Palliser Furniture

Theatrical Seat Moving System

Final Design Report

UNIVERSITY OF MANITOBA

MECH 4860 – Team 5

Project Advisor: Vern Campbell P.Eng., MBA, E.I.R. December 4, 2019

Team Members:

Jomar Tayactac ______________________________

Trenton Butler ______________________________

Xinxiang Zong ______________________________

Olamide Doreen Ainah ______________________________

December 4, 2019

Nicolas Jaramillo
Product Specialist

Dear Nicolas,

The purpose of this report is to provide you the required information of the final design for the theatrical seat moving system. This report lays out the technical information of all the components for the final design. The information will provide an update on the design, and for you to proceed with purchasing the required components. Prototyping will advance from this report; any feedback would be greatly appreciated in the success of the prototyping and testing stage.

The report starts out with an introduction which includes; the background of your company, followed by the problem that is needed to be solved. The problem is that their cinema recliners are difficult to clean around and under, causing an increase in time and money spent to clean. Project objectives are then laid out, followed by client needs, and related technical specifications, and project constraints. Following the design process of the team, our methodology follows. Our methodology looks at how concepts were created and selected. Followed by a look at the top concepts and a cost analysis for each. The motivation behind the selection of the final design concludes this section. The final design then gets analyzed into its distinct component. Each component has a detailed explanation of the part, including size, material, and any other relevant specification. As well as how the component interacts with other components, and how the specific component meets the needs for the project. Following the detailed design of each component is a bill of materials and finishing with a failure modes and effects analysis. Lastly, recommendations of forwarding this project into the prototyping phase are listed and finishing with a conclusion to the report.

Sincerely,

Jomar Tayactac   Trenton Butler   Xinxiang Zong   Olamide Doreen Ainah

December 4, 2019

Dr. Paul Labossiere
Associate Head of Mechanical Engineering Undergraduate Program
University of Manitoba
75 Chancellors Cir
Winnipeg, MB R3T 5V6

Dear Dr. Labossiere,

The purpose of this report is to describe the final design for the theatrical seat moving system designed for Palliser furniture. The information in this report will be used to create a prototype of the system. Palliser will order the required parts, and the team will complete prototyping and testing.

The report starts out with an introduction which includes; the background of Palliser as a company, followed by the problem they need solved. The problem is that their cinema recliners are difficult to clean around and under, causing an increase in time and money spent to clean. Project objectives are then laid out, followed by client needs, and related technical specifications, and project constraints. Following the design process of the team, our methodology looks at how concepts were created and selected. Followed by a look at the top concepts and a cost analysis for each. The motivation behind the selection of the final design concludes this section. The final design then gets analyzed into its distinct component. Each component has a detailed explanation of the part, including size, material, and any other relevant specification. As well as how the component interacts with other components, and how the specific component meets the client's need. Following the detailed design of each component is a bill of materials and finishing with a failure modes and effects analysis. Lastly, recommendations of forwarding this project for the prototyping phase are listed and finishing with a conclusion to the report.

Sincerely,

Jomar Tayactac Trenton Butler Xinxiang Zong Olamide Doreen Ainah

Executive Summary

Palliser furniture is a Winnipeg-based company that manufactures different types of upholstered products available in Mexico, United States, and Canada. One of Palliser's popular upholstery that can be found in many theaters today is their Encore Cinema Seats. A problem that all Palliser's theater clients face daily is the cleaning behind and underneath the seats. The current process for cleaning underneath recliners is ineffective and difficult to perform because the chair itself is in the way during cleaning. Palliser's customers have reported that the annual cost of cleaning is about half a million dollars. In this project, the team is tasked by Palliser to design a system that will improve the current cleaning process. The team set a goal to improve the cleaning process which will bring the reported annual cost down 25%, decrease cleaning time by at least 50%, and make the cleaning process more ergonomic.

The team created a design space to begin generating concepts that will solve the problem. A screening was done on the design space to eliminate incompatible alternatives with the design constraints. The screening gave us ideas on how the recliners can possibly be moved in order to expose the space underneath for cleaning. Design concepts created by the team were narrowed down into four using a Weighted Decision Matrix (WDM). A discussion with the client deemed the four concepts unfit to solve the problem due to the components of the designs being located mainly behind the seats. Seven new concepts were created by the team and further discussion with the client resulted with the final concept the team is going to move forward with. The main components of the final design are the DC motor, rack, pinion, seat bracket, rollers, and roller slots. These components are used in the theatrical seat moving system which will move the recliners forward in order to expose the floor underneath for cleaning.

The theatrical seat moving system uses the power output of a DC motor to move the recliners forward. The rotational motion of the motor shaft is translated into linear motion using a rack and a pinion. The rack is made stationary by bolting it into the floor. The pinion is connected to the motor shaft and the motor is mounted to the seat bracket which holds the five recliners together. The recliners are enabled to move forward by the rollers attached to the seat bracket and underneath recliners. Two fixed roller slots on both ends of the five recliners ensure the straight path of the recliners when moving forward. When not in operation, the system is secured by two pins at the front side and two blocking brackets at the back. The pins are simply inserted into the roller slots to block the rollers from moving forward. The blocking brackets are bolted into the floor and prevents

the recliners from moving backwards. The system can be operated by one person at a distance using the remote controller of the DC motor and the system can travel 34 inches forward in 18 seconds.

The next step for the team is to come up with a plan for testing our design. From the testing, the team expects changes that will further improve the design and ensure that customer requirements are met.

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1.0 Introduction

This section gives a brief background to the client and introduces the objective of the project. The problem was verified using the data collected from a survey given to the end users (customers). A voice of customer analysis was then used to identify the client needs and as a foundation to generate key metrics for the design concepts.

1.1 Project Background

Palliser is an upholstery and furniture company that makes high quality furniture for living rooms, bedrooms, and dining rooms. In 2014, Palliser adapted their company to also create cinema recliners, as the need for luxury seating was in demand. *Figure 1* shows two styles of Palliser's cinema recliners. In 2018, cleaning difficulties were brought to the attention of Palliser from their clients.

The visible areas of the recliners are straightforward to clean. However, because the seats are securely bolted to the ground, the accessibility to clean underneath and behind the recliners is limited.

Figure 1: Two styles of Palliser's cinema recliners at Grant Park cinema

The team visited Landmark Cinemas 8 at Grant Park, a theater that is equipped with Palliser's cinema recliners, to get a better understanding of what was reported as the problem. We interviewed the third-party cleaning crew as well as the cinema manager to gather information on the current cleaning process. In addition, we watched and timed the cleaning process of one of the theatre rooms which took approximately one minute and thirty seconds to clean a chair.

For the current deep cleaning process, the worker had to crouch and bend down to reach the spaces underneath and behind the recliner. The cleaning personnel also had to hold a flashlight in one hand and a vacuum in the other hand, while crouching or bending down. *Figure 2* shows the space available behind the recliners while *Figure 3* show the space underneath the recliners. The space underneath the recliners is accessed by lifting the seat cushion forward, this is the only method available for viewing underneath the recliners.

Figure 2: The Space Behind the Recliners

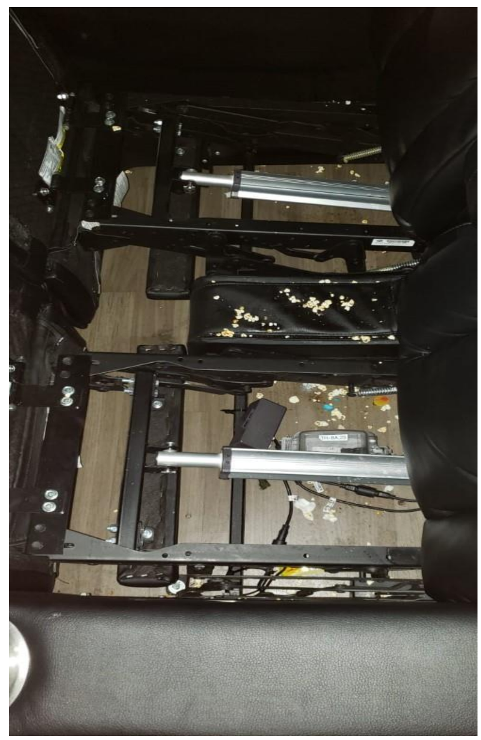


Figure 3: Access to Underneath the Recliners via the seat cushions flipping forward

From the *Figure 2* and *Figure 3*, it is noticeable that there is limited spacing behind and underneath the recliners which makes accessibility a problem and hence, why the cleaning personnel find it difficult to clean those areas. Thus, the purpose of this project is to design a device that will make cleaning simpler, more comfortable, and allow for better visibility underneath and behind the recliners.

1.2 Business Case

This section explains the primary reasons for prioritizing this project which were determined from the result of the survey sent to Palliser's clients shown in Appendix A.

- Cleaning cost:

The current average annual cleaning cost for 45% of the clients that responded to the survey is above $100,000. Also, 80% of clients experienced an increase in cleaning cost after the recliners were installed, hence, our design aim is to bring the annual cleaning cost down by 25%.

- Waste of resources used in the cleaning process:

For the current process, the vacuum cleaner is used for an extended period of time in attempt to clean behind and underneath the seats efficiently as commented in Appendix A - "*we try blow away the popcorn with leafblower, but the pipe/hose is too short so we need to sit on our knees*.". This results in excessive use of electricity. In addition, from the site visit, the cleaner had to use flashlights for visibility which results in added costs for recharging or purchasing batteries for the flashlight.

- Waste of time while cleaning:

Based on the interview with the cleaning team, it was reported that having to crouch and bend down to reach the spaces underneath and behind each of the recliners takes up time for the cleaning process. The survey results verify that the cleaning cost have increased since the installation of the recliners. This could be due to the time wasted per chair and the effort put into cleaning one chair. It takes between one to eight hours per week for deep cleaning one theatre room. The target is to reduce this time by 50%

- Ergonomics:

In addition to the crouching, the cleaner must hold a flashlight in one hand for visibility, and a vacuum in the other hand, to clean behind the recliner. To clean sticky spots, the cleaner must reach over the side of the recliner, in an uncomfortable posture, to wash the floor by hand using a wash cloth. A suggestion from the survey was to make it possible to lift the chair for easy access.

1.3 Process Purpose and Output

The purpose of this process is to fulfil and focus on the needs of the clients by collecting relevant information that can be used to describe the problem. This would be helpful to guide the team through the design process and to ensure the team focuses on meeting the client's needs.

TABLE I: SIPOC ANALYSIS

Supplier	Input	Process	Output	Customer
- Palliser - U of M Engineering Design Course - Engineering Design Advisor	- Problem statement - Project Charter - Survey from Palliser's Client in Appendix A - Customer needs - Interview with end users and Palliser's customers - Engineering Design notes and lectures - Advisor's feedback	- Verify the problem (Root cause investigation) - Design action plan & concept - FMEA	- Final design - Detailed analysis of how it meets Palliser's needs and solves problem - Prototyping and testing	- Palliser's (Theatre/ cinema) clients - End users of the design - CinemaCon 2020

The team verified the problem using a five why analysis to verify the root cause of the problem and establish a focus point that will be used to solve the problem.

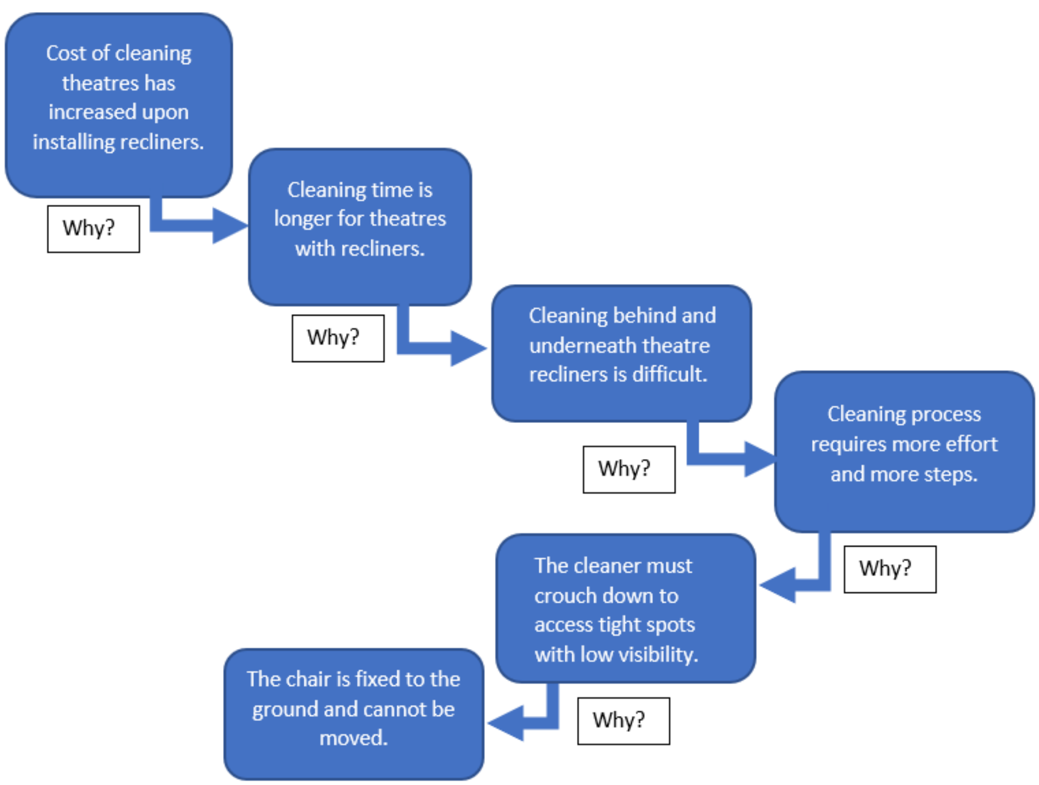


Figure 4: Establishing the root cause of the problem using 5 Why

Based on the root cause of the problem, an objective for the project is established which will have an overall impact on the project purpose described by the client on the project charter.

1.4 Project Objectives

The objective of this project is to reduce the approximate deep cleaning process time of 1 minute and 30 seconds for one recliner to 45 seconds by designing a system that will move the chair. The final developed design must be completed by March 3, 2020, to be showcased at CinemaCon 2020 in Las Vegas.

The team would also like to meet our own learning objectives of this project which are to learn successful client-customer interaction and also the process of developing a design and solving a problem. This process includes but is not limited to understanding the customer needs, creating a design to meet the needs, design analysis, and finally prototyping and testing the design.

1.5 Project Scope

In addition to the problem objectives, Palliser has laid out a scope for the project which lists the expected deliverables for the project. The expectations of the project are as follows:

- A working prototype:

The prototype of the design must be completed by March 3, 2020. This is to ensure that the device will be presented at CinemaCon 2020, to be showcased to Palliser's current and potential clients.

- A manufacturing instruction guide:

This is to ensure the device is being manufactured the same way every time to help eliminate any potential mistakes.

- An installation instruction guide:

This will optimize the installation process, reduce installation errors, and protect any part of the device from damage caused by improper installation.

- CAD models and related documents:

These documents will be the base for creating both the manufacturing guide, and installation guide, and are important when designing products.

- A cost breakdown analysis:

This will determine if this device is worth producing based on how much theaters will be willing to spend versus how much it will cost to produce.

1.6 Customer Needs and Specifications

Using the Voice of customer analysis, we would breakdown the broad needs to smaller components that are measurable. To meet the project objective, the client's four main needs were identified based on the team's meeting with Palliser, and a meeting with cinema cleaners during a visit to Grant Park cinema. The four main needs were summarized, and broken down into discrete needs, and organized into a hierarchy. The list of all the needs are found in TABLE II

TABLE II: CLIENT NEEDS STATEMENT HIERARCHY

Need	Client Needs Statement Hierarchy	Importance
1	**The design should be modular and compact**	
1.1	The mechanism must not be larger than the width of the recliner	5
1.2	System should be retrofittable to current recliner models	5
1.3	System should not be higher than the spacing available underneath recliner	5
2	**The system should be safe**	
2.1	System is unreachable to theatrical customer	5
2.2	Safety stop in case of interference of motion	5
2.3	Can't activate while recliners are occupied	5
3	**Easy for operator to use**	
3.1	System is easy to operate	5
3.2	Should not require much force from operator	5
3.3	System needs only one operator	4
4	**The system is economical**	
4.1	Low manufacturing cost	3
4.2	Easy to install	3
4.3	Easy to maintain	3
4.4	Easy to manufacture	3
4.5	Long life cycle	2

Technical specifications were created as a tool to verify that the customer needs are meet. The list of metrics that define the technical specifications are shown in TABLE III.

The marginal and ideal values are obtained by team discussion and interview with client. The marginal value shows the predicted range of acceptable values for each technical requirement. The ideal value is the predicted target value which the team will try to reach in the subsequent design process.

TABLE III: METRICS ASSOCIATED WITH CLIENTS NEEDS

Metric #	Needs Ref #	Metric Description	Units	Importance	Marginal Value	Ideal Value
1	1.1, 1.2, 1.3, 2.1, 4.2, 4.4	Height	inches	5	1 – 1.5	1
2	1.1, 1.2, 1.3, 4.2, 4.4	length	inches	5	20 - 34	34
3	2.1, 2.2, 2.3, 3.1, 3.2, 3.3, 4.1, 4.4, 4.5	Safety	N/A	5	1.2 - 5	2
4	3.1, 3.2, 3.3	Force needed to move 5 recliners	N	5	20 - 100	20
5	2.1, 2.2, 2.3	Safety reaction time	sec	5	0.1-3	0.5
6	1.1, 1.2, 1.3	Space available after recliner has moved	Inches	5	33-42	36
7	2.1, 2.2, 2.3, 3.1, 3.2, 3.3	Steps to activate system	Steps	4	2-5	3
8	2.1, 2.2, 3.1, 3.3, 3.5, 3.6, 4.1, 4.3	Manufacturing cost per system of 5 recliners	$ CAD	3	50 - 1000	600
9	4.3,4.5	Lifetime	Years	2	5-7	6
10	1.2, 4.2	Installation time	Min	2	10-30	15
11	4.3, 4.5	Maintenance frequency	Years	2	0.5-2	1

1.7 Project Constraints

Project constraints have also been identified, as these constraints may impede the progress of the project or restrict aspects of the design. The constraints are listed in TABLE IV

TABLE IV: BUSINESS AND DESIGN CONSTRAINTS

Ref #	Constraints	Explanation	Strategy
C1	Budget	The design budget given by the client for the prototype is $2000 per 5 chairs.	Design the device to have minimal costs. Once budget is in, if possible, upgrade parts that will best optimize the design.
C2	Client milestones versus project milestones	The client milestones are fast tracked which makes it challenging to combine with course milestones.	The deadlines are noted to keep track of progress and updates to the Gantt chart are being made regularly. Informing Palliser of any time line issues to best work around them.
C3	Time scheduling	Team members are registered in other final year courses that causes conflict with scheduling team meetings.	The team members have shared their schedules and are informing the others of any changes.
C4	Size	The design is limited by the available space. There is 1 inch underneath the recliner, 36 inches in front of recliner, and 6 inches behind the recliner.	The available space will be considered when creating design concepts.
C5	Locations of anchor points	The seats are anchored to the floor via bolts. The location of these anchor points cannot be altered.	Our system will incorporate the chair anchor points and allow for the chair to be anchored to our design. We must also properly secure our design to the floor.
C6	Theatre layout	Since different cinemas have different layouts, the design will be limited to the available spacing and positioning depending on the cinema.	The team will consider making a generic design than can be easily modified to the different layouts.
C7	Deadline	This project must have a final design report due December 5, 2019. This device must also be prototyped and ready to use by March 3, 2020.	The team will stay on top of deadlines and have weekly update meetings to keep track of progress.

2.0 Methodology

Based on the voice of the customer, the team worked in creating several potential concepts that could solve the problem that was brought to us. The team started by breaking down the problem into different components, which included movement direction, mechanically powered methods, electrically powered methods, and sliding methods. Ideas that could satisfy these components were collected and combined to make full concepts of potential designs. Eight concepts were created, and a weighted decision matrix was used to reduce to the top four concepts. These four concepts were shown to Palliser, however, Palliser had issues with all four designs. This was due to the issue of the device being located mainly behind the chair. There was a miscommunication of the importance of keeping the device under the chair. Palliser stated that the device must be retrofittable to all theater styles, and our design posed tripping risks for theaters that have a sloped layout. Keeping in mind the importance of keeping most of the components of the device under the chair, the team created seven new concepts, all seven designs are shown in Appendix B for reference. Some of the new concepts are redesigns of the last round of concepts and some are brand new. All seven concepts were brought to Palliser to review, and two concepts were preferred, shown in *Figure 5* and *Figure 6*.

