OMNI

SAFETY ORIENTED MINING EQUIPMENT

Bachelor of Industrial design 2020

Thesis Report

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OMNI: SAFETY ORIENTED MINING EQUIPMENT

by

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Abstract:

Occupational hazards are a substantial problem plaguing the modern mining industry. This includes problems such as traumatic injuries, occupational diseases, and musculoskeletal disorders. The scope of this thesis proposal is to help mitigate occupational hazards that underground mining personnel face on a daily basis by providing a new, innovative way of working safely in this situationally hazardous environment. A variety of research methods were used to gain insight into the life of the user, the current products they use, and the practices currently put in place to help this issue including user interviews, benchmarking, and observational studies. In order to understand the user experience, a full scale ergonomic model was produced to create metrics and understand and document user interactions. By creating a design solution to promote a safe working experience, the mining personnel benefit with the ability to work with safety and confidence, and the industries that rely on the efficient procurement of materials benefit due to the streamlined workflow.

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Problem Definition

Figure 1- Miner using pneumatic drill. Rich Pedroncelli

1: Problem Definition

1.1: Problem Definition

Underground mining operations remain one of the most dangerous tasks worldwide. Despite this there has been a large expansion in commercial mining operations worldwide. (Chong et.al, 2017). Current practices in the mining industry fail to deal with numerous occupational hazards involved with underground mining; In fact, it has become almost normalized within the industry (Saleh and Cummings, 2011). The problem being addressed revolves around creating a solution to enhance the quality of life and work for mining personnel. This begs the question; How might we mitigate occupational hazards in underground mining operations?

1.2: Investigative Approach

In order to understand the trials and tribulations that mining personnel encounter on a daily basis, various research and analysis methods are used. The following methods will aid in the understanding of user needs and help inform the ultimate design solution.

- Literature reviews
- Product benchmarking
- Surveying
- User interviews

- Advisor interviews
- Activity Mapping
- User observation
- Ergonomic studies
- Sustainability benchmarking

By understanding the problems previously mentioned from the users perspective it will allow for the most insightful and topical information about the current situation regarding occupational hazards in the mining community. These research methods were used to help give a better understanding of the problem space. Utilizing these research methods allowed for these key questions to be answered.

- What is the demographic info of mining personnel?
- What currently exists to aid them in their duties?
- How do they interact with this equipment?
- What are some ergonomic pitfalls of current solutions?

1.3: Background and Social Context

Underground mining is a notoriously difficult occupation, and has been for millenia. Not only are the tasks challenging and strenuous, but the environment is extremely unforgiving. The variety of differing tasks and differing situations make it unpredictable and strenuous for the mining personnel. Despite the advancements in mining equipment and practices over the decades, mining still remains one of the most dangerous and challenging occupations in the world. In China alone, over 13,000 coal miners were affected by diseases related to occupational hazards, and several thousand more suffered extremely debilitating injuries. (Chong et.al, 2014). Current advancements mainly focus on more efficient work output, and do not focus as much on the needs and wants of the end user, which is security, safety, and an opportunity to work without anxiety related to potential injuries.

Mining is an extremely important part of our culture due to the fact that it revolves around the process of procuring raw ores to be refined and used in a multitude of industries worldwide. The resources obtained by mining are undoubtedly ubiquitous and integral to the manufacturing industries of the world.

Figure 1.3.1 - Two Men Push Ore Wagons in Cerro Rico. Cerro Rico, Bolivia. By Hugh Brown.

Retrieved from: https://www.abc.net.au/news/2016-12-10/two-men-push-ore-wagons-in-cerro-rico/8089610

The ultimate end goal in mitigating occupational hazards in the underground mining industry is to create a more forgiving workplace environment. Creating equipment to make the tasks more safe and efficient is extremely beneficial not only to the mining personnel, but all of the industries that rely on the efficient procurement of materials.

Chapter 2:

User Research

Figure 2 - *The crew at Evolution Mining's Cowal operations welcomed the Melbourne Cup back to its birthplace. Retrieved from*

https://www.forbesadvocate.com.au/story/5437843/mine-spending-boosts-economy/?cs=722

2: User Research

2.1: Introduction to User Research

Introduction

Understanding the end user and the products they interact with is a vital part of the industrial design method, as it allows for better designed products through empathetic, evidence based user research. This section of the report will showcase the persona of the end user (primary, secondary, and tertiary) along with their interactions with current mining equipment solutions. This persona represents an average of the user and their activities.

Method

Multiple methods are used to analyze user behavior and demographics. Interviews and surveys, user observation techniques, and literature reviews. These techniques combined will aid in creating a fictional persona and scenario of the users and the products that are interacted with on a daily basis.

2.1.1: User Profile

Introduction

Defining the primary, secondary, and tertiary users are vital for designing a product to be as accessible and empathetic as possible. The methodology of generating a user profile and persona will assist in showcasing the average user of mining equipment. By understanding the average users relationship with the products they work with, along with the environment they work in will play a pivotal role in creating a design solution that assists the widest array of users possible.

Method

By researching and interpreting various resources online (Google Scholar, Humber library) relating to demographics, a persona can be gestured to create the aforementioned average user.

Primary user - Underground mining personnel:

The primary user who would interact with the designed product the most are those who work in underground mines as a career. These mining personnel spend most of their day underground performing various cutting, drilling, and excavation tasks. Due to these facts, these are the users who would be the most affected by a revolutionary design direction.

Secondary user - Foreman/office staffing:

The secondary user spends a larger section of their time daily by managing and delegating tasks in an efficient manner. These users often do not operate equipment, and rather handle backend tasks outside, rarely inside of the mineshafts. The secondary user is affected due to the fact that these staff often deal with the preparation and paperwork regarding injuries related to the primary user.

Tertiary user - Refinery/manufacturing staff:

The tertiary users are those who work in industries who require the efficient procurement of materials from mines such as ores that are refined into metals and used in worldwide manufacturing industries. The tertiary user is affected by this design due to the fact that a multitude of industries rely on the fast and effective procurement of materials.

Demographics

Searches throughout multiple scholarly sources were conducted to identify a user that best describes the findings. A wide array of locations and specific types of mining operations are considered. Keywords such as *mining demographic, mining income, and mining job statistics* were used in scholarly search engines like google scholar and the Humber library resources.

Although "Women shift from agricultural self-employment to the service sector." (Kotsadam, 2016). Mining still remains a male dominated industry by far. As previously stated, a common trend in identifying demographics is based on the type of ore being mined, and the country that the materials are mined in. However the secondary and tertiary users are often completely different demographics because mining is a very large industry worldwide. Through the research conducted about the primary user (mining personnel) in the U.S. a general demographic for the research topic is shown.

Table 16. Demographic Characteristics of Employees at All Mines

Demographic Characteristic	Survey Count	National Estimate	95% LCL	95% UCL	National Percent	95% LCL	95% UCL
Gender:							
Male	8,414	211,471	188,671	234,270	92.5	91.1	93.9
Female	577	17,213	12,403	22,024	7.5	6.1	8.9
Age (years)	8,673	43.3	42.4	44.1			
Highest level of education:							
Less than 9th grade	222	4,996	3,062	6,930	2.4	1.5	3.3
9th–12th grade (no diploma)	800	18,600	15,299	21,902	8.8	7.3	10.3
HS Graduate or Equivalent (GED)	5,452	136,599	121,769	151,429	64.7	61.3	68.1
Some College, Associate Degree, or Technical School	1,392	39,326	30,655	47,996	18.6	15.9	21.3
Bachelor's Degree or beyond	452	11,516	9,017	14,014	5.5	4.5	6.4
Ethnicity:							
Hispanic or Latino	927	26,622	17,120	36,123	12.1	8.9	15.4
Non-Hispanic or Non-Latino	7,766	192,839	172,663	213,016	87.9	84.6	91.1
Race:							
American Indian or Alaska Native	119	4,050	1,851	6,249	2.0	0.9	3.0
Asian	9	183	56	311	0.1	0.0	0.2
Black or African American	397	8,893	6,419	11,367	4.3	3.2	5.4
Native Hawaiian or Other Pacific Islander	14	634	140	1,127	0.3	0.1	0.5
White	7,717	194,016	174,955	213,077	93.6	92.1	95.0

Figure 2.1.1.1. Demographic Characteristics of Employees at All Mines in the U.S. McWilliams et.al. Retrieved from https://www.cdc.gov/niosh/mining/userfiles/works/pdfs/2012-152.pdf

As seen here, in the U.S. 93.6 percent of all employed miners are caucasian. Furthermore, 92.5 percent of all mining personnel in the U.S are male. With the median age of 43 years old this establishes a very dominant user in the overall demographics of mining personnel.

User Behavior

Mining is a very laborious job which entails long work days. This is due to two main well-known factors; The first being that mines have a limited lifespan, and mining is a contract job. Despite these factors mining is still a flourishing and expansive industry worldwide. Due to the fact that mines are almost never a permanent place of work, many experienced mining personnel move around once a job is finished.“When a mine establishes in a regional town, it is likely that many of the jobs created will go to incomers rather than existing residents because specialist skills are often required" (Reeson et.al). Mining operations are absolutely a team effort, meaning that mining personnel must be willing to work together not only with other underground personnel, but with the foreman and other workers such as structural engineers. (See Figure 1 and 2). Mining is often a high turnover job, meaning that there is a lot of new personnel flowing in, and a lot of more experienced personnel leaving (due to jobs being finished, or health reasons). Mining often does not yield specific degrees, according to the *National Survey of the Mining Population* (McWilliams et.al), 76.7 percent of coal mine workers in the U.S. have achieved the maximum education level of a high school diploma or a GED.

Mining itself is a very long and laborious task, with mining personnel often working an average of 47 hours a week (McWilliams et.al). Despite this, underground mining staff work in a variety of different scenarios. Due to the fact that mining is an extremely hardworking career, it becomes a lifestyle. This is proven by the fact that mining staff are often very willing to move far away from their homes to work in a new development. Mining is a specialist, skill-based task; So operations become more efficient with more experienced workers. Overall user behavior dictates hard working individuals with a passionate drive for their work.

User Persona

After using credible sources such as the Bureau of Labour Statistics and National Survey of the Mining Population.(McWilliams et. al. 2012) allowed for the creation of a user persona; as previously discussed. These were found from scholarly resource searching, as well as using references from some of these articles as primary data (IE. Bureau of Labour Statistics). This persona was created by using the raw data from the previously mentioned articles and image searches. These also provided information about the working hours and conditions, and from that; User behaviours are extrapolated and an ultimate persona is formed. The primary user is identified below.

Name: Daniel Odell

Gender: Male (McWilliams et.al)

Age: 43 (McWilliams et. al)

Location: Southwest Ontario

Income: 80,000 (Bureau of labour statistics)

Working hours: 47/wk (McWilliams et.al)

Education: High school diploma (Mcwilliams et. al)

Skills: Hands on, team player, problem solver

Figure 3 - *Miner Uğur Kandemiroğlu, 44. Retrieved from* https://www.dailysabah.com/feature/2018/10/05/absolute-darkness-a-day-in-a-miners-life

2.1.2: Current User Practice

Introduction

The focus of this data collection is to understand the frequency and situations that the current users operate their specified equipment while working underground.

Method

Using specific research regarding the previously established demographic, the current procedures and attitudes that are commonplace in the industry. By analyzing the data collected, a better understanding of the environment the user works in can be established.

Result

Underground mining personnel work upwards of 47 hours a week (McWilliams et. al). There is an extremely wide variety of tasks and scenarios relating to this, such as priority of task, team or individual task, and size of the mine.

The related tasks include jobs like bolting, drilling, cutting, and extracting, each with their own unique trials and tribulations. The reliant industries such as refineries and manufacturing facilities rely on these tasks to be done in an efficient manner; and underground mining jobs are not a seasonal occurrence.

Due to the extreme work hours and skills-based work, mining becomes a lifestyle choice for those who decide to pursue it. The gratification of knowing you are providing much needed materials to the industries, and therefore the world, is a large motivational point for mining personnel. Furthermore, the environment and tasks associated with it are challenging and require good problem solving skills, thus making it a more endearing and involved line of work, despite the extreme difficulty and risk.

2.1.3: Activity Mapping

Introduction

The purpose of this section is to understand the specific user observations involved with completing various tasks. In this case the task that was chosen to analyze was bolting, the practice of drilling and installing wire mesh screens on the ceilings of mine shafts. The reason this task was chosen was due to the fact that it covers multiple areas of work such as the manual elements, as well as equipment operations and standards.

Method

For the purposes of this assessment the decision was made to analyze a video of the task being completed. The video was analyzed with a professional gold miner via online communication.

Analysis

The selected video to be observed was:

Jory Dion. April 16th, 2019. *Maclean Bolting Practices.* Retrieved from: https://www.youtube.com/watch?v=hxKmld1_Iks&t=1256

1) Navigation

The first key activity analyzed in the navigation and movement of this specific

Figure 2.1.3.1 - User navigation

Maclean Bolting Rig. All navigation is done using the control panel near the rear end of the machine platform. It is seemingly difficult to navigate the machine while looking at the controls. This means that the user must be familiar with the many buttons and knobs prior to movement.

The user who assisted with the video analysis points out as well that the control panel is in an awkward position requiring the user to kneel down when faced with overhead rock formations like shown above. The user also points out that visibility can be problematic when higher up on the scissor lift.

2) Initial Development Drilling

The second key activity being analyzed is the initial drilling operation to clear a passage for the securing bolt and subsequent screen installation. This is extremely important and is mostly controlled using a small handheld control box.

Figure 2.1.3.2 - Development drilling

In the video itself the machine does shake quite violently, and also subsequently jams, causing the user to have to run back to the other panel to override and stop the drill.

The analyst also notes that this was handled very well, to safety standards despite having difficulties. The user then states the main safety concern here is the lack of guard rails on the sides of the machine. When the machine is shaking as violently as it does this can be a serious hazard. The analyst was quite surprised that this went unnoticed when operating this rig.

3) Support Bolt Installation

The third major key activity being analyzed is the installation of the support and receiver bolts to hold the screen and rebar in place. The user often sets up the tubes to be placed while the drill is still doing the initial development drill. These resin/stick powder tubes are rigid and get pushed into the hole with assistance from the head of the drill bit.

Figure 2.1.3.3 - Bolt installation

The user assisting with the video analysis states that it is extremely risky to do other work while the drill is in full motion, as if it stalls or jams it can easily deteriorate, or shake the machine further.

4) Screen Installation

The final major key activity under further analysis is the installation of the metal screens. These screens offer protection against falling debris and cave-ins and are crucial to underground mining operations. The screen is fed over the drill unit and rebar with capped head is inserted and fed through the negative space in the screen. As shown above the screen is handled haphazardly by hand.

Figure 2.1.3.4 - Screen installation

The professional user once again states the importance of guard rails. In image 2 the user nearly falls from an approximately 15 foot drop due to the lack of rails. The user does state that this is a professional standard. He also says that besides the guard rail situation, the user handles this task well, and admits that this is extremely challenging.

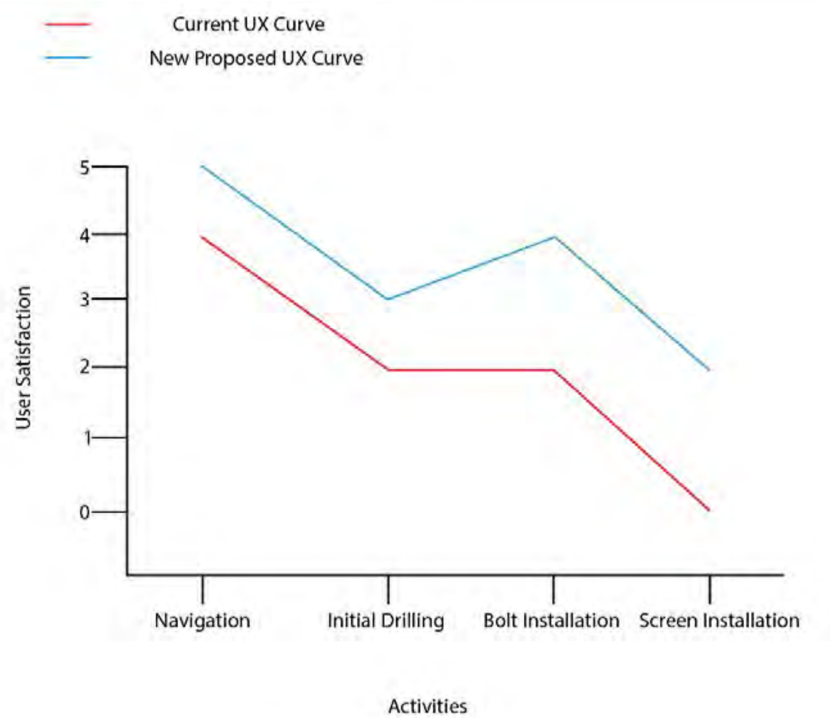


FIgure 2.1.3.5 - Projected UX curve

Currently the specific task of bolting in underground mines is a generally poor scoring on the user experience curve. The monotony and danger of the tasks is generally quite difficult and the only real high point is the navigation. The proposed user experience curve opts to mainly improve the lowest rated tasks such as the screen installation. By improving these tasks ergonomics, safety, and user considerations it would make an overall drastic improvement to the experience of working in underground mines.

2.1.4: Ergonomic Research

Introduction

Ergonomic considerations are crucial to designing successful equipment, especially for the mining industry. Understanding the interaction elements of a variety of equipment types is crucial for innovation in this field. By gaining an understanding of what is currently used in the industry, it creates a more informed, and relevant design.

Objectives

The primary objective of this section is to investigate existing products to understand the good and bad of current equipment solutions, and to find areas of opportunity for innovation.

Method

By researching existing products (appendix iii) and looking through images and promotional material from the respective websites, numerous equipment types were analyzed to give a better understanding of current ergonomic solutions in the industry.

Result

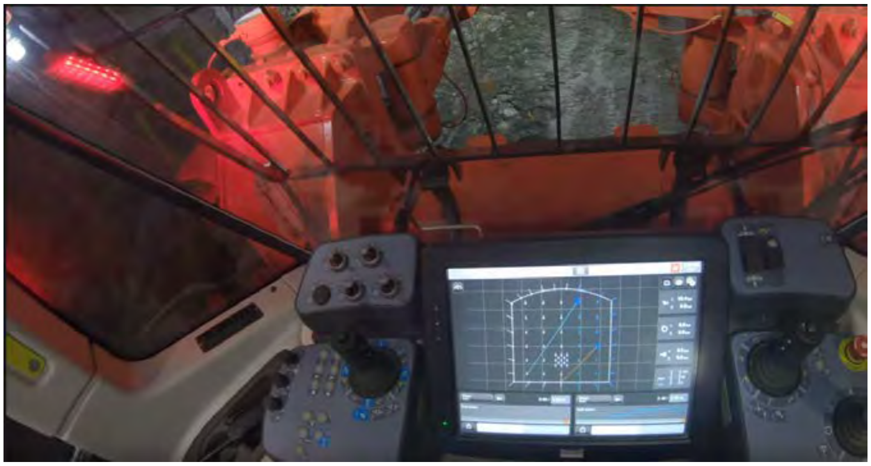


Figure 2.1.4.1 - Sandvik DD422I controls

Figure 2.1.4.2 - Steunick BBAS pneumatic drill mast

Figure 2.1.4.3 - Maclean scissor bolter operation

Figure 2.1.4.4 - Sandvik loader interior

Figure 2.1.4.5 - CAT transportation vehicle interior

Figure 2.1.4.6 - MWS83 drill operation

Analysis

By analyzing the above products, as well as conducting a literature review (appendix xiv), it is clear that although the industry is attempting to employ better ergonomic features there is still a clear lack of consideration for the end user, with cramped cabins, and exposure to open hazards. Certain products such as the Sandvik DD422i (figure 2.1.4.1) are unique in the simplicity of the control scheme, and the implementation of different technological aspects to aid the user. Items such as the Maclean scissor bolter (figure 2.1.4.3) showcase a problem with proper ergonomics due to the height of the control panel and the distance from the workspace and the control panel.

2.1.5: Health and Safety Research

Introduction

Health and safety is extremely important when referring to a job like mining; Due to the amount of hazardous situations faced on a daily basis. Health and safety is a top priority when designing equipment for this industry.

Analysis

Current benchmarked products (section 2.2-2.2.6) have a wide variety of safety and ergonomic considerations such as ergonomic cab designs, autonomy, and onboard safety kits. However current practice still does not offer enough to mining personnel to mitigate all of the occupational hazards they face daily which is a problem in the industry still not addressed to its full effect (McPhee, 2004). Due to the fact that these hazards are environmental, the equipment must be designed according to the environment that the tasks are completed in, however as previously mentioned, it is a multifaceted issue.

2.1.6: Interview Results (User)

Introduction

This section aims to reproduce the key content from the professional interviews conducted in order to understand the key user-centric takeaways from the primary user.

Method

User interviews were conducted via online communication. The full transcript can be found in appendix i. Key elements from both interviews are reproduced below. Both users are working professionals in the mining industry and were able to provide their stories about their trials and tribulations

Result

Mining personnel are often multidisciplinary, in this case participant one is a development miner who also occasionally works as an extraction specialist. While participant two also states that safety standards are considered a low priority in the mine he works in, he states that everyone has to be extremely diligent and careful. Due to the variety of workplaces that both of these participants work in, both state that the hazards they deal with are a multifaceted issue, and are challenging to deal with all at once.

2.2: Introduction to Product Research

Introduction

Researching the current product landscape is a crucial methodology to create revolutionary designs. By understanding what already exists and the opportunities for new market potential this analysis is about current related products in the mining industry.

Method

Analysis and insight into the current product market was conducted by analyzing the current tools used (as per the user interviews) and comparing them to the competitors to create a holistic benchmarking pool.

2.2.1: Current Product Profile

Introduction

Comparing similar products is done using a combination of methods to ensure that the most up-to-date benchmarking. For the sake of the design direction, underground drilling equipment is being analyzed on a micro-macro scale; from handheld pneumatic tools up to full scale bolting rig vehicles. Firstly, results taken from the previous survey were used to find current equipment solutions as a baseline. From using this method it ensured that the products being compared are topical and relevant. With this information, other products in similar categories were researched by looking at current mining companies and the equipment suppliers that help them mine effectively. These methods combined create a topical product landscape with the most current equipment practices in mind.

Current Products

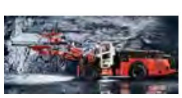
The list below provides all of the product names with a brief description. The highlighted options are the most relevant top 8 products for comparison in the table below.

- Atlas BBC 16 WS - Ubiquitous hydraulic underground rock drill from Atlas Copco (handheld unit)
- Maclean 928 Scissor Bolter - Scissor lifted drilling/bolting rig (vehicular)
- Atlas BBD 12 DCS - Portable pneumatic rock drill (handheld)
- Atlas BBC 34 DSI - Large pneumatic drill (vehicle mounted)
- Sandvik DD422iE Development Drill - Large scale electric drilling rig (vehicular)
- Sandvik DU412i Production Drill - Large scale “in-the-hole” (ITH) drilling vehicle (vehicular)
- Maclean MD-8 Excavator Drill - Excavator style drill with backhoe attachment (vehicular)
- Epiroc Boomer E2 Battery - Zero emission large scale face drill rig (vehicular)
- Atlas Pneumatic Jackhammer - Traditional rugged jackhammer design. (handheld)
- Stenuick Crawler Drill Rig - Semi-portable rig for small scale ground reinforcement (portable stationary)

Benchmarking Products

The top 8 products for comparison are analyzed below.

Item	Hole Depth	Weight	Air consumption	Length	Impact Rate
Atlas BBC 16 WS 	27-41mm	29.5 kg	69 l/s	710 mm	2340 blows/min

Maclean Scissor Bolter 	Up to 1.32 metres	22,000 kg	n/a	9.7x2.5 metres	n/a
Atlas BBD 12 DCS 	17-29mm	10.5 kg	22 l/s	560 mm	2580 blows/min
Atlas BBC 34 DSI 	27-41mm	31 kg	88 l/s	774mm	2280 blows/min
Sandvik DD422iE 	Up to 5270 mm	27,500 kg	250 l/m	5355 mm	95 hz (frequency)
Sandvik	1830 mm	30,000 kg	n/a	10,000 mm	n/a

DU412i 					
Maclean  MDA-8	2.3 m	295 kg	225 cfm @90psi	5830 mm	n/a
Steunick  BBAS	1 m	Around 500 lbs	60 mkg	Around 6.5 ft	75 tr/min

Table 2.2.1.1 - Benchmarked products

Identifying Features and Benefits

Through searching various online resources regarding the key recurring phrases regarding features and benefits were found and analyzed. Various websites and promotional materials were inspected for each product. Listed below are five of the most common phrases.

