DESIGN OF SHEET METAL HANDLING SYSTEM AT BRISTOL AEROSPACE LIMITED

MECH 4860 – CKW Design Group (Team 3)

Final Design Report

Submitted by:

David Costigane
Chuan Wu
Seval Karaman
Jian Wu

Team Advisor: Prof. J.M. Symonds

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Abstract

This report is about the improvement of Bristol's sheet metal handling system by CKW design team to reduced scratches and dents in sheet metal. These scratches and dents result in waste material or high rework by the company. In addition lots of time and money is wasted. This report includes a background about the problem and the general background about the company Bristol. Customer requirements and meetings are documented within the report to support recommended design decisions. Six recommended designs are listed within the report, to eliminate Bristol's problem of scratched and dented sheet metal. There is not one design that can solve Bristol`s problem therefore most, if not all of the six recommended designs should be implemented to reduce scatched as much as possible. Many tools for decision making can be found in the appendices. CKW design team found these tools very useful in making a decision and weighing the specific factors that were important to Bristol. The end result is six recommended designs that are believed to be a beneficial solution for Bristol with a positive outcome.

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1. Introduction

This design report discusses current problems with the sheet metal handling system at Bristol Aerospace Limited. Within the report, there will be a brief background of the problem as well as a background of the company, Bristol. Following the background will be the objective that will clearly state the purpose of this project and report and what was done to achieve the end result. It was important to address the customer's requirements and target specifications to meet the objective, therefore these two sections will follow the objective. The second last section of this report will list and discuss six recommended designs. The combination of these six designs will benefit Bristol greatly. There is also a detailed discussion about the function and cost of each design. Finally, everything will be brought together with the conclusion, which states how the recommended designs meet the objective of this project.

It should be known that the specific solution to Bristol's problem could not and cannot be achieved by only one recommended design. Therefore six designs were chosen, and most if not all designs should be used together to reduce Bristol`s problem as much as possible.

The Appendices contain the tools used by CKW design team to keep on task as well as make a good decision on designs. These tools are a screening matrix, Gantt chart, and decision matrix. The screening matrix allowed the group to weigh the criteria of each design by a +, -, or 0. The Gantt chart was a tool used to keep the team and the progress of the team on task. Finally, the decision matrix, like the screening matrix, was a tool to weigh criteria of each design through a numbering system, 1 to 10. A total of 15 designs were tested on both the screening matrix and the decision matrix where six designs were chosen to be the best. These tools will be further discussed later on in the report.

With the available information and observations of the actual process, CKW Design group developed many possible solutions and improvements. In consultation with Bristol aerospace, concept selection and weighting criteria were developed and applied to the initial set of solutions. Once the leading solutions were identified further effort, researched and developed for presentation to Bristol aerospace.

2. Background

Sheet metal is the most basic raw material used at Bristol Aerospace Limited. It is used to produce a wide assortment of finished parts and components as required by internal and external customers. The bulk of the raw sheet metal can be defined to three types: aluminum, titanium, and steel. The raw sheet metal is transported through several processes including shipping, receiving, inspection, storing, forming, and other manufacturing processes.

The issues of concern and purpose of this report is the scratching and denting of the sheet metal, specifically between the storage and shearing operations. This damage is a costly and troublesome problem for Bristol. Although damage can occur at all stages of the production process, a substantial portion of this damage happens between the raw material storage and the shearing operation. These two major processes take place after the initial intake inspection of the sheet metal. Improving the current sheet metal handling system between the raw material storage and the shearing operation would mean significant cost savings. Positive changes would also improve the delivery time of products because of reduced rework and lower rejection of nonconforming parts.

Transportation of sheet metal to other operations is done via forklift. The forklift removes the entire pallet shelf and all sheet metal of that type from a modular rack and pallet system. This pallet system and forklift can be seen below in figure 1. Visibility is limited when dealing with higher shelving. Because of this, the forklift forks often impact the rack supports on the next level, when holding the raw sheet metal. Additional damage frequently occurs on the edges of the sheet metal when sheets are slid onto and off of the pallet, or from high speed contact with the rack system, edges of adjacently stored metal or the prongs of the forklift.

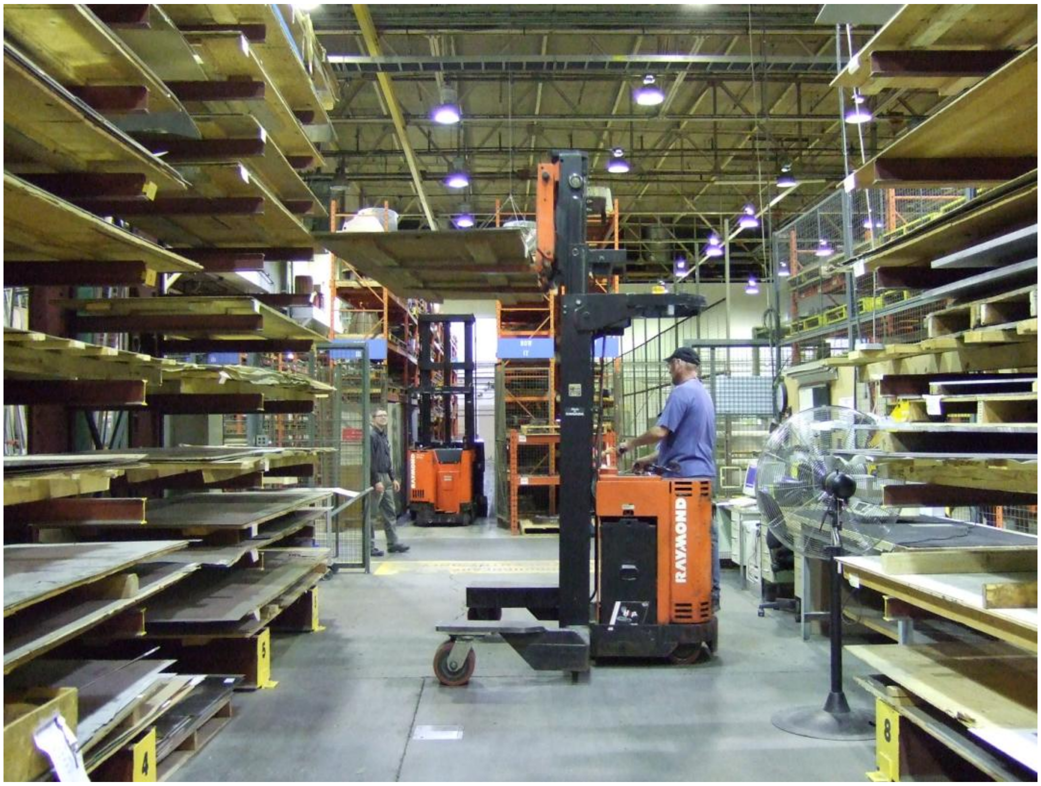

Figure. 1. Shelves and forklift [1].

Most of the occurrence of scratches is caused by metal-on-metal contact. When handling smaller sized sheets of metal that has been delivered to the shearing station, the shear operator slides the piece from the shelf onto an adjacent forklift and frequently this can result in surface scratches on aluminum sheet and softer steel sheet metal. Burrs, uneven edges, bent sheets and excessive material handling all contribute to the material damage.

The metal sheets are transported to the shearing operations by the forklift. The worker chooses the appropriate raw sheet metal stock according to the metal type required for that part and job sequence. The material batch number and traceability information are assigned to the work order at the shearing operation station, and appropriately sized raw material sheets are selected and slid from the pallet onto the shearing table. To reduce the defect rate of the scratches and dents caused by the current sheet metal, modifications must be made to the operation table, the size of the shelf, the forklift, and general handling of the sheets.