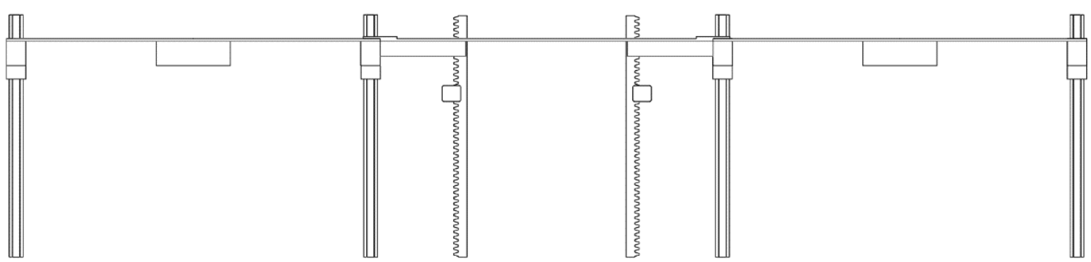


Figure 5: Concept 1 Slide rail with rack and pinion

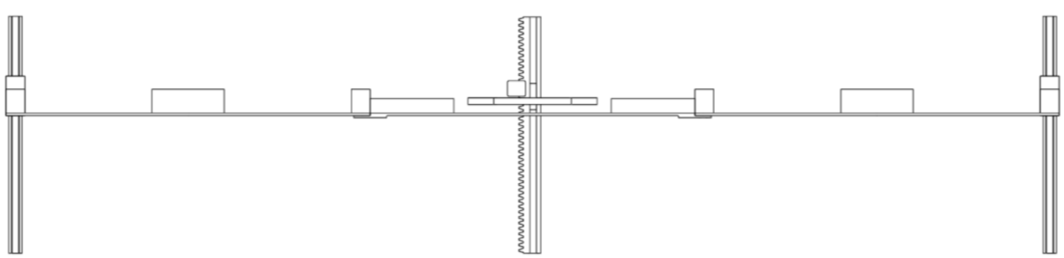


Figure 6: Concept 2 Single rack and pinion system

The first concept shown is a rack and pinion system, where a DC motor is used to power the pinion creating the motion forward or backwards. The chairs will be attached to slide rails at certain points, and casters will be added to areas that may need extra support. This concept uses two motors which are in the arms of the center chair. The second concept shown is also a rack and pinion system; the main difference is that there is only one motor, and it is in the center underneath the middle chair.

Both concepts are very similar in design which is why Palliser preferred both. To move forward with one design, a cost analysis was required to be completed on both concepts. While completing the cost analysis a third concept was created, this concept was the same as the second concept except the slide rails were removed and rollers were applied to each corner of each chair. This concept was created because slide rails are expensive and the rollers are cheaper; the rollers will allow for the same function at a much lower cost, *Figure 7* shows this concept.

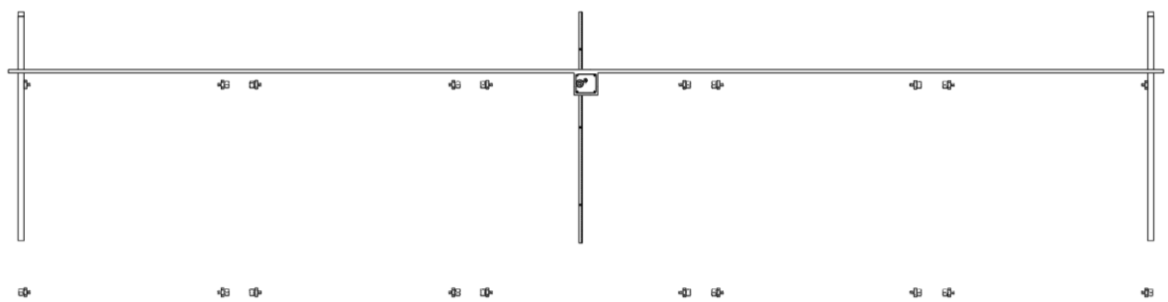


Figure 7: Concept 3: Roller wheels

The outer most rollers will need a track to prevent any unintended lifting motion while recliners are stationary. Overall, this design is cheaper, and has less of a tripping hazard. For a 5-chair set up the approximate cost for each is shown in TABLE V.

TABLE V: COST ANALYSIS FOR THE 3 FINAL CONCEPTS

Concept 1: Slide Rail Independent of Rack and Pinion			
Component	Cost/Part ($/part)	QTY	Total Cost ($USD)
Roller	31 [1]	8	248
Rail	182 [2]	4	728
Rack	30 [3]	2	60
Pinion	31 [4]	2	62
Support Structure	600	1	600
Motor	62 [5]	2	124
Total		19	$1822

Concept 2: Slide Rail with Rack and Pinion			
Component	Cost/Part ($/part)	QTY	Total Cost ($USD)
Roller	31 [1]	10	310
Rails	182 [2]	2	364
Rack-rails	262	1	262
Pinion	31 [4]	1	31
Support Structure	600	1	600
Motor	62 [5]	1	62
Total		16	$1629
Concept 3: Rollers with Rack and Pinion			
Component	Cost/Part ($/part)	QTY	Total Cost ($USD)
Roller	31 [1]	20	620
Roller Supports	5	20	100
Roller Rails	25	2	50
Rack	30 [3]	1	30
Pinion	31 [4]	1	31
Support Structure	600	1	600
Motor	62 [5]	1	62
Total		46	$1493

The total cost of each part is in USD due to the parts being found from US companies. Both the support structure and roller support are estimates, based on approximate size. The rack rail combination is also approximated based on the price of a rack and slide rail, with a $50 increase from additional processes required to make them into once piece. This was approximated due to the inability to find a price online.

It is determined that the lowest cost option is the third concept, which uses rollers as the primary sliding mechanism. This analysis was shown to Palliser and the third design was chosen by Palliser, due to the lower cost and an overall team consensus in favor of this concept. Therefore, concept three is the final selected design.

The following section will go into a detailed design of the third concept, including an overview of the design and an in-depth look at each component and the role that each component plays in fulfilling the problem solution.

3.0 Detailed Design

The design of the theatrical seats moving system consists of a seat bracket, motor mount, a rack, a pinion, shaft, motor, rollers, roller support, roller slots, and a safety pin system. The single DC motor in the system provides the rotational motion. The rotational motion is then translated into linear motion with the use of a pinion and a stationary rack. The DC motor is attached to the seat bracket which is attached to the recliners. Thus, when the motor is running, the recliners should move forward or backward. The recliners are enabled to travel forward by the rollers attached underneath. The roller slots on both ends act as a path and ensure the recliners are straight when moving. An overview of the system without and with the recliners are shown in *Figure 8* and *Figure 9*, respectively.

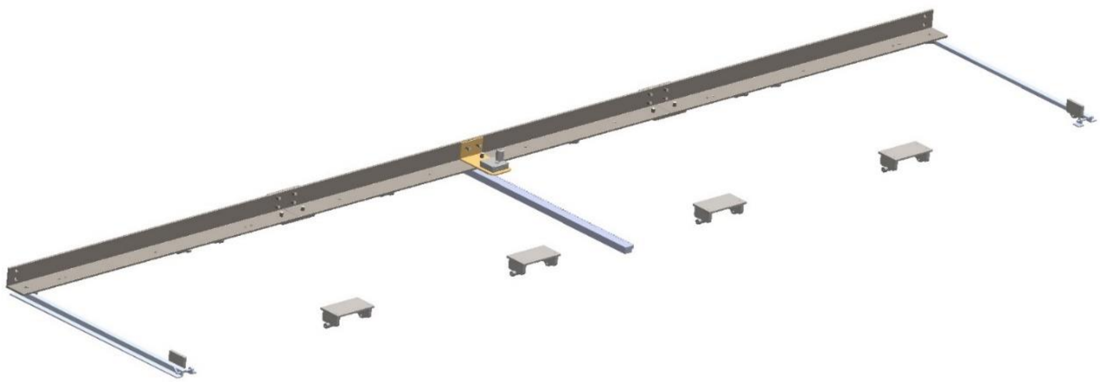


Figure 8: System overview without the recliners

Figure 9: System overview with the recliners

The moving system allows a bank of five recliners to move 34 inches forward which exposes the floor beneath the recliners. Once the recliners have been moved, the cleaning personnel will be able to clean the underneath floor as well as behind recliners. The system can simply be operated by a person pressing a button since the DC motor is remotely controlled. When the system is not being operated the system is secured by two pins which prevent the movement of the system. A thorough explanation for the seat bracket, motor mount, rack, pinion, shaft, motor, roller, roller support, roller slots, and a safety pin system is laid out in this section. Technical drawings of the system components are provided in the Appendix C.

3.1 Seat Bracket

A bracket connecting the five chairs together was designed to allow for the movement of the whole system during operation. Without this bracket, only one recliner equipped with the motor is going to move forward during operation as shown in Figure 10. Since it would be costly and impractical to equip all recliners with an extra motor, a bracket that can hold the chairs together was designed.

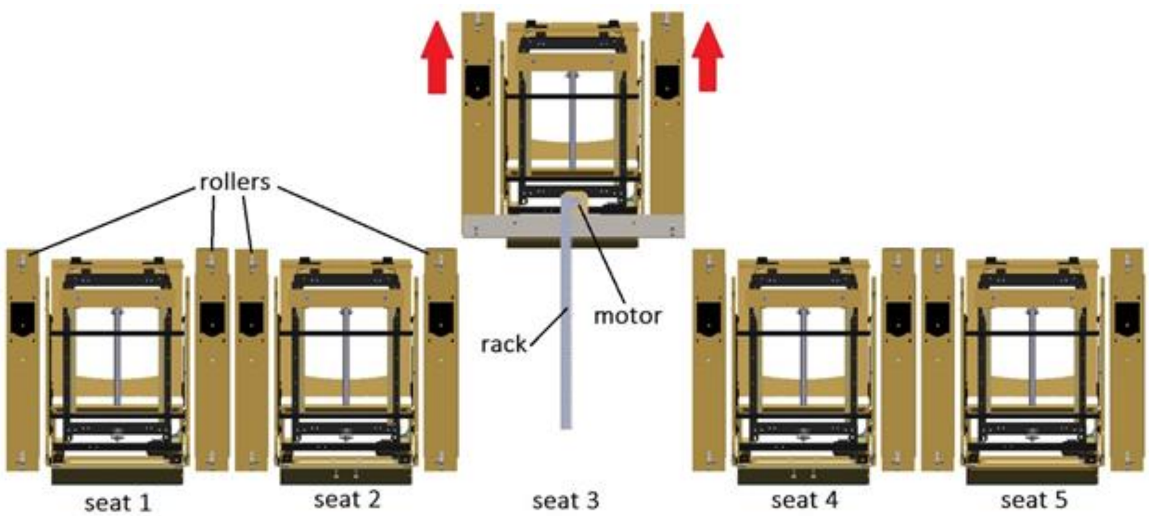


Figure 10: System without seat bracket

With this rigid structure connecting all the recliners, a forward motion of one seat will cause the movement of the whole system as shown in Figure 11. This structure will be located at the rear and bottom corner of the chairs. Bending of the bracket was a concern due to the weight of the chairs and thus, eight rollers were added on the bracket to act as supports to prevent bending of the seat bracket.

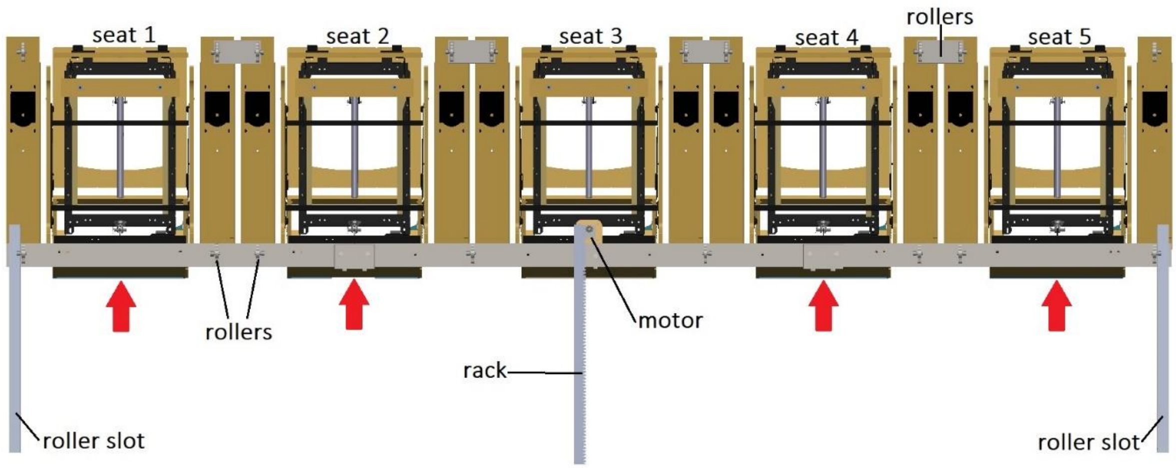


Figure 11: System with the seat bracket

Shown in Figure 12 is the exploded view of the seat bracket which consists of two main parts, bracket A and bracket B. The chairs are connected to the bracket by their anchor points. Bracket B is fastened to each end of bracket A using L-connectors, hex head bolts, and hex nuts. The team is focusing on making a design prototype for five chairs because of the client's objective to show this system in CinemaCon in March 2020. For a system that requires more or less than five chairs, bracket B can simply be replaced with another bracket that is shorter or longer in length. Bracket A is in the center of the structure and it is the bracket where the motor is attached. This makes the design modular as desired by the client's needs.

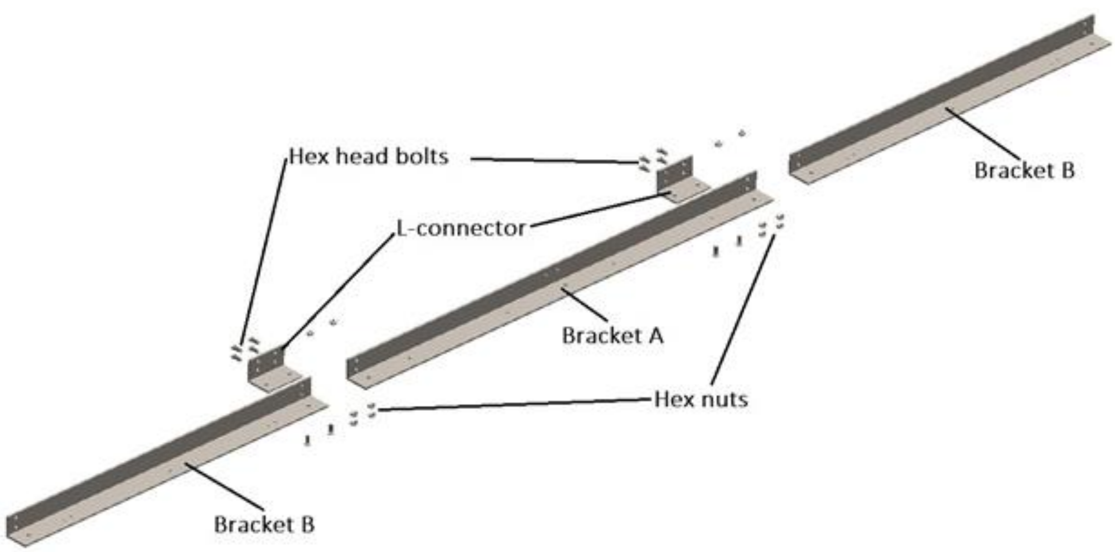
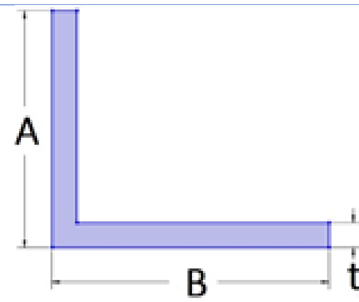


Figure 12: Seat bracket exploded view

3.1.1 Seat Bracket Specifications

The total length of the L-channel required for the system was determined by measuring the length along the five recliners. 304 Stainless steel was chosen as the material for the brackets due to its high strength and excellent corrosion resistance [6]. The specifications of the brackets are shown in TABLE VI. An L-channel for the bracket was chosen as it is readily available in the market and will not require additional processing besides from cutting and drilling.

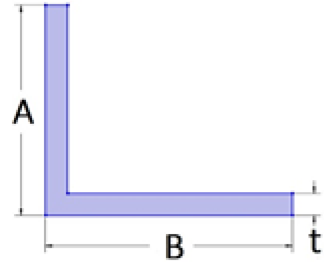
TABLE VI: SEAT BRACKET SPECIFICATIONS

Seat Bracket	
Manufacturer:	N/A
Material:	304 Stainless Steel
Total length:	174 inches (14.4 ft)
Bracket A length:	70 inches (5.8 ft)
Bracket B length (x2):	52 inches (4.3 ft)
A:	3 inches
B:	3.5 inches
t:	0.32 inches

3.1.2 Fasteners

To fasten the brackets A and B together; 6-hole L-connectors, M12 hex head bolts and nuts were used. As well, M8 hex head bolts and nuts were used to attach the recliners to the seat bracket. TABLE VII contains the specifications for the 6-hole L-connector.

TABLE VII: L- CONNECTOR SPECFICATIONS

6-hole L-connector	
Manufacturer:	N/A
Material:	304 Stainless steel
A:	3.3 inches
B:	3.7 inches
t:	0.32 inches

3.2 Motor Mount

The motor is attached to the seat bracket via the motor mount as shown in Figure 13. The motor mount is fastened to the bracket using three M12 hex head bolts and nuts to ensure the motor does not move or vibrate during operation. The motor mount is accessible from the rear side of the recliners allowing for easy access during maintenance. 304 Stainless steel was also the material chosen for the mount. The motor mount will be subjected to testing to verify that the mount can withstand the torque from the motor during operation.

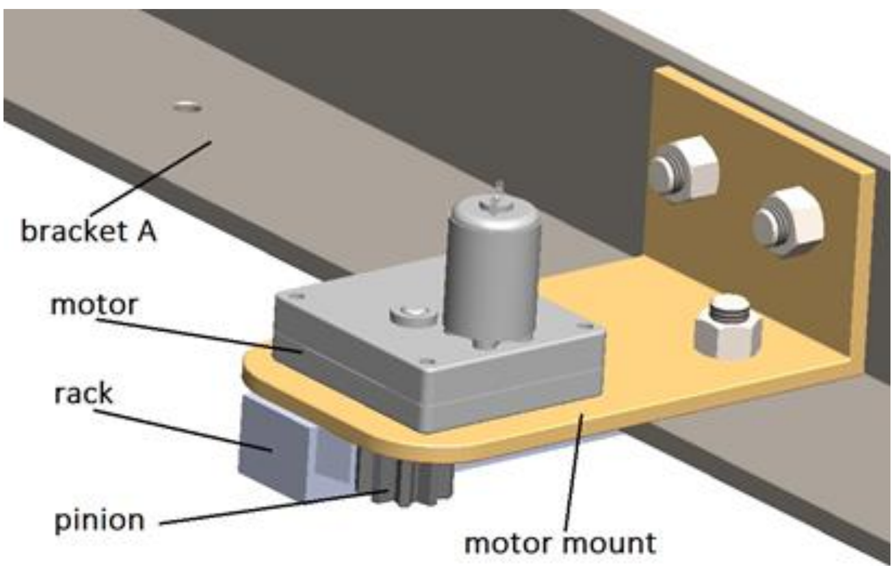


Figure 13: Motor mount configuration

3.3 Rack and Pinion Drive System

The rack and pinion driving system is consisted with a rack, a pinion, a shaft which transmits power from the motor and a coupler to connect the motor and pinion together. This section will introduce the standards for the rack and pinion, as well as the standards of designed shafts and other feature such as bolts and keys.

3.3.1 Selected Rack and Pinion

The rack and pinion are the stock parts chosen from KHK STOCK GEARS which is a vendor in Japan. The criteria used for selecting racks are the type of gear teeth, material, module, length of the rack, tooth finish, heat treatment, and mounting holes

The tooth of the rack and pinion could be spur or helical. By comparison, the spur gear will be chosen for the detailed analysis of the final rack and pinion drive assembly. The detailed comparison process is shown in Appendix D.

For the material applied on the rack, steel is selected because of its low material cost, good tensile and yield strength. The supplier only has racks made from S45C steel. Since the rack and pinion should be manufactured with same material, the material for pinon will be S45C as well.