Key Features:

1) Hydraulic power
2) Automation
3) Low noise
4) High Capacity Storage
5) Electric Power

Key Benefits:

1) Versatile
2) Compact
3) Reliability
4) Safety assurance
5) Lightweight

<u>Result</u>

Comparing all of the featured products is extremely informative to the design process. As stated previously, there is a large amount of versatility in mining equipment. From large scale vehicular designs to portable handheld elements each product accomplishes a task in a different manner. Knowing what scenario to use these products in leaves a big market gap for more versatile, hybrid design solutions. Although many of the products claim to be versatile, there is still a large opportunity for creating a design solution that could be used in a large variety of scenarios, combining the positive features of both ends of the product spectrum. This leaves a gap to design a versatile, hybrid solution for drilling/bolting operations in underground mining that helps mitigate occupational hazards while being accessible and scalable for a variety of unpredictable scenarios.

2.2.2: Benchmarking, Functionality

Introduction

Functionality in mining equipment is one of the highest priorities, in order to accomplish a task effectively.

Method

By analyzing the current product pool already established, an XY graph is created in order to showcase in a visual manner where opportunity for product innovation is.

Result

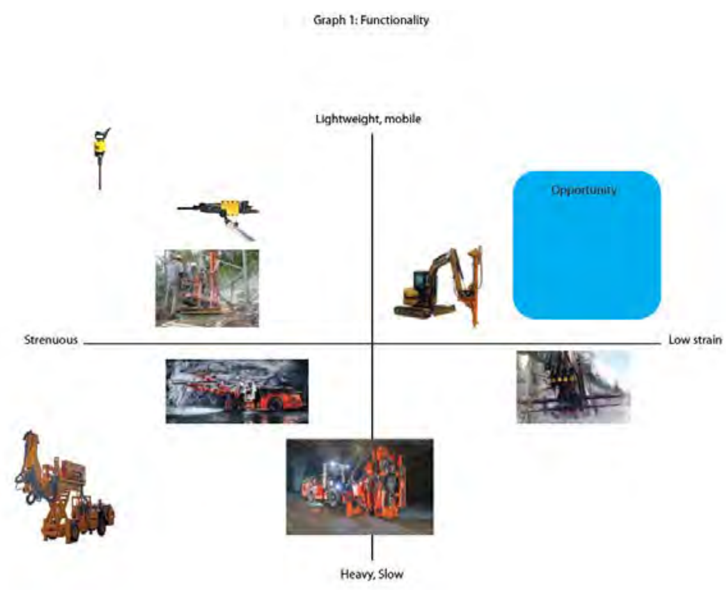


Figure 2,2,2,1 - Functionality graph

As shown above, a wide variety of products struggle in a specific scenario. The large vehicular solutions are overall less strenuous but lack the versatility and mobility in complex environments; While the handheld solutions are extremely difficult to use, more applicable to other situations due to their mobility. There is an opportunity to create a solution that is both less strenuous, and mobile for complex mine shafts.

2.2.3: Benchmarking, Aesthetics

Introduction

The aesthetic and semantic profile of mining equipment must radiate a certain design language

Method

By comparing the current pool of products, an XY graph is used to showcase the visual properties of each product, and show an opportunity to innovate.

Result

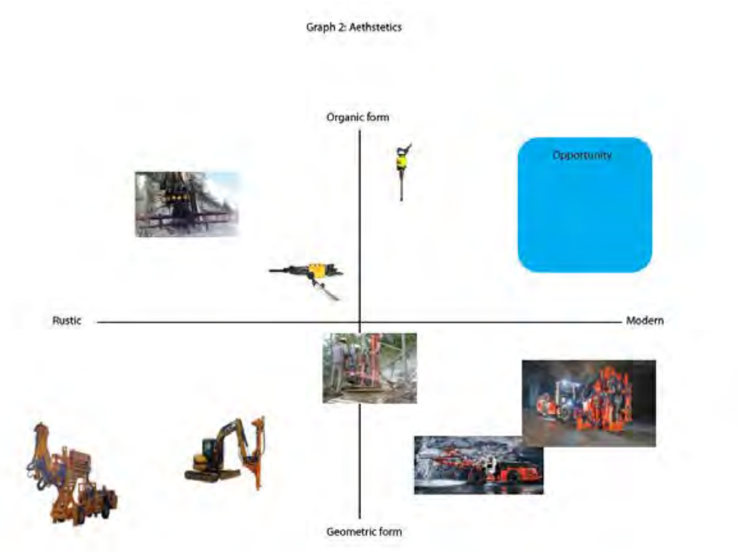


FIgure 2.2.2.2 - Aesthetic graph

The aesthetic graph shows that most equipment falls under a geometric form, with a divide between modern and rustic equipment semantics. This leaves an opportunity for marketing a product with a modern, more organic look while still retaining the styling cues of designing equipment.

2.2.4: Benchmarking, Materials and Manufacturing

Introduction

Due to the wide variety of products being addressed in the benchmarking, many different materials and manufacturing methods are used.

Result

For the large scale vehicular design solutions, a lot of engineering grade polymers and steel are used with some aluminum components. Often steel chassis are used, with the interior components consisting of the aluminum and engineering polymer components.

Regarding the small scale handheld items, a lot of injection and blow-molded parts were benchmarked, often using similar engineering grade polymers for their products as well. These polymers are used for their high end molding capabilities and impact resistance.

2.2.5: Benchmarking, Sustainability

Introduction

This section of the report will look into current sustainable developments in the mining industry in recent years. A variety of products were analyzed to see how current solutions are working towards a greener workplace environment.

Objective

To compare and understand the sustainable initiatives taken by mining equipment companies, as well as finding ways to incorporate and innovate for the final design.

Method

A technical report was written regarding sustainability of current products, and drawing conclusions for the final design, this report can be found in appendix x. The following result is a summary of some of the findings presented in this document.

Result

Due to the increase in sustainable development in the mining industry, some companies are opting to begin the development of hybrid or fully electric vehicles for this environment. One critical example of this is the Boomer E2 by Epiroc. This vehicle is a large scale drilling rig that is fully battery powered. The Boomer E2 has an onboard charging port and a large battery that can withstand long work hours and long tram distances. Furthermore, when the vehicle is being charged it does not affect usability, thus streamlining the drilling process. The capability to produce zero emissions while working coupled with the drastic cost savings when fuel purchases are not required offer an unprecedented level of sustainable elements to this design. The cost savings on diesel fuel compensate for the generally higher cost of the electrically powered vehicles. The carbon output of traditional diesel powered drill rig models has a negative impact on the environment on a micro to macro scale.

2.2.6 Interview Results (Products)

Introduction

This section aims to combine the information and benchmarking research done with the information received by the user regarding the current market landscape.

Method

User interviews were conducted with industry professionals (Appendix ii). The key points are summarized regarding their importance to product research.

Result

From the interviews conducted, participant 2 stated that equipment upkeep and maintenance is surprisingly difficult and tedious, adding to the risk of operating equipment when it is not in optimal condition. Furthermore, the equipment used is often so diverse that it creates unnecessary clutter and confusion, especially for new staff. Participant 1 also stated that the bolting rig that he works upon is often extremely difficult and dangerous to manage/control. These points infer that the need for higher accessibility and safety measures in modern equipment solutions is a must.

Chapter 3:

Analysis

Figure 3 - Coal Miner Retrieved from:

https://hermann70218.blogspot.com/2018/12/coal-boom-in-india-and-southeast-asia.html

3: Analysis

3.1: Needs Analysis

Introduction

As previously determined by the research established in section 1.1 and 1.3, mining is an extremely important part of modern society. The fast and effective process of procurement of materials is vital to keep up with industry power generation, and manufacturing industries rely on the materials in an efficient time frame. In 2.2.1 several products were analyzed to better understand the current landscape of products in this industry. This section focuses on the needs of the user and how it relates to the product research and user interviews conducted in previous chapters.

3.1.1: Needs/Benefits Not Met by Current Products

Introduction

As established in section 2.2.1, there is a wide variety of products used for drilling operations in underground mining operations. This section discusses the current gaps that these products do not fulfil for the end user.

Method

By reflecting on the sections 2.1 and 2.2, and previous preliminary information search results help to gain knowledge of the current product landscape. Reference to user interviews also helps to infer the current gaps that products do not cater very well towards.

Result

Needs	Improvement
Ergonomic considerations	- Reduction of tool/chassis vibration - Innovative method of control - Supportive stationary seating
Usability	- Usable in a variety of situations/environmental scenarios - Ease of navigation
Safety considerations	- Helps face the multifaceted issue of occupational hazards - Long term wellness - Short term protection

Efficiency	- Must perform the task better than current products, while being adaptable

Table 3.1.1.1: Needs vs Improvement

Discussion

Table 3.1.1.1 showcases the potential areas for the design solution to improve the needs that are currently not met properly according to user interviews and product benchmarking. Current needs that are in fact met by the products in 2.2.1 are as follows.

- Rugged, (built to last)
- Styling (appears as machinery)

The current needs not met by these products are as follows.

- Adaptability to a variety of scenarios
- Safety and ergonomic considerations for the work environment
- Sustainability (diesel particulate matter)

Current product solutions still do not provide an experience that is safe enough, efficient enough, and scalable for current underground mining operations.

3.1.2: Latent Needs

Introduction

The needs of the end user are especially important when designing a product that they will interact with perhaps every day of their career length. With this product being equipment for the mining industry, it must meet the extensive requirements and considerations needs of the user fundamentally. This section focuses on those needs of the user when interacting with the proposed design solution. This solution must care for the needs of the individual on a long term and short term scale.

Method

By referring to sections 2.1 and 2.2 as well as Maslow's Hierarchy of Needs are utilized to understand the needs of the user currently.

Result

The following table illustrates the fundamental needs that the user and product relate to. This references Maslow's Hierarchy of Needs.

#	Product Need	Fundamental Human Need	Relationship with Benefits
1	Ergonomic	Control, Self-esteem, Security, Protection	Strong

	considerations		
2	Usability	Control, Stability	Strong
3	Safety considerations	Protection, Security, Self-esteem, Freedom from Fear	Strong
4	Efficient workflow	Stability, Reputation, Self-fulfilment	Strong

Table 3.2.1.1: Fundamental Need

Ergonomic Considerations

Regarding equipment designs, ergonomics is a fundamental element in the human factors associated. Improved ergonomics will provide a more empowering, confident working experience for miners.

Usability

Usability refers to the accessibility and ease of use for the product. Proper usability connects with the user's control and stability whilst performing various tasks.

Safety Considerations

Safety conditions specifically answer the user's needs for working with equipment that is reliable and can hold up to the conditions that it will be used under, while keeping the user free from harm. This concept connects to Maslow's Hierarchy of Needs in almost every regard.

Efficient Workflow

This refers to the effectiveness that this product can help the end user accomplish their tasks. Mining is crucial to many industries so they rely on efficient procurement of materials.

3.1.3: Categorization of Needs

Introduction

With the needs established, it is helpful to categorize them into groups regarding their immediate, latent, and wishful needs in current products.

Method

Using information from the expert interviews, surveying methods, and user observation regarding the equipment they use, this section will reflect on these needs and categorize them into three groups.

Result

Immediate needs:

- Protection
- Better ergonomics
- Reduction of tool vibration
- Mitigate repetitive strain injuries
- Heightened visibility

Wishes/Wants

- Increases working efficiency
- Intuitive control scheme
- Better user experience considerations

Latent needs:

- Unique look (different from current equipment)
- Easy to maintain (dust, dirt)
- More efficient than current solutions

3.1.4: Needs Analysis Diagram

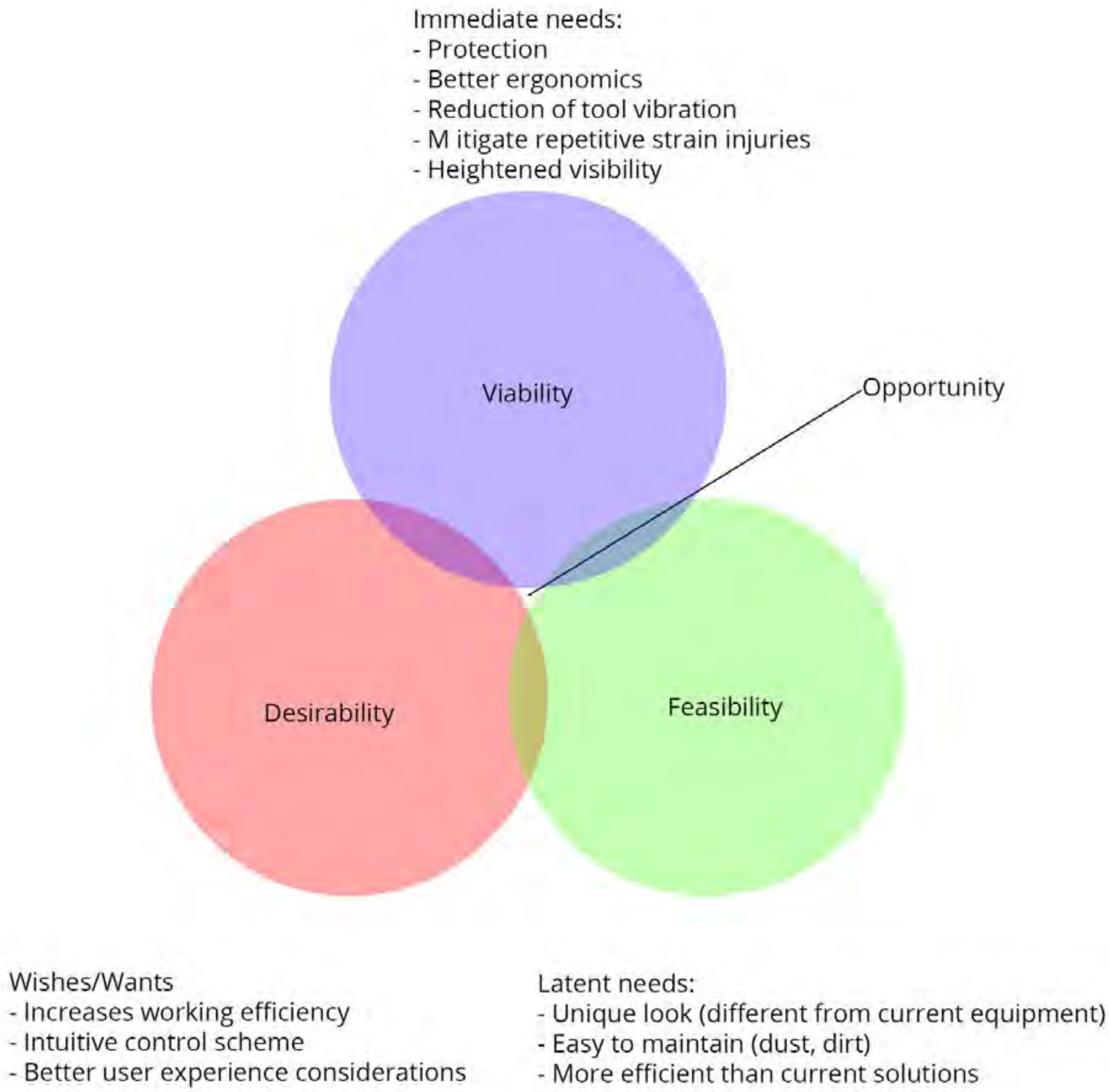


Figure 3.1.4.1 - Needs analysis diagram

Viability

The final design solution must be able to apply itself well to the environment of underground mining. The latent needs of the user must be understood and met in order to create a viable product design solution.

Desirability

The desire to work with equipment that would in-turn provide a safe, innovative, and ergonomic experience is highly appealing to the end user. This design solution aims to satisfy the desirability needs of the user by creating a safer working experience and environment.

Feasibility

In order to be a feasible design solution this design must satisfy the immediate needs. The necessity to reduce the effects of hazards faced on a daily basis is a prime point for the design to fulfill.

3.2: Functionality

3.2.1: Activity Mapping

Introduction

Understanding the operation and working standards of current solutions is a vital part of understanding the necessary improvements that can lead to a revolutionary design solution.

Method

By referring to section 2.1.3 key notes from the observation can be used to apply to the latent, wishes/wants, and immediate needs of the end user.

Result

1) Navigation

Currently the process of navigating the mines is troublesome due to the lowered visibility, uneven terrain, and in the case of this observation the accessibility in this terrain. In the video being analyzed the user has to bend down awkwardly to avoid being hit in the head by the ceiling of the mine. The amount of problems happening at once creates a difficult and frustrating experience for the user, whilst lowering confidence.

2) Initial Development Drilling

The drilling process is extremely cumbersome and once again, the user is reliant to do multiple tasks at once with little assistance from the equipment, and little safety concern. The user is working directly beside moving machinery, whilst lifted off of the ground.

3) Support Bolt Installation

Installing the bolts leads to the issue of working near moving equipment and the risk involved. In the video analysis the user experiences a tool jam, and it takes several seconds to get to the control panel and stop it. If the user was mid-installation the tool could run the risk of catching the bolt and moving the user involuntarily. This leaves room for better more ergonomic control scheme solutions.

4) Screen Installation

The primary purpose of the screen installation is to stop rockfall hazards. This however is still an extremely risky task where the product design does not help the user complete the task in the most holistic and effective manner. The lack of safety measures on this particular bolting rig prove to be problematic.

3.2.2: Activity Experience Mapping

Introduction

This section focuses on how we may improve the current user experience.

Method

By using the activities mentioned in sections 2 and 3.2.1, a table is generated off of the current UX curve and how this experience can be improved.

Result

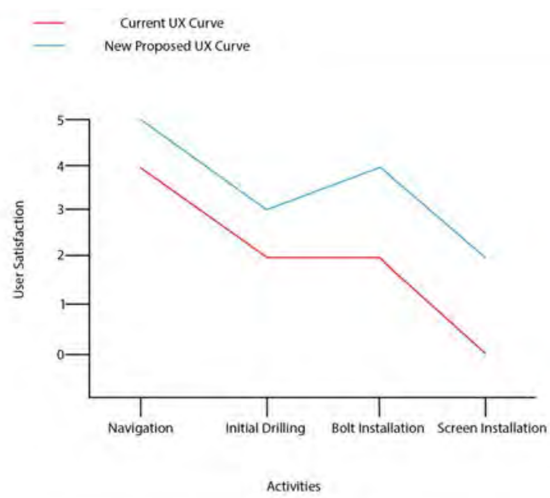


FIgure 3.2.2.1 - Projected UX curve

Key activity	Steps	Current user experience	Potential improvement
Navigation	-User operates a far control panel. -Operates direction and height.	-Cumbersome. -Low visibility. -User operates controls while looking ahead.	-Unified movement. -Improved lighting/visibility -Front end controls.

Initial drilling	-User starts drill using the front panel. -Drill is driven to appropriate depth.	-Lots of movement between control panels. -Hard to approximate depth. -If tool jams the back panel must be accessed.	-Single panel operation. -Precision depth measurement. -Improved workflow.
Bolt installation	-User begins loading bolts while drill is going - User loads bolt onto drill unit. -Once installed, the bolt is expelled	-Operation by hand near moving equipment. -Unnecessary steps taken to load/expel bolts.	-Hands off of drilling equipment. -Chambered bolting system.

	by the user.		
Screen installation	-User feeds wire mesh screen over bolt installation. -User assists drill to support wire screen.	-Lack of safety precautions (IE. railings). -User is constantly in line of danger. -Screen is held in awkward manners.	-Assisted screen holster. -Are where users are not at risk of falling hazards or overhead hazards.

Table 3.2.2.2 Activity Map

3.3: Usability

Introduction

Currently in the industry most equipment and vehicular solutions have a wide variety of ergonomic issues that are not being properly addressed. Many of these considerations are involving cab designs and the consideration of current manual labour practiced (McPhee, 2004). This feeds into the underlying problem of ergonomic issues affecting the working habits of mining personnel, who already work in an extremely dangerous field with many occupational hazards. Therefore the design solution proposed creates an operable piece of heavy equipment that feels like an extension of the user to allow for accuracy and efficiency while mitigating the hazards of the environment, as well as the hazards typically caused by the equipment. The ergonomic studies conducted led to crucial takeaways such as the following. The cab design must feature a control scheme that is easy to understand and allows for tool accuracy while working, traversal in cramped environments, and being adaptable in a variety of situations. The design solution proposed creates an ergonomic design that assists the end user with a multitude of operations in underground mines.

Literature Review

By reviewing literature related to ergonomics as well as specific ergonomics in the mining industry this assisted in the process of coming to conclusions about the design. The goal for this design and the ergonomic assessment is to create a system that is inherently safe and ergonomic. This means that human error has less of an impact on safety and comfort (Alvin R. Tilley and the Dreyfuss Associates, 2002). Due to the intermittent dangerous conditions in underground mining scenarios the controls and seating must be of a high standard of ergonomics and comfort for the user (McPhee, 2004). By using resources such as The Measure of Man and Woman specific dimensions were extrapolated and included in the design. One area that this was helpful in was handle dimensions for optimal comfort. 1.25" diameter cylindrical handles are utilized to create a holistic experience. Other dimensions for control panel height and operable ranges were extrapolated (Alvin R. Tilley and the Dreyfuss Associates, 2002).

Methodology

The analysis of the ergonomics of mining equipment was evaluated under these considerations:

Objectives

The goal of doing this ergonomic assessment is to understand the challenges that the user faces and how it can be applied to the full-bodied human interaction design (FBHID) of the thesis criteria with three major touchpoints and interactions (Kappen, Thomson, and Burke, 2018). These criteria must be met while creating a new paradigm shifting experience for the user.

Decisions to be made

The aforementioned full-bodied human interaction design must facilitate mining personnel in three major interaction area points. Thus creating a positively holistic experience for the user.

1) Entrance and navigation of the unit. (Legs, hands)

2) Control mechanisms of the device. (Hands, arms, shoulders)

3) Comfort and rest. (Torso, back)

Description of Users Targeted by Product

The users targeted to the analysis were aged 20-45 to fit roughly within the demographic of mining personnel. Despite the fact that mining is primarily a male dominated industry, a 5th percentile female was also observed to give the best descriptive purpose of the whole design. A 95th percentile male was also observed to observe both ends of the user spectrum.

Evaluation Process

The evaluation of the ergonomics of this design solution called for a 1:1 scale buck made from cheap materials to quickly and easily assess the spatial needs, and human elements of the design. This buck allowed for the analysis of the following

1) Spatial needs of the control system in relation to the user
2) User interaction with the control system
3) User's vision and blindspot areas.

Description of User Observation Environment Used in this Study

Due to the fact that this ergonomic buck primarily focused on the interior control components and spatial needs, a taped off area was measured in an area in Humber's workshop to provide precise dimensions of internal space needs.

