when it arrives, and 2) create a project within CSCL to either produce a final production design, or adapt the concepts used in the prototype to the original carts.

Several things should be done to evaluate the effectiveness of the prototypes new concepts. Foremost is to check the functionality of the moving parts; the hinges, air springs, and gate mechanisms. A simple tolerance issue could cause any of these three devices to function poorly, or not at all. Then the prototype should be presented to the assembly technicians, who should be asked to provide critiques of its concepts. Also, the prototype should have the tabs fitted as necessary, and loaded with parts so that the jostling and part stability issues can be checked.

A major part of this project, and the team's redesign, was the new surfacing material. This should be checked by using the power washing equipment to clean the prototype as prescribed by the CPS contamination standards. Following cleaning, the surfacing material should be checked for any failure points; either detachment from the substrate, or surface tearing. The effectiveness of the drainage holes incorporated in the design should be checked; there should be minimal pooling and/or puddling in the compartments of the prototype. Once it is sufficiently cleaned, the surfacing material's protective effectiveness should be tested. We would suggest using some discarded or sample parts to try and scratch or dent them on the surface.

This data should then be analyzed by a small project team within CSCL. This team should then determine the effectiveness of the concepts applied to the prototype, and determine the feasibility of implementing new carts or adapting these methods to the original carts.

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