The module of the rack and pinion is set at 2 which is a common value for spur gears.

The length of the rack is chosen to be 34 inches which is the length of the recliners. Since the system should be hidden underneath the seat, the length of the rack must be less than 34 inches.

The tooth finish refers to the quality of the gear, which is divided into high precision and standard quality. Since the rack and pinion are designed for low torque and low rotation speed, therefore, the standard tooth finish is selected to minimize the cost.

Adding heat treatment to racks will improve their surface durability and increase their torque capacity. Since the transmitted force and torque applied on the rack and pinion is small, no heat treatment is needed. The transmitted force needed to move 5 recliners are introduced in Appendix D.

The standard mounting hole on the side of the gear rack is needed since the rack is designed to be fixed on the ground.

3.3.2 Technical Specifications for Selected Rack

With all the criteria determined, the rack with catalog number SRFD2-1000 is selected. The length of the rack is 860.8 mm and the thickness is 20mm. The specifications for SRFD2-1000 is shown in TABLE VIII

TABLE VIII: SPECIFICATIONS FOR SRFD2-1000 RACK

Parameters	Rack
Catalog Number	SRFD2-1000
Material	S45C
Module	2.0
Addendum	2
Tooth Depth	4.5
Effective Number of Teeth	137
Total Length (mm)	860.8
Width (mm)	20
Tooth Finish	Cut
Heat Treatment	None
Tooth Type	Straight Teeth
Bending Strength (Nm)	3833
Surface Durability (Nm)	775
Precision Grade	KHK R 001 Grade 4
Pressure Angle	20°

The pinion rotates at 25 RPM which is assumed to be working under uniform load with light impact, this sets the dimension factor of root stress to 1.25. The safety factor is set to be 2 from the project technical specifications. The resulting allowable tangential forces for bending strength and surface durability are calculated to be 1777.0312N and 98.0773N. Since the force needed to move 5 recliners is only 8N, the rack SRFD2-1000 could be applied in the rack and pinion system.

3.3.3 Technical Specifications for Selected Pinion

For pinion selection, the number of teeth positively correlates with pitch diameter since the module is fixed. To minimize the size of the pinion, the minimum number of teeth is chosen. To avoid interference, the pinion teeth number should be at least 18 as shown in Appendix D. Therefore, a pinion gear with 18 teeth and a pitch diameter of 36mm is selected. The catalog number for the pinion is SS2-18J17 and its specifications are shown in TABLE IX.

TABLE IX: SPECIFICATIONS FOR SS2-18J17 RACK

Parameters	Pinion
Catalog Number	SS2-18J17
Material	S45C
Module	2
Number of Teeth	18
Pitch Diameter (mm)	36.0
Bore Diameter (mm)	17
Bending Strength (Nm)	39.28
Surface Durability (Nm)	2.23
Precision Grade	JIS N8
Bending Strength (Nm)	39.28
Surface Durability (Nm)	2.23
Pressure Angle	20°
Tooth Finish	Cut
Tooth Hardness	(Less than 194HB)
Weight	0.159kg

The allowable tangential forces for bending strength and surface durability are calculated to be 1049.1575N and 21.2298N. Both allowable forces are larger than 8N. Therefore, the pinion SS2-18J17 is the appropriate pinion for the rack and pinion system.

3.4 Shaft

This section will introduce the detailed design of the shaft and its features.

3.4.1 Coupling

Coupling is a mechanical feature which can be used to connect two shafts together at the end to transmit power. The coupling will be chosen from the stock part of McMaster-Carr. McMaster-Carr has two types of couplings in stock: rigid and flexible. Rigid couplings connect two shafts that are aligned. They are also good for handling high-torque applications. Flexible couplings connect two shafts that are misaligned [7]. There are several constraints for coupling selection which are listed below.

- The rigid coupling is required since two shafts need to be aligned.
- The motor shaft diameter is 7.9375mm and the pinion bore diameter is 17mm. Therefore, the shaft diameter for coupling should be 7.9375mm.
- The coupling should be applied for the keyed shaft.
- No shaft misalignment is allowed.

- The material should be steel
- The price of the coupling should be as low as possible.
- The couplings selected should be able to handle the torque and RPM of the motor selected.

According to the constraints set, the most feasible coupling selected from McMaster-Carr is coupling 5395T212 and its specifications are listed in TABLE X.

TABLE X: SPECIFICATIONS FOR 5395T212

Part number	5395T212
Material	Black-Oxide Steel
For Shaft Diameter	8mm
Overall Length	25mm
Outside Diameter	17mm
Keyway Width	2mm
Keyway Depth	1mm
Maximum Allowable Speed	3,450 rpm
Maximum Allowable Torque	98 in.-lbs.
For Shaft Type	Keyed
Shaft Mount Type	Set screw
Price	$6.33

The maximum speed and torque allowed for the coupler are larger than the speed and torque of the motor with the safety factor of 2 considered. Therefore, the coupling 5395T212 will be applied to the system.

3.4.2 Specification for Key

The key for the pinion depends on the specifications of the pinion. The type of the key is selected to be a square type which is introduced in Appendix D. According to the engineering drawings of pinion, the size of key could be obtained. The square key should have the width and height of 5±0.015 mm.

The oversized stock keys fit tightly in a keyway which is use in high-torque applications or to replace a key in a worn keyway. Slightly smaller than the size listed in the table, undersized stock is the choice when you need a slightly looser fit or when you have an inconsistent keyway. It is used when parts need to be taken apart frequently, such as during maintenance or prototyping. Since the rack and pinion system is not designed for high torque applications and will require maintenance, the undersized stock key is chosen.

According to the required dimension of the key, stock key part number 92288A725 of McMaster-Carr is selected. The specifications for 92288A725 are listed in TABLE XI.

TABLE XI: SPECIFICATIONS FOR SQUARE KEY 92288A725

Key Type	Straight
System of Measurement	Metric
Material	1018-1045 Carbon Steel
Height × Width	5mm × 5mm
Total Length	305mm
Length for Pinion	30mm
Tolerance Rating	Undersized
Length Tolerance	-3.175mm to 0.000mm
Width Tolerance	-0.030mm to 0.000mm
Height Tolerance	-0.030mm to 0.000mm
Price	$2.41

The minimum length of the key is calculated in Appendix D to be 0.08636mm. The actual length of the key in contact with the shaft is set to be 30mm. Therefore, the straight key 92288A725 is an appropriate selection for the system.

3.4.3 Shaft Material Selection

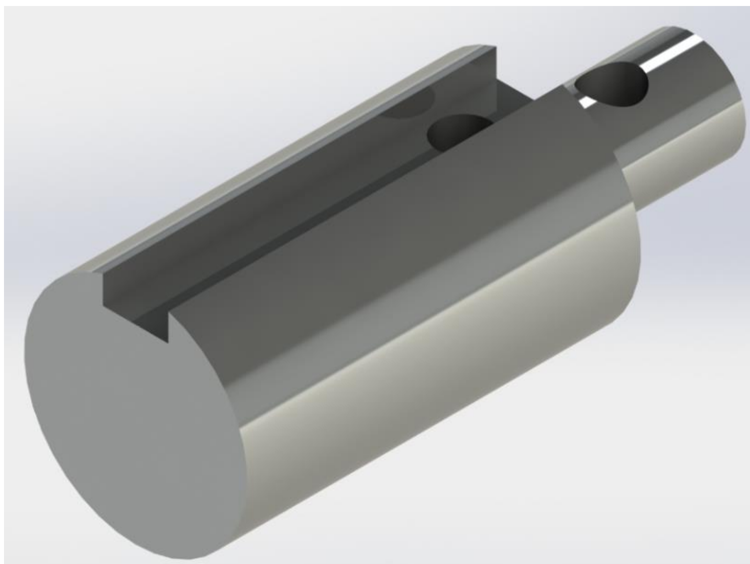
The following section presents the process of material selection of shaft and gear. According to the knowledge learned in Eng. Material 2, the material of shaft and gear should be the same. Since the material for rack and pinion has been selected, which is S45C steel. Therefore, the material used for shaft will be S45C steel. The mechanical properties for S45C steel are listed as followed:

- Density (kg/m3) 7700-8030
- Young's Modulus (GPa) 190-210
- Tensile Strength (Mpa) 569 (Standard) 686 (Quenching, Tempering)
- Yield Strength (Mpa) 343 (Standard) 490 (Quenching, Tempering)
- Poisson's ratio 0.27-0.30

3.4.4 Specifications for Shaft

The shaft is a designed part which will be used to transmit power between motor shaft and pinion. The input motor shaft has a diameter for 8mm, and pinion has a bore diameter for 17mm. Therefore, the shaft should be a step-down shaft which has a diameter of 17mm and step down diameter of 8mm. When designing the length of the shaft, the minimum allowable length should be chosen to minimize the space the system will occupy. The minimum allowable length is 42.5mm which is shown in Appendix D. Therefore, the designed shaft should be 42.5mm in length.

Figure 14: Shaft of rack and pinion system



The specifications for designed shaft are listed in TABLE XII.

TABLE XII: SPECIFICATIONS FOR DESIGNED SHAFT

Parameter	Shaft
Material	S45C steel
Total length	42.5 mm
Step-down section length	12.5 mm
Diameter	17mm
Step down section diameter	8mm

The top view, side view and bottom view of the shaft are shown in Appendix D.

The designed shaft is then tested with FEA and is shown in Appendix D and the maximum stress is 6.9165 MPa, which is smaller than the yield strength of S45C steel with the safety factor of 2, which means the designed shaft will not fail.

3.4.5 Bolts for Coupler, Pinion and Rack

Bolts for shaft will be used to fix the coupling and pinion on the shaft, bolts for rack are used to fix the rack to the ground.

According to the specifications of the pinion, rack and coupling, five M7 bolts are needed for rack, two M4 bolts are needed for coupling and two M4 bolts are needed for pinion.

The bolts are stock parts chosen from McMaster-Carr, the specifications for bolts are listed in *TABLE XIII* and *TABLE XIV*.

TABLE XIII: SPECIFICATIONS FOR BOLTS FOR PINION AND COUPLING

Parameters	Bolts for pinion and coupler
Part number	91280A132
Amount	4
Price	$7.08 per 100
Thread Size	M4
Thread Pitch	0.7 mm
Length	10 mm
Material	Steel
Head Type	Hex
Drive Style	External Hex

TABLE XIV: SPECIFICATIONS FOR BOLTS FOR RACK

Parameters	Bolts for rack
Part number	91280A423
Amount	5
Price	$9.17 per 100
Thread Size	M7
Thread Pitch	1 mm
Length	40 mm
Material	Steel
Head Type	Hex
Drive Style	External Hex

3.5 Motor

A motor is the driving force in moving the chairs forwards and backwards. The motor that will be selected must be able to move 20 chairs, between 10 to 25 seconds. To select the correct motor, a few criteria must be known, including the friction force of the rollers, the diameter of the pinion, and the overall mass of the chair. The two critical specifications of the motor that will be needed is the RPM and the torque output.

3.5.1 Technical Specifications

The RPM of the motor will determine the time it will take the chairs to move completely forward, and the speed at which the chairs will travel at. To determine this speed, equation (1) was used.

$$V = d_p \times RPM \times \frac{\pi}{60} \qquad (1)$$

Where V is the linear velocity, RPM is the revolutions per minute that the motor produces, and d_p is the diameter of the pinion in meters.

From the velocity, the time it takes to move the chair forwards can be determined by equation (2).

$$t = \frac{V}{d} \qquad (2)$$

Where V is the linear velocity, d is the distance the chair is moved, and t is the time taken to move the chair.

Using an excel spreadsheet, found in Appendix E, the RPM range is calculated based on the diameter of the pinion, which is 0.036 m, and the total distance needed to move the chairs, which is 34 inches. The RPM range to completely move the chairs in 10 to 25 secs is 18 to 45 RPM.

Now that a range of RPM for the motor has been determined, the minimum torque required to move the chair must be determined. The minimum torque of the motor will be compared against the force required to push the chair forward, therefore the force required to overcome the friction and move the chair must be determined. To determine friction force produced by one chair, equation (3) can be used.

$$F_f = \mu \times W_c \times g \qquad (3)$$

To determine the force created by the motor, equation (4) will be used.

$$F_t = \frac{T}{r_p} \tag{4}$$

Where F_t is the force created by the motor torque, T is the torque in Nm, and r_p is the pitch radius of the pinion.

Now comparing the required force to move one chair and the force created from the torque of the motor, this can determine how many chairs the motor can move, using equation (*5)*.

$$Chairs\ moved = \frac{F_t}{F_f} \tag{5}$$

Based on section 3.3 the pinion pitch radius is 0.018 m and based on section 3.6 the coefficient of friction is 0.003. The remaining variables are based on chair dimensions, and motor specifications. Using an excel spreadsheet, found in Appendix E, the optimal torque required has been determined. To move 20 chairs, the motor will need at least 82 in-oz of torque.

For selecting the motors, the torque value must be met as a minimum, and the RPM of the motors must fall in the desired range.

The last restriction to the motor is the input power required. This will be an electric DC motor, the power the motor uses comes from the same source that the current linear actuator uses. The linear actuator uses 29 volts, and 2 amps, therefore the motor cannot exceed these values.

The selected motor must meet the specifications shown below in TABLE XV.

TABLE XV: OPTIMAL SPECIFICATIONS FOR A MOTOR

Torque of motor	≥ 82 in-oz (0.579 Nm)
RPM range	18 – 45 RPM
Voltage	< 29V

3.5.2 Selected Motor

The motor selected is a compact square-face DC gear motor, the specifications of this motor are shown in TABLE XVI.

TABLE XVI: SELECTED MOTOR STOCK SPECIFICATIONS

Supplier	McMaster Carr
Torque	320 in-oz
RPM	25 rpm
Voltage	12V DC
Full load current	1.3 A
Cost	$62.74

This motor can move up to 78 chairs on its own which surpasses the number of chairs that Palliser has defined for us to be able to move, which is 20 chairs as stated in Section 1.6. The total time it will take to move the chairs is 18.3 seconds, this will provide access under all the chairs in a reasonable amount of time. The power consumption is 18 W, which is in the range of the power consumption stated in Section 1.6. If the system is used once per day the power usage will be 0.252 W*hr/day. TABLE XVII shows the specifics of the motor.

TABLE XVII: THE SPECIFICS OF THE SELECTED MOTOR

Maximum number of chairs moved	78 chairs
Time chairs take to move	18.3 seconds
Power used	18 W
Power consumption per day	0.252 W*hr

This square face motor was selected because it will be easier to mount to the motor bracket. Also, the torque exceeds the minimum requirement, the RPM falls in the desired range, and the voltage needed is within the supplied limit. This motor is only a suggested motor, as there are multiple options available, we suggest that Palliser reach out to their suppliers and find the lowest cost motor that will meet the desired specifications.

The motor will be connected to the chair and to the shaft that connects to the pinion. A motor mount will be used to connect to the chair and a coupler will be used to connect the motors shaft to the pinion shaft.

3.6 Rollers

Rollers are used to easily allow the chair to move across the floor. The rollers are a critical feature and must meet certain criteria. The criteria includes; the height added is in the range of the technical specifications, the load capability must be able to support the chairs weight which is 120 lbs dynamically, the load capability must be able to support the chairs weight which is 120 lbs and a 300 lbs human statically, and ideally a low friction to reduce the amount of force needed to move a chair.

3.6.1 Technical Specifications

The height criteria is defined as the allowable range of added height and it must be between 1 inch and 1.4 inches. This to allow for the best comfort in leg position, any higher may cause some peoples legs to hang which would not be ideal for comfort. The current height of the chair from the floor is 1 inch and would be optimal to maintain.

The load capabilities, both dynamic and static, can be determined by force distribution. To determine the force distribution the center of mass and position of rollers must be found. The center of mass was determined by the CAD model of the chair, and the positions of the rollers were varied. An excel spreadsheet, found in Appendix F, solved the resulting load at each of the rollers for 4 potential roller positioning. The calculated roller positions are shown in Figure 15.

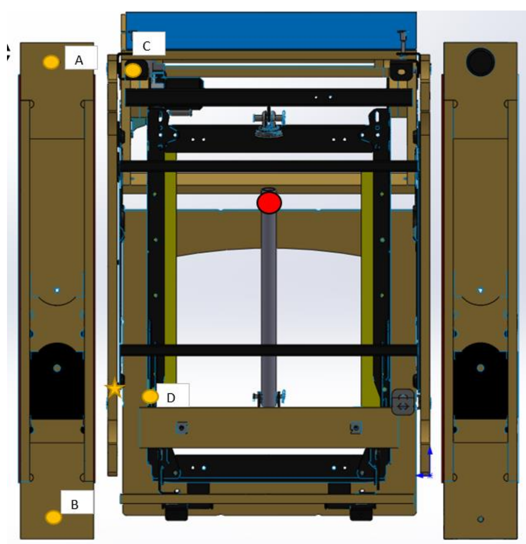


Figure 15: Potential location points of the rollers

The red circle represents the center of mass, the yellow circles represent the potential roller locations, and the yellow star was for the reference point of the coordinate system. TABLE XVIII, shows the force at each location, depending on where each roller is placed.

TABLE XVIII: FORCES AT EACH OF THE ROLLER LOCATION POINT WHEN STATIC

	AB	AD	CB	CD	Units
F1	1088.363	875.9031	1103.308	891.2636	N
F2	1088.363	875.9031	1103.308	891.2636	N
F3	780.2087	992.6683	765.2635	977.3078	N
F4	780.2087	992.6683	765.2635	977.3078	N

F1, F2, F3, and F4 are the forces that the roller will experience and are shown in Figure 16 on where each one acts at. The results from TABLE XVIII are based on a safety factor of two, and when the chair is static.

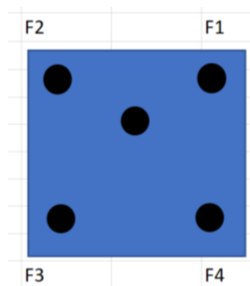


Figure 16: Location of F1, F2, F3, and F4 on the recliner

For the dynamic situation, the same process was used, however with only the weight of the chair. The results are shown in TABLE XIX, where the factor of safety was used as two.

TABLE XIX: THE FORCES AT EACH ROLLER LOCATION WHEN DYNAMIC

	AB	AD	CB	CD	
F1	310.9608	250.258	315.2308	254.6467	N
F2	310.9608	250.258	315.2308	254.6467	N
F3	222.9168	283.6195	218.6467	279.2308	N
F4	222.9168	283.6195	218.6467	279.2308	N

The last criteria is low friction, there is not set value for low friction but looking for a roller with a bearing will be optimal. Roller specifications based on calculations and technical specifications are listed on TABLE XX

TABLE XX: ROLLER REQUIREMENTS

Height (including the support to the chair)	1 inch – 1.4 inch
Dynamic load capabilities minimum	315 N
Static loading Capabilities minimum	1.1 kN

3.6.2 Selected Roller

A cam follower roller was chosen due to their small size, high load capabilities, bearing interface, and a stud for easy mounting. The selected cam follower roller is a McGill CF ¾ SB. The roller specifications are shown in TABLE XXI.

TABLE XXI: SELECTED MOTOR TECHNICAL SPECIFICATIONS

Supplier	Motion Canada
Brand	McGill
Roller Diameter	0.75 inches
Static Load Capacity	1500 lbs (6.67 kN)
Dynamic Load Capacity	1660 lbs (7.38 kN)
Bearing type	Needle Rollers
Coefficient of Friction	0.003
Material	Chrome Steel
Coating	Black Oxide
Stud Length	0.875 inches
Stud Diameter	0.375 inches
Roller Width	0.50 inches
Thread size	3/8-24
Cost	$31.20 CAD

The model of the selected roller is shown in *Figure 17*. Note that the model does not show the threaded feature.

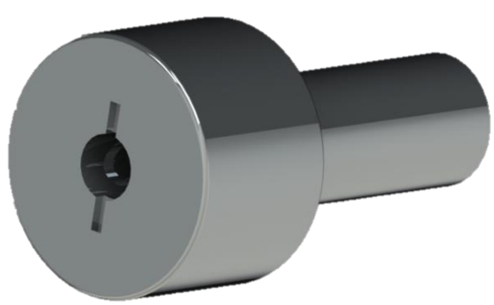


Figure 17: Model of the selected roller

The overall height of the roller is 0.75 inches, which is less than 1 inch, however allows for a support to the chair to be installed with the possibility of maintaining a 1-inch height. Both the static and dynamic loading capabilities are well above the minimum, therefore the roller will be strong enough. The threaded stud will allow for easy installation, and easy replacement.