Ergonomic Diagrams

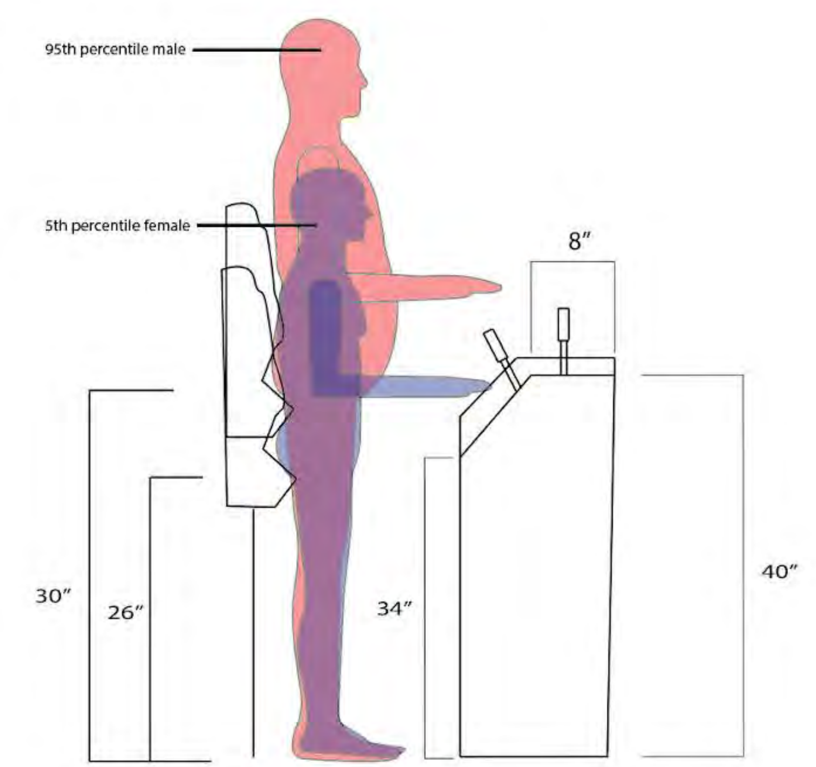


Figure 3.3.1 - Diagram 1

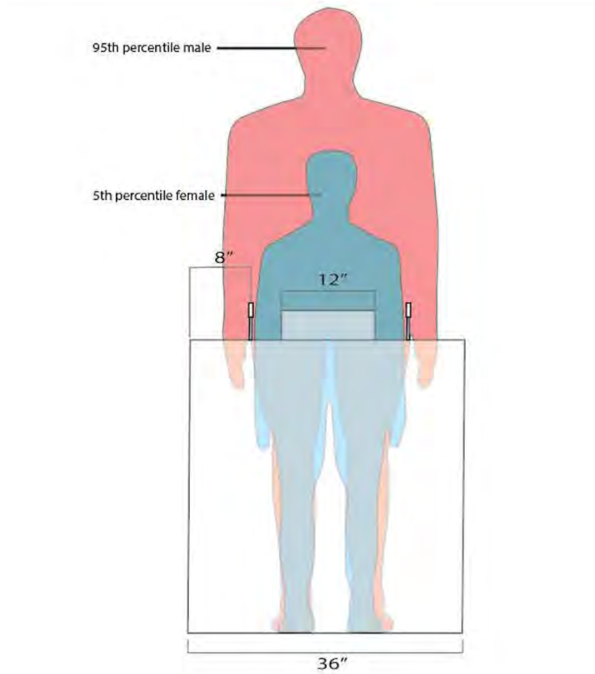


Figure 3.3.2 - Diagram 2

Ergonomic Buck

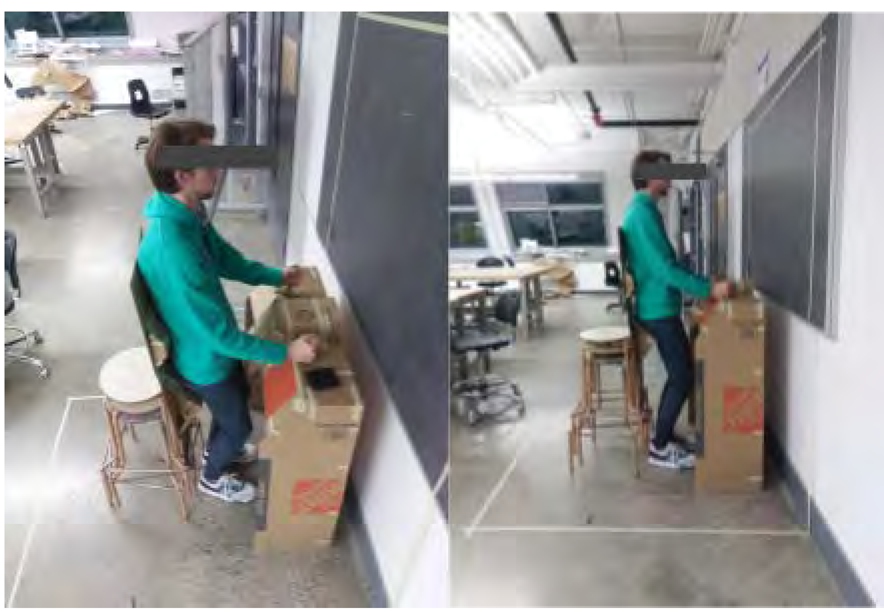


Figure 3.3.3 - 95th percentile male interaction

Figure 3.3.4 - 5th percentile female interaction

Analysis

The creation and testing of the ergonomic buck was very informative and helpful to understanding the design and the spatial aspects of the final design solution. The photos of the model shown above were taken after many adjustments were made to ensure that critical dimensions were accessible for both the 95th percentile male and 5th percentile female. The cardboard elements showcase the control scheme and seating interaction. The tape around the blackboard and the ground represent the internal dimensions and the window panel to ensure that both users are able to have a high range of visibility, as this is a key requirement for mining personnel. Even after the modifications the hub/work surface height could potentially be lowered to increase the range of motion, as this would be controlled in a free manner.

The seating was modified on the fly by using the cardboard pieces as the seat/lumbar support, while stools were stacked on top of eachother to better reference dimensions related to the seating. Although the dimensions were figured out this was a difficult element to prototype due to the fact that it did not maintain its rigidity. Dimensions for the seating were referenced directly depending on the defined user and their height. The 95th percentile user can be seen relaxing and bending into the position to lightly demonstrate the pseudo-seating element of the design.

The handle and joystick dimensions were generally regarded as comfortable by both users, having the ability to be widely adjusted to accommodate for the aforementioned wide array of motion. Both users stated that an extra articulation point on the handle bar would add to a more extensive and more fluid control scheme that feels more human and natural.

This buck mockup gave a great sense of scale to the design which is a necessity before final design details are resolved. The workspace and interaction area underwent many modifications before getting to this final set of dimensions. Further interior elements are to be explored in the detail development phase of the design process. The main goal of this buck was to interpret the main user interaction points to provide an accurate use case for the human centered design elements.

Limitations and Conclusions

1) Although the supported standing position feels more natural in this control scheme, the difficulty of prototyping it was somewhat inconclusive in terms of comfort.
2) The joysticks could have further articulation methods to increase the human connection and accuracy. As well as the natural movement patterns.
3) The shape of the control panel could be adjusted to increase the comfort and usability of the system

In conclusion, designing and creating the ergonomic buck was an extremely helpful task in assisting in the analysis of the design ergonomics and human factors. Some elements such as the seating/standing, and the placement of certain control elements still have room for improvement and require further prototyping.

3.4: Aesthetics and Semantics.

Introduction

Aesthetics and semantics are important to creating a successful design. Semantic profiling helps distinguish a design function and form and the context that the product is used in (Krippendorff, 1984). This section of the report will focus on the aesthetic and semantic profiling of the benchmarked products covered in section 2.2 to establish the symbolic and aesthetic traits of these products and the takeaways that can be used for the design direction.

Method

The comparison of similar products is done using a combination of search methods to ensure that the most relevant benchmarking as per the user research. For the sake of the design direction, underground drilling equipment is being analyzed on a micro-macro scale; from handheld drill tools and full scale vehicular bolting rig solutions. Using results from the survey collection was crucial to finding the most up to date equipment used by current mining personnel.

Aesthetics

The benchmarked products listed previously generally share a very similar aesthetic style. Whether the product is a handheld unit such as the Atlas BBC 16 or a large vehicle like the Sandvik DU412i they both have similar styling cues and aesthetic considerations. All of the items benchmarked, either small scale handheld equipment or large scale vehicular tools, are all equipment. This means that they generally have a rugged aesthetic style. Most of this equipment is described as rugged or heavy-duty in a lot of the advertising materials and website resources. However there has been recent developments to create more interesting and organic form-factors whilst still maintaining the rugged stylization of heavy-duty equipment designs. The handheld solutions tend to use a variety of bright colours such as yellow on select sections matched with a high contrasting colour such as black. The vehicular solutions typically have darker shades of bright colours such as orange or yellow with the same contrasting black detailing colour. Many of the interiors of the vehicles are modern with a lot of geometric form factors. The colour scheme is generally black, the main outlier being the Sandvik DU412i which has a lot of lighting, screens, and high contrast control switches. The disconnect between the very sleek modern interiors of the vehicle solutions and the rugged exterior opens up a market opportunity for a more unified aesthetic design language.

Semantics

The symbols and representative nature of these products has a very strong semantic profile. A lot of the symbolisms used in heavy machinery and equipment are present, and it presents a semantic profile that is very distinct in its usage. The central member is reliant on the mechanical nature of these designs. Usually a lot of the mechanical elements are completely visible, creating a generally honest design language; with only the main internals being covered (engine, motor). Other semantic features in the benchmarked products are the usage of the large tyres, with the exception of the Steunick Crawler being a main outlier due to its size. The heavy tyres paired with the outriggers and the visible hydraulics create a semantic profile of honest, yet rugged design symbolism for the vehicular solutions. For the handheld solutions, they often use a lot of exposed piping and fasteners. Fasteners such as hex head bolts are used to create emphasis on the strength and rigidity of these handheld solutions.

3.5: Sustainability, Health, and Environment

Introduction

Sustainability in the mining industry is extremely crucial not only to the environment and the industry, but also to the workers and their quality of life. The ability for these individuals to work aptly in a healthy environment is undoubtedly crucial to the success of underground mining operations.

Method

By analyzing peer reviewed studies guided by responses from the surveys and interview analyses, ideas of the current landscape were achieved.

Result

In the current landscape of mining equipment, sustainability is a growing area of interest. Due to the fact that many vehicles and larger scale equipment are still primarily diesel powered there is a large risk of off-gasses created by diesel particulate matter. Diesel particulate matter (DPM) is the solid matter expelled from diesel powered engines (Ristovski et.al, 2012). DPM creates an extremely hazardous airborne chemical compound that has the potential to cause a plethora of respiratory problems in underground mines (Ristovski et.al, 2012). DPM is an issue for all workers, and the environment they work in.

3.6: Commercial Viability

Introduction

Commercial viability is an important aspect of this design, as understanding the market potential, as well as the cost of materials and manufacturing are important to ensure that the design is viable in the industry. A full bill of materials and manufacturing report can be found in appendix ix.

3.6.1: Materials and Manufacturing

Introduction

A multitude of materials and manufacturing processes are utilized to optimize the performance and cost of Omni. This section will focus on the specific materials and manufacturing processes used.

Objective

The objective of this section is to understand the materials and manufacturing elements for Omni.

Result

The resulting table is a general overview of different materials and processes. A full bill of materials can be found in appendix ix.

Parts	Materials	Manufacturing Methods
Hands, arm linkages, shoulders, drive wheels, suspension springs, handrails, control sticks, arm bolts, seat adjustment	Aluminum	Extrusion, machining, stamping, casting, forming
Chassis, main panels, main arms, step, axle, drive wheel spacer, arm bolts	Steel	Stamping, break press, casting
Textured mats (interior and exterior)	Natural rubber	Injection molding
Environmental lights, window	Polycarbonate	Thermoforming, injection molding
Tracks	Butadiene rubber	Injection molding
Medical kit, tool kit, interior wall	Makroblend	Blow molding
Control sticks, dashboard screen	Makrolon	Injection molding
Control sticks	Texin	Overmolding

Seat, centre console	Bayblend	Thermoforming, blow molding
Seat cushions	Medium density PU foam	Molding, stitching

Table 3.6.1.1 - Materials and manufacturing

3.6.2: Cost

Introduction

Mining equipment is generally an expensive yet necessary investment for companies. Equipment is often ordered in masses before projects begin, to ensure that there is enough equipment to make a project successful.

Method

Multiple companies' product lineups were analyzed to create a general price range to make Omni as profitable for the industry as possible.

Result

The following table represents estimated costs for a variety of equipment based on weight, labour cost, and motor type to generate a capital cost. These numbers were found from the Mine and Mill Cost Estimator's Guide (retrieved from https://costs.infomine.com/).

Product	Units	Weight (lbs)	Motor type	Capital cost
Hydraulic shovel	1	131,000	Diesel	$1,025,000
Loader	1	109,900	Diesel	912,500
Tractor crawler	4	36,670	Diesel	320,900
Water truck	1	n/a	Diesel	253,000
Service truck	1	n/a	Diesel	167,400

Table 3.6.2.1 - Cost comparison

By analyzing these numbers, and considering the electrical componentry and reduced weight of Omni, the price range for one unit is $150,000 to $250,000. However this costing can be drastically different depending on the number of units bought in bulk, and connections with suppliers.

3.7: Design Brief

1) Help mitigate occupational hazards by providing a safer working experience.
2) Improve sustainability and health by eliminating diesel particulate matter.
3) Improve the working efficiency of mining equipment by creating an innovative control scheme.
4) Create a revolutionary design solution that is versatile in a variety of scenarios.

5) Reduce the risk of long term respiratory problems by protecting the immediate working area.
6) Improve ingress and egress of mining equipment.
7) Improve navigational capabilities.
8) Create a method of drilling, cutting, surveying etc. without having the user in range of danger.
9) Include environmental illumination to help with visibility.
10) Integrate advanced technologies to help the user accomplish a variety of tasks such as leveling, loading, bolting, screen installation.

Chapter 4:

Design Development

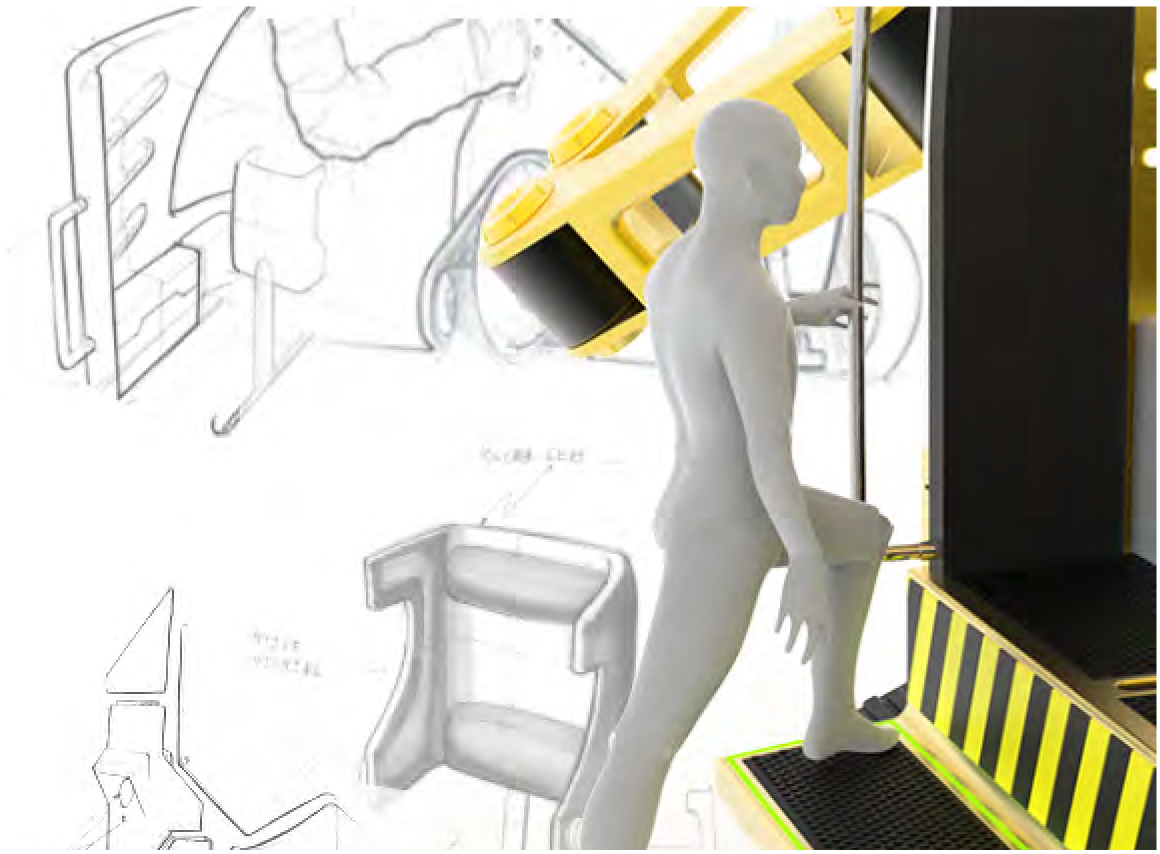


Figure 4 - Design development

4: Design Development

4.1: Ideation

Introduction

Beginning the physical design process, numerous concepts were generated with the goal being to generate as many distinctly different concept directions as possible to answer the problem statement. The initial proposed concepts are directly reflected by the user research and product benchmarking to create a paradigm shifting concept design.

Objective

The objective for this stage is to begin generating solutions to the issue of occupational hazards in mining. By generating numerous concept sketches with differing features and abilities it creates an effective pool of ideas to make the decision easy regarding concept development.

Result

The resulting sketches are the initial concept directions detailing six distinct concepts. The resulting six sketches below are a result of an in-class sketching exercise.