3. Objectives

The objective of this project is to develop an improved process and procedure for storing and handling sheet metal at Bristol Aerospace Limited. The proposed solutions to solve Bristol's sheet metal storage and handling problem must be easily implemented internally in the company. Furthermore, the design should meet many criteria such as: implementation cost, cost of implementing, durability, efficient, ease of operation, ease of manufacturability and cost of maintenance.

Recommended solutions to this problem must reduce the occurrence of scratches and dents at all stages of the sheet metal handling system. Specific attention should be made for the initial stage when the material is most susceptible to scratching and denting. The occurrence of scratches and dents should be reduced by no less than half of the current defect introduction rate. The desired end result should be a zero defect and zero rework condition where all parts produced conform to associated engineering drawings, surface conditions and tolerances without the need for rework, reject, or defects. The primary concern and costly issue is the metal-on-metal scratching on exposed surfaces of sheet metal.

4. Customer Requirements

Bristol Aerospace Limited has three main business units: the aerostructures business manufactures metal and composite aircraft structures and components. The aeroengine unit manufactures and repairing engine components. The Space business unit designs and assembles small orbiting satellites and satellite components [2]. All three of those businesses handle sheet metal and share the shearing and metal storage process where a high risk of material damage exists. In the aerospace industry, those scratches and dents cost a large amount of time and money to rework, and cause some serious issues for part delivery schedules and customer satisfaction for Bristol's external customers.

As a result, our client is eager to find a feasible way to reduce scratches and dents, so as to produce more highly acceptable products while using the same amount of sheet metal material. In other words, they want this project to bring a higher productivity and a lower defect rate to their raw material operations. From the economical point of view, the client also wishes to solve this issue internally, using the existing equipment, machinery and space as much as possible and start to make changes in a short period of time.

4.1. Target Specifications

The focus of the project is on making recommendations for improvements between the raw material storage and shearing process of Bristol's sheet metal handling system. Scratches and dents must be reduced to an acceptable tolerance that will be different for different material types and sizes. Bristol's request is that defect rate be reduced to zero or as close to zero as reasonable possible. With this in mind it was agreed by CKW Design Group and Bristol that there is a limit to the cost of quality and below a certain defect rate, the cost of further material damage reduction would be more costly than the realized savings. With the currently available data, financial information and statistical process analysis information, it is not possible to determine the most cost effective or true target reduction rate. All concepts and improvements will be analysed with consideration and weight given to their net cost and net benefit.

4.2. Discussion with Lead Users

In customer meetings and plant tours at Bristol Aerospace Ltd, CKW Design group was able to observe the entire material transport and operation sequence for several metal sheets. The team members talked in detail with key personnel involved in the material transportation and shearing processes. Throughout the discussions, production rate and ease of operation were emphasized by the front line personnel. They were concerned with the user interface and ergonomic considerations of any solution, and expressed concern that any changes might slow the factory throughput or limit the material processing speed [3]. CKW Design group did not perceive a high degree of interest or appreciation for material inspection or handling care and scratch avoidance from the material transport and shear operators. This information was highly beneficial in making a recommended design decision.

5. Concept Analysis & Selection

In the first stages of the conceptual design process, 15 ideas were considered. All 15 ideas are listed in Appendix A and C in the screening and decision matrix. Only the six recommended designs will be discussed in detail later on in the report, in the section, Recommended Designs. Using the following seven criteria listed and discussed below, CKW Design Team analyzed all 15 ideas to determine which would be most suitable and which offer the best potential. The criteria that were most important to this project were decided by both CKW Design Team and Bristol Aerospace. All designs were tested on a decision matrix and a screening matrix with these specific criteria; cost to implement, time to implement, cost of maintenance, ease of operation, efficiency, efficacy, and, durability.

5.1. Criteria

The criteria were selected based on the ultimate goal of Bristol Aerospace; profitability and customer satisfaction. Bristol Aerospace has three guiding principles of business: on time delivery, cash flow and no defects. We expanded these concepts and made them directly applicable to the sheet metal handling process. By specifying and appropriately weighting our selection criteria, CKW Design group was able to impartially assess and select the best solutions while minimizing personal influences or perception biases.

5.1.1. Cost to implement

All costs associated with the project, from design approval and acceptance until the initial full function operation of the solution were considered as part of the cost to implement. Equipment, training, true material costs as well as intangible costs such as additional floor space, lost productivity time and internal engineering effort were also included in this consideration. In keeping with generally acceptable accounting principles, a best estimate and financially conservative analysis was made for each concept.

5.1.2. Time to implement

The total timeline from idea acceptance and approval to full productivity of the solution is the time span considered for implementation time. This includes lost time for direct and indirect labor allocation, as well as temporary reductions in overall equipment efficiency. Both the total calendar time span short term, direct labor and engineering effort to implement each solution were considered.

5.1.3. Cost of maintenance

Both direct and indirect costs were considered for maintenance and running costs. Disposable/durable parts and components, as well as time and skill level required to perform routine maintenance and repairs were considered in the analysis.

5.1.4. Ease of operation

The skill level required and human factors such as ergonomics and repetitive strain injury concerns were of paramount importance to the customer and a primary consideration. Bristol made specific mention of this consideration on the initial IDEAS application submission. Because of the bulk volume of material that is processed through the sheet metal handling and shearing operations, a high degree of repetition is prevalent. Shearing precision is required for the sheet metal and aerospace tolerances and specifications must be maintained. A solution that is highly effective but requires extensive training or excessive setup time and uncomfortable or unsafe operation is not feasible.

5.1.5. Efficiency

The shearing and sheet metal transportation/handling process handles a large majority of all material that passes through the customer's factory. Any decrease in local efficiency can have a large impact on the plant's overall business process. Current material shearing rates for throughput and labor must be maintained. Additional labor may be allocated to the solution if the according solution offers an improvement in the material damage rate that greatly exceeds the cost of additional labor.

5.1.6. Efficacy

All potential solutions will be measured according to their perceived and estimated ability to reduce scratching and denting of raw sheet metal. This is the primary purpose of the entire project and was given the highest weighting factor. Because our team only has limited statistical information on the causes and origins of the scratches and dents, the efficacy of each solution was assessed in a subjective manner.

5.1.7. Durability

The long term reliability, mean time between failures and average time between service and repair also need to be considered. The scheduling department and production planning departments rely on short lead times and need to be able to release sheet metal to the shearing department without possible delays because of maintenance or unexpected repairs. Even if maintenance or repairs are inexpensive and quickly dealt with, the solution should have little impact on the schedule and process planning of the entire factory.

6. Recommended Designs

From the initial brain storming sessions, research into other industry standards and methods used by competitors and industries, fifteen initial concepts and rough designs were short listed. In talking directly with Castle Metals, B & M metals, Russel metals and other sheet metal sales and distribution companies CKW design group was able to further assess the designs, with six leading solutions proposed herein. These leading solutions offer the best value and have been selected because of their strong alignment with the criteria set out by Bristol Aerospace.

6.1. Roller bearing table

This solution moves the sheet metal from a delivery rack to the actual shear. It is very easy to modify from the original operation table. The sheet metal is easily slid across the roller surface by laying it on parallel rows of roller bearings or caster wheels. Instead of sliding and scraping across a flat surface with possible burrs and metal chips, the sheets can be rolled into place.

This proposed solution has many of the same advantages and disadvantages as an air cushion solution, but doesn't require an air fan or complex electrical and mechanical systems. It is only capable of supporting and maneuvering one sheet at a time and only reduces material handling damage at the shearing station.

The main function of the roller bearing table is to slide the sheet metal from the delivery rack to the shearing operation along the parallel bearing-rolls. The only way to eliminate all the scratches from the surface of the sheet metal is to minimize the friction between the surfaces as much as possible. For example the air cushion table can lift an object in the air, or how an item floats in the magnetic suspension system. The similar idea is applied to here in our design. The scratches also can be reduced as the friction between the rollers and surface of sheet decreases.