The rollers will be mounted on to the roller mount and tightened with a 3/8 -24 nut. The rollers on the ends will be in contact with the roller slots, for guidance and to inhibit the lifting of the chairs while in regular theater use. The rollers on the front end will be in contact with the safety mechanism as well during regular use.

Initially the idea of casters was brought forward, however casters are quite large. The smallest caster that was found had a 2-inch diameter, which is outside the desired height increase. Along with the height, Palliser did not like the idea of casters, as they have tried using them before with little success. Casters may be used during prototyping to determine their viability as they are less expensive compared to rollers, however are not part of the final design

3.7 Roller Mount

The rear side of the recliners is lifted approximately 1.32 inches from the ground due to the added height by the roller and thickness of the bracket. To ensure the recliners are parallel with the ground the front side of the recliners will be lifted using the rollers and roller mounts. Rollers are a good choice for this application as it allows the recliners to glide forward smoothly. Shown in *Figure 18* are the two types of roller mounts that are used; (a) single-type and (b) dual-type. At the front side of the recliners, there are two single-type and four dual-type mounts. The dual-type mount consists of two single-type mounts connected by a rectangular plate. The rectangular plate is there to connect the recliners by their armrests, as shown in *Figure 19*, which helps ensure the recliners are straight when moving forward. At the rear side, all eight mounts are single-type. The mounts at the front side are placed exactly at the location of recliner stands. The mounts at the rear side are placed specifically so that it can act as a support to the seat bracket to prevent bending. Single-type and dual-type mounts are fastened to the recliners using M4 and M6 socket head screws, respectively.

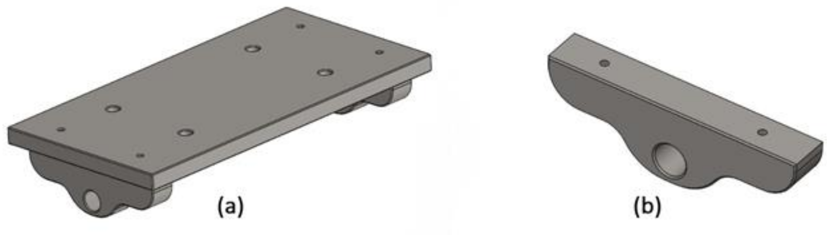


Figure 18: Roller types used in the system

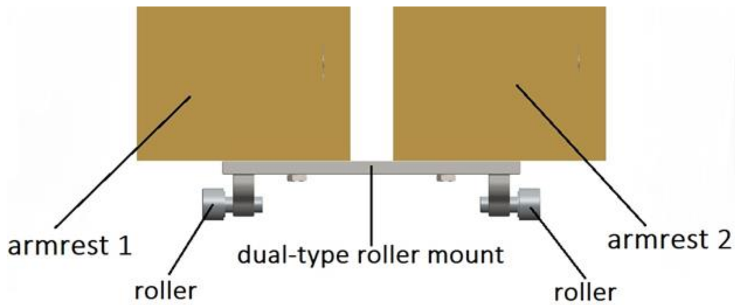


Figure 19: Dual-type roller mount configuration

3.8 Slot Rail

The slot rail is an Aluminum T6 – 6061 plate bent to a Z-shaped structure which is used to guide the roller wheels along the linear path and as a level for installing the rollers in the correct position. The slot rail is fixed to the floor, which is assumed to be concrete, using a ¼” steel flat head concrete screw which could be purchased from any retailer in bulk. The flat-head screw allows the screw to be flushed into the slot profile to prevent tampering and to maintain a low slot rail height of 0.9 inches. As shown in the *Figure 20*, the slot has cut out pin holes which would be used for the locking pin. The total mass of the slot modelled following the dimensions of the roller is 4.526 lbs.

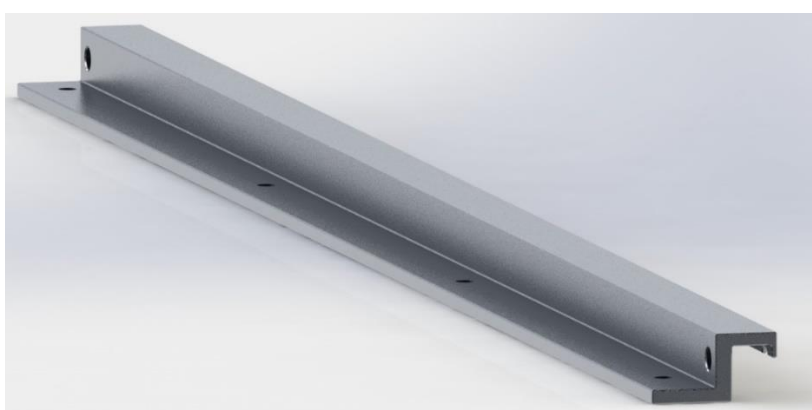


Figure 20: roller slot CAD model

3.9 Locking Mechanism

To fully restrain the recliners from movement while in regular theater use, a locking mechanism is used to restrict the recliners from being pulled forward. The locking mechanism is a pin lock system, where a pin will go through a hole just in front of the front roller on the slot rail, will cross in front of the roller, and then go through a support structure as shown in Figure 21. The pin lock is used due to its simplicity, and its ability to prevent the unwanted motion. This method will force the cleaner to go to every point a pin is located to remove it, however the cleaner must wipe down every chair already. Therefore, this does not create additional operation time.

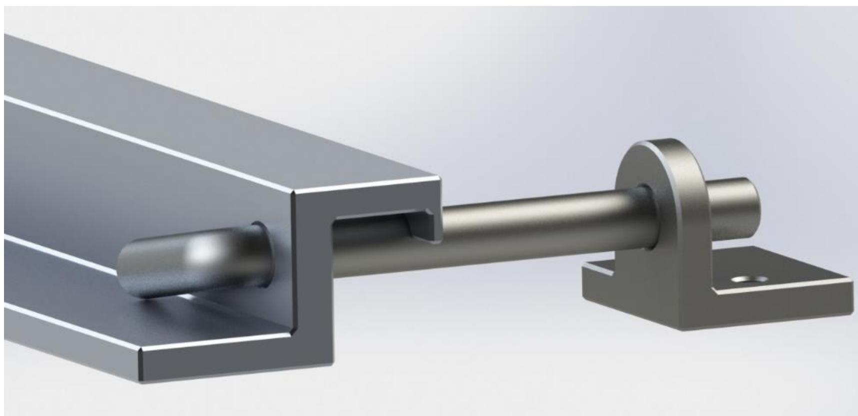


Figure 21: Model of the locking mechanism

Figure 22, shows the locking mechanism along with the roller and roller support for clarity of how the locking mechanism with prevent the forwards motion when in regular theater use.

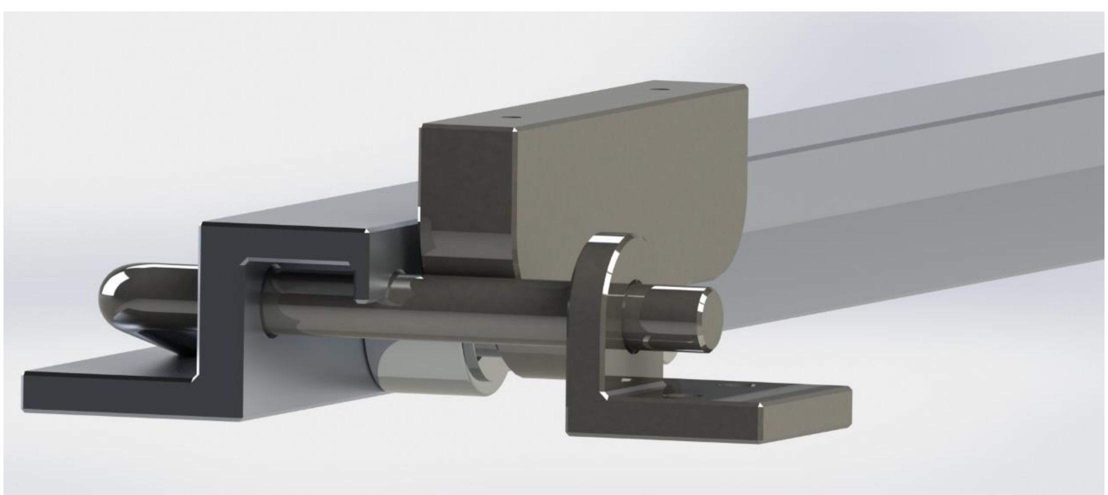


Figure 22: Assembly of locking mechanism and rollers

3.9.1 The Pin

The pin can either be manufactured or bought from stock. The pin should be heavy duty to withstand any force without breaking. The length of the pin is 80mm, and the diameter of the pin is 8 mm. The pin has an L shape to it, this will prevent the pin from being pushed too far through and allow it to be easier to grab. The material of the pin 304 stainless steel, this is due to the high strength of this steel, its corrosion resistance, and due to it being a common type of stainless steel [6].

3.9.2 Pin Support

The pin supports main purpose is to allow the pin to sit horizontally while the pin is in place, and too reduce any play that there may be due to the hole size and pin diameter. The support is a simple structure, with a hole to allow the pin to sit in, and the structure will be bolted to the floor. The whole diameter will be 8 mm, with a tolerance that will allow sliding between the pin and hole. The material will be 304 stainless stress, due to the same reasons the pin is 304 stainless steel. Refer to Appendix C for technical drawings with full dimensions.

3.10 Control System

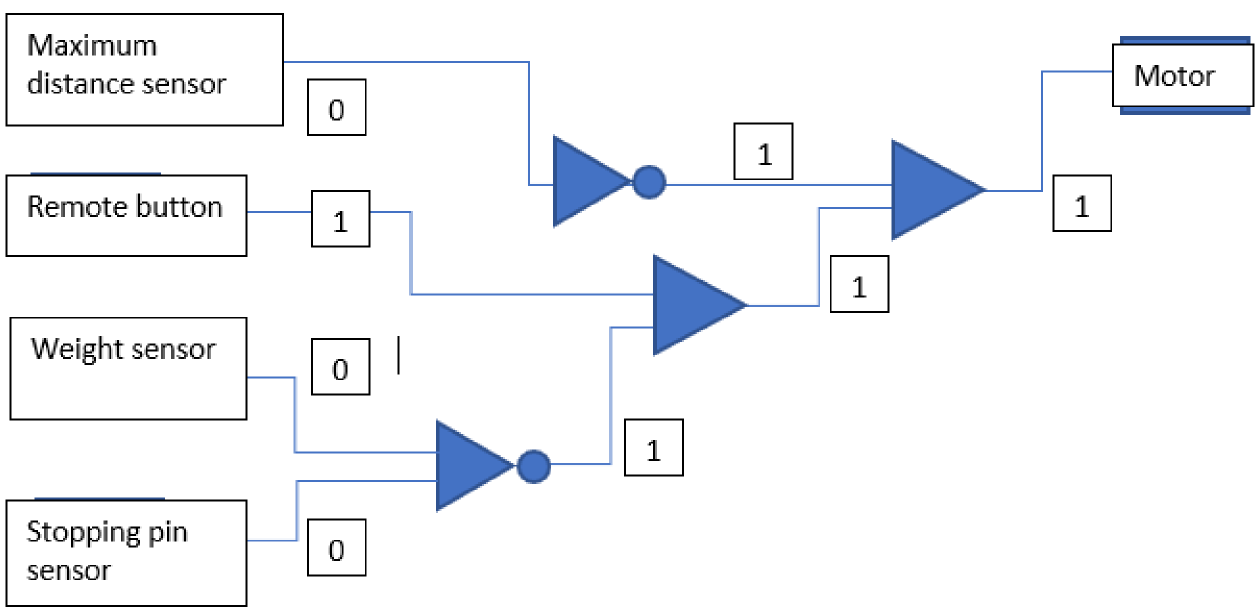


Figure 23: Logic gates control

The control system follows the logic circuit connection as shown in the figure above. This circuit would ensure safety of the design when not in use. The motor would not power on if the maximum distance, weight and stopping pin sensors conditions do not satisfy Boolean logic even if the button is activated.

3.11 Bill of Materials

All purchased and designed components for the design of the theatrical moving system are listed in the Bill of Materials, shown in *TABLE XXII*. It is recommended that Palliser checks with their own suppliers, as they may have a lower cost. All technical specifications for each component are found in their corresponding sections. Cost is in terms of Canadian currency, the exchange rate from USD to CAD is used as 1.33.

TABLE XXII: BILL OF MATERIALS

Product Name	Part #	Supplier	Quantity	Individual Cost (CAD)	Total Cost (CAD)
Square-Face DC Gearmotor	6409K17	McMaster-Carr	1	$83.44	$83.44
3 X 3.5 X 3/8 304 Stainless Steel Angle (10 ft)	Depends on vendor	Vendor of choice	2	Contact Selected Vendor	Contact Selected Vendor
Motor mount	Depends on vendor	Vendor of choice	1	Contact Selected Vendor	Contact Selected Vendor
L - connector	Depends on vendor	Vendor of choice	2	Contact Selected Vendor	Contact Selected Vendor
Single-type roller mount	Depends on vendor	Vendor of choice	10	Contact Selected Vendor	Contact Selected Vendor
Dual-type roller mount	Depends on vendor	Vendor of choice	4	Contact Selected Vendor	Contact Selected Vendor
M12 Hex head bolts	91310A712	McMaster-Carr	15	$0.78	$11.73
M12 Steel hex nuts	91423A150	McMaster-Carr	15	$0.35	$5.25
M8 Steel hex head screw	91310A536	McMaster-Carr	10	$0.28	$2.80
M8 Steel hex nuts	91423A120	McMaster-Carr	10	$0.09	$0.90

Product Name	Part #	Supplier	Quantity	Individual Cost (CAD)	Total Cost (CAD)
M6 Button head hex drive screw	92095A240	McMaster-Carr	24	$0.28	$6.72
M4 Button head hex drive screw	92095A196	McMaster-Carr	16	$0.14	$2.24
McGill CF ¾ SB	00097401	Motion Canada	18	$31.20	$561.60
3/8 – 24 Hex Nut	1000134948	Home Depot	18	$0.21	$3.78
Quick Release Pin	Depends on Vendor	Vendor of Choice	2	Contact Selected Vendor	Contact Selected Vendor
Pin Support Structure	Depends on Vendor	Vendor of Choice	2	Contact Selected Vendor	Contact Selected Vendor
Roller slot	P3316T6	Metals Depot	2	$29.65	$59.30
Fasteners	90160A644	McMaster Carr	8	$0.30	$2.40
Rack	SRFD2-1000	KHK STOCK GEARS	1	$16.20	$16.20
Pinion	SS2-18J17	KHK STOCK GEARS	1	$79	$79
Pinion shaft	Depends on Vendor	Vendor of Choice	1	Contact Selected Vendor	Contact Selected Vendor
Key	92288A725	McMaster Carr	1	$2.41	$2.41
Coupling	5395T212	McMaster Carr	1	$6.33	$6.33
Bolt for shaft	91280A132	McMaster Carr	4	$7.08 per 100	$7.08
Bolt for rack	91280A423	McMaster Carr	5	$9.17 per 25	$9.17

3.12 Failure Mode and Effect Analysis (FMEA)

The FMEA identifies ways that the design components can fail, and the methods used to reduce the risks of failure. It is set to meet the customer requirements of designing a functioning prototype and as a result, create a history of preventive actions which will allow for future improvement of the design.

[redacted]

Figure 24: Frequency (FREQ) rating scale [11]

[redacted]

Figure 25: Severity (SEV) rating scale [11]

The potential failure mode, effect and cause are analyzed and rated based on the severity and frequency of the potential failure mode. As shown in Figure 24 and Figure 25 , the severity (SEV) and frequency (FREQ) scales goes from 1 (Extremely low) to 10 (very high). The detection rating scale shown in examines the possibility of preventing failure before it occurs using the control process put in place in the design phase.

Figure 26: Failure detection ranking scale [11]

The FMEA in Figure 26 used key components of the design that fulfild the design purpose of moving the recliner seats. This in turn satisfies the customers requirements of making the cleaning process easier. Control measures are established for the possible failure modes and hence, improves the safety of the design. Components with high risk Priority Number (RPN) will be optimized to improve the safety during the testing phase.

TABLE XXIII: FMEA

Component	Potential Failure Mode	Potential Effect	SEV	Potential Cause	FREQ	Current Controls	DET	RPN	Recommend Action
Roller slot	Horizontal deflection due to rolling motion of roller wheels	Interference with roller wheels and roller support	1	a) Roller wheel not aligned properly and pushing on side of the roller slot. b) External push from cinema customers.	2	Using a lever when mounting components.	1	2	Tolerance and precision calculation should compensate for precision. Design could also be self-correcting by installing a robotic roller support. Action: Monitor
Roller support	Overloading	Compressing or bending	4	a) The maximum weight of design is exceeded. b) The life cycle of part is reached.	1	The factor of safety of 2 for the component is set to accommodate twice its design load.	3	12	Perform maintenance and checks when necessary and as scheduled. Action: Monitor
Roller wheels	Misalignment from travel path	The fixed roller support might break due to shearing force from rollers	2	Assembly tolerance and precision when mounting is not precise.	2	Installing the roller support with precision and making sure it is aligned correctly	1	4	Performing frequent checks using a level to make sure the roller support has not shifted due to frequent use. Action: Monitor
Pinion shaft	Shearing	Physical forces pushing chair back when is in use.	4	External physical force pushing against the direction of motion	2	Give detailed instructions on operation methods and what not to do when device is in use.	5	40	Include a “poka yoke” control that shuts the device down when not used properly. Action: Monitor

Component	Potential Failure Mode	Potential Effect	SEV	Potential Cause	FREQ	Current Controls	DET	RPN	Recommend Action
Rack & pinion	Interference of gear teeth	Grinding and worn out teeth	2	a) gear is not meshed properly. b) The life cycle of part is reached.	1	Ensure the correct gear sizes are purchased and use the same module for both rack and pinion to match the number of teeth and teeth mesh.	1	2	Ensure proper alignment of the rack to reduce any strain effect on the pinion teeth. Action: Monitor
Motor	Power surge	Burnt motor	4	Excess power is channeled to motor through actuator.	1	The control system will be used to regulate the amount of power flowing to the motor	1	4	A safety fuse to power down motor in case of power surges can be installed. Action: Monitor
Motor bracket	Fracture at fastening points	Detach from recliner	7	Motor vibrations and twist motion when in use causing wear around bolted points.	4	The bolts and nuts used can withstand high tensile stress.	5	140	Post testing optimization Action: Act
Seat bracket	Overload	Bending and visible deflection	8	a) The maximum weight of design is exceeded. b) The life cycle of part is reached.	6	a) A thicker frame to withstand overloading b) The factor of safety of 2 for the component is set to accommodate twice its design load	3	144	Post testing optimization Action: Act

4.0 Conclusion

The goal of this project is to develop a design and prototype that will make it easier to clean under Palliser's recliners installed in cinemas. The root cause of the problem was analyzed and it was evident that moving the cinema seat would make it easier for the cleaners to clean the areas that were difficult to reach.

The final design specifications were based on the client's needs and design constraints, interviewing the end users (cleaners and theatre staff) and feedback from project advisor. The most important specifications for the design included safety, a modular design that can move five chairs and that is restricted to the dimension of the recliners and easy to operate. The engineering analysis for the key components was based on a safety factor of 2 which allows the design to withstand twice the design factor.

The modularity of the design is a result of the extending and connecting the seat bracket using bolts and nuts that is connected to a motor which has the capacity to move a maximum of 13 recliners. The rack and pinion assembly is used to translate motion from the motor to the roller wheels connected to the base of the recliners.

The prototyping is set for the next phase of the course where we will test and optimize our design. The final design will be displayed in the Las Vegas CinemaCon, March 2020.

The learning and skills acquired by the team includes interacting with the client and end users frequently, understanding the client's needs. Accommodating changes to client needs and also the process of developing a design using different analytic methods to solve a problem.

Recommendations for the design is to follow the process improvement strategy which will help the team identify and prioritize problems that needs to be resolved. As well as verifying that the problem is solved by using a lean improvement technique.