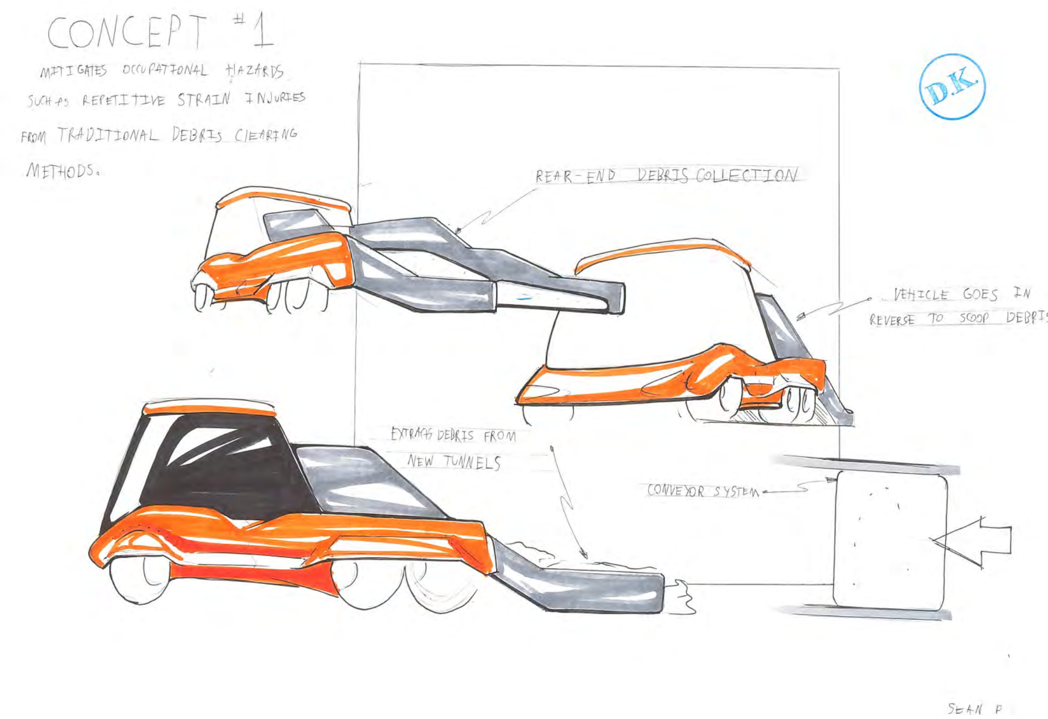


Figure 4.1.1 - Concept 1

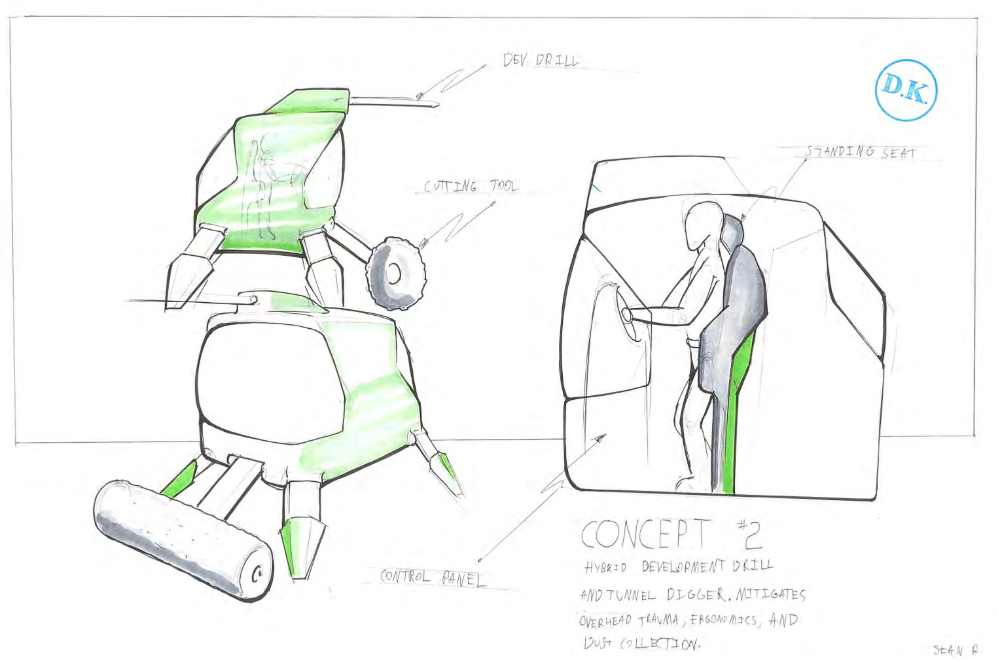


Figure 4.1.2 - Concept 2

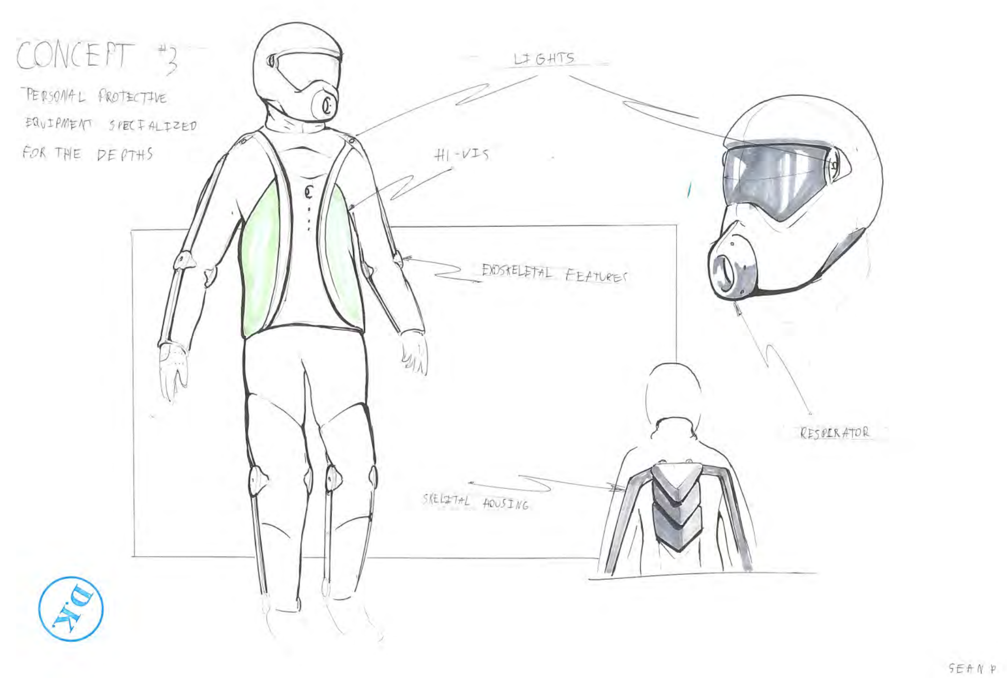


Figure 4.1.3 - Concept 3

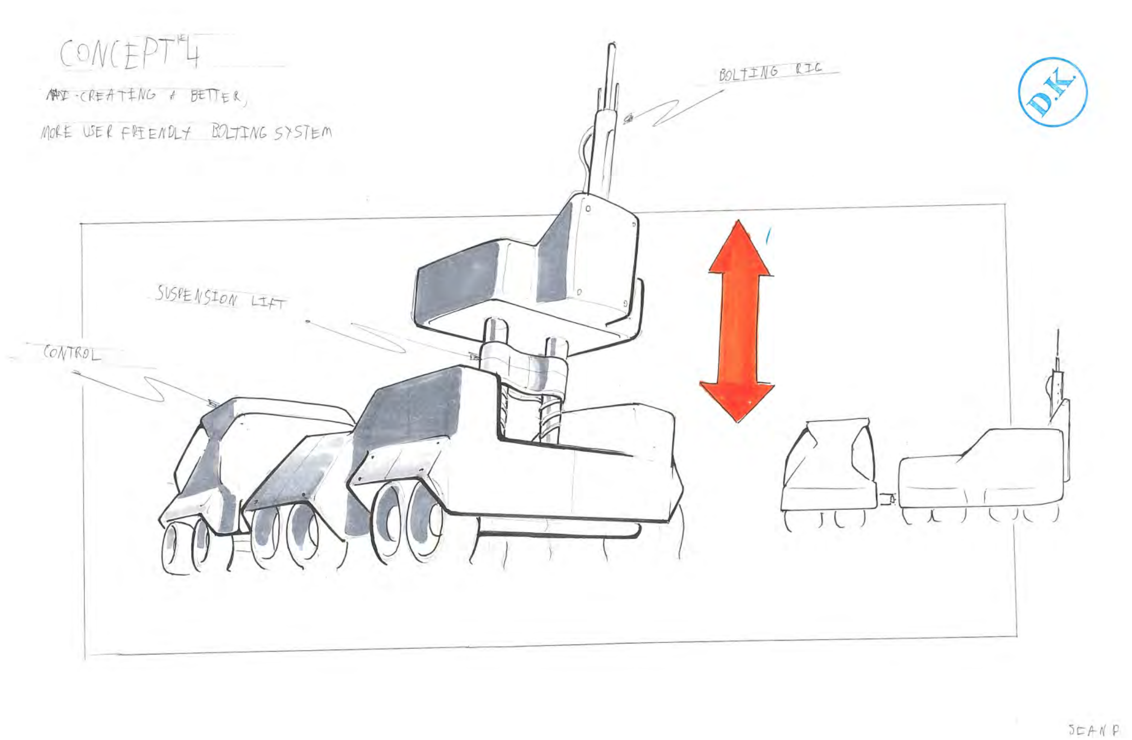


Figure 4.1.4 - Concept 4

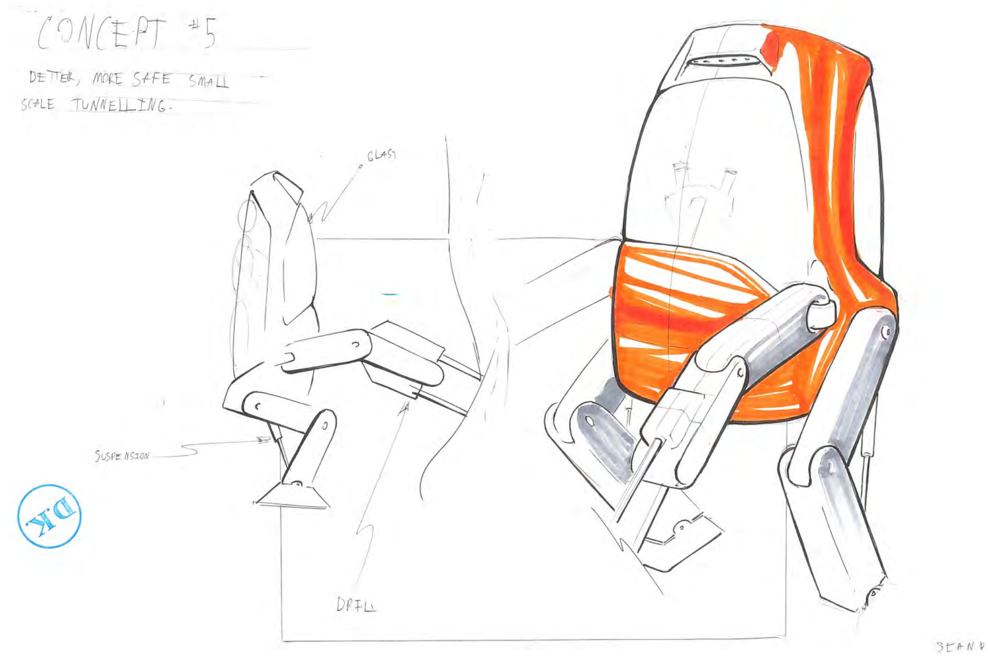


Figure 4.1.5 - Concept 5

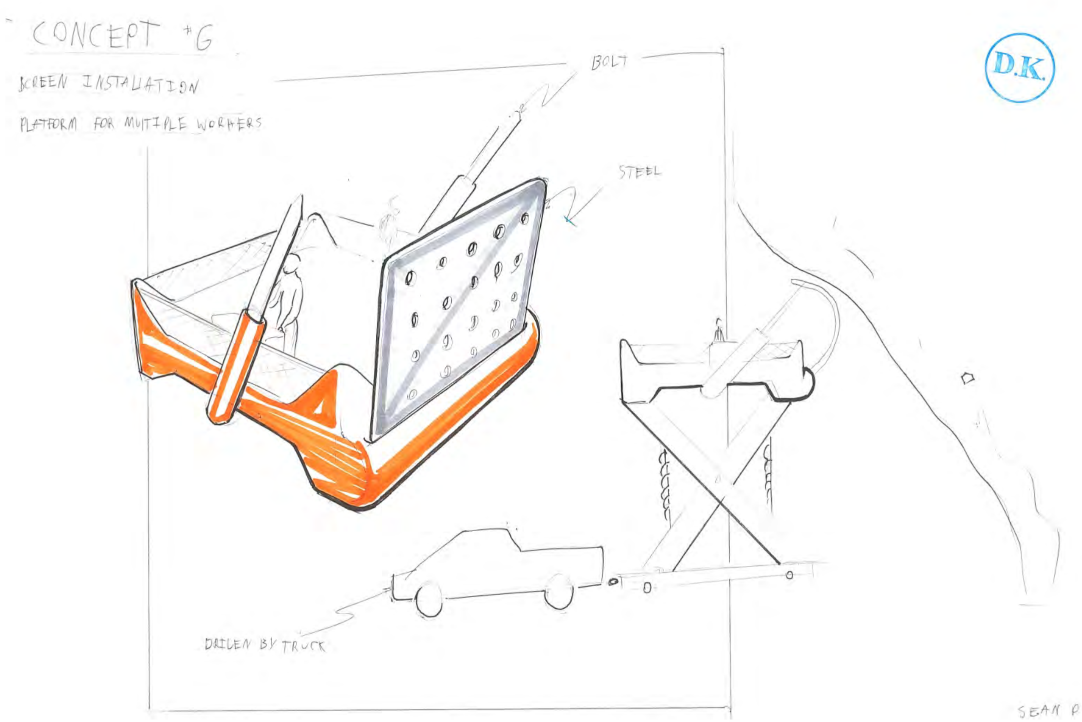


Figure 4.1.6 - Concept 6

By exploring a multitude of concepts pertaining to various tasks and specific hazards as well as ergonomic considerations it allowed for high coverage of the multifaceted issue of mining hazards. Concept five (Figure 4.1.5) Is the chosen final design concept that was taken forward.

4.2: Preliminary Concept Exploration

Introduction

After completing the initial concept stages, one design was chosen as a final direction to continue with styling and detailing. This concept goes through multiple styling iterations and configurations to ensure a feasible design for the finalization stages.

Objective

The goal for this stage is to develop a chosen design from a functional and styling perspective, while starting to refine detailing elements.

Result

The design direction chosen was concept five (Figure 4.1.5) which focused on a diverse, safer equipment solution with a variety of applications. The following sketches represent in class sketching exercises as well as personal development away from class in order to refine the design.

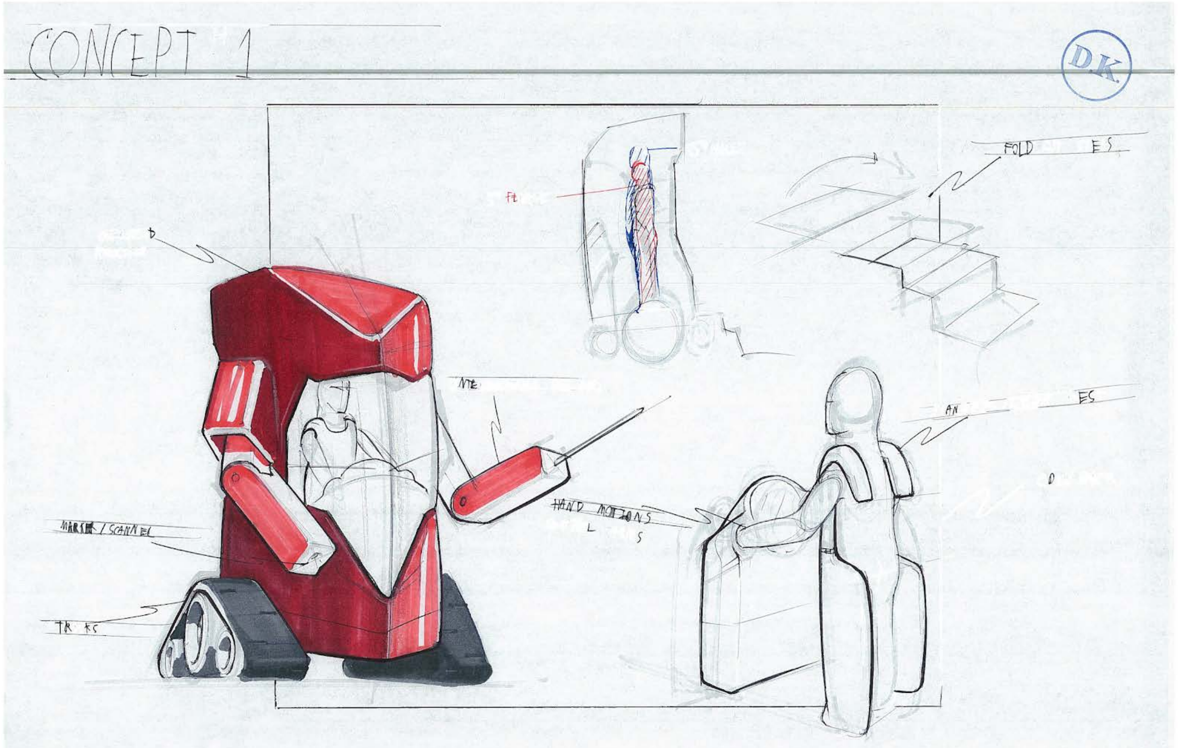


Figure 4.2.1 -Chosen Styling Direction 1

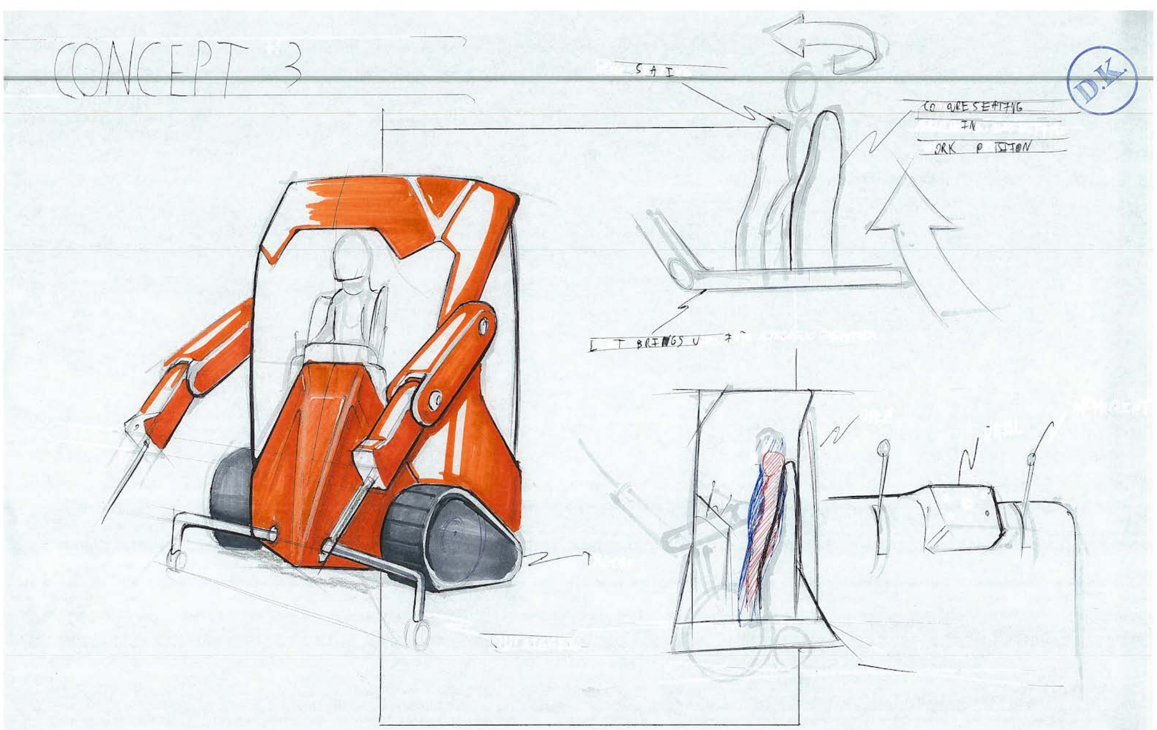


Figure 4.2.2 - Chosen Styling Direction 2

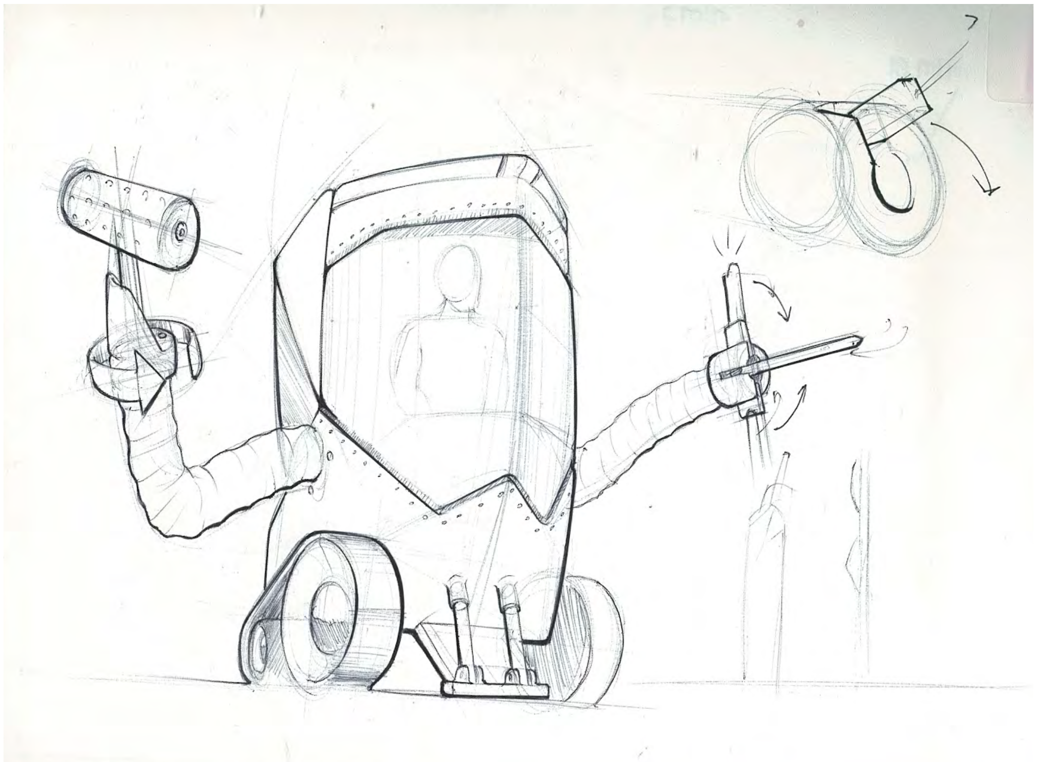


Figure 4.2.3 - Styling Refinement 1

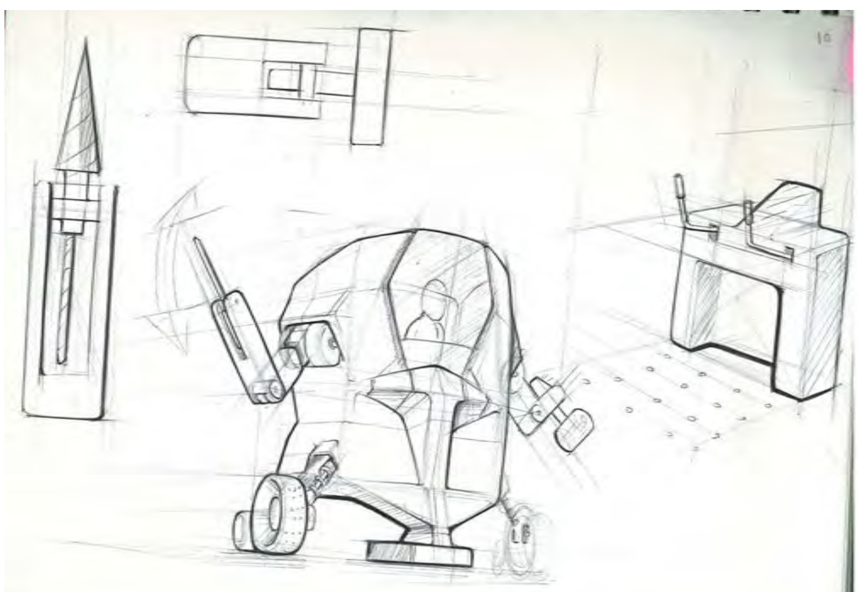


Figure 4.2.4 - Styling Refinement 2

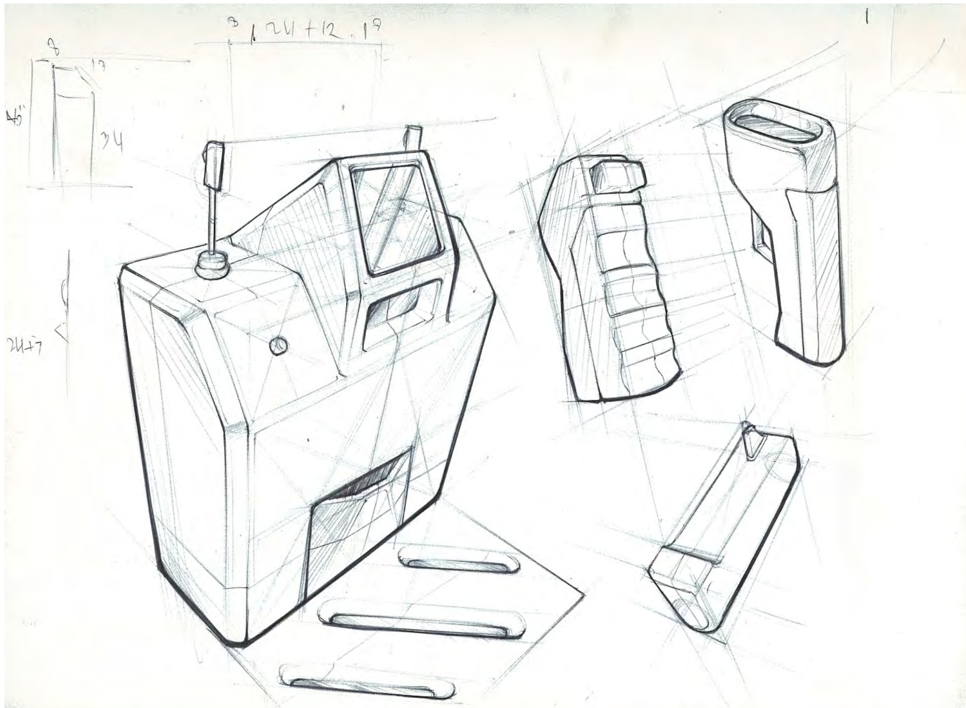


Figure 4.2.5 - Interaction element sketches

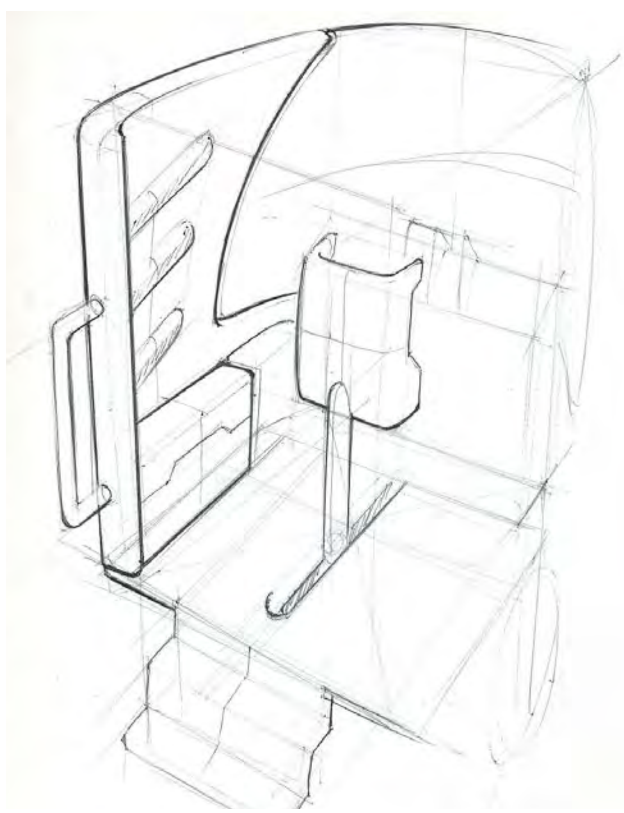


Figure 4.2.6 - Interior sketch

4.3: Concept Refinement

Introduction

In the concept refinement stage of the design the form factor is close to a final direction, while working on details and functionality. As well as ergonomic details and refinements this will become the finalized physical design. All of the design elements and information used in the previous figures are implemented and modified to create a holistic, cohesive final design. This phase of the process was achieved by doing numerous sketches in class as well as in sketchbooks during personal time.

Objectives

The objective for the concept refinement phase is to reach a detailed final design direction with resolved elements, as well as ensuring the functionality and ergonomics are sound and incorporate the three touch points needed to meet the requirements of the project.

Result

The proceeding sketches represent the overall final design direction. These sketches were completed in class with various design elements incorporated from figures 4.2.1 through 4.2.6. At this stage the design reached a point where the functionality of the tool storage element was implemented, while still being explored in the following sketches. The exterior of the design takes styling cues from figures 4.2.3 and 4.2.4. The interior detailing was refined from the previous sketches in figures 4.2.5 and 4.2.6. All of these details were combined to achieve this final design.