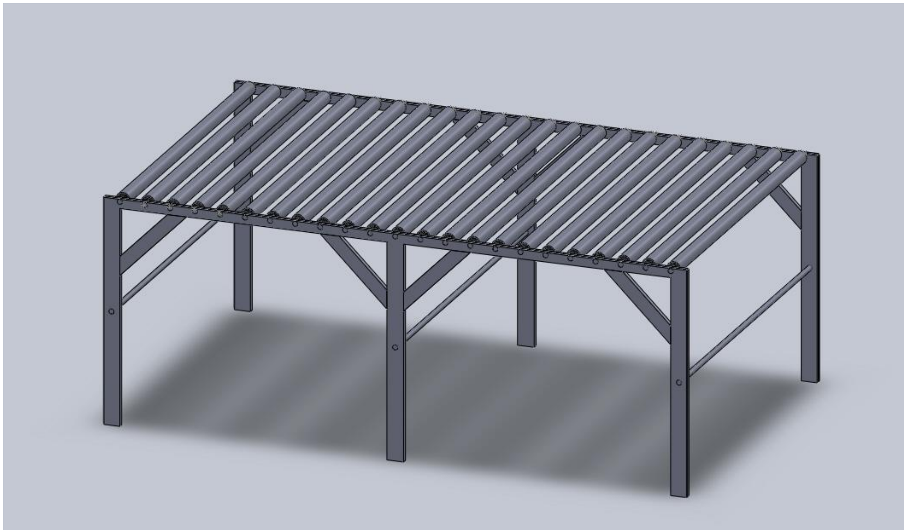

Figure. 2. Shearing table.

The roller bearing includes the two regular bearings, the roller and the shaft placed in the two bearings. In this design, there are 23 parallel roller bearings, and installed on the table with dimensions of 3m x 2.1m x 1.3m (L, W, H). The designed size is suitable for the operator to work easily and conveniently, and fits the entire regular size of the sheet metal. The important thing in the design of the table is that rubber covers the surface of the roller instead of using only the steel roller. Because rubber has elasticity, it can handle the sheet metal without any of the scratches occurring, and it can prevent the sheet metal from sliding off the table.

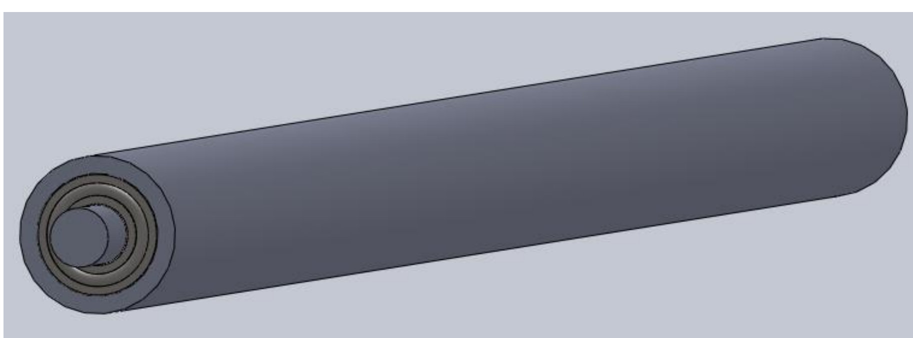

Figure. 3. Rubber roller bearing.

To design the bearing table, there are several criteria we are concerned with. First, the type of the bearing should be defined as one of the most important parts as each design of rolling bearings "has a great impact on the performance, life and reliability of bearings. Consequently, it also affects the operating quality and economy of machines on which the bearings are used."[4] In our design, both the ball bearing and roller bearing will work. In order to achieve the optimal design, high performance and low cost, we will choose the deep groove ball bearing and cylindrical roller bearing and give some basic information, then compare them in different criteria.

The deep groove ball bearings are most the common and recommended for use in this design. The advantage of the deep groove ball bearing is that it can hold the radial load and bi-axial load in the high-speed rotation. Also, it has low noise and low vibration while it is in operation. In the market, the anti-dust steel cover and rubber seal will be supplied on the deep groove ball bearing, and the amount of grease and lubricant are filled inside of the bearing to keep the bearing working properly.

Figure. 4. Deep groove ball bearing [5].

The cylindrical roller bearings have some differences from the deep groove ball bearings. The cylindrical roller bearings can bear large amounts of radial load, which comes from the heavy load and shocking load in the high-speed rotation, but cannot bear bi-axial loads. Because of the structure of the cylindrical roller bearing, there is a line contact between the cylindrical roller and the roller path. Therefore, compared with other bearings that are the same size, the cylindrical bearings can carry twice the radial load as the ball bearing. Most of the cylindrical roller bearings are used for the spindles that have the axial displacement because of the elongation by the heat in the rotation. The cylindrical roller bearings can be separated easily at any time. Since this roller bearing is very rigid it is mainly made for machine spindles, supporting axels on automobiles, etc.

Figure. 5. Cylindrical roller bearing [6].

This is a table from “Emerson Bearing” [7]; it shows the performance of eight different types of bearings in seven criteria. After comparison, deep groove ball bearing will generally be better than others in terms of the quality and performance.

TABLE I

DIFFERENT BEARING TYPES [7]

The table compares the performance of different bearing types with regard to load, accuracy, speed, noise and friction.

Bearing type	Radial load	Axial load	Compensation of misalignment	Accuracy	High speed	Low noise	Low friction
Deep groove ball bearing	Good	Normal	Normal	Normal	Very good	Very good	Very good
Single row angular contact ball bearing	Good	Good (in one direction)	Unsuitable	Normal	Very good	Good	Good
Spindle bearing	Good	Good (in one direction)	Unsuitable	Very good	Very good	Very good	Very good
Cylindrical roller bearing with cage	Very good	Unsuitable ... good *)	Sufficient	Good	Good	Sufficient	Good
Tapered roller bearing	Very good	Very good (in one direction)	Sufficient	Sufficient	Normal	Good	Good
Spherical roller bearing	Very good	Good	Very good	Unsuitable	Normal	Sufficient	Good
Axial spherical roller bearing	Sufficient	Very good (in one direction)	Very good	Unsuitable	Good	Sufficient	Unsuitable
Plain bearing	Very good	Sufficient	Normal	Sufficient	Good	Normal	Sufficient

***) N and NU design: Unsuitable, NUP design: Good, NJ design: Good (in one direction)**

The cost is an important factor and there are 46 bearings on the rolling bearing table, so the price of the bearings will be a big cost if the bearings are very expensive. From the research, our design can choose either the 6000 series ball bearing or 1000 series roller bearing, 60/30 Ball Bearing with dimensions of 30mm*62mm*10mm. The rubber seals cost $1.50 per ball bearing, and the 10/30 Roller bearing cost $ 10.50 per roller bearing. The prices of these two equal sized bearings, have substantially different prices. These prices do not include related shipping, installation or duty and import costs. It is obvious that the deep groove ball bearing will be most appropriate bearing we can recommend in terms price and suitability.

To reduce metal to metal contact of the sheets a 48 inch wide rubber roll will cover the roller. The main purpose of the rubber on the roller is to prevent scratches caused by the friction between the surface of the roller and the surface of the sheet metal. Also, the rubber has an anti-skid function, and keeps the sheet metal moving straight along the table. For the intended application a sheet roller with a medium durometer number (50) is best suited. Durometer is a term that is used to indicate the hardness of plastic or rubber, the higher the durometer, the harder it is, [8]. From the Rubber Sheet Roll Company, a 48 inch wide roller sheet with 0.062 inches thickness will cost $ 10.25 per foot linear rolled foot [9]. The circumference of the roller is 0.66 feet; the total length of 23 pieces of rollers will be 15.18 feet for a total cost of the rubber roller of $ 155.60. This number does not included shipping, duty, installation or any considerations for projected lifespan and anticipated service duration.