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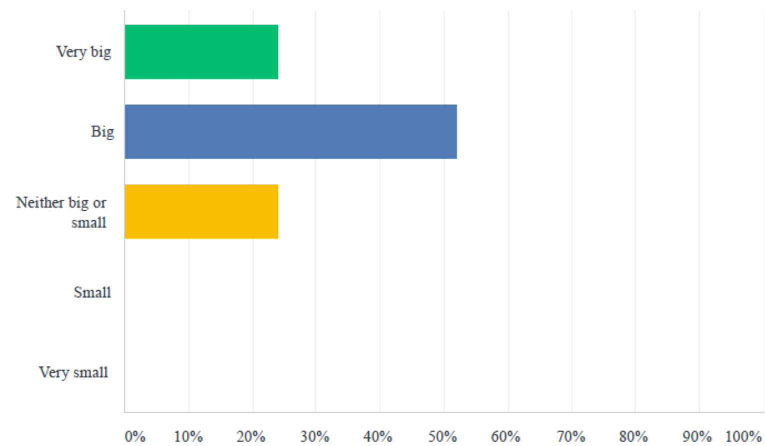
Appendix A – Client Survey Results

Palliser submitted a survey to their current clients to get information

How big of a problem is it to clean around recliners that are fixed to the floor and have hard to reach areas?

Answered: 25   Skipped: 0

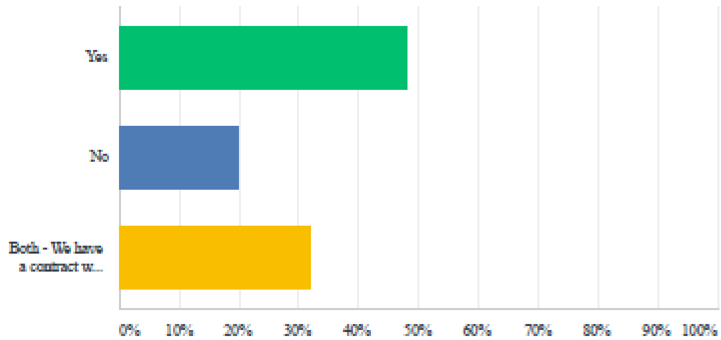


ANSWER CHOICES	RESPONSES	
Very big	24.00%	6
Big	52.00%	13
Neither big or small	24.00%	6
Small	0.00%	0
Very small	0.00%	0

This result shows 76% of the clients involved in the survey have a problem in cleaning around the recliners that are fixed to the floor. This proves that there is a problem linked to installing the fixed recliners.

Do you currently contract your theater cleaning services to a 3rd party provider?

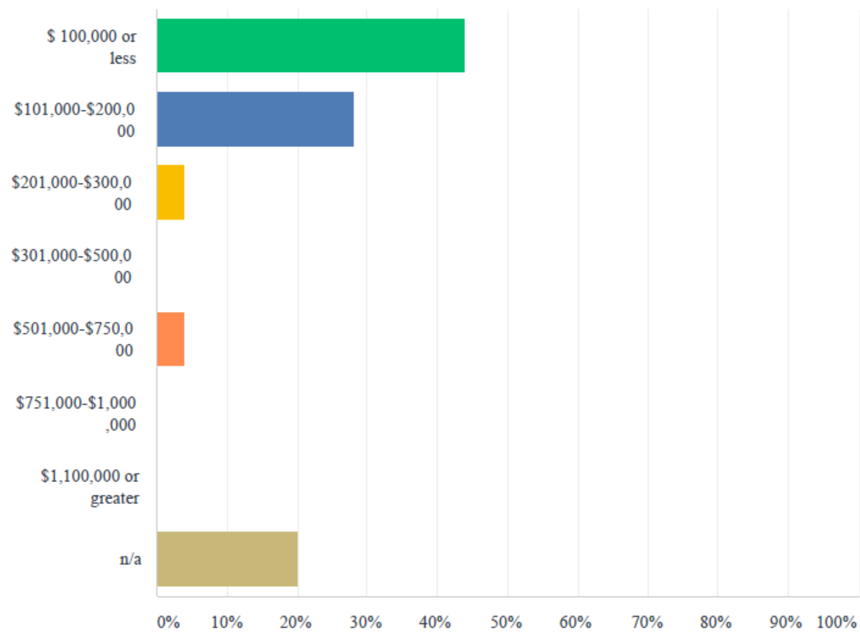
Answered: 25   Skipped: 0



ANSWER CHOICES	RESPONSES	
Yes	48.00%	12
No	20.00%	5
Both - We have a contract with a 3rd party and do some cleaning ourselves	32.00%	8
TOTAL		25

If using a 3rd party provider, approximately how much do you spend on cleaning your auditoriums per theater location.

Answered: 25 Skipped: 0

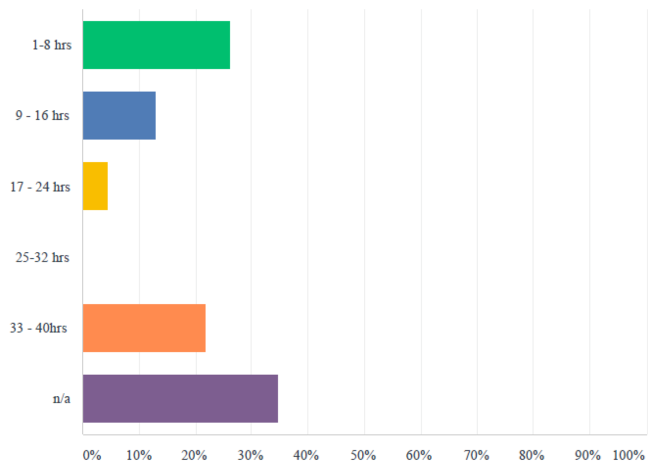


ANSWER CHOICES	RESPONSES	
$ 100,000 or less	44.00%	11
$101,000-$200,000	28.00%	7
$201,000-$300,000	4.00%	1
$301,000-$500,000	0.00%	0
$501,000-$750,000	4.00%	1
$751,000-$1,000,000	0.00%	0
$1,100,000 or greater	0.00%	0
n/a	20.00%	5

Out of the 25 clients that took the survey 20 had a range of cleaning cost while the other 5 didn't, based on the results for 20 clients, 45% of the clients spend over $100,000/yr on cleaning cost in a year while 55 % spend $100,000 or less.

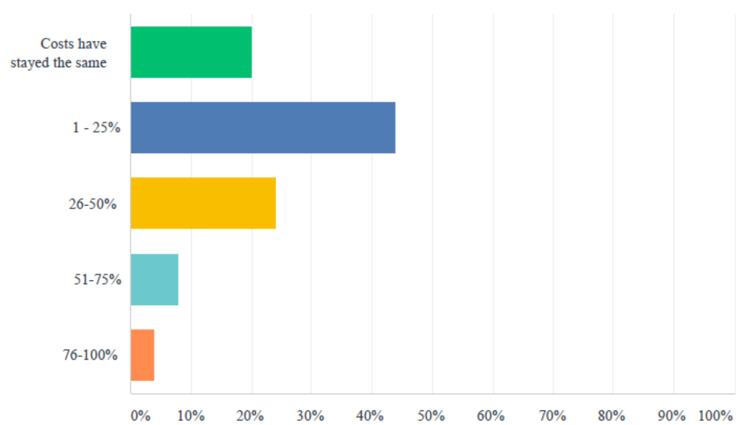
If you clean your theaters yourself, approximately how much time do you spend on cleaning your auditoriums per theater location each week

Answered: 23 Skipped: 2



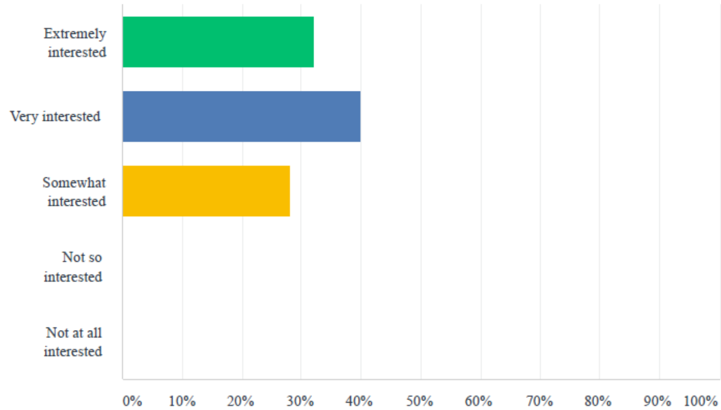
How much would you say have your cleaning costs increased since installing recliner seating?

Answered: 25 Skipped: 0



If a product was developed that promised to reduce cleaning times by at least 25% how likely would you be to buy the product?

Answered: 25 Skipped: 0



ANSWER CHOICES	RESPONSES	
Extremely interested	32.00%	8
Very interested	40.00%	10
Somewhat interested	28.00%	7
Not so interested	0.00%	0
Not at all interested	0.00%	0
TOTAL		25

Comments considered in root cause analysis

What is your biggest challenge with cleaning your theater seating?

Answered: 18 Skipped: 7

RESPONSES (18) WORD CLOUD TAGS (0) Sentiments: OFF

PAID FEATURE
Text Analysis lets you search and tag comments and see word clouds of frequent words and phrases. To get this feature, upgrade to a plan.

UPGRADE Learn more »

Apply to selected Filter by tag Search responses

Showing 18 responses

Your seating is too close to the ground, it should be higher off the ground like Irwin's

11/8/2019 8:35 AM View respondent's answers Add tags

A quick way to clean every seat between shows. But mainly a way to remove the popcorn and other things underneath the seats.

11/1/2019 4:33 AM View respondent's answers Add tags

Cleaning under the seats. Hard to clean spills with the wiring and hardware underneath.

10/23/2019 4:23 PM View respondent's answers Add tags

detail cleaning on a large scale.

10/23/2019 8:09 AM View respondent's answers Add tags

Related to cleaning your theater seats, what product/service would be a "wow" for you if we could make it happen?

Answered: 13 Skipped: 12

RESPONSES (13) WORD CLOUD TAGS (0) Sentiments: OFF

PAID FEATURE
Text Analysis lets you search and tag comments and see word clouds of frequent words and phrases. To get this feature, upgrade to a plan.

UPGRADE Learn more »

Apply to selected Filter by tag Search responses ?

Showing 13 responses

Raise the seating off the ground and all the frame, cables etc.

11/8/2019 8:35 AM View respondent's answers Add tags

vacuum cleaning or blowing away popcorn underneath seats.

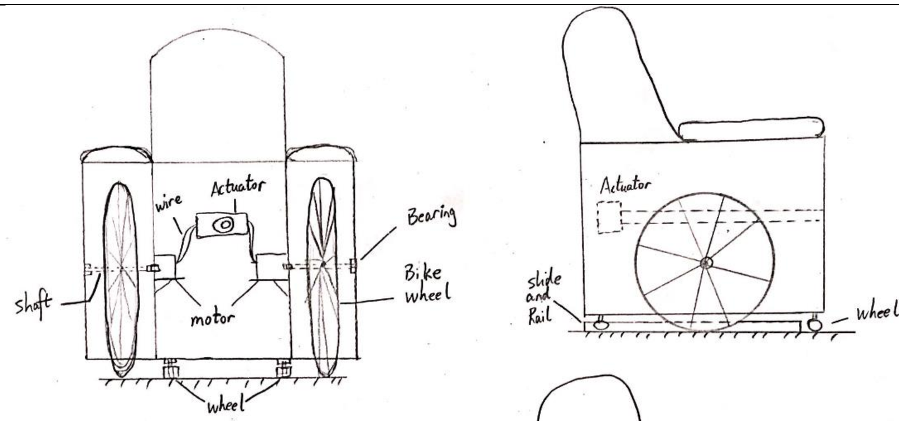
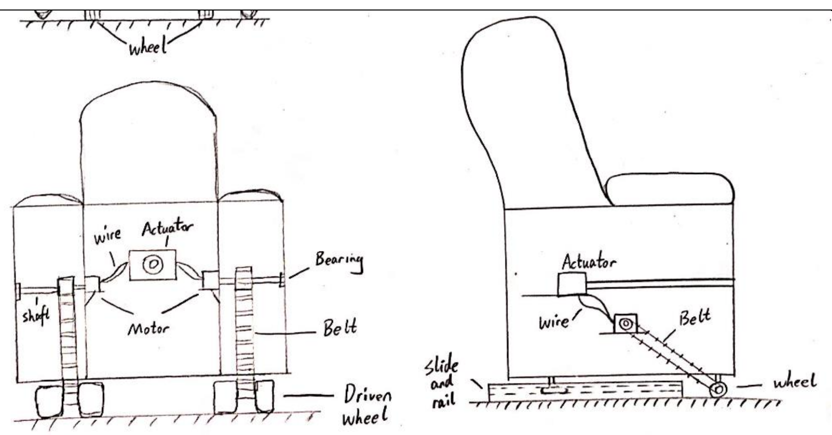
11/1/2019 4:33 AM View respondent's answers Add tags

Blower with extended narrow pipe/hose to blow away popcorn underneath seats. (we try blow away the popcorn with leafblower, but the pipe/hose is too short so we need to sit on our knees. or vacuum cleaner to remove the popcorn underneath the seats, one that has a piece than can get underneath the seats and gets out all the popcorn.

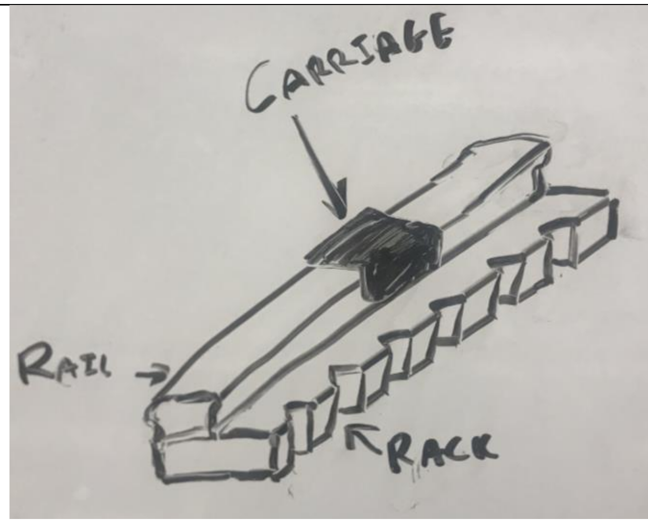
10/11/2019 3:13 AM View respondent's answers Add tags

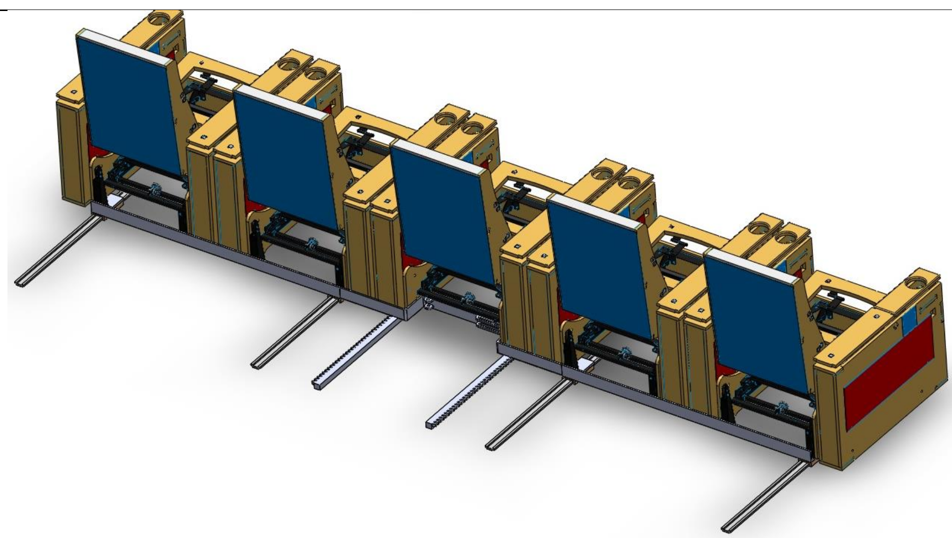
Appendix B – New Concepts Post CDR

After the CDR new concepts needed to be created to meet the design requirement of keeping the system under the chair as much as possible. The team brainstormed new concepts and reworked some prior concepts to create 7 new concepts. The following table shows the 7 new concepts with some information about each concept.

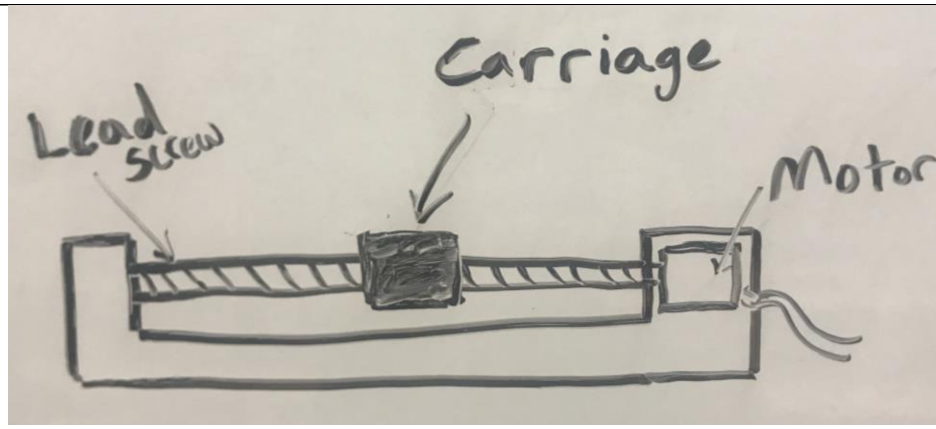
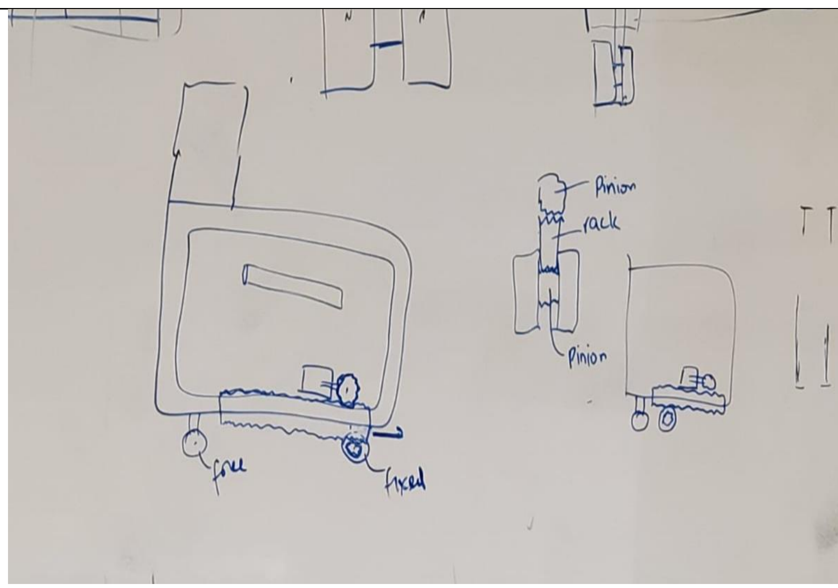
<table>
<tr><td>Concept</td><td>Bike Tire</td></tr>
<tr><td>Figure</td><td>
</td></tr>
<tr><td>Features</td><td>- Bike tire inside arm of chair. - Electrically powered. - Hard to install
Advantages: Cheap, can be mechanical, easy to operate, no tripping hazard, can reduce number of slide rails, less components, easy to manufacture.</td></tr>
<tr><td>Concept</td><td>Belt Driven Front Wheel</td></tr>
<tr><td>Figure</td><td>
</td></tr>
<tr><td>Features</td><td>- Powered front wheel via a belt. - Electrically powered. - Hard to install

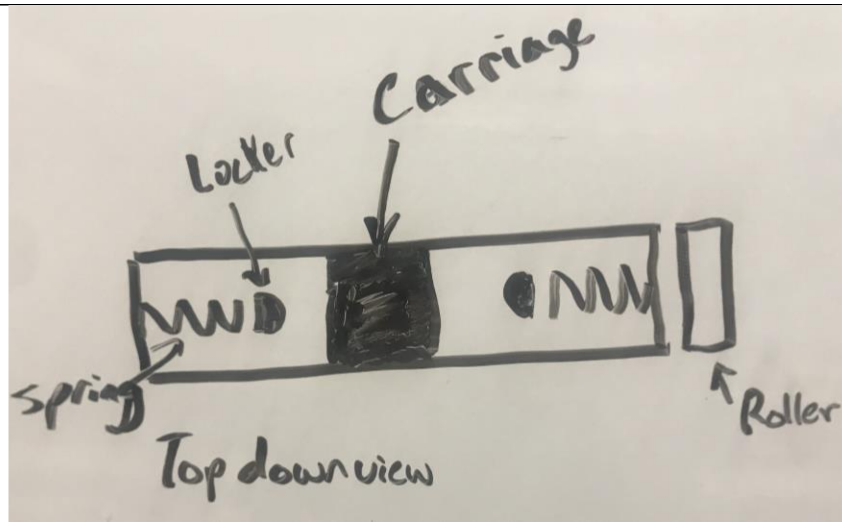
Advantages: No tripping hazard, less components, easy to manufacture, can move independently.</td></tr>
</table>

<table>
<tr><td>Concept</td><td>Sideways rack and pinion (rack and rail are one piece)</td></tr>
<tr><td>Figure</td><td>
</td></tr>
<tr><td>Features</td><td>- Slide rail with sideways rack. - Motor placed inside chair.