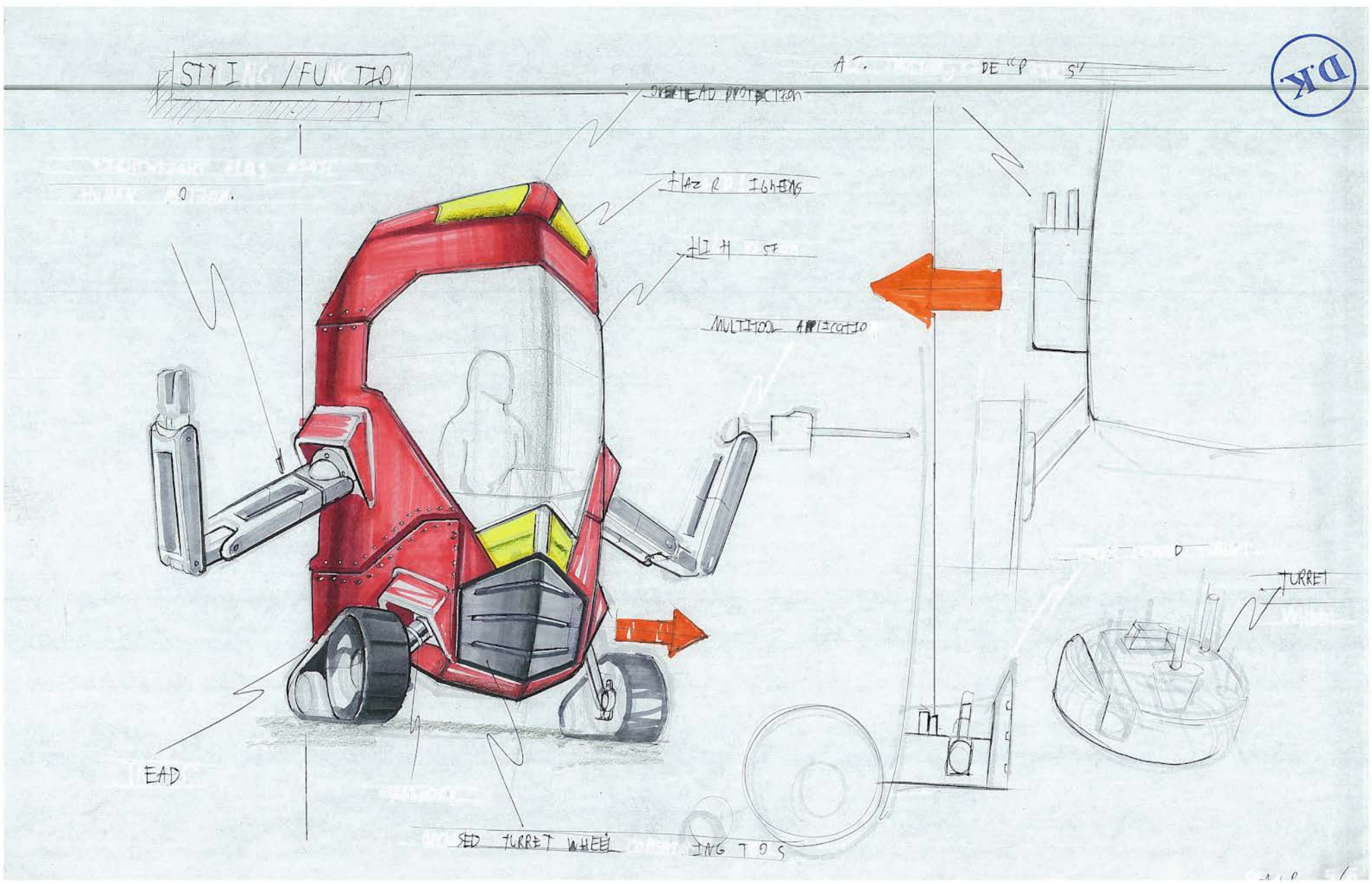


Figure 4.3.1 - Finalized exterior sketch

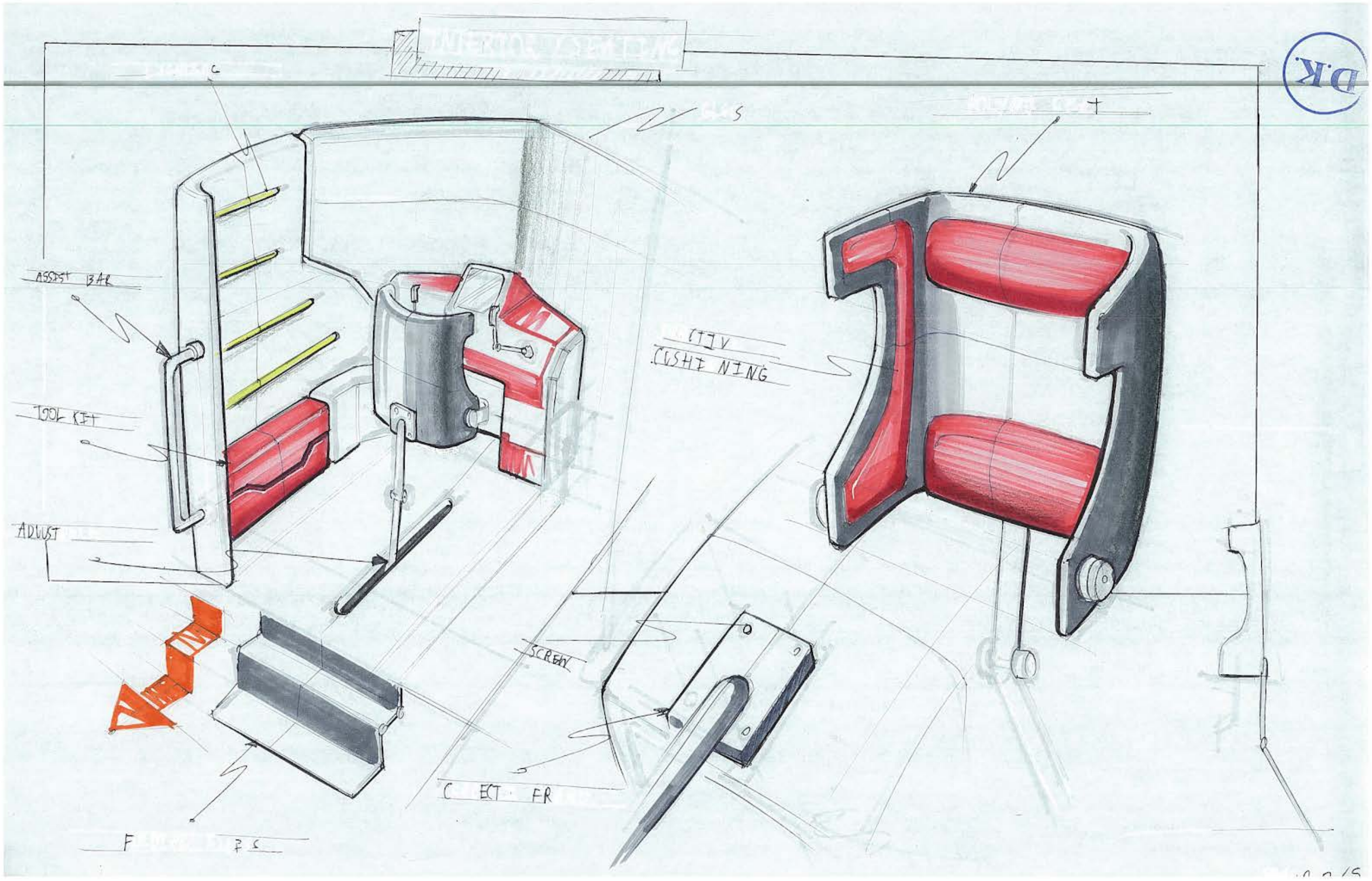


Figure 4.3.2 - Finalized interior sketch

4.4: Detail Resolution

Introduction

During the detail resolution stage there is a focus on resolving many of the details regarding structural assembly, and functionality. The form factor of the exterior and interior were resolved in 4.3.1 and 4.3.2. The further details in this section revolve around the usability and core assembly of the physical design, as well as ensuring maximum feasibility and realism.

Objectives

The primary objective of this phase is to generate the finalized details of the design, and to have all of the data necessary for the processes of sketch model making and the computer aided design (CAD) phase.

Result

By generating numerous sketches in class many important details were developed and resolved in order to proceed into the aforementioned CAD and prototyping phases. The following sketches were developed in class during a sketching assignment.

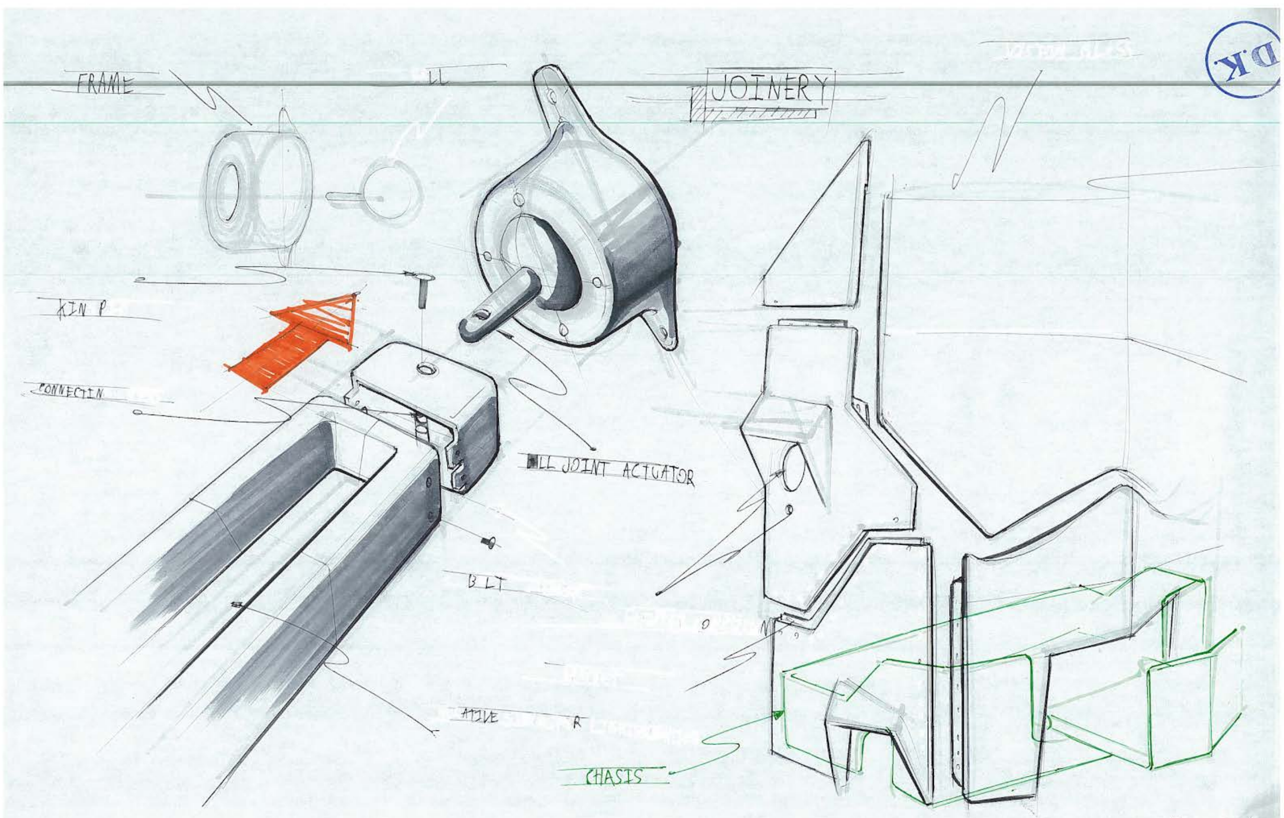


Figure 4.4.1 - Joinery and exploded view

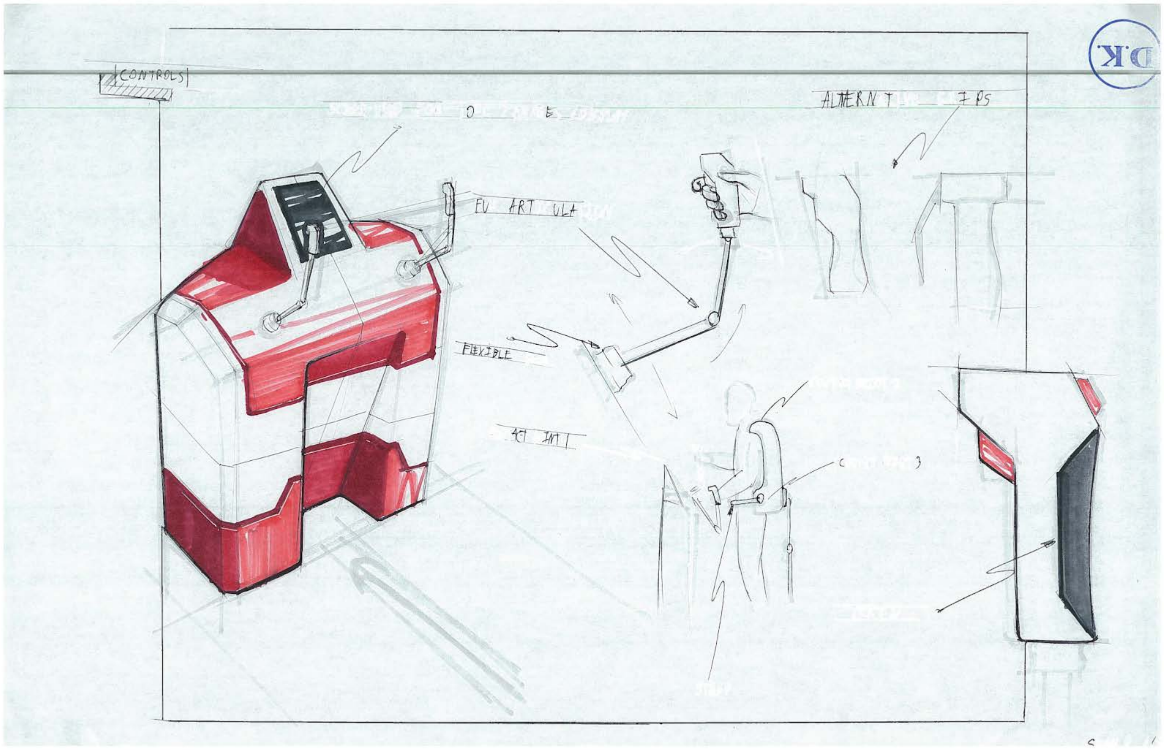


Figure 4.4.2 - Interaction element detailing

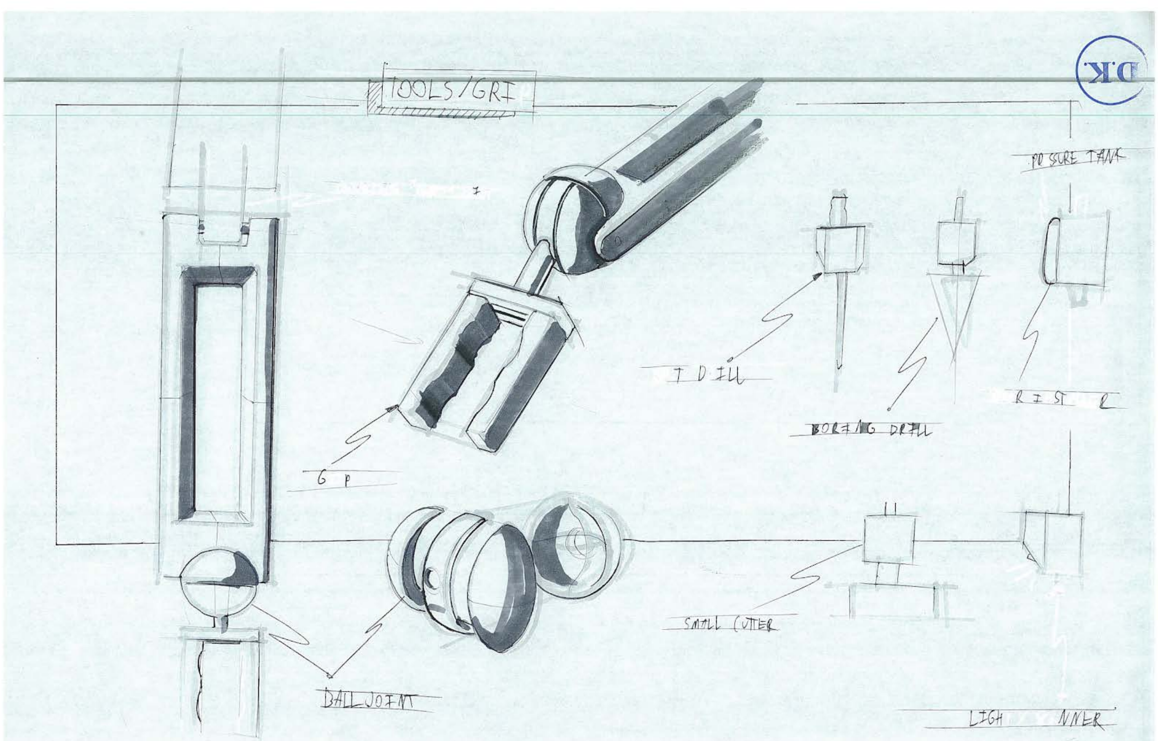


Figure 4.4.3 - Arm, hand, and tool detailing

4.5: Sketch Models

Introduction

In order to understand the physical design to a further extent a scaled sketch model was produced. This sketch model allowed for more final details to be refined in a realistic space along with proper scale from previous ergonomic studies. This model also gave further dimensionality and form to the physical design elements so that the form could properly be understood and refined accordingly with hard points.

Objectives

The objective of this scaled sketch model is to generate a volumetric and accurate representation of the final design form, details, and to create a reference point for the final CAD design.

Result

The resulting sketch model was developed in 1:10th scale in order to give enough space and surface area to accurately create details such as paneling and packaging for the final design. This model helped validate that the design would be functional, as well as give a sense of realistic detailing to ensure the design feasibility. The sketch model was made using foam core and illustration board. The following images are the final result of the scaled sketch model.

Figure 4.5.1 - Sketch model front view

Figure 4.5.2 - Sketch model side view

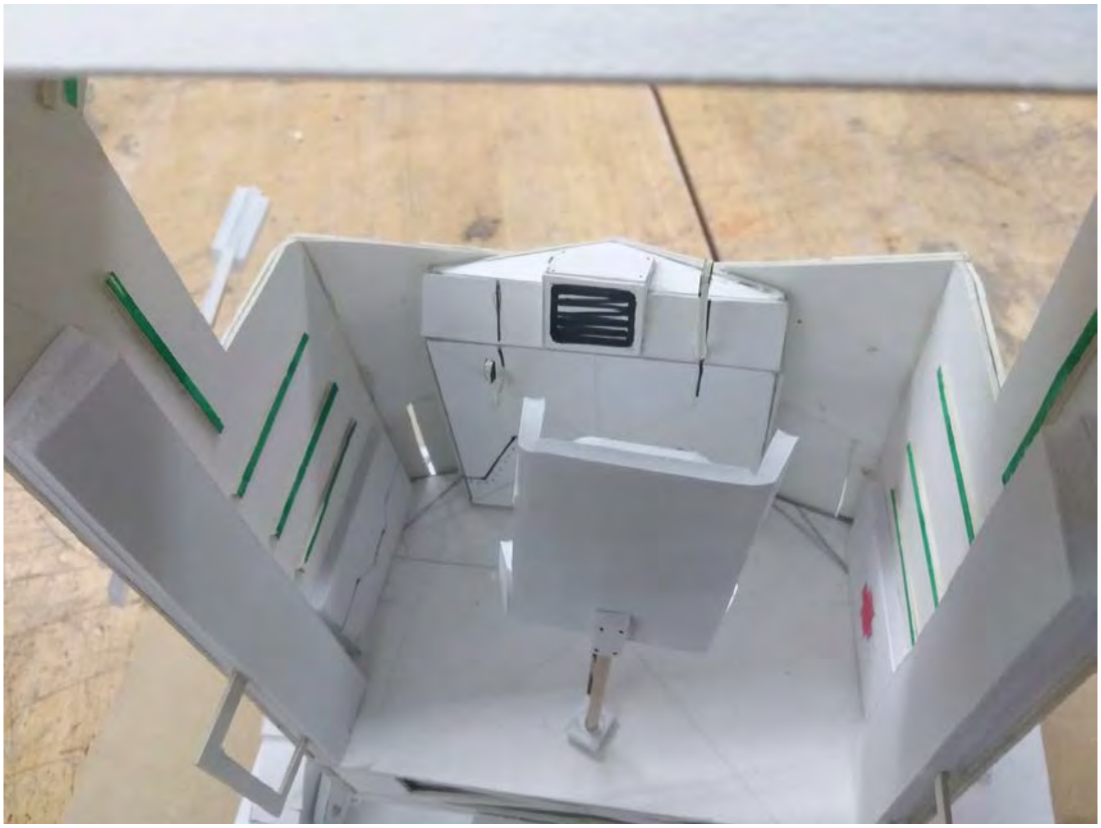


Figure 4.5.3 - Sketch model interior

Figure 4.5.4 - Sketch model tool storage

Figure 4.5.5 - Sketch model platform detail

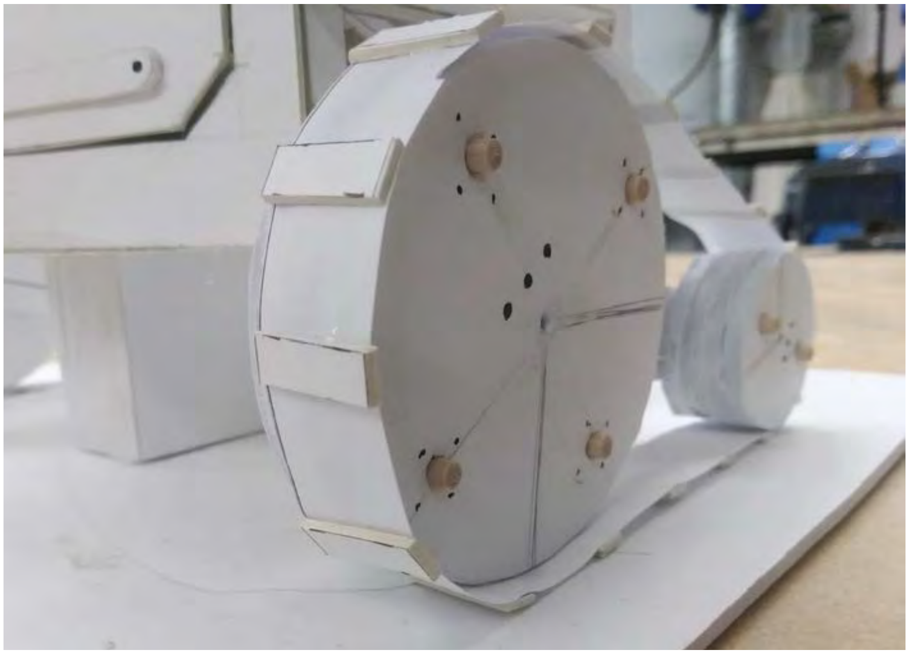


Figure 4.5.6 - Sketch model wheel detail

4.6: Final Design

Introduction

This section reflects the final design, a culmination of the previous phases to showcase the finalized design. The finalized design is a diverse, safety oriented piece of mining equipment that is able to withstand and function in many tasks and areas.

Objective

The objective of this section is to reflect on, and showcase the final designs form and detail resolutions.

Result

The following image shows the final design overall from the interior and exterior. Features and assembly methods were refined from section 4.5 and a high amount of detail was added to each element to increase the realism factor.

Omni is designed to be rugged and industrial, with a lot of care and detailing to ensure that it fits the rugged semantic profile while remaining futuristic and functional.

Figure 4.6.1 - Final design exterior

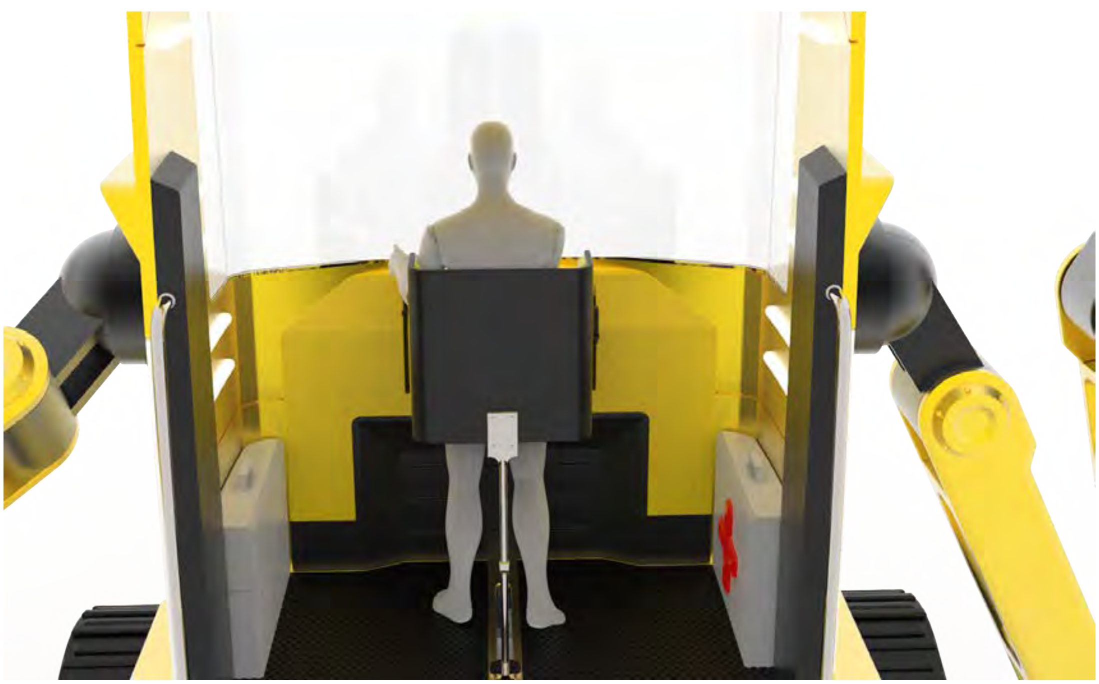


Figure 4.6.2 - Final design interior

4.7: CAD Process

Introduction

The CAD process aims to culminate the previous stages with the refined design elements to create a CAD file for the construction of the final prototype. Using Solidworks, a three dimensional model is made at the appropriate scale for rapid prototyping methods using the previous sketch model as reference.

Objective

Using CAD software to model the design with a sense of realism to make the final model using rapid prototyping methods.

Result

The following series of images document the CAD process at numerous stages.