Figure. 6. Rubber roller [10].

A standard box and bar stock roller table can be purchased or made inexpensively in house. Several inexpensive modular frame and bolt systems are available and a single supporting frame structure would cost less than $300 for a durable industrial model.

A similar design is the ball transfer table which is more convenient and versatile compared to the roller bearing table. It is easy to move and rotate the sheet metal in any directions the operator may want. The following picture is an example of the ball transfer table.

Figure. 7. Ball transfer table [11].

In accordance with the capacity of the ball transfer, Omnitrack, a ball transfer manufacturer in Canada, sells the three kinds of the ball transfer designs; there are high capacity ball transfer units, medium duty ball transfer units and the light duty ball transfer units. The head shape, operating service conditions ball size are also variable and able to be tailored to Bristol's specific applications. Bristol carries several kinds of the sheet metal and the thickest and heaviest sheets shall guide the selection process. Steel has highest density which is 7.9 g/cm3, the density of the titanium is just below that of the steel’s, and the aluminum is the lightest material in these three kinds of sheet metal. But the largest size of sheet metal is titanium. Based on the stacking heights and number of sheets per batch number or pallet, calculations reveal the heaviest sheet metal is titanium, and is about 200 kg per sheet. To support these loads there are two viable options: Stromberg stud mounted style ball transfer (SMC and NSMC) and machined press-mount style ball transfer (MPC). The following figures below show these two types of ball transfer.

Figure. 8. SMC [12].

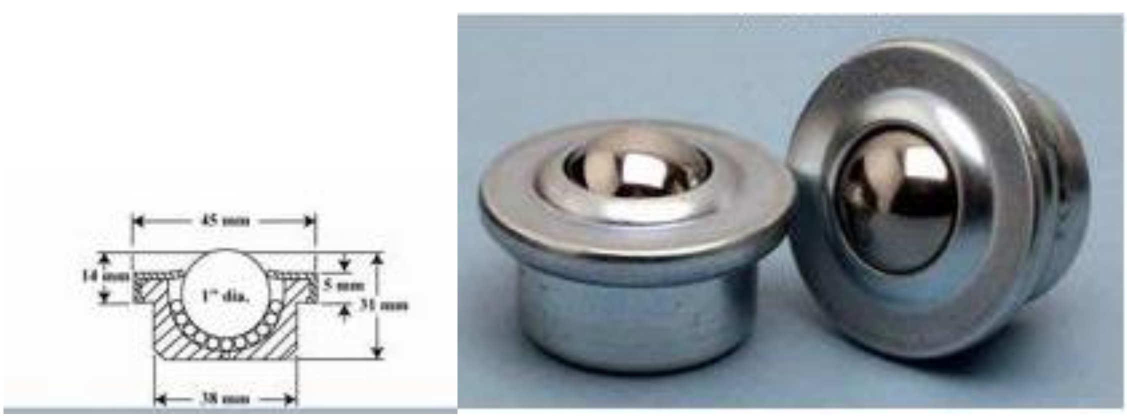

Figure. 9. MPC [13].

The following table summarizes the specifications of these two types of the ball transfers support bearings and their unique characteristics and suitability.

TABLE II
BALL TRANSFER SPECIFICATIONS [12, 13]

	Ball Material	Housing Material	Capacity	Stud Size	Price Each	Price 50-100	Price 101-499	Price 500+
SMC	Carbon Steel	Carbon Steel	250 lbs.	3/8-16	$17.98	$14.37	$12.39	$11.36
NSMC	Nylon	Carbon steel	250 lbs	3/8-16	$26.52	$21.22	$18.86	$17.44
MPC	Carbon Steel	Carbon Steel-Zinc Plated	440 lbs. Up		$26.14	$21.17	$17.84	$13.99

To finish our design, about 350 ball transfer units are required, each section contains 15 units, and 23 sections will be paralleled in the table which is 4 ft width* 8 ft length. Also the NSMC from the table are chosen for this project, total cost will be $7427. The frame of the table cost $1500. Therefore, the final product is around $9500 that includes the freight.

Future concerns for both designs is maintenance cost, we can't make sure that the table will be good all the time after it is made. A roller bearing table is not easy to disassemble and or assemble and due to the sealed nature of the rollers, replacement of the balls would be required instead of any repair or in depth maintenance. A ball transfer table has greater function than a roller bearing table, but the cost of design is higher than. After the comparing of the total cost that is design cost and maintenance, both of the two products have the advantages and disadvantages, but ball transfer table is recommended because of the higher suitability and ease of material handling in many directions of motion.

6.2. Cardboard between each sheet

This is a common industry solution that is used to reduce handling and transport damage of industrial sized sheet metal. Equivalent sized sheets of cardboard are placed between each sheet of metal in alternating fashion. The price of regular cardboard is about $1 per sheet and can be reused multiple times and for multiple types of metal. Only once the cardboard sheet is excessively damaged will a new sheet of cardboard be required. Double corrugated cardboard is durable and can last for many cycles before requiring replacement.

Cardboard sheets can be placed between the metal sheets during the receiving phase when quality control initially inspects and inventories the raw material. The sheets would remain between the metal from the receiving dock all the way through to the delivery at the shearing process where each metal sheet would be slid off the underlying cardboard sheet without risk of metal to metal contact between sheets. Cardboard can also be placed in between sheets of metal by the company that provides aluminum sheets to Bristol, B&S Alloys Inc.

The cost, ease and speed of implementation for the cardboard sheet solution is unmatched amongst all other options. Cardboard sheets would be collected at the shearing station and returned to the shipping and receiving bay where they would be reused if necessary.

However, cardboard sheets only protect the exposed faces and surface of the sheet metal and only protect against mild surface scratching. Edge damage and large dents from impact and forklift handling are not mitigated with the cardboard solution. Having that said, Bristol has indicated that their main concern is scratches caused by metal-on-metal contact [14]. Therefore, the solution to implement cardboard between every sheet of metal is not only necessary but highly recommended.

Cardboard can be implemented in many ways but the two possibilities that are listed belong are the most efficient and cost-effective. The first possibility is for the sheet metal manufacturers of aluminum, B&S Alloys Inc., is to provide sheet metal with cardboard already in-between each sheet metal. The second possibility is for Bristol to order cardboard from a cardboard producing company, such has Smurfit MBI located in Winnipeg, and then insert sheets of cardboard manually between sheets of metal.

Because Bristol documents their inventory of sheets by pounds rather than number of sheets, a close approximation was made to assume a certain number of sheets. It is approximated that the factory currently holds fifteen racks and each rack has 8 separate levels. It is approximated that each level holds about ten sheets; therefore, there are approximately 850 sheets. Since cardboard is not expensive, 850 sheets can be rounded off to approximately 1000, accounting for any error in assumptions. The prices quoted below are an estimated cost for 1000 sheets of metal. B & S, a major supplier of sheet metal to Bristol was very willing to offer bulk discounts for larger orders of cardboard and sheet metal, depending on the quantity of sheet metal [14].

An estimated cost for the first alternative could not be given by B&S Alloys Inc. Bristol would have to discuss this with B&S for a good price quote. Although, because Bristol purchases aluminum sheet metal from B&S, adding cardboard to the order would not change the cost very much. A phone conversation with a representative from B&S revealed that the addition option of cardboard between sheet metal is a service available to customers. At the current time, B&S is providing thin brown sheets of paper between the sheet metal they send to Bristol. The brown sheets of paper can be replaced by corrugated cardboard rolled sheets of paper, as said by the representative at B&S [15].