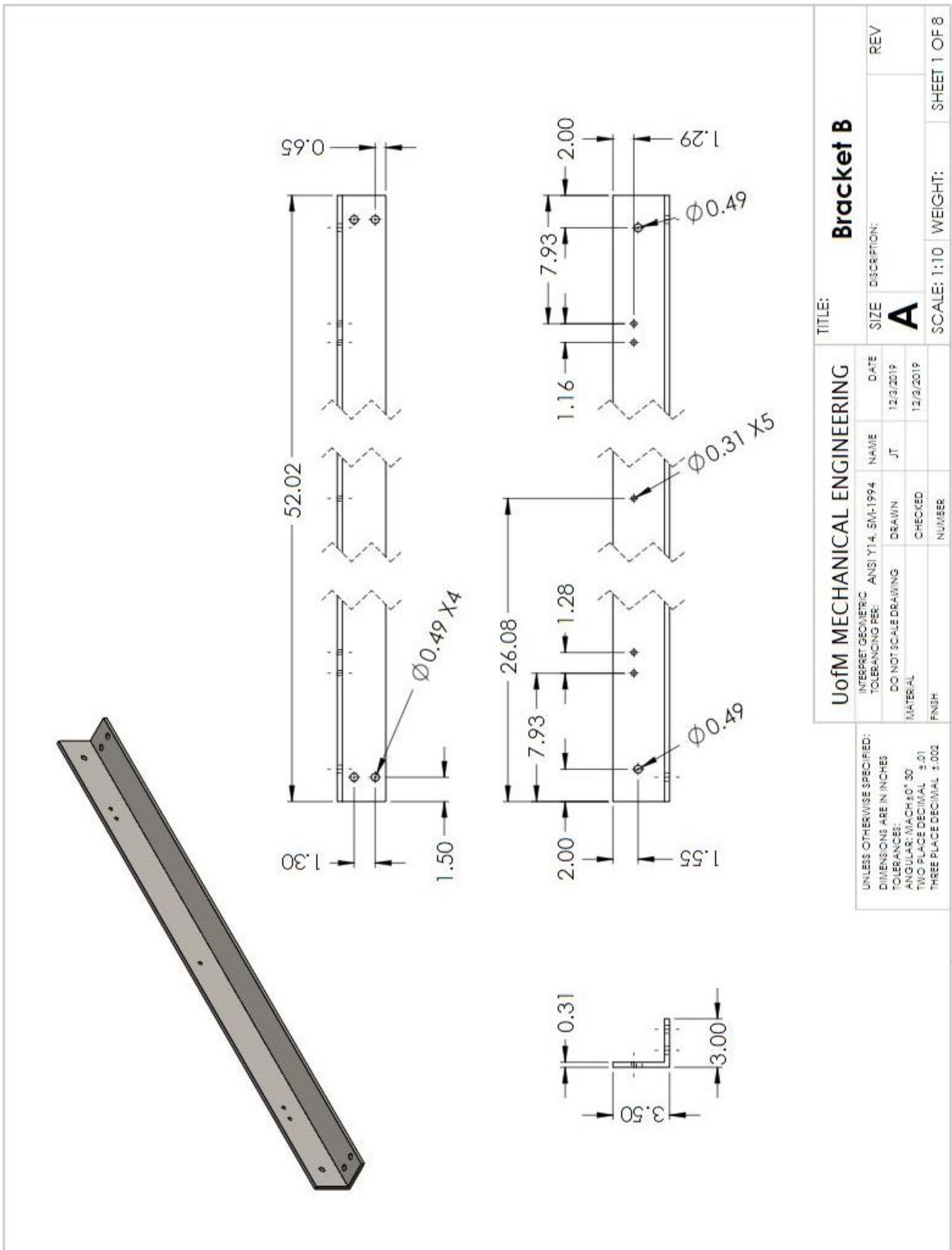
Advantages: Low profile, popcorn cannot get stuck in it easy to use, low slide rail only tripping hazard, moves as many chairs as motor can</td></tr>
<tr><td>Concept</td><td>Sideways rack and pinion (rack and rail are separate)</td></tr>
<tr><td>Figure</td><td></td></tr>
<tr><td>Features</td><td>- Slide rail with sideways rack. - Motor placed inside chair.

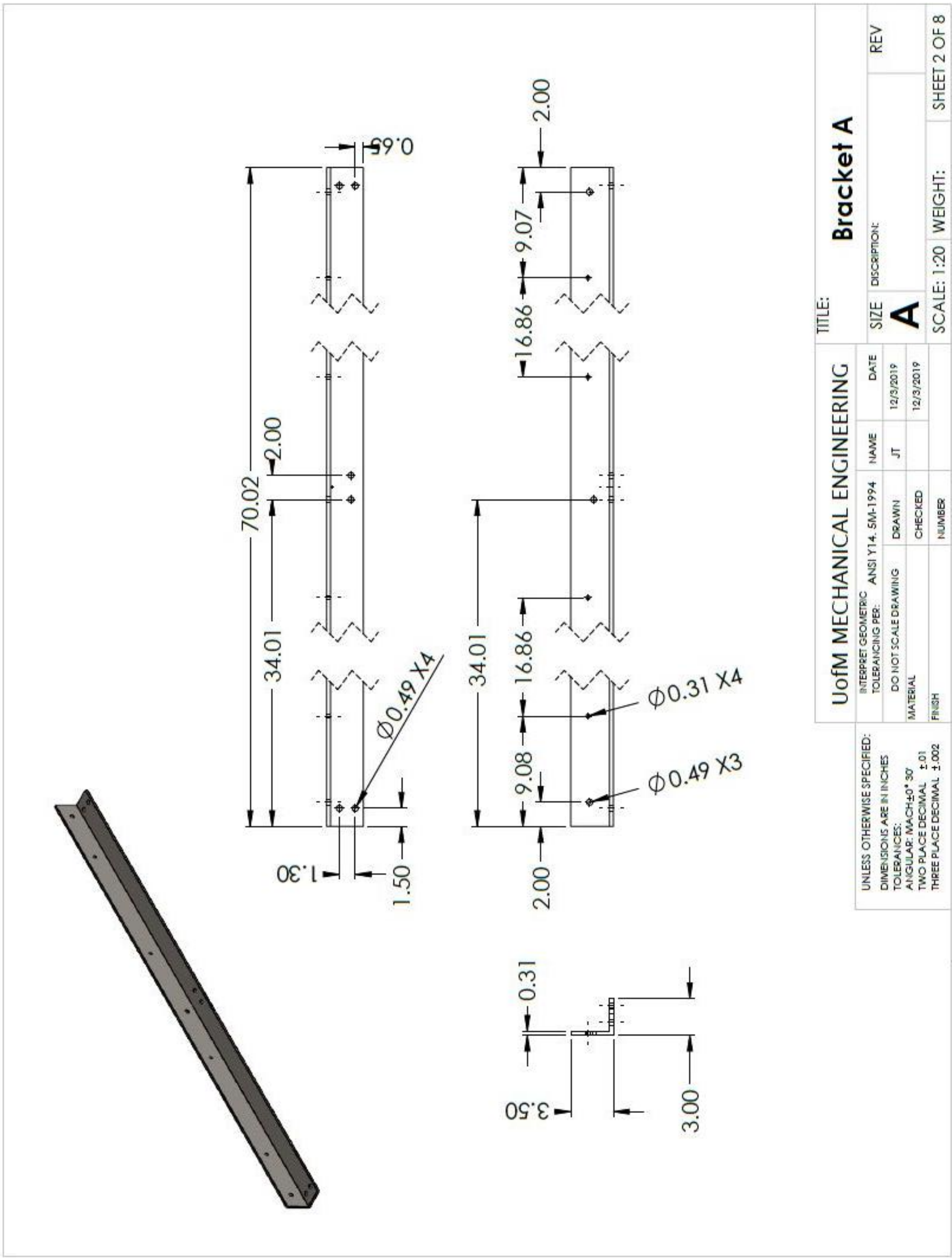
Advantages: Low profile, popcorn cannot get stuck in it easy to use, low slide rail only tripping hazard, moves as many chairs as motor can</td></tr>
</table>

Concept	Motorized Lead Screw
Figure	
Features	- Slide rail with lead screw in it. - Motor in slide rail. - Moderate tripping risk Advantages: No chair modifications required, easy to install, moves as many chairs as the motor can handle
Concept	Double Sided Rack and Pinion
Figure	
Features	- Rack and pinion system, double sided rack with pinion on both sides Advantages: Not a tripping hazard, easy to add a locking mechanism, motor moves as many chairs as it can.

Concept	Spring and Lock
Figure	
Features	- Springs inside slide rail with locking mechanisms Advantages: Mechanical design, low profile, one operator Disadvantage: Physics may be an issue

Appendix C – Technical Drawing

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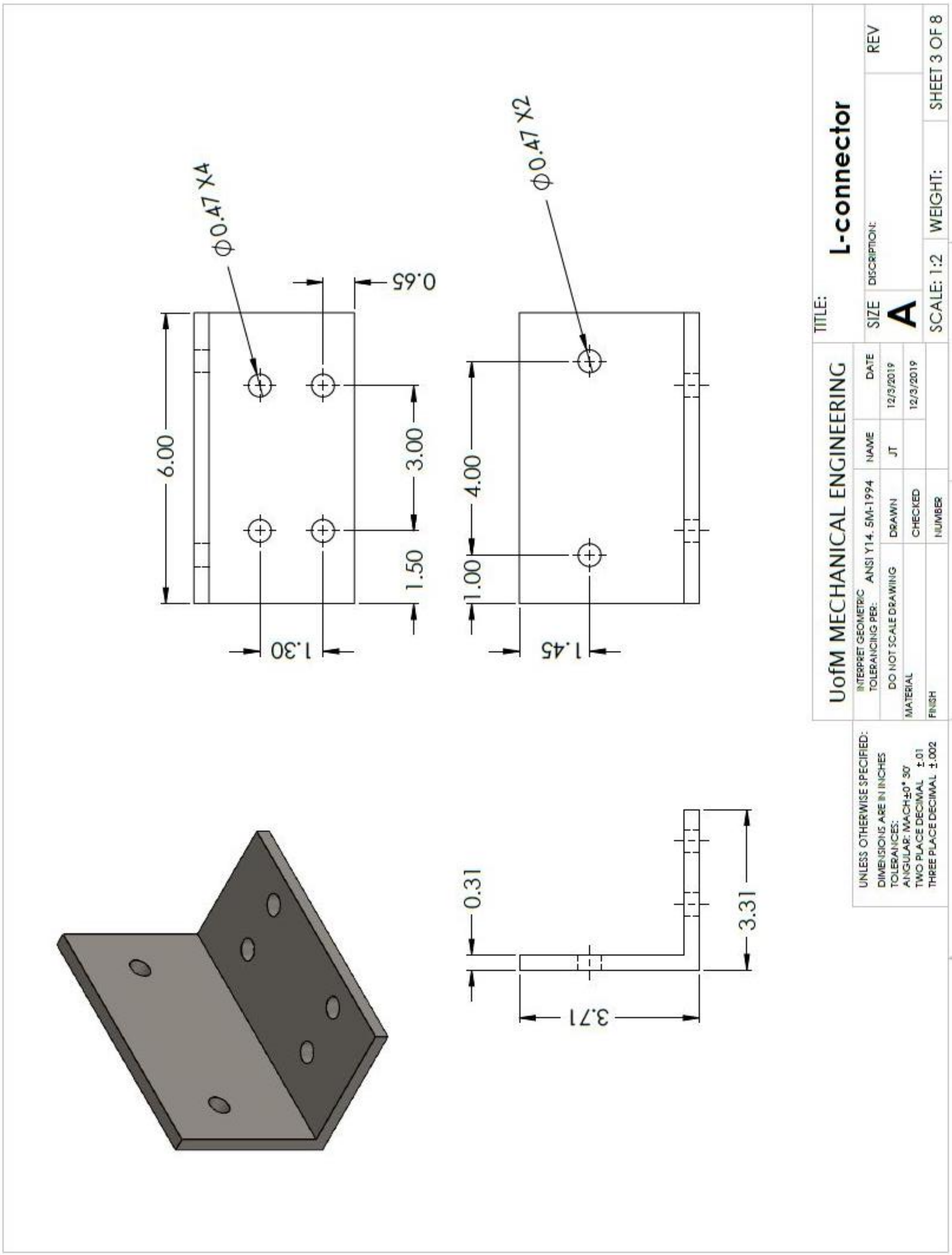

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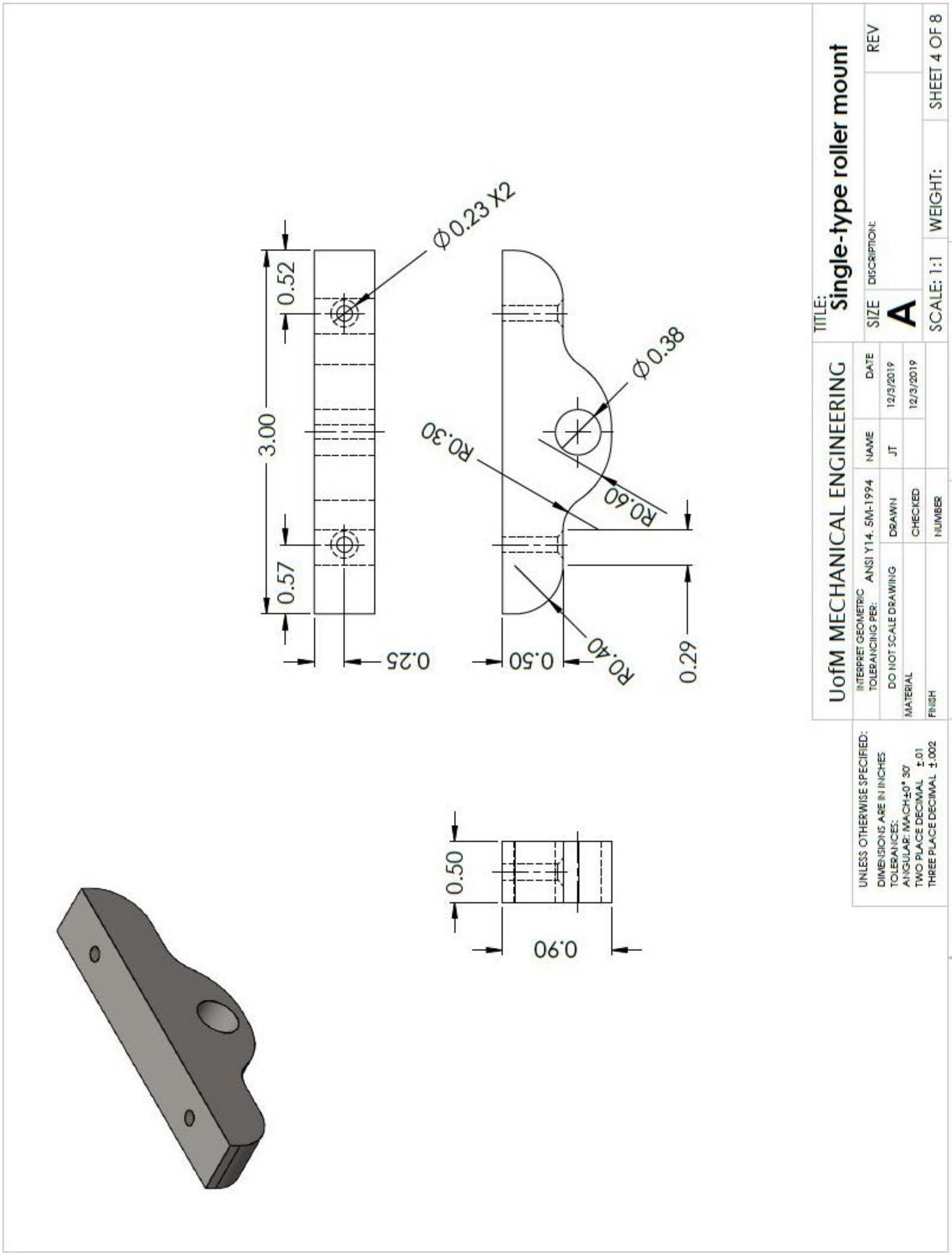

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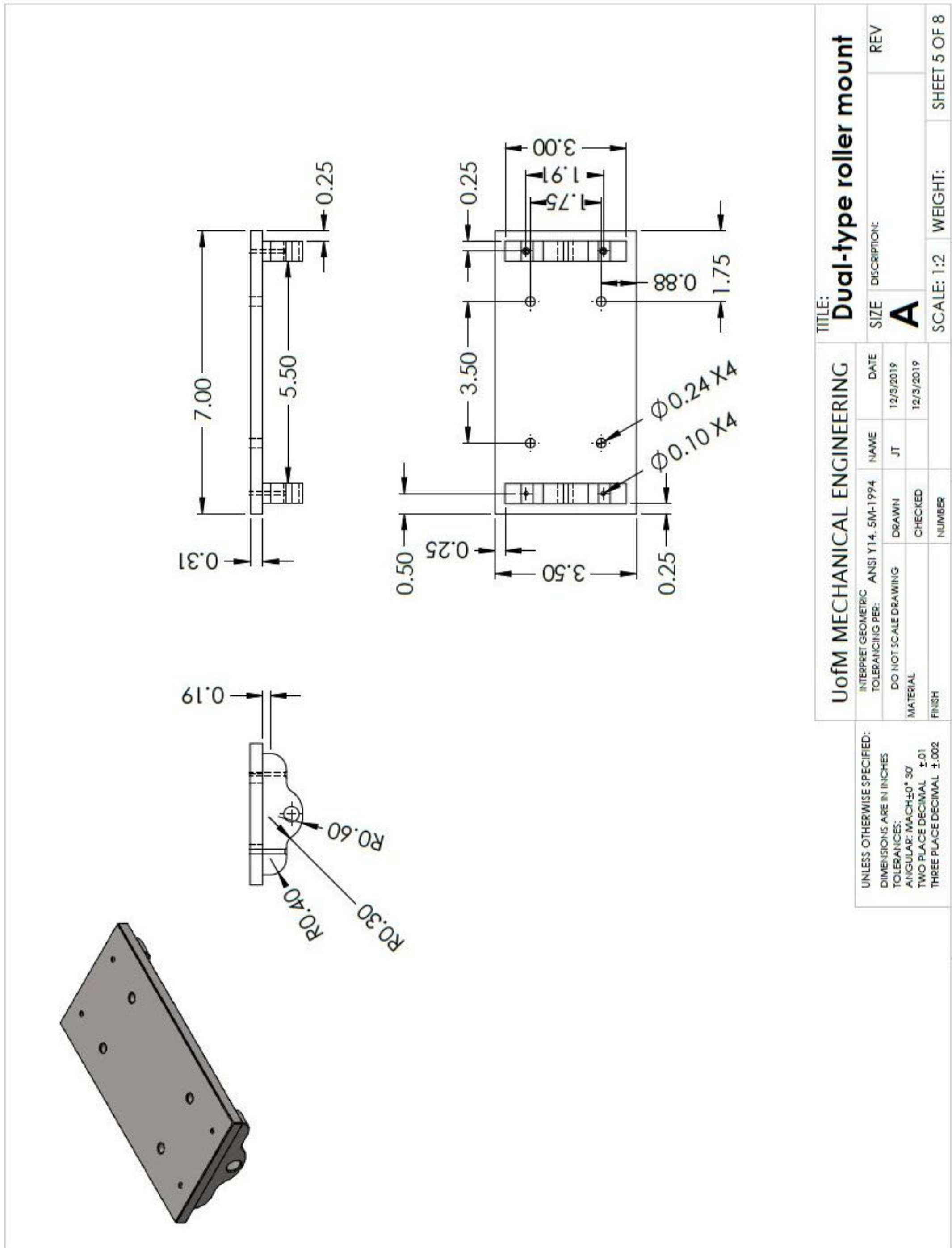