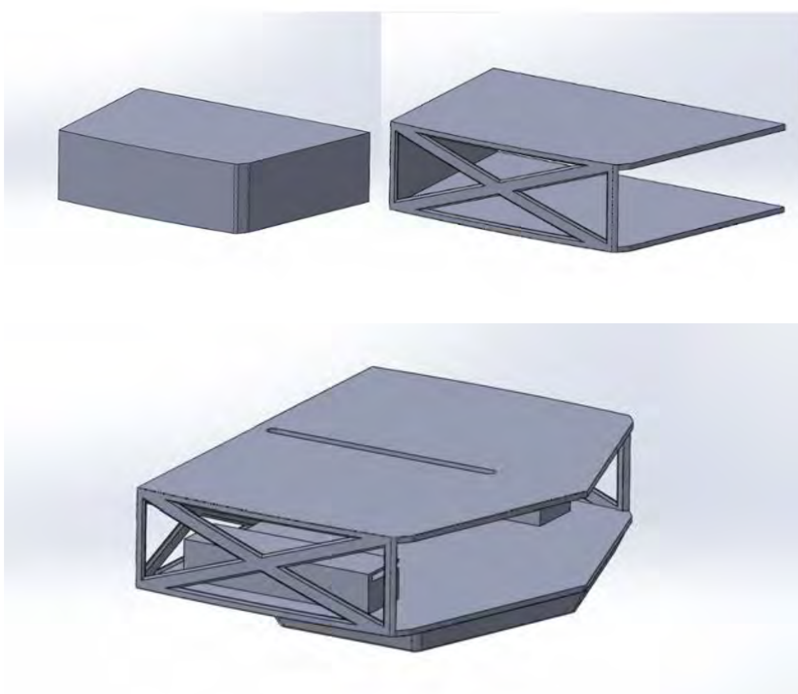


Figure 4.7.1 - Chassis model

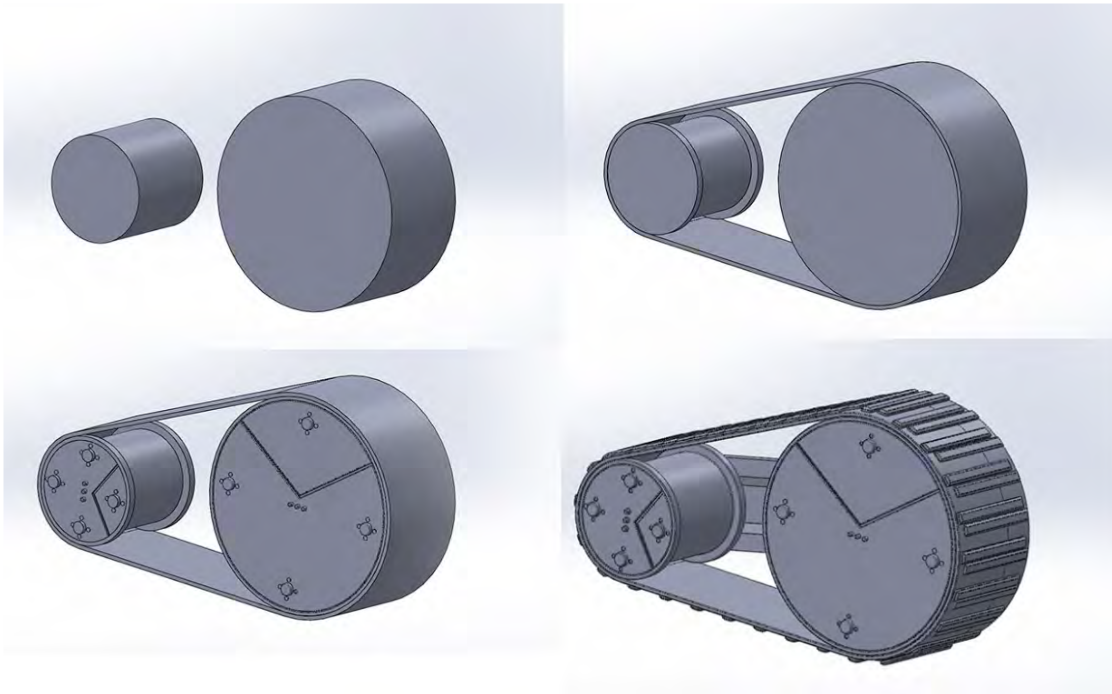


Figure 4.7.2 - Drive wheel model

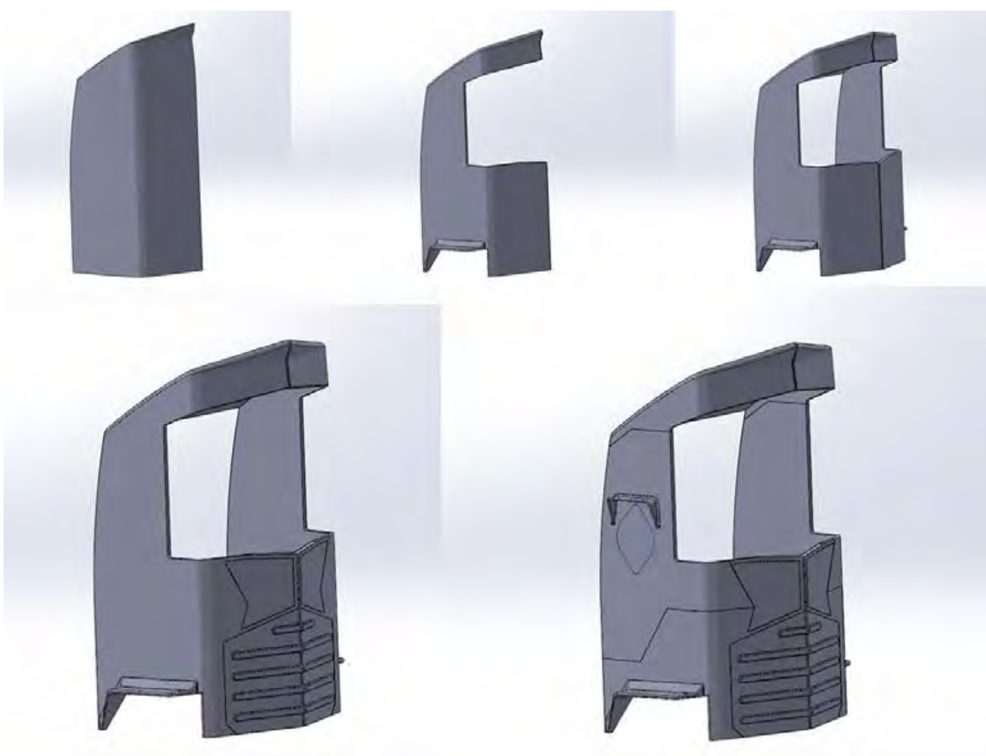


Figure 4.7.3 - Main body modelling

Figure 4.7.4 - Interior modelling

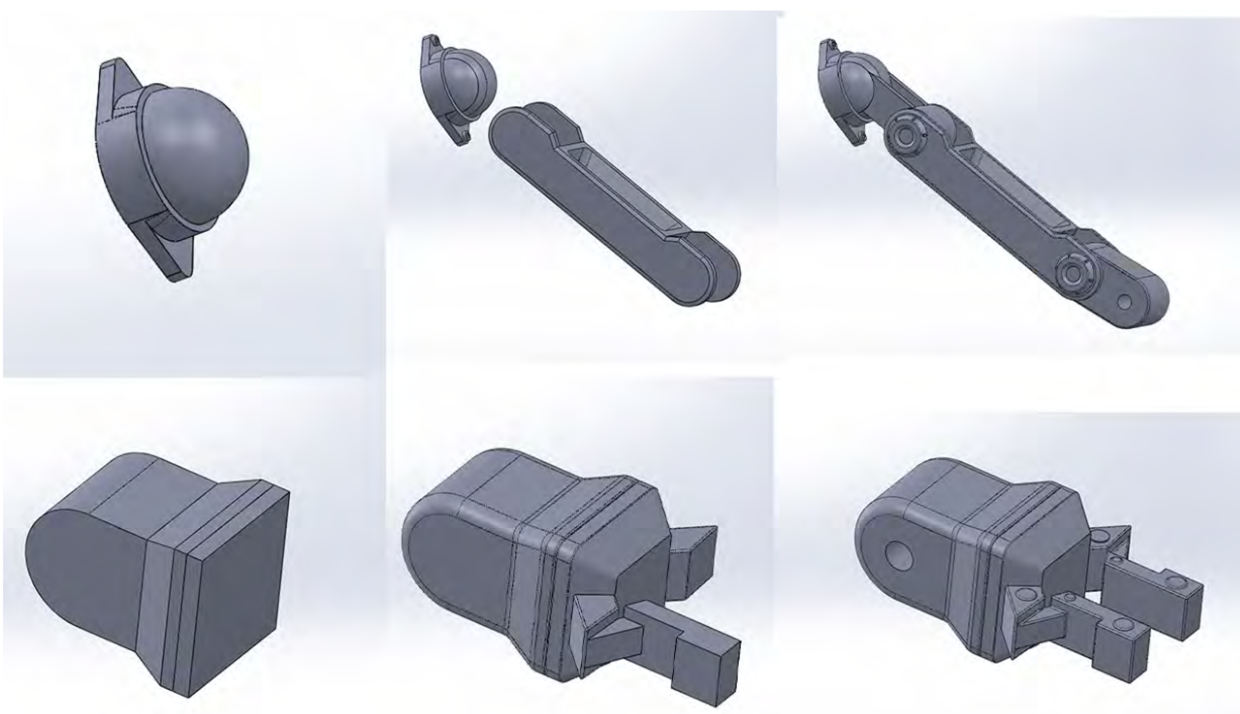


Figure 4.7.5 - Arm modelling

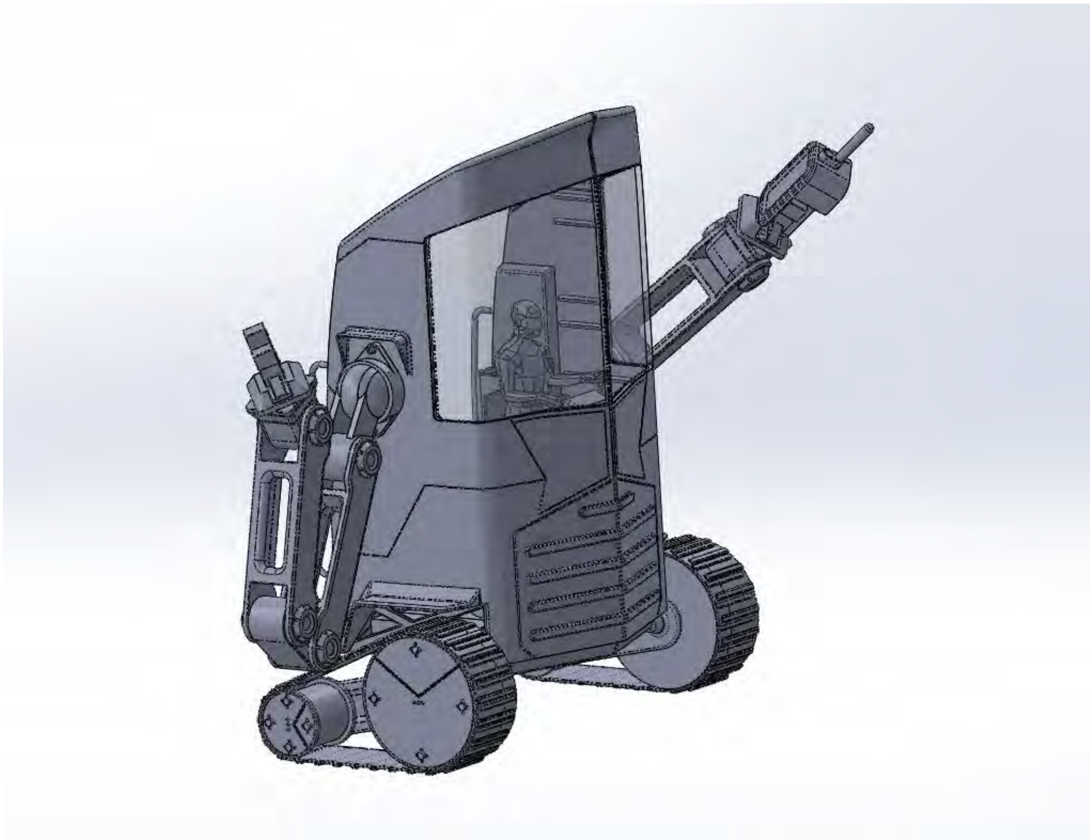


Figure 4.7.6 - Front view

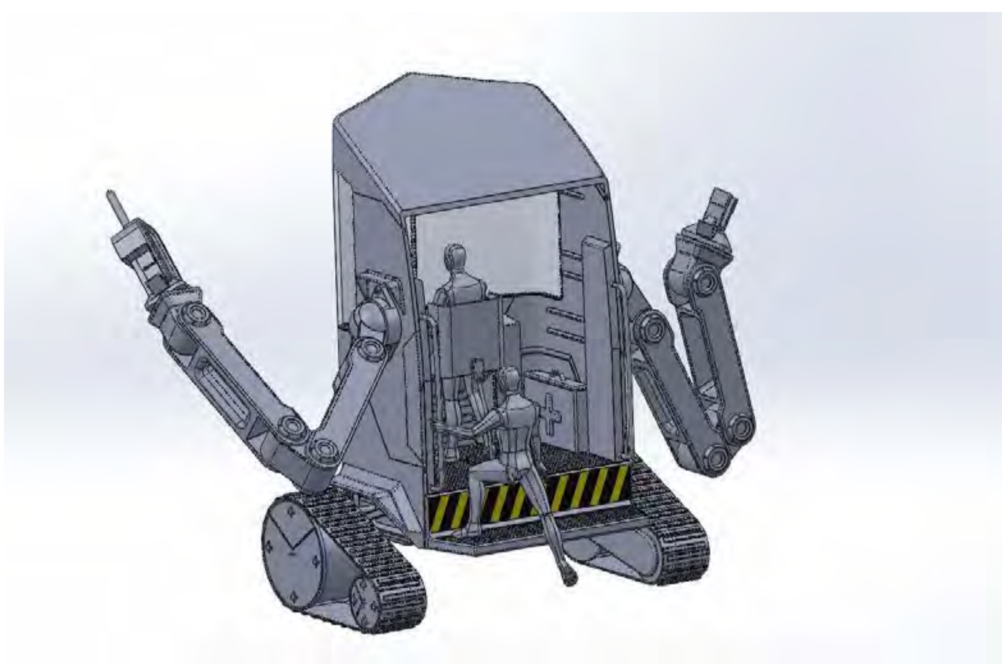


Figure 4.7.7 - Rear view

4.8: Hard Model Fabrication

The following images document the fabrication of the final physical model. Much of the components were printed using SLA printing, while some components were handmade to reduce cost.

Figure 4.8.1 - Wheel fabrication

Figure 4.8.2 - Wheel attachment

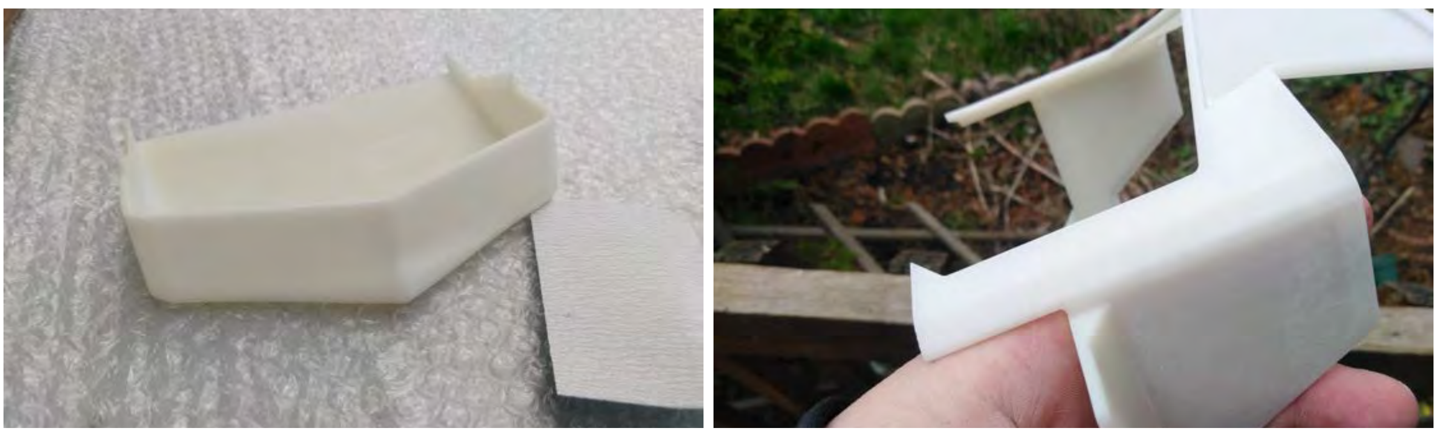


Figure 4.8.3 - Sanding the main body

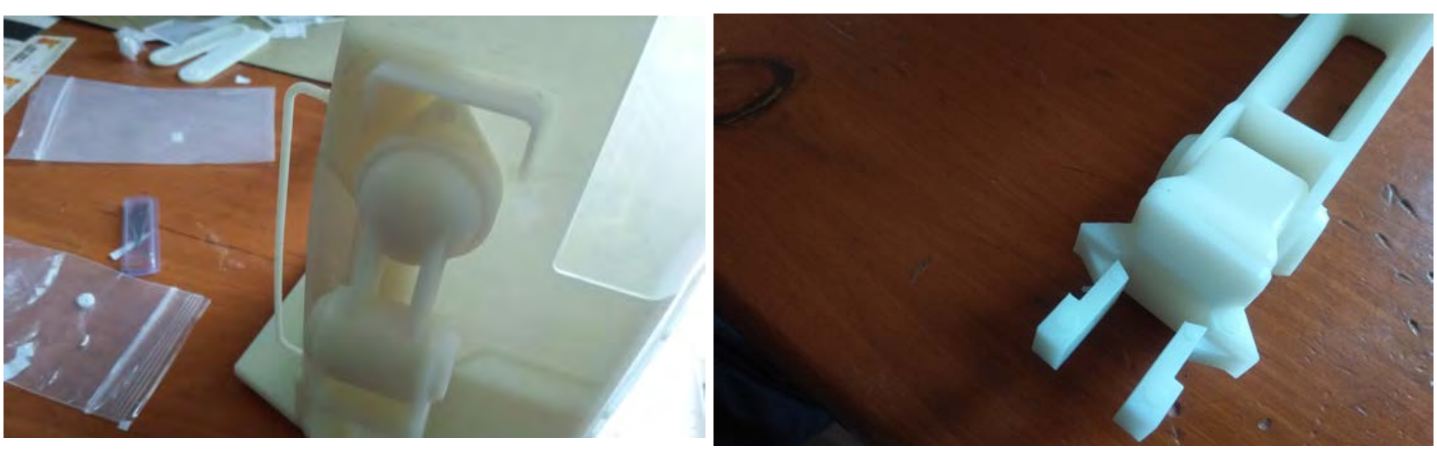


Figure 4.8.4 - Arm assembly

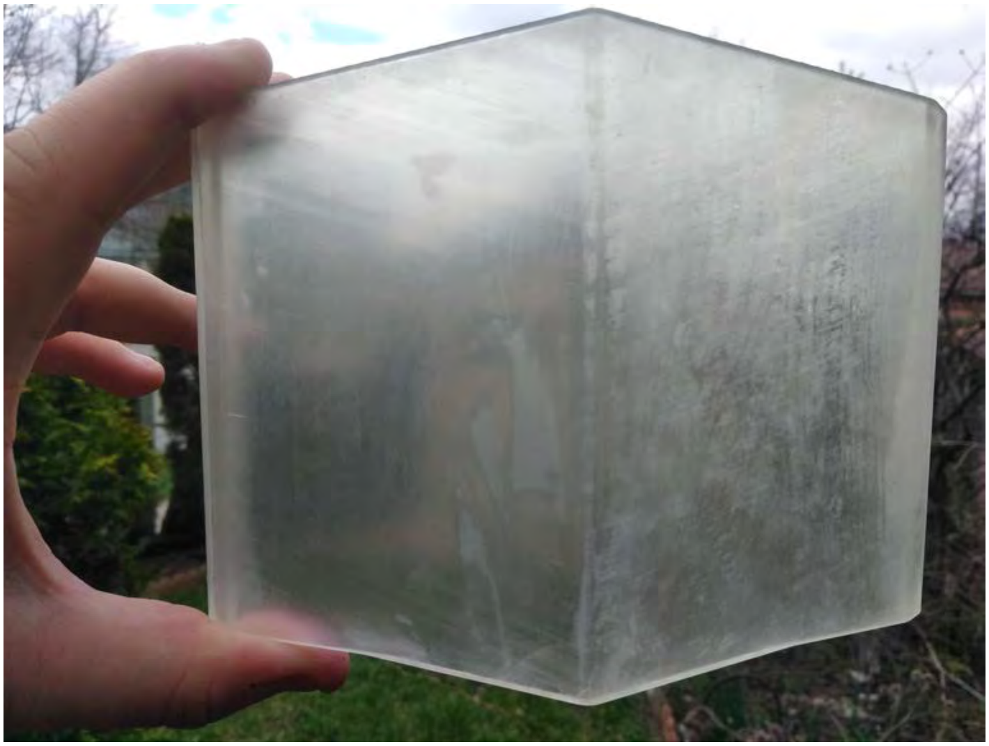


Figure 4.8.5 - Sanding clear parts

Figure 4.8.6 - Interior assembly

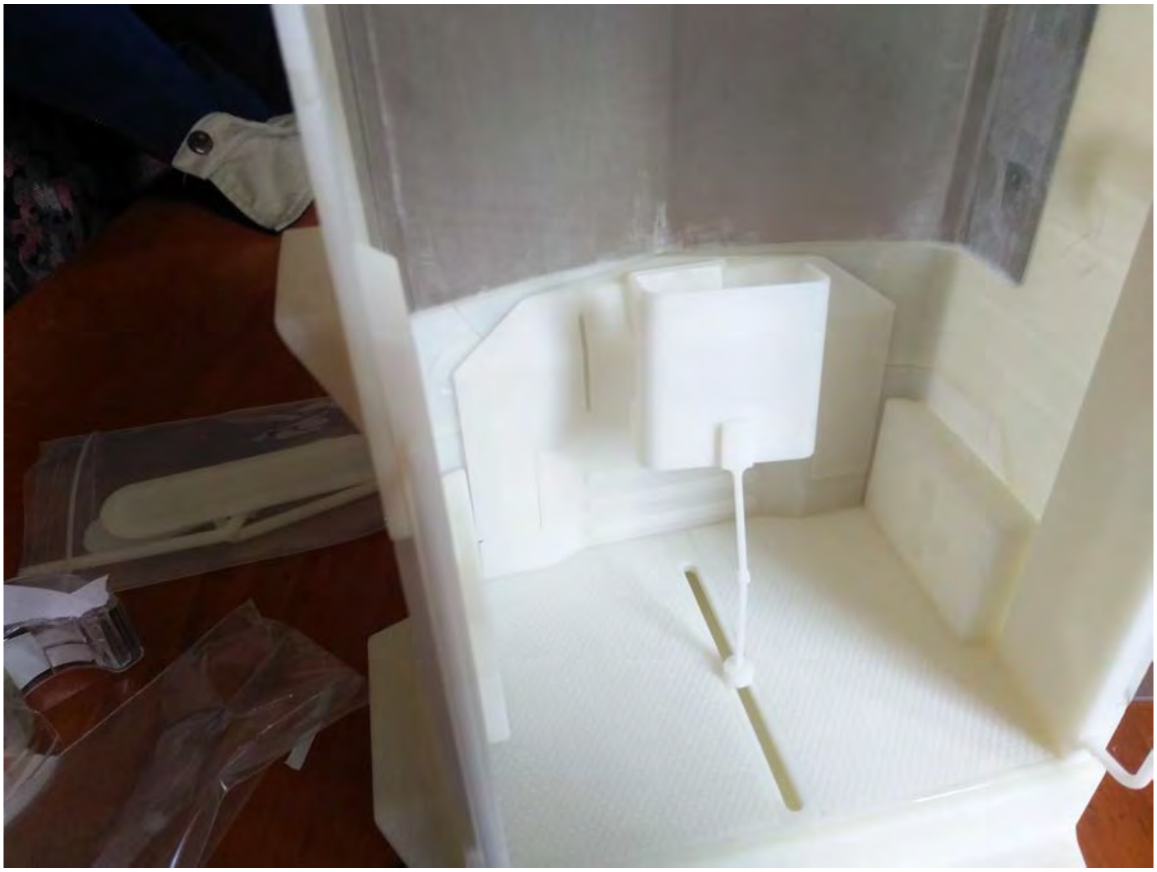


Figure 4.8.7 - Interior features

Figure 4.8.8 - Handrail detail

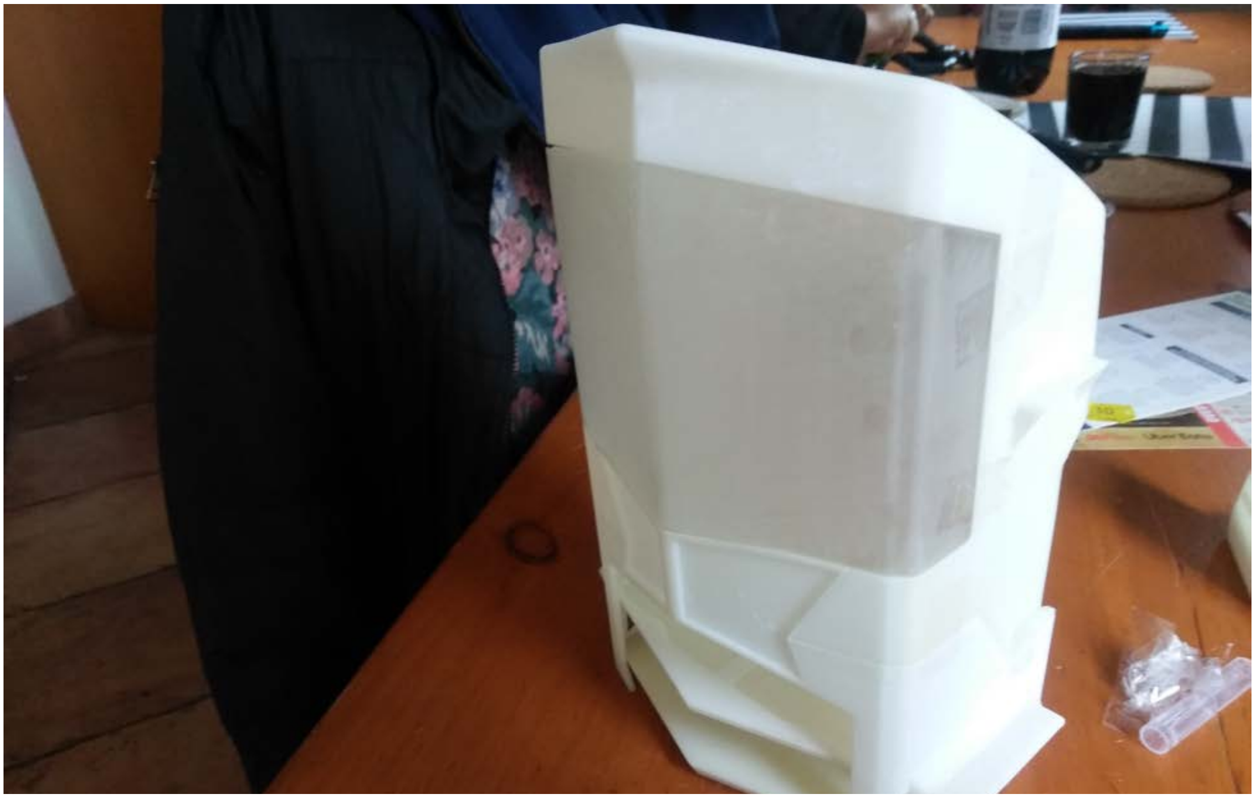


Figure 4.8.9 - Main body assembly

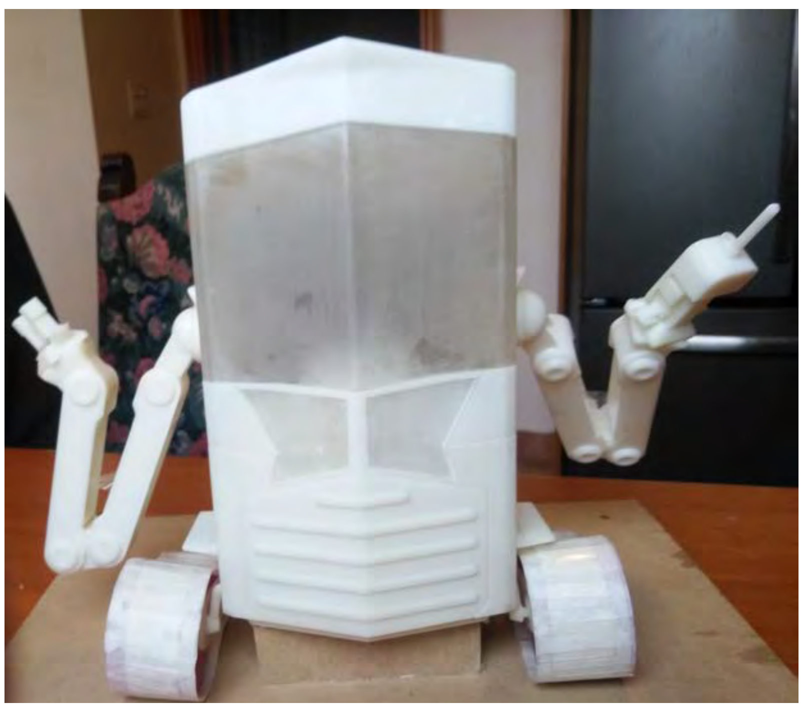


Figure 4.8.10 - Full assembly

Chapter 5:

Final Design

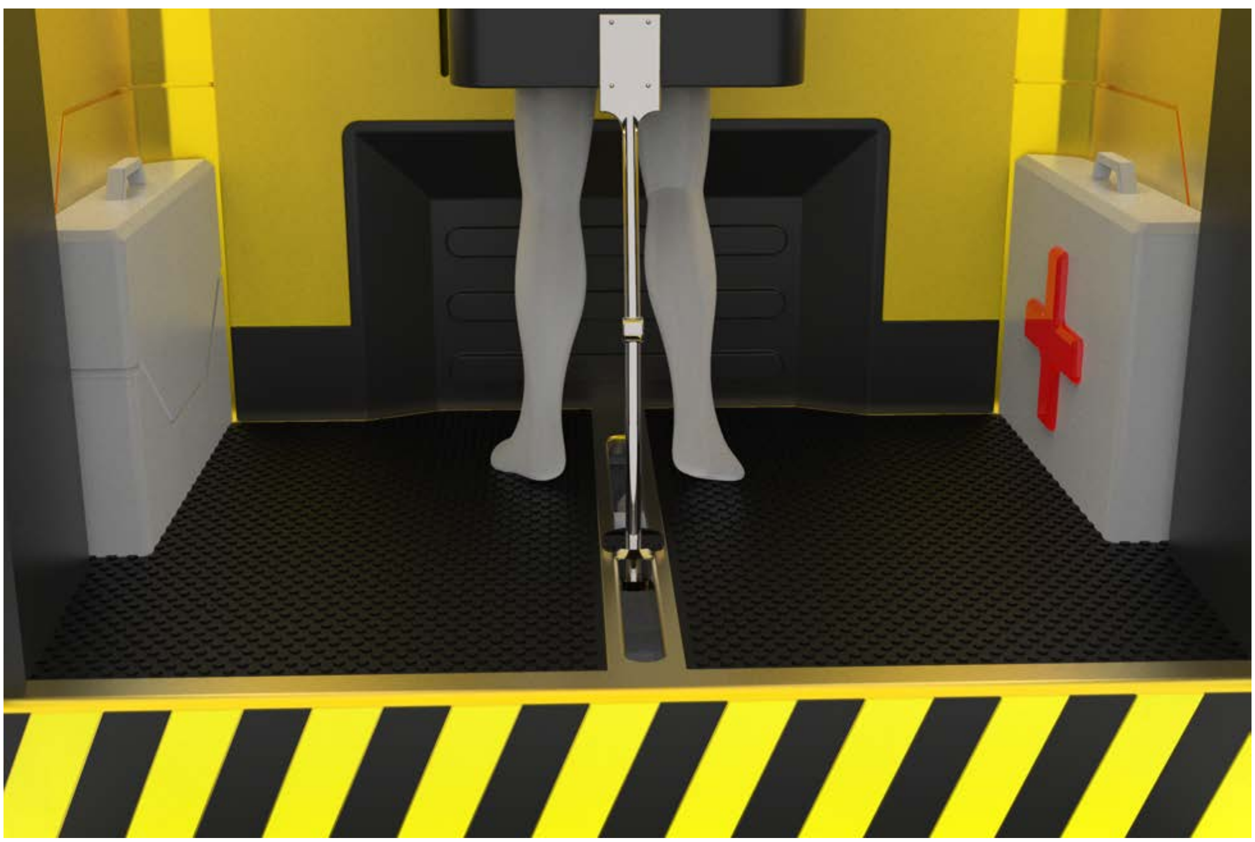


Figure 5 - Final design interior

5: Final Design

5.1: Summary

Description

Omni is a versatile piece of mining equipment designed for the safety of the worker from a multitude of hazards.

Explanation

Underground mining is, and has been one of the most dangerous occupations in the last millenia. Underground mining personnel face numerous hazards while operating equipment in this environment. Mining personnel have to deal with numerous ergonomic problems such as repetitive motions, laborious tasks, and musculoskeletal diseases. These issues coupled with the environmental hazards such as overhead hazards and debilitating medical issues. Current equipment struggles to remain safe and efficient in certain environmental conditions. This thesis aimed to find a solution and create a unique design for the mining industry. Omni provides safety for the users as well as an innovative control scheme and workflow. Omni is a human centered design that helps with many of the tasks that are required in underground mining, while being customizable for any scenario. Omni is a revolutionary concept that includes many features to reduce its environmental impact, such as the removal of diesel particulate matter, and the ease of access for construction and repair, as well as disassembly.

Benefits statement

Omni provides a unique take on mining equipment not currently seen in the industry. The unique control scheme provides a full range of motion that is able to be maneuvered and operable in a variety of areas, while being significantly more compact than current mining equipment solutions. Omni provides a safe workspace sheltering users from the unpredictable dangers of the mines. These features paired with the sustainable focus of the design provide a definite potential improvement for the industry.

5.2: Design Criteria Met

5.2.1: Ergonomics

Omni is designed for people, with numerous features to ensure the comfort of the user while operating. The standing support is adjustable to accomodate for all users, while being cushioned to avoid potential harm from vibration. Furthermore, the controls have a height adjustment feature, as well as being fully usable from any position. These features ensure that the user can work from a comfortable position to completely mitigate awkward movements. The screen on the dashboard is angled up comfortably to reduce the amount of uncomfortable neck movements, making it easier to use while operating. The cabin of the design is spacious enough to avoid feeling claustrophobic, as well as gives enough room to allow the user to use their full range of motion while operating. The on-board tool kit and medical kit are opened from the top making it possible to access them from a standing position very easily. The vertical orientation removes the need to awkwardly bend down to access these essential items.

The rear entrance of Omni incorporates a step and a bar to help make the ingress and egress more safe and comfortable for the user. The ingress and egress are important because the uneven terrain and potential for falling hazards is high in mining scenarios. Omni adds numerous features such as a rubberized grip area on the platform to avoid slips and falls. The added lighting ensures visibility, and makes access much easier. By incorporating these features it makes the entrance and exit from Omni safe and easy.

Omni meets the three touchpoint requirements wholeheartedly, with major touchpoints such as the back, hands, and feet accommodated for in every scenario. Omni is an ergonomic design that improves the working conditions for the users. All ergonomic aspects of the design are covered, from entrance and exit, to the operation of the equipment itself. By incorporating the aforementioned full range of motion the full bodied ergonomics play a big factor in creating an operable piece of equipment to minimize vibrations and maximize comfort. The adjustability for the main control and supporting features allows for the 5th and 95th percentile users to easily access and control Omni to its full potential. Omni is a paradigm shift for the industry, and incorporates full bodied ergonomics in all aspects.

5.2.2: Materials, Processes, and Technologies

Materials

A multitude of materials are incorporated into the design. As covered in section 3.6.1, steel, aluminum are used for all of the metal components such as the chassis and suspension spring. Steel is used for the main panelling to ensure strength and a long product life cycle. Blow molded and injection molded engineering polymers are used for areas such the first aid kit, tool kit, and dashboard area. Subassemblies such as the electric components and internal tools are outsourced.

Processes and technologies

The construction of Omni reiles on a lot of stamped and folded metal parts, and a mixture of blow molded and injection molded plastic components. Items such as fasteners are outsourced specifically for this design.

Omni utilizes a variety of technologies to enhance the design. Some of these technologies are being used in the mining industry to enhance equipment, while other tech is still in its early stages of use. Some of the technology that Omni uses include:

- Touch screen work terminal
- Semi-autonomy (used for tool changing)
- Electric motor

- Adjustable control scheme
- Environmental and interior lighting
- Regenerative battery power (when idle)

5.2.3: Manufacturing Cost Report

The cost of manufacturing is based off of the research portrayed in section 3.6.2, as well as various other sources. The table below is divided up into A-class, B-class and C-class items to divide the high cost items from low cost items. The full bill of materials can be found in appendix ix.

		A-CLASS ITEMS		
Part(s)	Material(s)	Description	Manufacturing method(s)	Cost
Electric components	Various	Various motors and supporting components	Outsourced	80000
Control systems	Various	Systems for measuring arm/movement control	Various	17000
Main panels	Steel	Outer shell	Stamping, break pressing	16000
Window	Polycarbonate	Impact resistant	Thermoforming	10000
Chassis	Steel	Main frame	Stamping, assembly	9000
Main arms	Steel	Main lengths	Cast	8000
Drive wheels	Aluminum	Small and large	Machining	5100
Tools	Various	For drilling, cutting, scanning tools. Cost will vary	Outsourced	9500
Interior wall	Makroblend	Housing and handrail connection	Blow molding	5000
Batteries	Various	Supporting components for charging	Outsourced	6500

Arm bolts	Steel, aluminum	x16	Cast	3000
			Total=	169100
		B-CLASS ITEMS		
Part(s)	Material(s)	Description	Manufacturing method(s)	Cost
Hands	Aluminum	Fingers and receiver	Cast	2700
Step	Steel	Exterior safety step	Stamping	2000
Textured mat (Interior)	Natural rubber	Interior cabin mat	Injection molding	1950
Environmental lights	Polycarbonate	Exterior lighting front, side, environmental	Injection molding	2500
Tracks	Butadiene rubber	x2	Injection molding	2700
Axle	Steel	Centre axle and suspension receiver	Extrusion, bending	2500
Drive wheel spacer	Steel	Connection between wheels	Cast	1500
Interior lighting	Apec	Large and small lights	Thermoforming	1750
Centre console	Bayblend	Top and bottom	Blow molding	2250
Medical kit	Makroblend	Including supplies	Blow molding	1750
Tool kit	Makroblend	Including hand tools	Blow molding	2500
Fasteners	Various	Various screws and bolts	Various	1875
Various internal components	Various	Internal wiring, reinforcement, and computer systems	Various	1900
			Total=	27875
		C-CLASS ITEMS		
Part(s)	Material(s)	Description	Manufacturing method(s)	Cost
Arm linkages	Aluminum	Elbow parts	Extrusion	1000
Shoulders	Aluminum	Main body connection	Machining	950
Textured mat (step)	Natural rubber	Exterior mat	Injection molding	750
Suspension	Aluminum	x2	Bending	500

springs				
Handrails	Aluminum	Exterior	Bending, extrusion	300
Panel screen	Makrolon	Screen in centre console	Extrusion	1000
Control sticks	Aluminum, Makrolon, Texin	x2	Extrusion, injection molding	300
Steat	Bayblend	Frame only	Thermoforming	175
Cushions	Medium density PU foam	Including fabrics	Molding, stitching	100
Seat adjustment	Aluminum	Including metal bars and locking mechanism	Cast, extrusion	150
			Total=	5225
			TOTAL COST OF ALL ITEMS=	202200

Table 5.2.3.1 - Manufacturing cost report

The total cost of one unit of Omni is approximately $202,000. However this price would vary depending on numerous factors. Mining equipment is often purchased as a large order with many units to support the mining personnel. The cost in table 5.2.3.1 reflects the approximate cost of a single unit, including the cost of the tools themselves. This means that the price can fluctuate depending on the amount and type of tools being supplied for Omni. The final factor is the cost of the electrical components and batteries, as the cost may lower over time due to increased development for cost efficiency. This estimated cost is generally lower than a lot of heavy equipment due to the reduced weight and the elimination of fuel costs.