During a conversation with the customer service at Smurfit MBI, a rough estimate of cost was established. Bristol had placed orders at Smurfit MBI back in 2009. This specific order cost $4 per sheet, where a quantity of 400 sheets of 64 X 100 inch was ordered. It was estimated by the customer service at Smurfit MBI that the specific requirements for this application would cost around $3 to $4 per sheet, with sheet sizes ranging from 48 x 96 inch to 48 x 120 inch sheet. For larger sheets such as 4 X 144 inches and bigger, an approximate price per sheet would be $4 to $6. Also, costs of freight/shipping must be considered but that cost would be very low due to the fact that both Bristol and Smurfit MBI are both in Winnipeg, Manitoba. An additional consideration is the larger the order, the cost per sheet of cardboard would go down [16].

6.3. End caps on I-Beams

Large dents are often created in the center of top or bottom sheets from the loading and removal of sheet pallets from the Bristol rack system. The entire pallet of metal sheets are often raised up or lowered into the protruding edge of a supporting I beam, resulting in a distinctive I beam sized dent in the center of the top or bottom sheet.

Rubber end caps on the external tip of every supporting I beam would serve to attenuate the impact force and reduce or even eliminate the large dents that are present in the center of many sheets of metal. Bristol has expressed additional concern over the dents and scratches that are in the center of the sheet because it makes larger sheets less useful as they can no longer be used for single large pars and dents need to be cut around.

Commercial I beam caps are available for similar industrial applications and a custom rubber end cap could be developed and manufactured in house with low relative cost. Full installation would be complete in a matter of a few hours and they require almost no maintenance beyond replacement due to damage. With careful material selection, vulcanized rubber can remain soft and pliable for many years before it becomes brittle and begins to lose its impact attenuation characteristics.

Despite their efficacy at reducing dents, the I-beam end cap solution only mitigates a specific type of damage from a specific step in the material handling process. When loading and removal of sheet metals from the rack units, the entire pallet of metal sheets are often raised up or lowered into the protruding edges or corners of a supporting I beam. This often causes an obvious I beam sized dent in the center of the top or bottom sheet. Not just large dents, the sharp corners of I beam can also create some deep scratches, which might be hard to detect in the production process. When the quality inspectors find those scratches, they will cost many money and time to rework. In order to reduce or even eliminate the dents and scratches that come from contacting protruding I beams, rubber or plastic ends would be placed on the tip of every supporting I beam.

In the sheet metal storage, all racks are constructed by one standard type of S-shape I beam except for one rack that stores defective products. The rack for defective product does not need to be considered because all the parts on this rack will be sold for scrap with no intrinsic requirement for surface condition. The S-shape I beam used in most racks has a depth of 4 inch and a flange width about 2.6 inch. From the table on Mechanical of Materials, this is standard S 4×7.7 I beam [17]. After contacting several North American industrial supply and even specific I beam cap manufacturing companies, no specific application sized covers were found. Given the small requirement of approximately 300 end caps, a custom production run is not economically viable.

There is another alternative to cover I beam. Instead of using end caps, I beam pads can also stop sheet metals run into I beams. One I beam pad that is currently available on the internet is shown in figure 10. There are six different color selections: red, blue, green, yellow, tan and black. The main structure of this pad is made of cross-link foam, which can absorb a huge amount of energy. The covering is a 14 OZ fire resistant laminate vinyl. 2 inch wide Velcro strips are used to attach the pad to I beams that required protection.

Figure. 10. Sample I beam cap [18].

The major implementation cost will be spent on buying enough pads. The price of the pad depends on size of the beam. The length of those beams is 6 ft. AGM, the pad manufacturer, provided a price table on their website. From this table, it is obvious that the length and thickness of this kind of pad are constant and they are the right size to cover those I beam in on the racks. The only variable for estimating the price is the flange width. The smaller the flange width is, the cheaper the pad will be. The minimum flange width is listed in table 3 is 4 inches but the required width is about 2.6 inches, so the desired pad is out of the range. However, AGM claims that they are able to produce pads to fit customer's requirement, so the contents of the table still can be used to approximate the price of pad in desired dimension. The price of the pad decrease with the width of the flange by $5 per inch. Volume price should be approximately $80 including the shipping cost. Nearly, 15 racks are used to store sheet metals and each rack has 8 I beam, so at least 120 pads are needed. The total cost is around $96000 which is the product of the total number and the individual price. In reality, tax will also increase the cost. Eventually, the cost will be more than ten thousand US dollars. The amount of cost is acceptable for Bristol Aerospace as they should save more.

TABLE III

LIST OF PRICE FOR SELECTED PADS [18]

Size	Ship	Retail Price	Volume Price
4" x 6' x 1 3/8"	Ground	$85.00	$77.35
5" x 6' x 1 3/8"	Ground	$90.00	$81.90
6" x 6' x 1 3/8"	Ground	$95.00	$86.45
7" x 6' x 1 3/8"	Ground	$100.00	$91.00
8" x 6' x 1 3/8"	Ground	$105.00	$95.55
10" x 6' x 1 3/8"	Ground	$110.00	$100.10
12" x 6' x 1 3/8"	Ground	$115.00	$104.65

Once enough pads arrive at the plant, around 10 workers can complete the installation in 3 hours. The pads should last very long. If any pad gets damaged, Bristol Aerospace just needs to arrange a replacement as soon as possible. The pads will also act as safety equipment. If any operator hit those beams, pads will reduce his pain or even save his life. The attached pads should not have any impact to the ease of operation. The pads will absorb collision energy, so no scratch will occur from having sheet metals run into those tough beams.

6.4. Improved process and work instructions

Many of the surface scratches and edge dents result from the presence of burrs and improper material care and handling. The root of this solution would be to create and sustain a localized corporate culture of accountability. Creating an internal customer and supplier mentality would force each station and process to only accept quality raw materials that are free of damage. Instead of leaving quality control to the quality control inspectors, it would be an intrinsic part of the shear and forklift operator's job to inspect for and report damage caused to material before it becomes urgent.

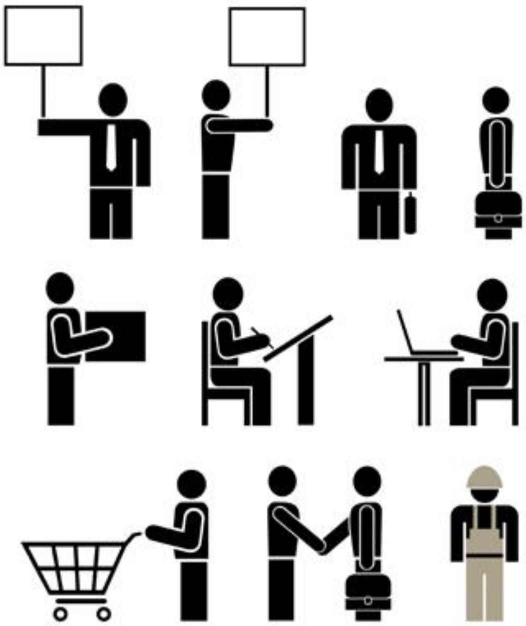

Figure. 11. Pictograms and Work Instructions [19].

By standardizing the processes of material transportation and handling, the variability and apparently random nature of the damages would evaporate. The leading root causes of damage would be more readily identified and targeted specific solutions could be implemented.

Examples of this solution would include ensuring that the back area of the shear is clear of scrap metal so that freshly sheared sheets don’t fall and scrape across off cuts from the previous batch.