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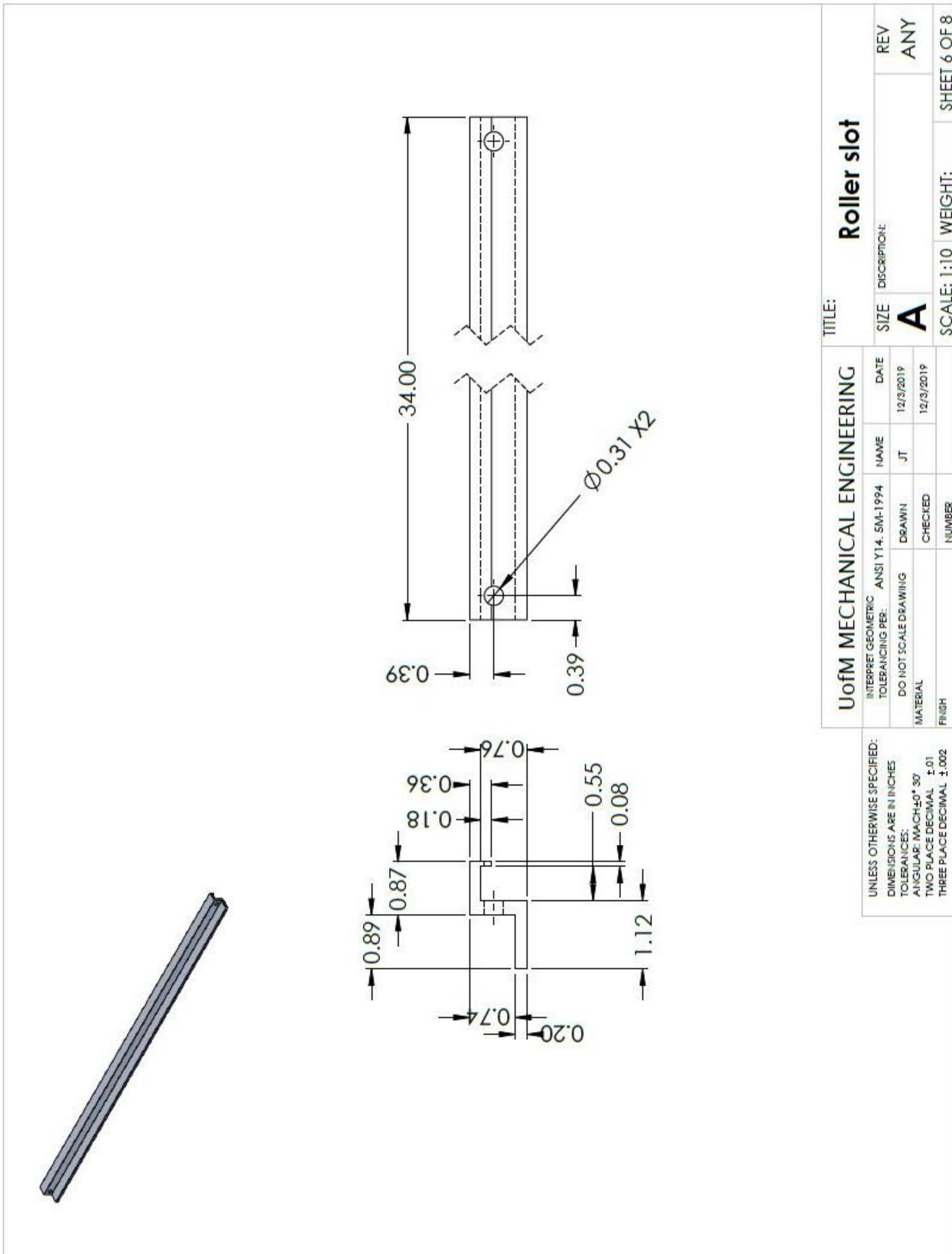
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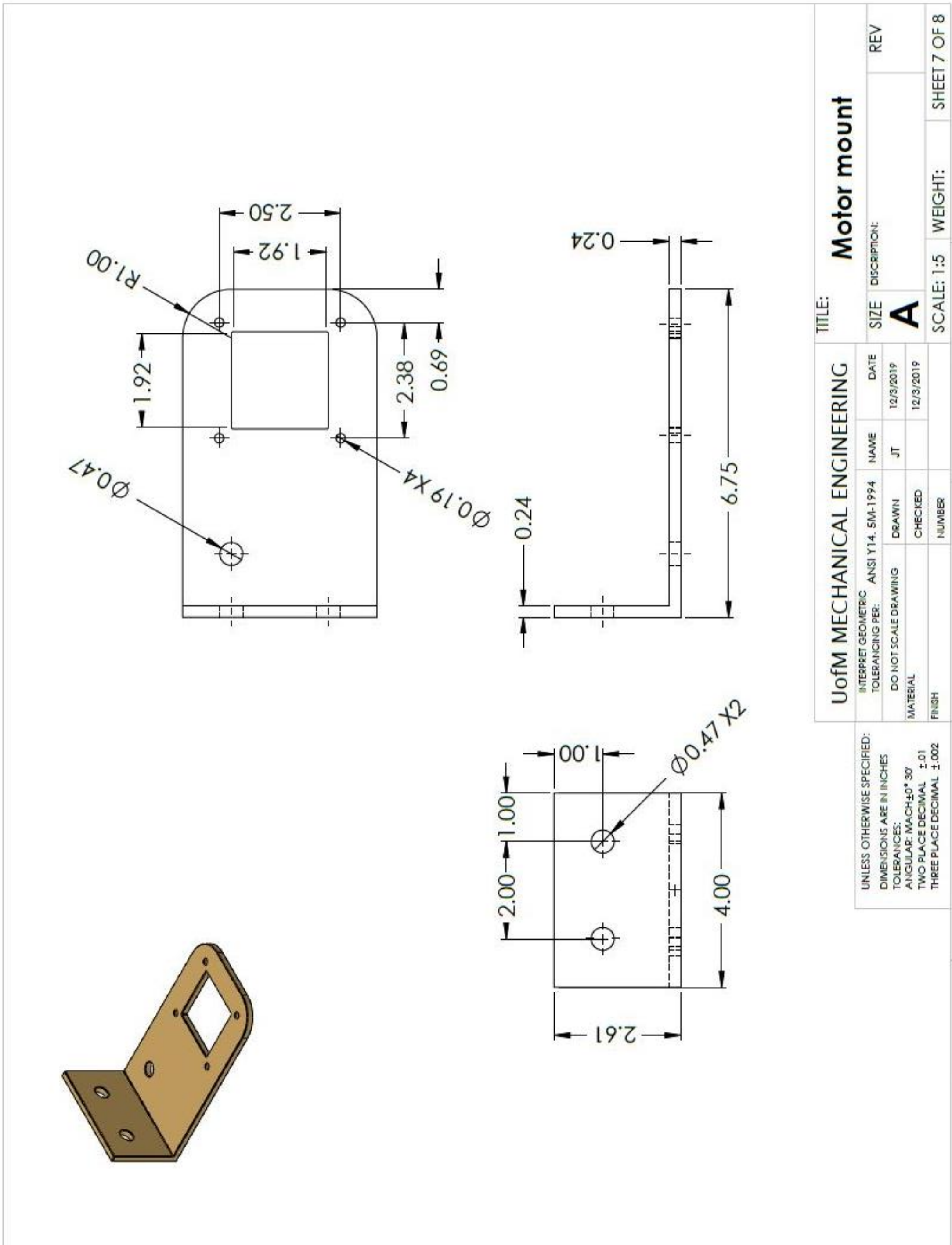
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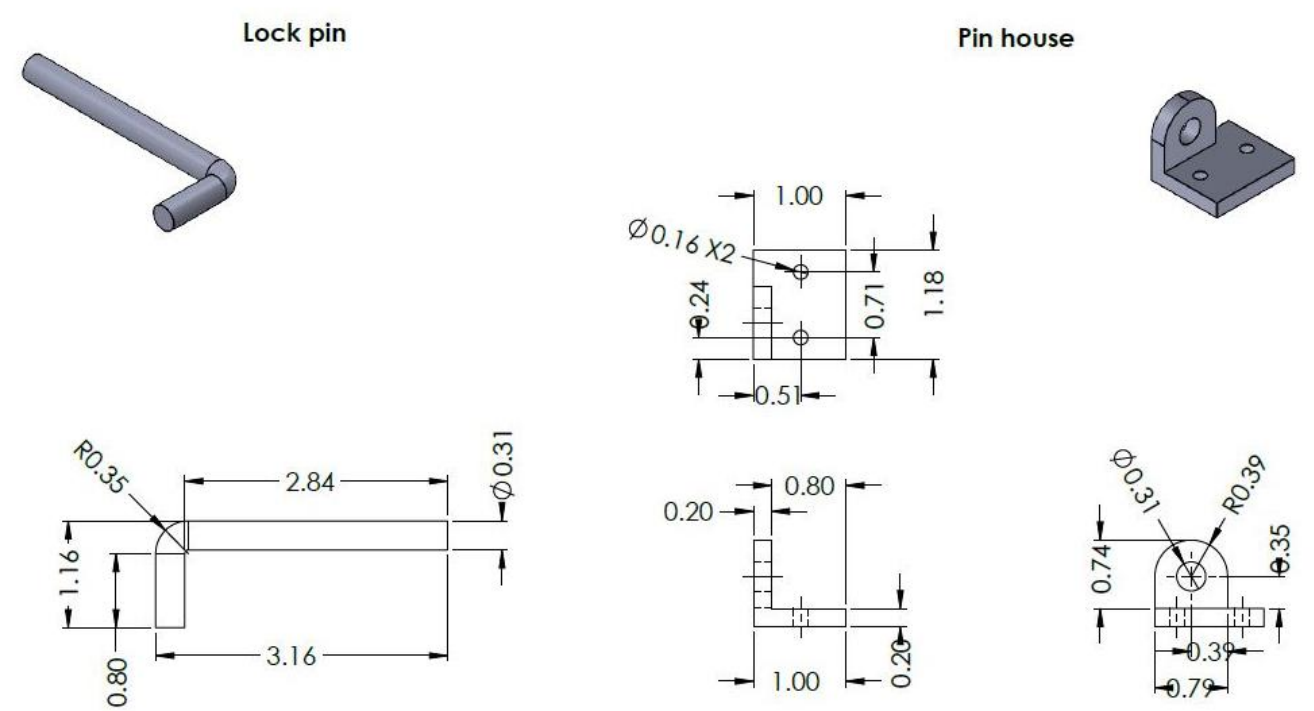
SCALE: 1:5
WEIGHT:
SHEET 7 OF 8



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL

FINISH

	NAME	DATE
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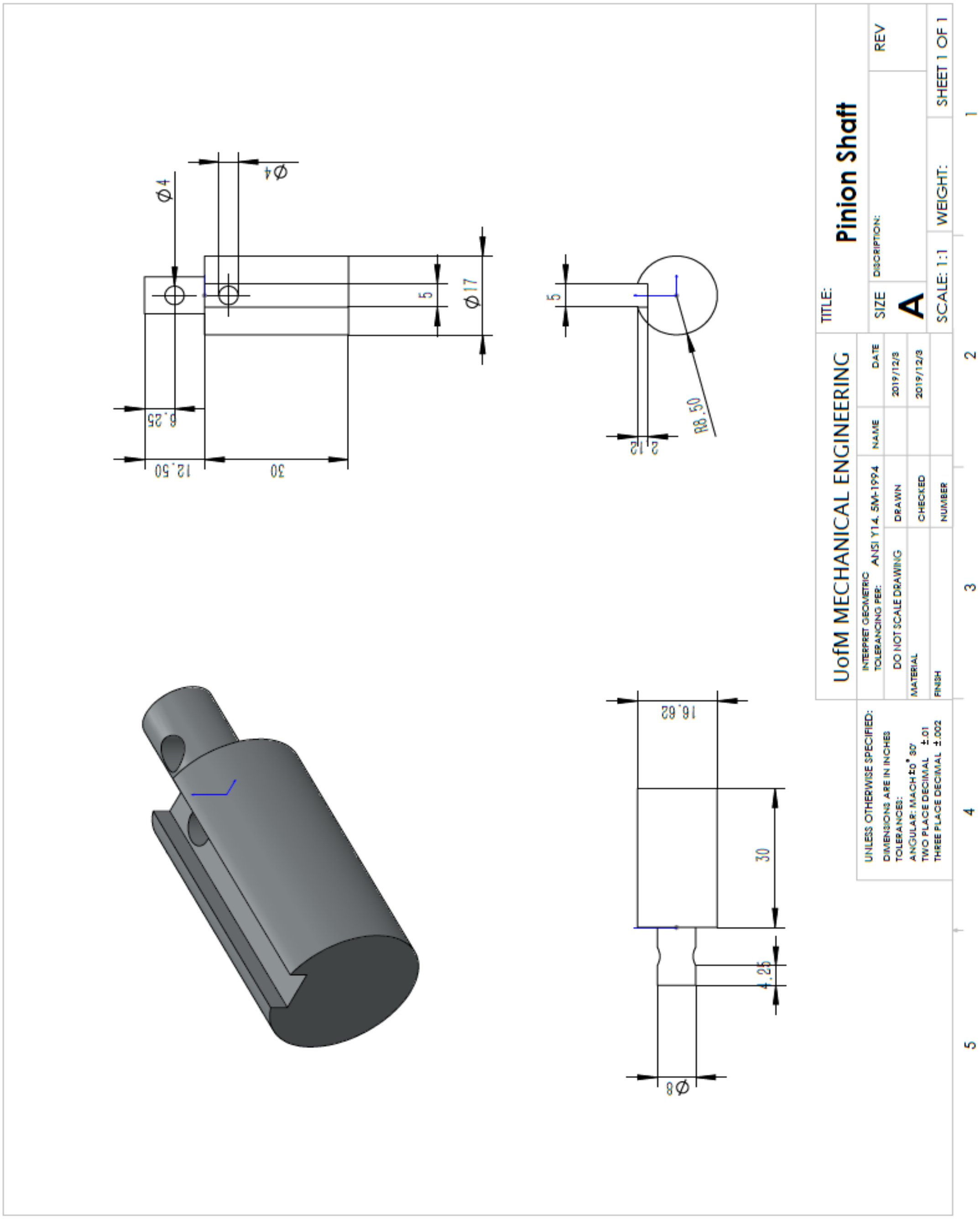
CHECKED		12/3/2019
NUMBER		

TITLE: **Lock Pin & Pin house**

SIZE A | DISCRIPTION: | REV

SCALE: 2:1 | WEIGHT: | SHEET 8 OF 8

5 4 3 2 1


Pinion Shaft
UofM MECHANICAL ENGINEERING
TITLE:
SIZE
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SHEET 1 OF 1
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5M-1994
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5

Appendix D – Rack and Pinion Technical Details

Detailed introduction for the process of choosing between spur and helical gear.

The rack and pinion system is consisted by a linear gear called rack and a circular gear called pinion. The system can be considered as a type of linear actuator which could translate rotational motion into circular motion.

The rack and pinion drive system can be used to transfer power in this project. It can be designed into two types of rack and pinion system according to the American Gear Manufactures Association (AGMA) methodology. The two driving systems will be introduced and compared, the most feasible structure will be selected

Rack and pinion system background

This section provides a brief introduction of spur and helical rack and pinion.

Spur rack and pinion

Figure 1: Spur rack and pinion *[1]*

Spur rack and pinion is shown in Figure 1. Spur pinion gear is also called straight cut spur gear, which straight cut teeth are parallel to the rotation axis. Spur rack can be considered as a spur gear with infinite pitch diameter.

Advantages:

- Cheaper and easier to produce
- Reliable
- Simple to design and manufacture
- More efficient than helical gear with same size

Disadvantage:

- Creates a lot of noise when operated at high speed
- The stress concentrates at the teeth
- Applied for low speed rotating pinion

Helical rack and pinion

Figure 2: Helical rack and pinion *[1]*

As shown in Figure *2*, pinion and rack with helical teeth consist the helical rack and pinion.

The helical gears can be used for the same applications of spur gears.

Advantages:

- Able to handle more load than spur rack and pinion with same size of teeth
- Produce less noise due to gradual teeth engagement

Disadvantages:

- Higher manufacturing cost than spur rack and pinion
- Low mechanical efficiency due to sliding contact between teeth

Rack and pinion system selection

The design team evaluated the two rack and pinion systems in several concepts and found the best option feasible for the requirement. The following criteria include manufacturing difficulty, efficiency, material cost, noise level, durability and application will be used for evaluation.

- Manufacturing: the level of difficulty that the system is manufactured. High level manufacturing difficulties increase the cost.
- Efficiency: the percentage of actual power will be used delivered through the power transmission system. Low efficiency will lead to insufficient energy for operation.
- Material cost: the money spends for building a driving system
- High speed: the ability to perform smooth operation under high speed.
- High load: the maximum thrust loads can be applied to the gear without failure or sacrifice of gear life.
- Vibration: the vibration of tooth is produced during meshing because of the tooth stiffness. The vibration will lead to misalignment between gears, which will speed up the wearing of the gears. A smooth operation with minimized vibration is preferred.
- Gear Size: the size of gear drive is constrained due to limited design space; small number of teeth is preferred for the design.

In design consideration, the manufacture cost is the most important part. The system is designed for commercial application with a high quantity demanded. Palliser wants to control the cost price to sell the system at a proper price which the buyers could get payoff in the shortest period. Therefor the manufacturing cost should be as low as possible. Moreover, the system is driven by a low rotation speed motor, the high-speed criteria is expected to be the least important part. Since the system will only operate before and after daily cleaning and gears rotate at a low rotating speed, the noise criteria could be neglected.

TABLE I: CRITERIA WEIGHTING MATRIX

	Manufacturing (M)	Efficiency (E)	Material cost (C)	High speed (S)	High load （L）	Vibration (V)	Size (GS)
M	M	M	C	M	M	M	M
E	-	E	C	E	E	E	GS
C	-	-	C	C	C	C	C
S	-	-	-	S	L	V	GS
L	-	-	-	-	L	L	GS
V	-	-	-	-	-	V	GS
GS	-	-	-	-	-	-	GS
Total Hits	6	4	7	1	3	2	5
Relative Weight	0.2143	0.1429	0.25	0.0357	0.1071	0.0714	0.1786
Rank	2	4	1	7	5	6	3

According to the TABLE I, the design team can conclude that the material cost is the most important criteria and manufacturing is the second important criteria. Size, efficiency, high load, vibration and high speed ranked from the most important to the least important.

TABLE II: WEIGHT DECISION MATRIX FOR GEAR TYPE

Criteria weight	0.2143	0.1429	0.25	0.0357	0.1071	0.0714	0.1786	Total = 1	
Concept	M	E	C	S	L	V	GS	Total Score	Rank
Spur	10	8	10	7	8	7	8	8.82	1
Helical	8	9	8	10	10	10	9	8.75	2

From TABLE II, spur gear will be chosen for detailed analysis for final rack and pinion drive system design.

Force analysis for moving five recliners

The force needed to move one chairs is calculated to be 1.6N, so the total force needed to move 5 recliners will be 8N. The transmitted force will be 8N. The torque on the pinion shaft is depended on the radius of the pinion, which is the product of transmitted force and pinion radius. The number of recliners to be moved and its corresponding transmitted force required are shown in TABLE *III*.

TABLE III: TRANSMITTED FORCE REQUIRED WITH DIFFERENT NUMBER OF RECLINERS TO BE MOVED

Number of recliners	Transmitted load Wt [lbf]	Transmitted load Wt [N]
0	0	0
1	0.359694	1.6
2	0.719388	3.2
3	1.079082	4.8
4	1.438776	6.4
5	1.798470	8.0
6	2.158164	9.6
7	2.517858	11.2
8	2.877552	12.8
9	3.237246	14.4
10	3.596940	16.0

Interference of the gear

The phenomenon that contact portions of teeth are not conjugate is called interference, which is due to the contact point of driving tooth and driven tooth is not located in the involute curve. To avoid inference, the minimum teeth number of the pinion (N_p) is defined as equation (*1*):

$$N_{p=}\frac{2k}{(1+2m)sin^2\Phi}(m+\sqrt{m^2+(1+2m)sin^2(\Phi)}) \quad (1)$$

Here N_p is the minimum teeth number of the pinion, m is the ratio of teeth number of gear (N_G) to the teeth number of pinion (N_P), k=1 for full-depth teeth, k=0.8 for stub teeth and Φ is the pressure angle.

$$m=\frac{N_G}{N_P} \quad (2)$$

For this design, the pressure angle will be equal to 20° as it is almost universally used in recent years and provides a gear with good strength and without fillet undercut in pinions of as few as eighteen teeth.

Types of key

Key is a mechanical feature on the shaft which can be used to deliver the power from the input shaft to any drive elements such as belt, chain or gear. Due to some misalignments between the shaft and drive elements in operation, it is indispensable to install a key to ensure a smooth power transmission while allowing for those misalignments. The key should be designed with some allowances to fit in the key seat. Introductions of different types of keys will be presented as follow.

Parallel Key

Parallel key can be called as square or rectangular key for its cross section is either square or rectangular. And its two opposite sides are designed to be parallel as it is called. The key seat for parallel key is designed as seen in Figure *3*, the half of its height is carried in the hub of drive elements and the other half is carried in the input shaft. Parallel key would cause higher stress concentrations when it is installed into the shaft as its edges are sharp, and it therefore is necessary to add fillet or chamfer before the installation. Parallel key is recommended when the torque in one-direction is required, and less load is applied. [2]

[redacted]

Figure 3: The Layout for Key and Key Seat *[3]*

[redacted]

Figure 4: Square key *[4]*

Taper Key

Taper key as an alternate to parallel key can also provide the same function as parallel key does. However, the installation process for taper key is different. Taper key should be inserted from the end of shaft after placing the drive elements whereas parallel key should be first placed before sliding the hub of the drive elements. [3]

[redacted]

Figure 5: Taper key *[5]*

Woodruff Key

Woodruff key can lead to easier installation in comparison to the other key [3]. The elliptic shape of woodruff key can make it be installed into taper shaft, and its extra depth can efficiently stop it from being slid out of the shaft. On the other hand, woodruff key provides little tolerance on the axial movement between the shaft and drive elements [6]

[redacted]

Figure 6: Woodruff key *[4]*

Key Type Selection

This section covers step-by-step analysis for the key design. Based on the specifications of pinion and the team discussion, the team decided to use the square key as the choice for the key.

Minimum length for the key

As the key could encounter two major potential failures caused by shear stress and compressive stress, force analysis must be made upon the key to derive the minimum length for the key, the minimum length can be calculated using equation (3).

$$L = \frac{4TN}{DWS_y} \tag{3}$$

Minimum allowable length of the shaft

The minimum length of the shaft should be 42.5 mm, which is the sum of the width of the pinion and half of the coupling. The gear will took 30mm length of the shaft and coupling will to 12.5 mm of the shaft.

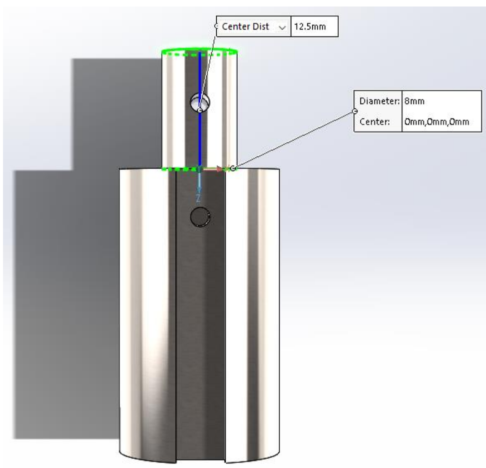

Figure 7: Front view of shaft

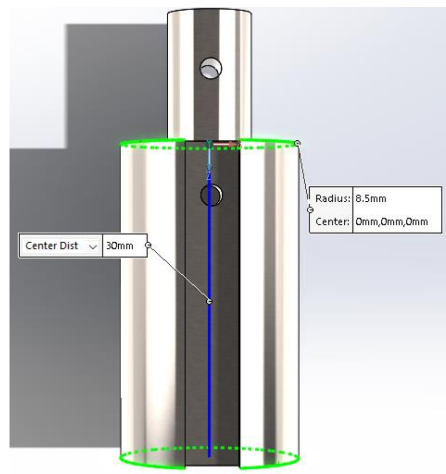

Figure 8: Front view of shaft with diameter shown

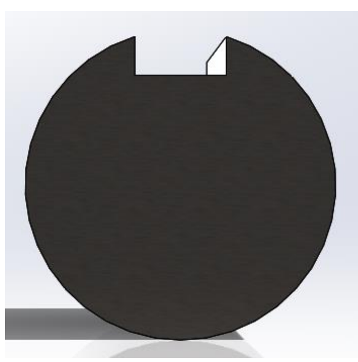

Figure 9: End View of shaft

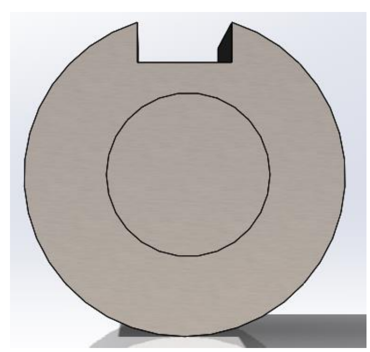

Figure 10: End view of shaft on smaller shaft side

Numerical analysis of the shaft

The FEA analysis was applied to test the stress of the shaft during operation. To simulate the transmitted force, an 8 N force is put on one side of the key slot. The direction of the force tangent to the shaft. According to **Error! Reference source not found.**, the maximum stress in the shaft is 6.9165 MPa, which is smaller than the yield strength of the S45C steel.

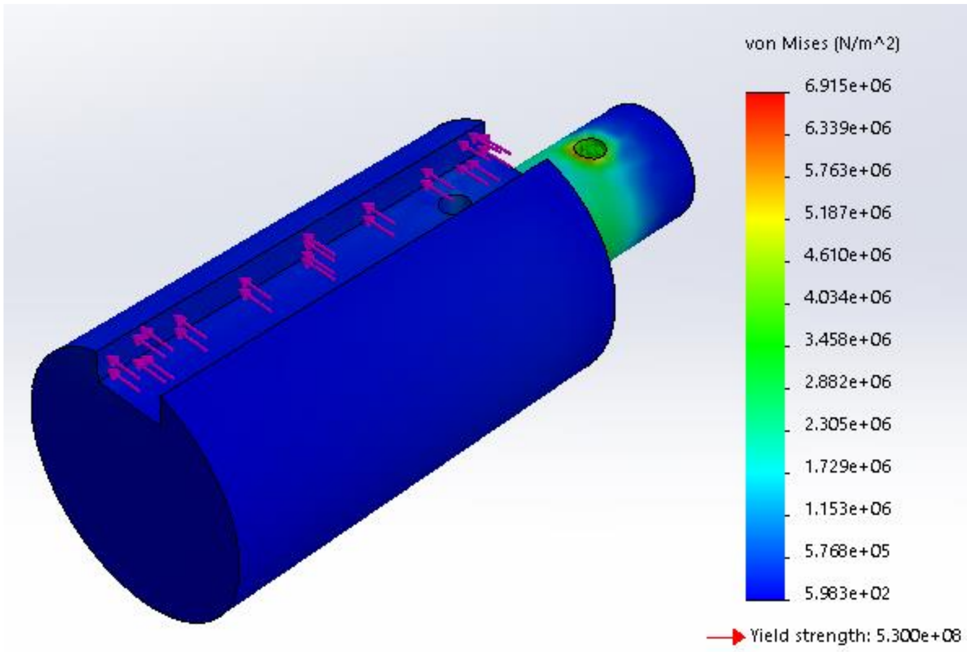

Figure 11: FEA stress test of the designed shaft

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[4] "Pionner PK-13-25-Woodruff-key," Amazon, [Online]. Available: https://www.amazon.com/Pioneer-PK-135-25-Woodruff-Key-Ford/dp/B000EQBASG.. [Accessed 1 December 2019].

[5] "John Deere PRO 16 Cotton Picker Row Unit Key, Taper Shaft," [Online]. Available: https://www.jensales.com/products/john-deere-pro-16-cotton-picker-row-unit-key-taper-shaft-n195970.html. [Accessed 1 December 2019].

[6] "Advantage and disadvantage of woodruff key," Blogger, [Online]. Available: https://www.mechstuff4u.com/2017/03/advantage-and-disadvantage-of-woodruff.html%20.. [Accessed 1 December 2019].

Appendix E – Motor Excel Spread Sheet

To determine the motor that will be used in the design a spreadsheet was created using the equations in section 3.5. TABLE *I* was used to calculate the required information.

TABLE I: EXCEL SPREADSHEET LAYOUT FOR MOTOR CALCULATIONS

Input								
Motor			Chair			castor		
RPM	25		mass	120	lbs	dw	2	in
Torque	320	in-oz	mass	54.42177	kg	μr	0.003	
Torque	2.2597	Nm	μf	0.003	roller			
Pinion			distance	34	in			
radius	0.7087	in	distance	0.863602	m			
radius	0.018	m						
diameter	0.036	m						

		Based on motor selected, pinion size, track	
2.259697	Nm	Tp	is the torque on the pinion from the motor in Nm
25	rev/min	np	is the RPM of the motor
0.018	m	rp	radius of the pinion in meters
0.003		μf	is the coefficent of friction based on the roller
0.036	m	dp	is the diameter of the pinion in meters
0.0508	m	dw	is the diameter of the castor
0.003		μr	
		Constants	
9.81	m/s^2	g	gravity
54.42177	kg	mc	mass of the chair
0.863602	m	d	is the distance the chair is moving
		Calculated	
125.54	N	Frm	Force on the rack from the motor
1.60	N	Ff	Force on the rack needed to move one chair
0	N	Fr	Force on the rack to move one chair
78	chairs	frm/fr	number of chairs moved
0.047124	m/sec	vmax	is the maxium linear velocity cretaed by the motor
18.33	sec	t	time itll take to move the chairs
Calculations			
125.5387	Frm	Frm = Tp/rp	
1.601633	Ff	Ff=mc*g*μf	
0.047124	vmax	vmax=np*dp*pi/60	
18.3262	t	t=d/vmax	
78	frm/fr	rounded down to whole value	

The first section of the excel spreadsheet is where the input values go, these are values from the motor, the chair, the track, the pinion, and the castor wheel. The next section lays out all the important input variables in the correct units with the symbol and meeting next to them. The third section is the constant values that are not changed but needed for the calculations, along with the corresponding symbol and meaning. The forth section is the calculated values based on equations used in the fifth section which are shown in section 3.5 of the report. The forth section is the important outputs based on the inputs and are used to verify if the motor is good. The input values are based on the final design components and selected motor.

In section 3.5, the minimum torque was determined to be 82 in-oz and the RPM range is between 18-45 RPM. These values were determined via the same spreadsheet; however, the input torque and RPM were not a specific value but a table of values, in which the number of chairs moved, and time taken were calculated for each step increase of the torque and RPM. TABLE *II* shows how the number of chairs that can be moved varies due to input torque.

TABLE II: HOW THE NUMBER OF CHAIRS MOVED VARIES WITH MOTOR TORQUE

# of Chairs	Torque (in-oz)	# of Chair	Torque (in-oz)	# of Chair	Torque (in-oz)	# of Chairs	Torque (in-oz)	# of Chairs	Torque (in-oz)
0	1	5	21	10	41	14	61	19	81
0	2	5	22	10	42	15	62	20	82
0	3	5	23	10	43	15	63	20	83
0	4	5	24	10	44	15	64	20	84
1	5	6	25	11	45	15	65	20	85
1	6	6	26	11	46	16	66	21	86
1	7	6	27	11	47	16	67	21	87
1	8	6	28	11	48	16	68	21	88
2	9	7	29	12	49	16	69	21	89
2	10	7	30	12	50	17	70	22	90
2	11	7	31	12	51	17	71		
2	12	7	32	12	52	17	72		
3	13	8	33	12	53	17	73		
3	14	8	34	13	54	18	74		
3	15	8	35	13	55	18	75		
3	16	8	36	13	56	18	76		
4	17	9	37	13	57	18	77		
4	18	9	38	14	58	19	78		
4	19	9	39	14	59	19	79		
4	20	9	40	14	60	19	80		

The table stops at 90 in-oz of torque, as the number of chairs move has been satisfied, and more data will not add any additional information.

TABLE *III* below show how the RPM effects the time it will take to move the chair.

TABLE III: HOW MOVEMENT TIME VARIES WITH MOTOR RPM

Time (sec)	RPM	Time (sec)	RPM	Time (sec)	RPM
649.35	1	24.98	26	12.73	51
324.68	2	24.05	27	12.49	52
216.45	3	23.19	28	12.25	53
162.34	4	22.39	29	12.03	54
129.87	5	21.65	30	11.81	55
108.23	6	20.95	31	11.60	56
92.76	7	20.29	32	11.39	57
81.17	8	19.68	33	11.20	58
72.15	9	19.10	34	11.01	59
64.94	10	18.55	35	10.82	60
59.03	11	18.04	36	10.65	61
54.11	12	17.55	37	10.47	62
49.95	13	17.09	38	10.31	63
46.38	14	16.65	39	10.15	64
43.29	15	16.23	40	9.99	65
40.58	16	15.84	41	9.84	66
38.20	17	15.46	42	9.69	67
36.08	18	15.10	43	9.55	68
34.18	19	14.76	44	9.41	69
32.47	20	14.43	45	9.28	70
30.92	21	14.12	46	9.15	71
29.52	22	13.82	47	9.02	72
28.23	23	13.53	48	8.90	73
27.06	24	13.25	49	8.78	74
25.97	25	12.99	50	8.66	75

This table shows the input RPM from 1 to 75, more data points can be added however do not add additional information. Figure 1 shows how these data points look compared to each other, from 1 RPM to 120 RPM.

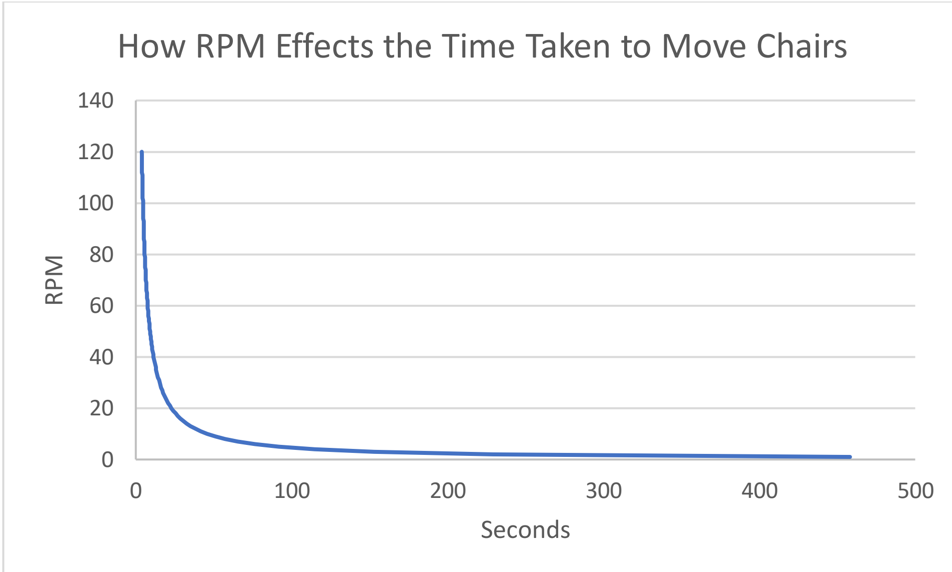

Figure 1: Graphic representation of time taken to move verses the RPM

Figure 2 shows the optimal range of RPM based on the time range of 10sec – 25sec

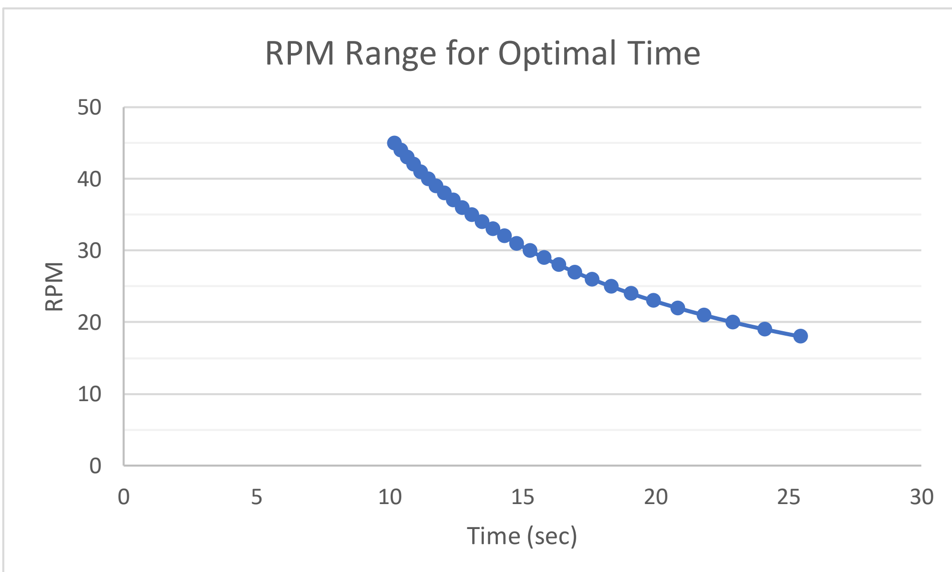

Figure 2: Graphic representation of optimal RPM based on time

Appendix F - Roller Loading Calculations

To start off, different measurements of the chair were recorded based on the model. Figure 1 shows lengths that were recorded, and TABLE I is the list of all the lengths.

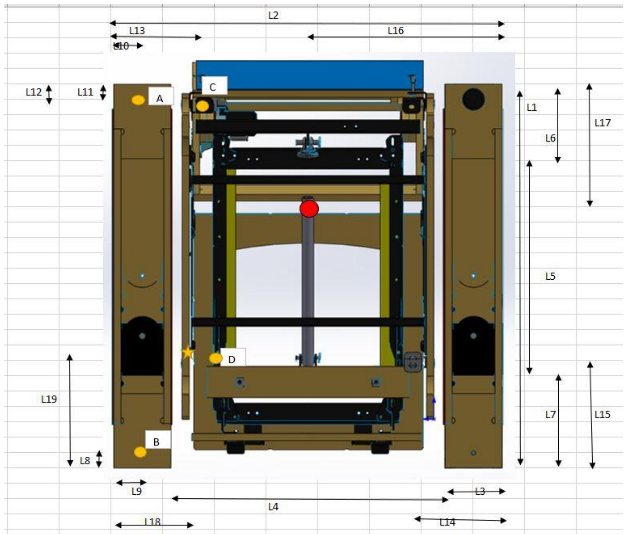

Figure 1: Dimensions of the cinema recliner

TABLE I: MEASUREMENTS OF THE RECLINER

	mm	in
L1	863.34	33.99
L2	863.8	34.01
L3	127	5.00
L4	609.8	24.01
L5	528.73	20.82
L6	167.31	6.59
L7	167.31	6.59
L8	34.13	1.34
L9	63.5	2.50
L10	63.5	2.50
L11	34.13	1.34
L12	44.9	1.77
L13	203.9	8.03
L14	198.4	7.81
L15	204.3	8.04
L16	431.9	17.00
L17	366.11	14.41
L18	152	5.98
L19	109.53	4.31

Next was to lay out the weight of the chair, occupied and not occupied. TABLE II shows the corresponding weights.

TABLE II: WEIGHT TABLE

Weight (C)	120	lbs	54.42177	kg
Weight (P)	300	lbs	136.0544	kg
Weight (T)	420	lbs	190.4762	kg

Next the force layout was determined, and simple force equations were used. Based on a safety factor of 2, and the force vector locations as shown on Figure ##, the results of the loading scenarios are shown in TABLE III.

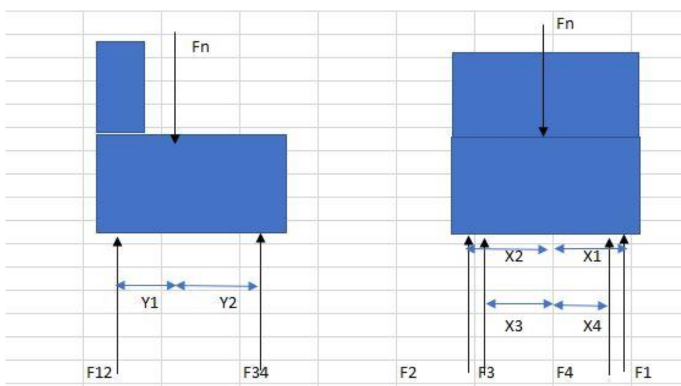

Figure 2: The points at which the forces act through

TABLE III: RESULTANT FORCES AT EACH ROLLERS

	AB	AD	CB	CD	
F1	1088.363	875.9031	1103.308	891.2636	N
F2	1088.363	875.9031	1103.308	891.2636	N
F3	780.2087	992.6683	765.2635	977.3078	N
F4	780.2087	992.6683	765.2635	977.3078	N