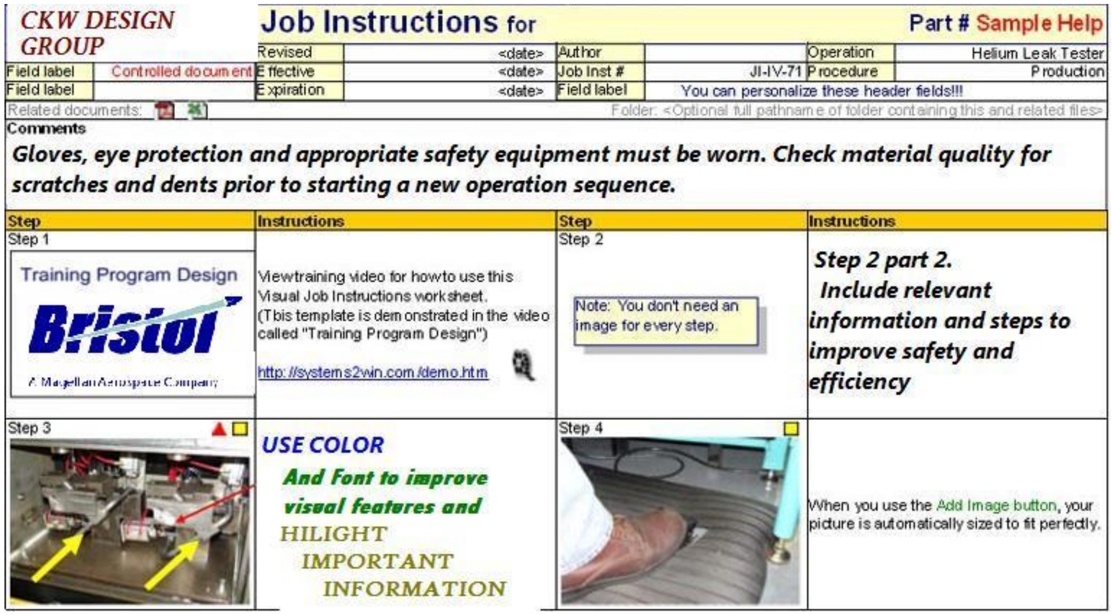

Figure. 12. Work instruction template [20].

Many sheets of metal are quite visibly damaged within the material storage area and yet remain unreported and unaddressed. The corporate culture of "over the wall" material delivery and processing would need to be addressed in an attempt to identify and eliminate the actual causes. Work instructions also serve to help quickly educate new employees and ensure consistency of results. The costs associated would include the time required for a qualified industrial or manufacturing engineer to perform requisite time studies and create detailed work instructions using existing Bristol work instruction templates and terminology. By supporting and refining the exiting work instruction documentation system, Bristol will be able to improve efficiency, reduce damage, improve consistency, increase labor flexibility and many other benefits.

The existing software support and technical writing/documentation knowledge base is already in place at Bristol. As an aerospace company, most of the assemblies and components made at the plant are complex, precise, expensive and must adhere to fine tolerances driven by their customers and the industry. To achieve these results consistently across many employees, the process is tightly controlled with specific work documentation and procedures in place to help teach and train employees to do the same job with the same result each time.

The tight control of a process allows for a high degree of tracking and control, and makes anomalies more apparent. By training shear operators and fork lift drivers to perform first line quality inspection and reject or rework parts early in the manufacturing process, the amount of wasted cost and effort of making scrap parts or performing extensive rework can be reduced.

If clearly written, simple and easy to follow directs are written for a process, it allows for more flexibility in the allocation and distribution of labor and skilled employees within the plant. With many people trained and capable of reading and following the work instructions, no one specific person or skill is required to perform a specific task. This allows for a more robust workforce and prevents the monotony of repetition.

When a task is performed in the same manner regardless of the operator, statistical process control and management by exception can be used to great advantage. By tracking the frequency, costs and type of defects resulting from a specific process, a true root cause or Pareto analysis can be performed to address issues and quickly develop and implement a solution. Consistent processes yield consistent results and remove excessive variability which can reduce scrap, rework and scheduling delays.

6.5. Reorganized storage layout with separate storage racks for each length of sheet

Currently many varying lengths of sheet material are stored in a haphazard method without heed for material storage space or interference with adjacent materials. The result is frequent denting and scratching of adjacent material stacks when a nearby material stack is removed or replaced in the rack.

The cost related to rearranging the material storage locations would be miniscule and only involve the time necessary to sort and group all large sheets in one area on one dedicated long sheet rack. By arranging long sheets separate from shorter ones, the metal sheets will be much less likely to bend and sag onto adjacent sheet stacks and cause difficulties and damage when removing and replacing pallets of metal.

A great number of dents and scratches are the result of haphazard storage without considering the interference between adjacent sheet metals, which is explained in the following four points:

1) Bristol Aerospace purchases sheet metal in many different sizes from its suppliers. However, those received sheet metals are currently mixed in rack units in a random way. There are two different sheet metal lie next to each other, the edges and corners of the smaller sheet metal must contact the surface of larger one. Although papers are placed between adjacent sheet metals to prevent contacting, it is still quite possible for the sharp edges and corners to cause scratches on the exposed sections of the larger sheet metals.

2) In the production process, one full sheet metal might not be used completely, so the remaining part will be converted back to the storage rack. Usually the remaining part will be put in the unit containing the full size sheet metal. This arrangement makes the sheet size become different. Figure 13 demonstrates this effect.

Figure. 13. One way of metal-on-metal contact.

3) Some racks are not long enough to store sheet metals properly. In this case, the two ends of over-length sheets will be bent down by gravity, and then the ends would point their sharp edges and corners to the sheet metals below. Once the operator use forklift to move sheet metals underneath, the uncovered surface of sheet metals underneath might hit those sharp edges and corners to produce scratches. This is conceptually shown in figure 14.

Figure. 14. Another way of metal-on-metal contact.

4) Also, those sheet metals stored on the racks are mainly made of aluminum, steel or titanium. These three metals have quite different hardness numbers which will enhance the effect of any kind of scratches.

There are two methods to reorganize the sheet storage racks according to size and length. Each method will be evaluated according to the six criteria: cost to implement, time to implement, cost of maintenance, ease of operation, efficiency and efficacy.

The First method is to keep the current racks and try to rearrange the sheet metal locations to avoid the above four problems. The cost related to rearranging the material storage locations will be minuscule. Nothing needs to be purchased. The only cost to implement is the cost of labours hours for planning, sorting and grouping all sheet metal in storage.

Instead of keeping a lot sheet metal in stock, Bristol Aerospace orders sheet metal periodically from its suppliers. Therefore, the reorganization will not take very long due to limited number of sheets need to deal with. Specific rules to sort the new arrangement will be developed in the process of reorganization. To maintain the new organization, the inventory operators can just follow these rules when handling sheet metals. No other required cost for maintenance.

This method has very small impact to the skill required for operators and human factors. After the reorganization complete, operators might need a few weeks to get used to the new organization. At this period of time, the operators might have some anxieties. However, once everyone gets familiar with the new organization, it should work even better than the current organization.

The efficiency of the entire sheet metal handling system will not decrease after operators become familiar with the new organization. Efficacy of this method is fair because of the minimum cost. Most problems that might cause scratches between two adjacent sheet metals will be solved except that the current racks still cannot handle those over-length sheets.

Second option is to purchase a new set of racks and reorganize all sheet metals according to their size and length. For example, the racks manufactured by Steel Storage System fit the requirement very well. The largest advantage of the new racks is that it can accommodate material sizes up to 72 inches X 144 inches [20]. The metal sheets will be much less likely to bend and sag onto adjacent sheet stacks and cause difficulties and damage when removing and replacing pallets of metal.

The main implement cost will be the price of the new racks. Some labour hours will also be required on installing the new racks and reorganize sheet metals in stock. The actual time to implement new racks depends on the cooperation with the Steel Storage System. Bristol Aerospace will only stop production flow at the day those racks arrive at the plant, and all implementation should be finished in that day. The best situation is that the delivery comes on Saturday morning and installation is completed before the next coming week, so no weekday will be wasted.

Those new racks are made of steels that can last several decades without any special maintenance. The new storage arrangement can also last years as long as the sorting rules are obeyed. Inventory operators will certainly get some training about how to use the new storage racks. At the beginning, workers might not be that fluent in handling sheet metal, but after people obtain enough experience, they certainly will get along with the new racks as well as the new sorting rules.

Operators might not immediately get used to the new racks, but they will gradually be more comfortable with those new racks. Eventually, the efficiency will be greatly elevated after workers have enough experience with the new racks. All the 4 possibilities listed previously to have scratch between two adjacent sheet metals in storage will be eliminated in principle.

6.6. Full-length support pallets with edges made for specific sized sheets

A great deal of the material handling damage comes from interactions with the forklift, metal sheets and rack system currently in place. Even If the sheets aren’t dented or scratched they are often bowed, arced and stretched from storage and transportation on undersized material handling pallets.

The best way to keep the sheet metal flat at all times is through the use the full-length support pallets. In the raw material storage, there are several different sizes of support pallets that are currently used on the shelves. The pallets are susceptible to damage and leave the edges, corners and weight of the sheets unprotected and unsupported on larger sheet stock. All pallets are made of wood and not customized or specific to the size and weight of metal sheets that are carried.

Figure. 15. Full size handling pallets [22].

Adding raised edges, making them width, depth and metal weight specific would make the pallets more integral to the material handling process. This would expose the materials to fewer damage opportunities. Sheets would be contained within the pallet and become less warped and bent. Each batch or type of material (Bristol Address) would be assigned its own unique handling pallet that holds a specified number of sheets of a specific material. The pallet would slide into and off the racking easily and cover and protect exposed edges of the sheets.

Figure. 16. Current forklift and pallet arrangement [1].

The pallets would have to be durable enough to resist damage and endure impacts associated with an industrial environment. The pallets would be significant in cost at startup and need occasional repairs but the concept could be introduced in phases and is completely scalable. High throughput, high damage metal sheets could be set up with unique pallets first and the initial success or failure of the concept could be applied to subsequent pallet design and application. A batch of 5-10 ply wood and 2x4 customized pallets would cost less than $1000 for an initial trial.

7. Conclusion

In conclusion, CKW design team is confident that the six recommended designs listed in this report will reduce most of the scratches and damage occurring in the sheet metal at Bristol. The recommended designs are a combination of six areas that need improvements at Bristol. The combined recommendations will reduce metal-on-metal damage, which is Bristol’s main source of scratches. The recommended designs will also reduce dents in the surface and on edges of sheet metal, which is an additional source of damage. Finally, all six recommended designs take into consideration cost of implementing, ease of implementing, ease of use, and many other important factors that were discussed in the criteria section. Therefore, not only do the recommended meet our objective but there meet Bristol’s and CKW design groups’ criteria selection factors.

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9. Appendix A: Screening Matrix

TABLE IV

SCREENING MATRIX

Concept A	Air cushion support
Concept B	Roller bearing table
Concept C	Cardboard between each sheet
Concept D	Oil and grease between each sheet
Concept E	End caps on I beams
Concept F	Rubber covers on forklift back stops
Concept G	Limit switch for forklift so it cant drive into sheets or push sheets by edge
Concept H	Full length support pallets w edges made for specific sized sheets
Concept I	Improved process and work instructions
Concept J	Reorganized storage layout with separate storage racks for each length of sheet, 12, 14, 16 18 foot sheets stored separately so they don't interfere with
Concept K	5S improved for shear area to prevent presence of metal filings
Concept M	Magnetic or suction cup pickup of sheets to prevent sliding
Concept N	Employee education program to educate and show support for nonconformance & reject process, and avoid "shoot the messenger"
Concept O	Sheet metal carrousel system
Concept P	One roller suspended slot per sheet

Selection Criteria	Concepts														
	A	B	C	D	E	F	G	H	I	J	K	M	N	O	P
Cost to Implement	-	+	+	0	+	+	-	0	0	0	+	-	0	-	0
Time to Implement	-	-	+	+	+	0	-	0	+	0	0	0	0	-	-
Cost of Maintenance	-	_	0	0	0	0	-	0	0	0	0	0	0	-	0
Ease of Operation	+	+	0	+	0	0	+	+	-	0	-	+	+	0	+
Efficiency	+	+	0	0	0	0	+	0	0	+	0	+	0	+	+
Efficacy	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+
Durability	0	+	+	0	+	0	0	+	0	0	0	0	0	0	0
Sum +'s	3	5	3	3	4	2	3	3	2	2	2	3	2	2	3
Sum -'s	3	2	0	0	0	0	3	0	1	0	1	1	0	3	1
Sum 0's	1	0	4	4	3	5	1	4	4	5	4	3	5	2	3
Net Score	0	3	3	3	4	2	0	3	1	2	1	2	2	-1	2
Rank	NO	YES	YES	YES	YES	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO

10. Appendix B: Gantt Chart

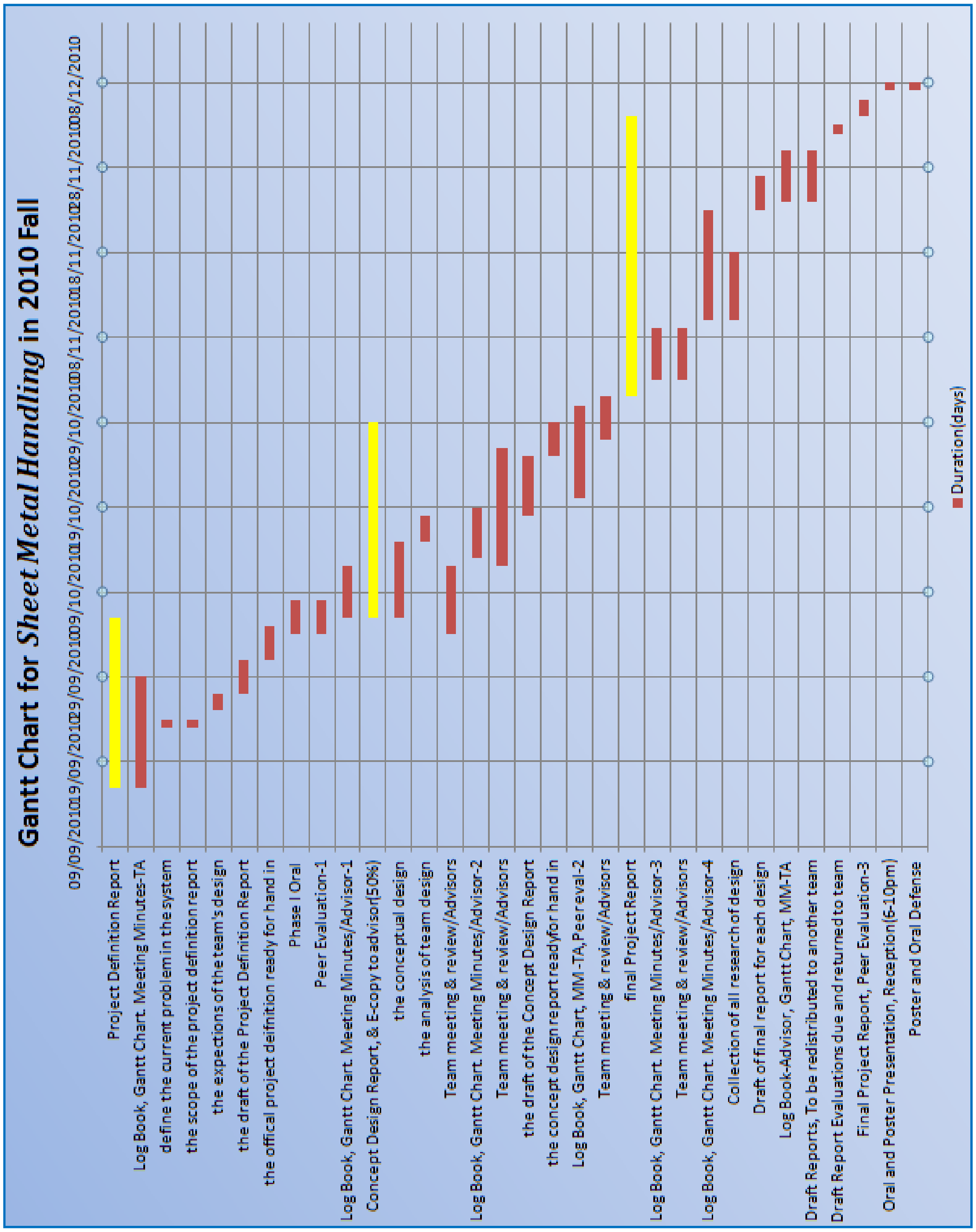

Figure. 17. Gantt chart.

11. Appendix C: Decision Matricies

TABLE V

DESICISION MATRIX FOR CONCEPTS A, B, C, D, & E

Concept A	Air cushion support
Concept B	Roller bearing table
Concept C	Cardboard between each sheet
Concept D	Oil and grease between each she
Concept E	End caps on I beams

Selection Criteria	Weight	Concept A Rating				Concept A Weighted Score	Concept B Rating				Concept B Weighted Score	Concept C Rating				Concept C Weighted Score	Concept D Rating				Concept D Weighted Score	Concept E Rating				Concept E Weighted Score
Cost to Implement	0.13	4	3	4	3.67	0.48	5	5	3	4.33	0.56	9	8	8	8.33	1.08	8	7	7	7.33	0.95	9	7	4	6.67	0.86
Time to Implement	0.07	5	2	4	3.67	0.27	5	7	3	5.00	0.37	7	8	9	8.00	0.59	9	7	6	7.33	0.54	9	7	6	7.33	0.54
Cost of Maintenance	0.12	4	3	6	4.33	0.52	9	8	8	8.33	1.00	8	8	7	7.67	0.92	7	8	6	7.00	0.84	9	6	2	5.67	0.68
Ease of Operation	0.14	8	7	8	7.67	1.06	9	8	8	8.33	1.16	9	8	8	8.33	1.16	9	8	6	7.67	1.06	9	6	7	7.33	1.02
Efficiency	0.19	7	8	6	7.00	1.36	7	8	6	7.00	1.36	5	5	5	5.00	0.97	5	6	5	5.33	1.04	9	7	5	7.00	1.36
Efficacy	0.19	7	8	6	7.00	1.36	6	8	6	6.67	1.30	8	5	8	7.00	1.36	8	6	3	5.67	1.10	6	7	6	6.33	1.23
Durability	0.15	9	7	7	7.67	1.14	8	8	8	8.00	1.19	5	7	5	5.67	0.84	9	7	2	6.00	0.89	9	5	8	7.33	1.09
Net Score						6.19					6.94					6.93					6.43					6.79
Rank		11					3					4					9					6				

TABLE VI

DESICISION MATRIX FOR CONCEPTS K, M, N, O, & P

Concept F	Rubber covers on forklift back stops
Concept G	Limit switch for forklift so it cant drive into sheets or push sheets by edge
Concept H	Full length support pallets w edges made for specific sized sheets
Concept I	Improved process and work instructions
Concept J	Reorganized storage layout with separate storage racks for each length of sheet, 12, 14, 16 18 foot sheets stored separately so they don't interfere with sheets adjacent

		Concept F					Concept G					Concept H					Concept I					Concept J				
Selection Criteria	Weight	Rating				Weighted Score	Rating				Weighted Score	Rating				Weighted Score	Rating				Weighted Score	Rating				Weighted Score
Cost to Implement	0.13	9	8	5	7.33	0.95	7	3	3	4.33	0.56	5	7	4	5.33	0.69	9	6	6	7.00	0.91	6	3	8	5.67	0.73
Time to Implement	0.07	9	8	4	7.00	0.52	7	3	3	4.33	0.32	6	7	3	5.33	0.40	6	5	3	4.67	0.35	4	3	7	4.67	0.35
Cost of Maintenance	0.12	9	7	2	6.00	0.72	9	3	5	5.67	0.68	6	6	2	4.67	0.56	9	7	7	7.67	0.92	9	6	9	8.00	0.96
Ease of Operation	0.14	9	7	3	6.33	0.88	9	7	6	7.33	1.02	9	7	7	7.67	1.06	9	7	4	6.67	0.93	9	6	8	7.67	1.06
Efficiency	0.19	9	7	3	6.33	1.23	9	8	4	7.00	1.36	8	7	8	7.67	1.49	9	7	7	7.67	1.49	9	7	8	8.00	1.56
Efficacy	0.19	7	6	5	6.00	1.17	6	8	2	5.33	1.04	8	7	7	7.33	1.43	9	7	9	8.33	1.62	9	7	6	7.33	1.43
Durability	0.15	8	7	6	7.00	1.04	9	5	2	5.33	0.79	9	8	8	8.33	1.23	9	6	6	7.00	1.04	9	8	8	8.33	1.23
	Net Score					6.51					5.77					6.86					7.25					7.32
	Rank	8					14					5					2					1				

TABLE VII

DESICISION MATRIX FOR CONCEPTS F, G, H, I, & J

Concept K	5S improved for shear area to prevent presence of metal filings
Concept M	Magnetic or suction cup pickup of sheets to prevent sliding
Concept N	Employee education program to educate and show support for nonconformance & reject process, and avoid "shoot the messenger" mentality
Concept O	Sheet metal carrousel system
Concept P	One roller suspended slot per sheet

		Concept K					Concept M					Concept N					Concept O					Concept P				
Selection Criteria	Weight	Rating				Weighted Score	Rating				Weighted Score	Rating				Weighted Score	Rating				Weighted Score	Rating				Weighted Score
Cost to Implement	0.13	8	3	5	5.33	0.69	4	3	2	3.00	0.39	4	6	2	4.00	0.52	3	2	2	2.33	0.30	2	3	2	2.33	0.30
Time to Implement	0.07	5	3	2	3.33	0.25	3	3	3	3.00	0.22	2	3	3	2.67	0.20	2	2	4	2.67	0.20	1	3	3	2.33	0.17
Cost of Maintenance	0.12	8	6	3	5.67	0.68	5	3	4	4.00	0.48	7	7	3	5.67	0.68	4	2	6	4.00	0.48	4	3	6	4.33	0.52
Ease of Operation	0.14	9	7	2	6.00	0.83	7	8	8	7.67	1.06	9	7	2	6.00	0.83	6	8	8	7.33	1.02	7	7	8	7.33	1.02
Efficiency	0.19	8	7	9	8.00	1.56	6	8	7	7.00	1.36	8	8	6	7.33	1.43	8	8	7	7.67	1.49	9	7	7	7.67	1.49
Efficacy	0.19	7	7	8	7.33	1.43	8	8	7	7.67	1.49	8	8	4	6.67	1.30	7	8	9	8.00	1.56	8	8	5	7.00	1.36
Durability	0.15	9	8	6	7.67	1.14	7	6	4	5.67	0.84	9	8	9	8.67	1.28	7	6	5	6.00	0.89	7	6	2	5.00	0.74
	1																									
Net Score						6.57					5.85					6.24					5.94					5.61
Rank		7					12					10					13					15				