5.3: Final CAD Renderings

Figure 5.3.1 - CAD front view

Figure 5.3.2 - CAD rear view

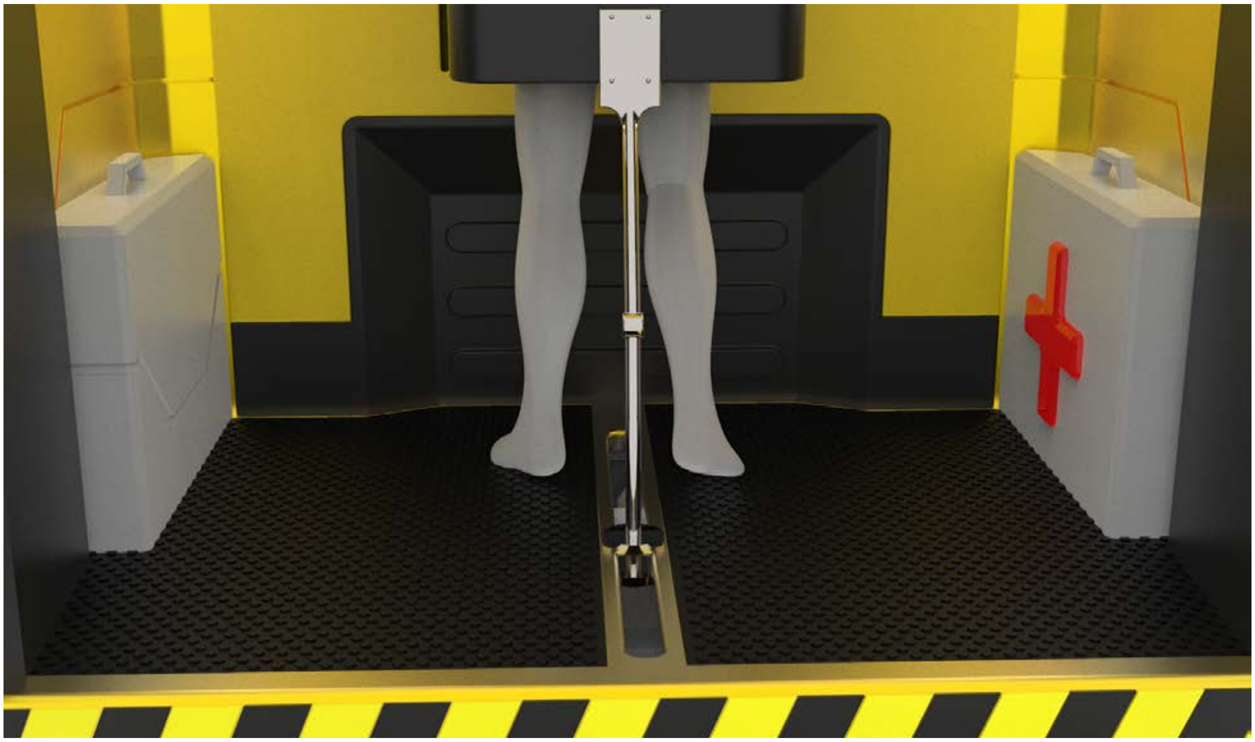


Figure 5.3.3 - CAD lower interior

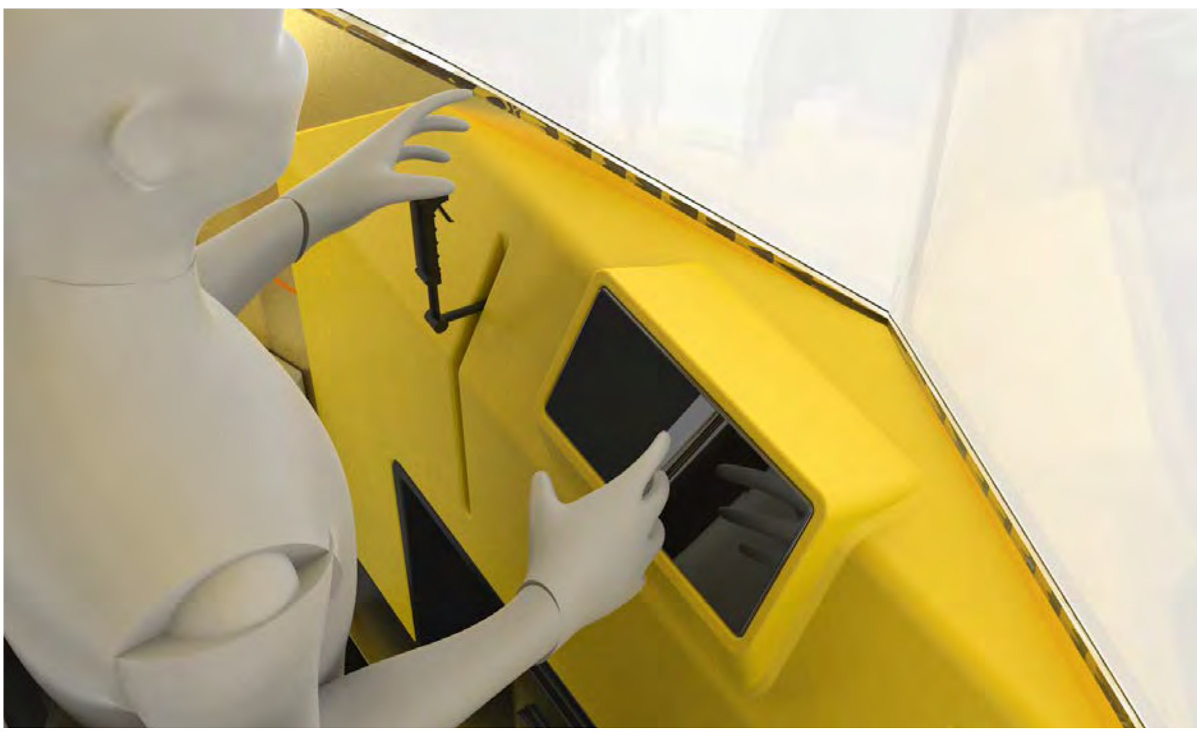


Figure 5.3.4 - CAD interaction elements

Figure 5.3.5 - CAD tool storage

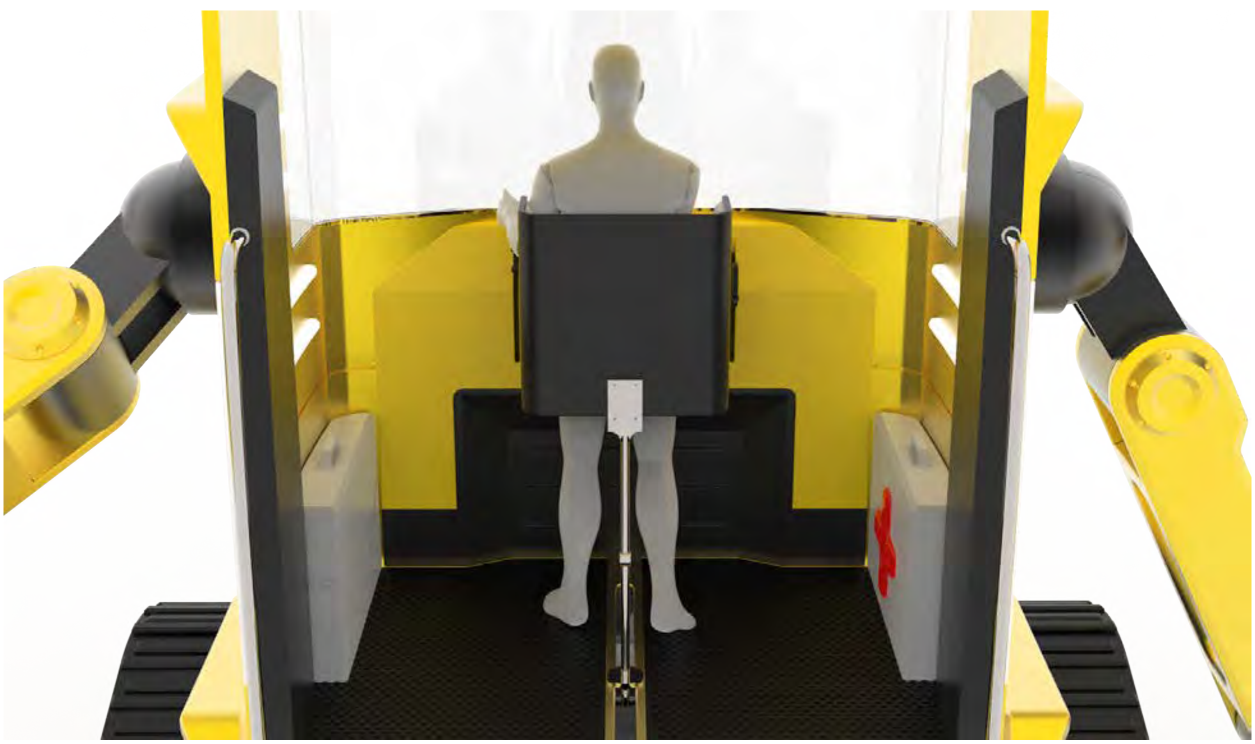


Figure 5.3.6 - CAD interior

5.4: Hard Model Photographs

Figure 5.4.1 - Hard model front

Figure 5.4.2 - CAD interior

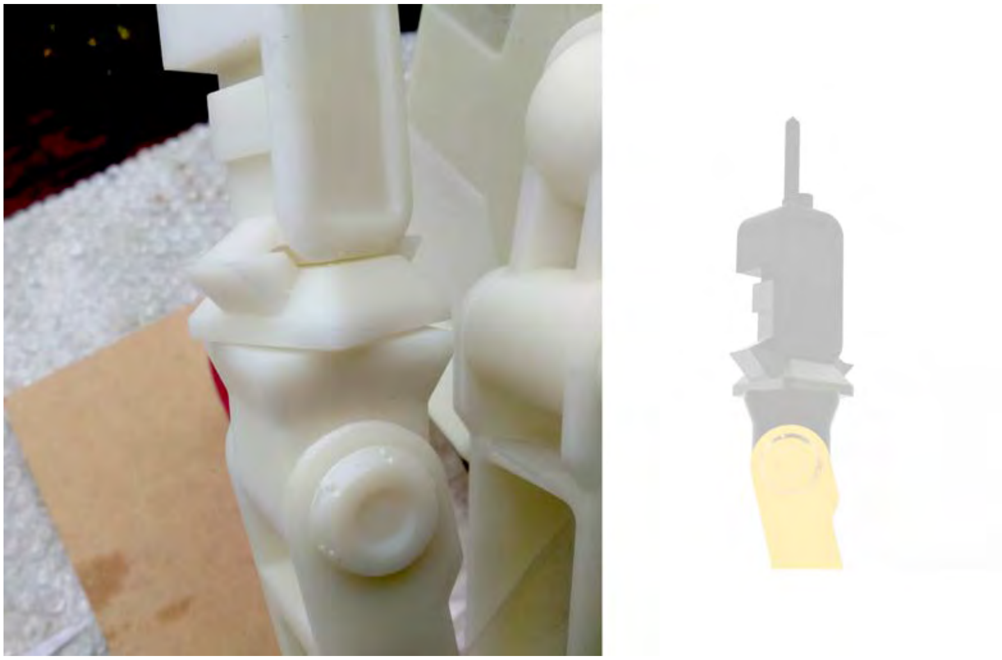


Figure 5.4.3 - Model hand detailing

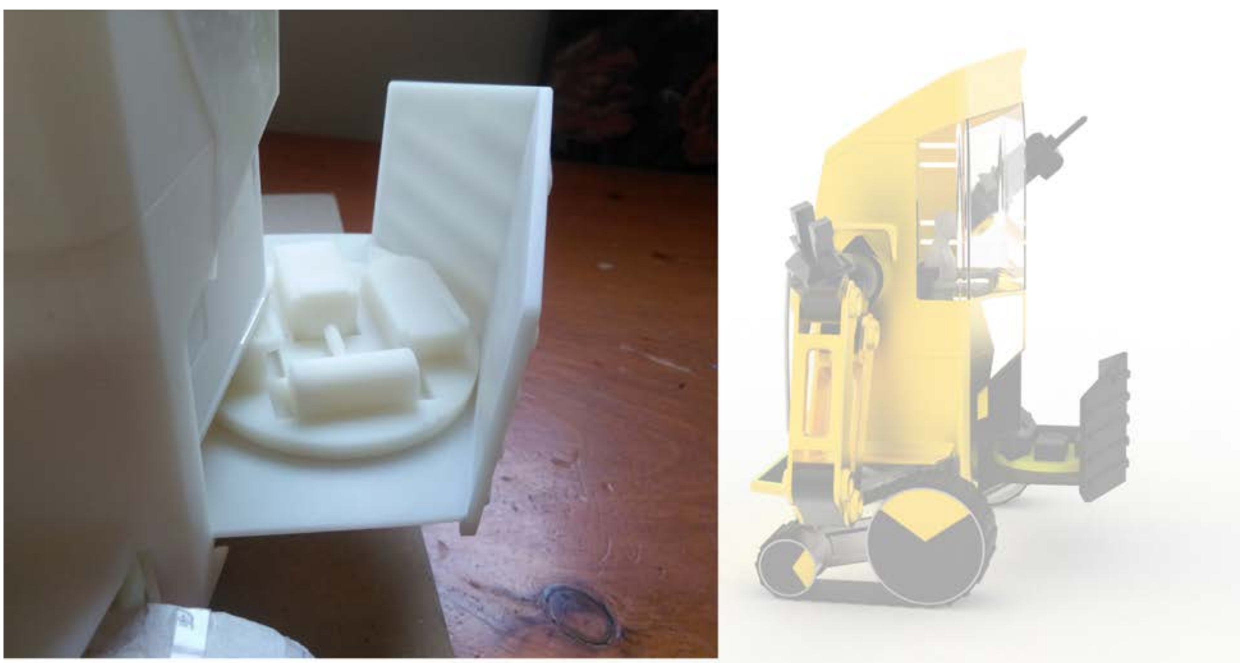


Figure 5.4.4 - Model tool storage

Figure 5.4.5 - Model medical kit

Figure 5.4.6 - Seat and floor texturing

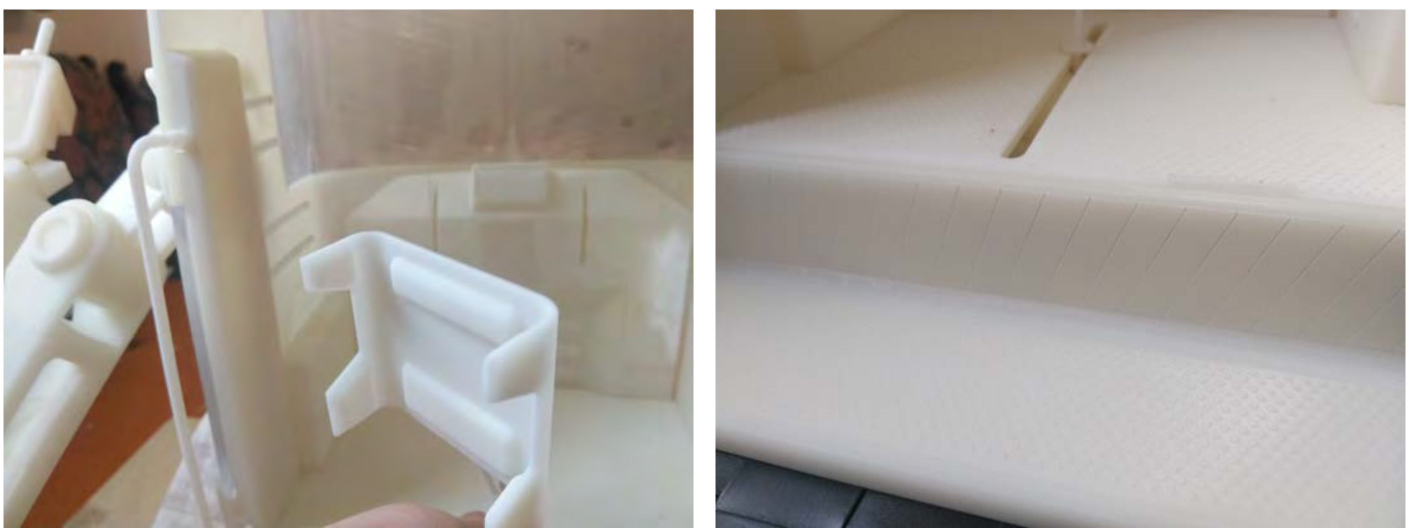


Figure 5.4.7 - Model handrail

5.5: Technical Drawings

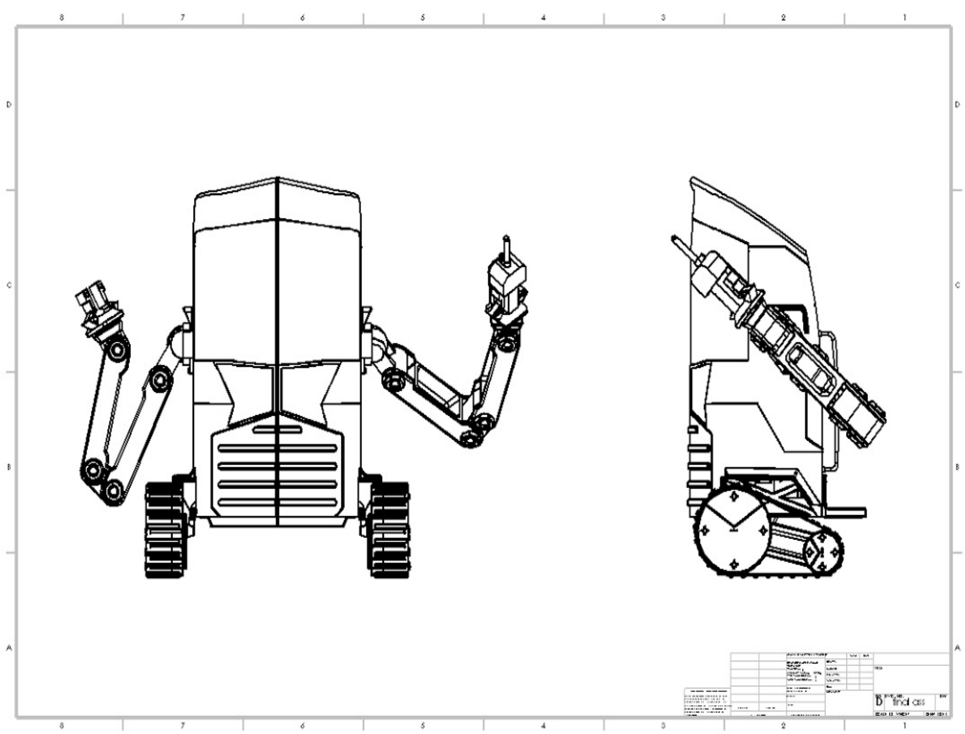


Figure 5.5.1 - Technical drawing front and side

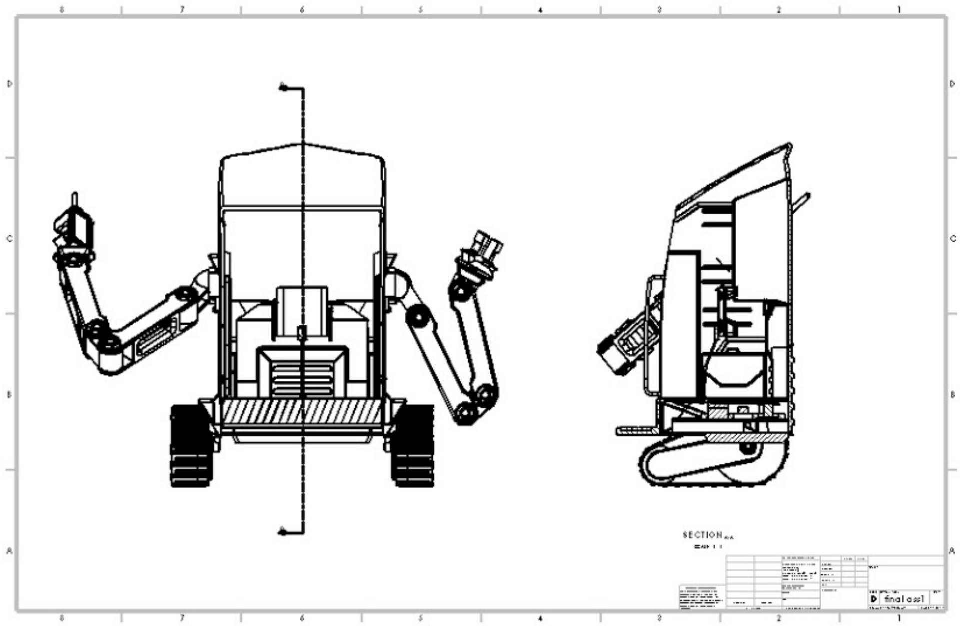


Figure 5.5.2 - Technical drawing section view

5.6: Sustainability

Omni incorporates sustainability into all aspects of its design such as health and safety, product life cycle, and environmental consciousness. Regarding health and safety, Omni eliminates the diesel particulate matter (DPM) that commonly occurs with larger vehicles by having electric motorized components. Furthermore, Omni protects the user by providing a sturdy shell over the user to ensure they do not suffer from any overhead hazards or traumatic injuries debris in the front. Providing a supported standing seat, with a suspended chassis and frame allows the user to feel virtually no vibrations from the tools whatsoever. Omni is dedicated to providing a safe working experience for the user.Omni refines its life cycle by being very accessible to repair and maintain, and using simple construction methods allows for a long extensive product life cycle. Due to the fact that omni is meant to be in harsh environments, many of the outside materials (anything directly exposed to the mine shaft) is made from reinforced steel, so that it is durable and able to withstand the unpredictability of the mines. The usage of engineering polymers and aluminum for the remaining metal parts means that it is easily recyclable, creating a product that has an optimized life cycle from assembly to end of life.

These features combine to create an environmentally conscious design solution that promotes green working. Omni aims to help the mining industry by increasing the efficiency of work so that materials can be procured and refined worldwide. Due to the high impact of this design, it is crucial as a designer that the solution is as green as possible. Sustainable design elements are a crucial factor in designing a solution that meets the thesis requirements.

Chapter 6:

Conclusion

Figure 6 - Final design arm details

6: Conclusion

In conclusion, this thesis report reflects the research and physical design process for underground mining equipment oriented to mitigate occupational hazards. Omni is the representation of all of this research and design development. Omni aims to provide a safe working experience for miners while also introducing an innovative control scheme with interchangeable tools. Omni is designed to tackle the numerous environmental hazards as well as the strain from using typical mining equipment on a daily basis. Omni provides a full bodied human interaction design with a variety of adjustable features to accomodate for the high and low percentiles. Sustainable elements are introduced with the electric motor assembly, as well as the thought and care for the product life cycle. Omni helps mitigate occupational hazards by providing an innovative, sustainable human centered design along with numerous safety features.

Figure 5.6.1 - Insitu render

Chapter 7:

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Chapter 8:

Appendices

Appendix i

Participant 1: Interview Transcript

Method

This interview is an excerpt from a survey that was hosted on Reddit. This was posted to the community called r/mining, which has over 10,000 members. Due to the high volume of members, the questions were ensured to be open ended to obtain a clear response pertaining to the user specifically. The questions were all text answers in order to get more diverse responses from a wide variety of different potential end users. The questions are listed below.

Question 1: Please specify your age.

Question 2: What is your role/job title in your workplace?

Question 3: How long have you worked in this industry?

Question 4: What commodity/ore do you specialize in working with?

Question 5: Do you experience hazardous situations on a daily basis? If so, what are some of these hazards?

Question 6: Have you ever been seriously injured in your workplace? If so, what happened?

Question 7: What kind of equipment do you operate in your workplace?

Question 8: How much time daily do you spend using this equipment?

Question 9: What is the most difficult part about using this equipment?

Question 10: How do you go about avoiding these problems currently?

Findings/evidence:

User name: Tim (Reddit user sublevelstoping)

Contact: https://www.reddit.com/message/compose/?to=sublevelstoping

Date/time of interview: Monday, October 7th. 12:14am

Transcript:

Question 1: Please specify your age.

A: I am currently 34 years old.

Question 2: What is your role/job title in your workplace?

A: I work as a development miner. I operate heavy equipment and work with a large team to dig underground and create the tunnels and supports in the mineshafts. I am also trained as an extraction specialist.

Question 3: How long have you worked in this industry?

A: Just about 15 years.

Question 4: What commodity/ore do you specialize in working with?

A: Right now I mostly work with gold. In the past I have worked with coal, tungsten, and silver.

Question 5: Do you experience hazardous situations on a daily basis? If so, what are some of these hazards?

A: Because I work with creating the tunnels and whatnot, the potential hazard for wall bursts, tunnel collapses, and falling debris are not uncommon. This specific job is extremely loud and creates a lot of dust.

Question 6: Have you ever been seriously injured in your workplace? If so, what happened?
A: Not really an injury but I've had silicosis a couple of times in the past. This was back when I was working in silver mines despite the fact that I was always wearing respirators. I haven't had a serious physical injury but plenty of my colleagues have had broken bones from falling debris.

Question 7: What kind of equipment do you operate in your workplace?
A: Nowadays I mostly operate large bolting rigs (specifically MacLean Bolter) to help install supports and wire mesh on the mine walls.

Question 8: How much time daily do you spend using this equipment?
A: Right now I typically work about 9-10 hours a day, most of that is spent on the machines (when we aren't strategizing or analyzing).

Question 9: What is the most difficult part about using this equipment?
A: Operating loud machinery for 9 hours a day is not easy. The bolting rig I typically operate is really inconvenient, lots of repetitive motions and lifting. Also almost all

of the features and tools are placed awkwardly to the point where I am always turning and twisting while operating and carrying tools. The supplies that I use to build support structures are almost always grounded, so I have to constantly lower and lift heavy rebar and resin boxes.

Question 10: How do you go about avoiding these problems currently?
A: I try to optimize my build sections so I have the least amount of movement while operating the rig, but I can only do so much.

Participant 2: Interview Transcript

Method

This interview is an excerpt from a survey that was hosted on Reddit. This was posted to the community called r/mining, which has over 10,000 members. Due to the high volume of members, the questions were ensured to be open ended to obtain a clear response pertaining to the user specifically. The questions were all text answers in order to get more diverse responses from a wide variety of different potential end users. The questions are listed below.
(Same questions used)

Findings/evidence:

User name: Robert (Reddit user orloy)

Contact: https://www.reddit.com/message/compose/?to=orloy

Date/time of interview: Tuesday, October 1st. 3:45pm

Transcript:

Question 1: Please specify your age.

A: I am 26 years old.

Question 2: What is your role/job title in your workplace?

A: I am employed as a field technician/engineer at the mine that I work at. I help maintain and operate machinery and equipment that is used for material excavation. I do a lot of "odd jobs" and help out a lot of different operations.

Question 3: How long have you worked in this industry?

A: Currently going on 9 years.

Question 4: What commodity/ore do you specialize in working with?

A: The mine that I work in has almost exclusively copper and gold in it.

Question 5: Do you experience hazardous situations on a daily basis? If so, what are some of these hazards?

A: I work in a mine that is extremely deep (about 2 miles deep I think) so the path to get to a station, or to help an injured staff member is really long and confusing.

Besides that I personally experience respiratory dangers, repetitive strain, rockfall exposure, extreme thermals, and equipment failures. Monitoring in the mine is not a top priority, so diesel particulates and different gases have caused issues. I work near a lot of large equipment such as cutting tools, which could be extremely risky.

Question 6: Have you ever been seriously injured in your workplace? If so, what happened?

A: The worst injury I have faced was a broken shoulder when I was hit by a swinging door from a nearby excavation vehicle. However, safety is not a top priority in my mine, there was an incident a few years back when someone actually drowned due to poor water management, deaths related to inhalation of certain toxins, and a lot of fractures and such from slips, falling rocks, and equipment mishandling, although these are not as common.

Question 7: What kind of equipment do you operate in your workplace?

A: I operate a wide variety of equipment, such as gyratory crushing machines (huge machines for breaking down ores), large cutting tools, and plenty of small scale hand operated tools such as jackhammers and pneumatic penetrative devices.

Question 8: How much time daily do you spend using this equipment?

A: I work about 8-10 hours a day, 6 days a week.

Question 9: What is the most difficult part about using this equipment?

A: Some of the big core saws we use are really unreliable and difficult to operate, which leads to issues with sample collections. Overall ergonomics and weight of the hand equipment I use is really unwieldy especially when I'm wearing heavier uncomfortable PPE. There are a lot of pinch points and repetitive motions I experience that make doing this job way more difficult than it should be. I do a lot of maintenance on the larger equipment and it can be difficult to access the components, especially with the lack of visibility.

Question 10: How do you go about avoiding these problems currently?

A: There’s not really much I can do honestly. I just try my best to be safe and watch my surroundings. As I mentioned before safety doesn’t really feel like a top priority at the mine I work in.

Preliminary information searching

Key Article 1

Method

A key article for this topic was sourced and selected. Required article content (Abstract, Introduction, and Conclusion sections) was copied and highlighted.

-Search Engine: Humber Library Discover

-Key words “Mining occupational hazards”

Summary Statements

1) Recent years have shown a large expansion in commercial mining operations. This brings the need for more safety options and better supervision and structural support.
2) In 2014 in China, 13,243 cases of disease related to occupational hazards were identified, thus providing a need for a safer work experience.
3) Set pair analysis is used to help assess the possibilities of hazards in mine shafts. However this is often only helpful to a degree due to the unexpected nature of the occupational hazards in this environment.
4) Numerous operations in China show attempts at supplying options to help mitigate the effects of occupational hazards, to little-to-no avail
5) Occupational hazards often are not related to a SINGLE factor of harm. They are typically caused by MULTIPLE issues that can arise. These factors are generally very hard to predict, and hard to combat when faced.

Key Article 2

Method

A key article for this topic was sourced and selected. Required article content (Abstract, Introduction, and Conclusion sections) was copied and highlighted.

-Search Engine: Humber Library Discover

-Key words “mitigate hazards in mining”

<u>Summary Statements</u>

1) Mining remains one of the most dangerous jobs worldwide, caused by explosions, cave-ins. The safety culture in the mining industry is not taken as seriously as it should be.
2) These incidents are almost normalized, despite the hundreds of deaths and injuries from occupational hazards.
3) Risk analysis efforts still fail to see the unpredictable, perhaps incomprehensible environment that current mining personnel work in on a daily basis.
4) Poor survivability conditions and lack of connection to emergency response proves problematic when a serious incident occurs.
5) Prolonged exposure to hazardous environments such as mines can lead to severe lung damage, pneumoconiosis, as well as other issues such as hearing problems.
6) Immediate dangers include blunt force and penetrating trauma and other non-lethal (but still harmful) injuries as well.

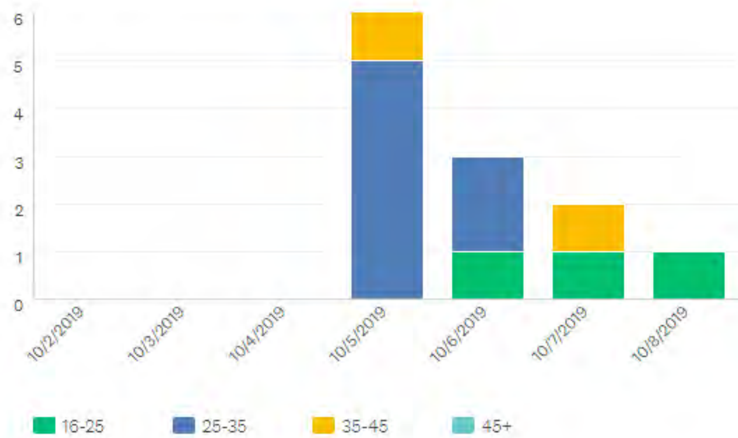
Survey

Q2 (by day)

Chart Type Display Options Trend by... Zoom

Please specify your age group.

Answered: 12 Skipped: 0 First: 10/5/2019 Zoom: 10/2/2019 to 10/8/2019

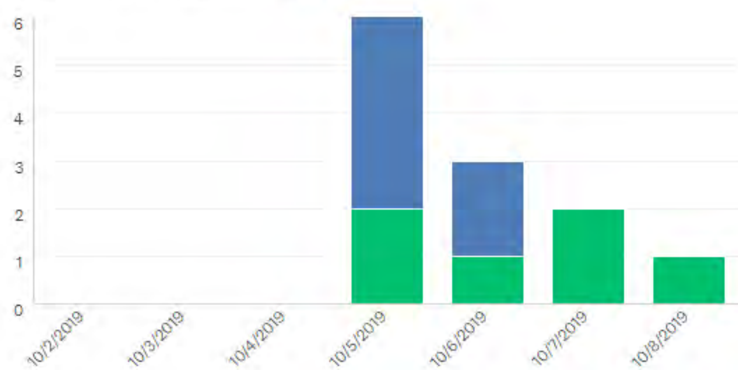


Q3 (by day)

Chart Type Display Options Trend by... Zoom

How long have you worked in this industry?

Answered: 12 Skipped: 0 First: 10/5/2019 Zoom: 10/2/2019 to 10/8/2019



Appendix ii

User Observation

Needs Statement

The objective of this thesis project is to design a solution to assist in the mitigation of occupational hazards in underground mining scenarios. Underground mining is an extremely dangerous job with a multitude of different hazards that need to be addressed. This means that there is a definitive need for products that assist mining personnel to accomplish tasks safely and efficiently. This will in-turn not only diminish the risks of immediate hazards, but long term issues such as respiratory problems. This design solution needs to be adaptable to a variety of scenarios, comfortable and ergonomic for the end user, and the ability to resist the elements.

Research Objectives

The objective of this user observation is to gain personal insights on current industry practices, and to find out areas/activities that can be improved to create a better user experience for the daily lives of mining personnel. The professional opinions are going to be a crucial element to creating a successful design. Another objective of this observational study is to ensure that the designer remains unbiased to create evidence based designs. Most mining personnel will spend a majority of their working time. Navigation and mobility are going to be observed as well to understand some of the finite user experience issues that current equipment solutions face.

Target Users

The primary user in this thesis topic is the mining personnel. Those who work underground in the mines directly working with ore and extractions. The mining personnel are directly using the proposed design solutions. The secondary users are those who work in the logistics/office sectors of mines. These are the users who need to organize rescue expeditions, do the necessary write-ups when the miners are injured, and deal with the destination of the ore once it is extracted from the mine. The tertiary users are those who rely on the efficient procurement of ores. Industries like refineries and fabricators require quick and effective ore extraction.

User Environment

The specific environment being analyzed is underground ore mines. For the sake of this observation it would be a liability to experience the mine first hand without several months of training and experience. A primary user (opted to remain anonymous) who operates equipment in an underground gold mine was able to assist with this observational study by analyzing a video of another primary user alongside the primary video analysis conducted. This still gave professional insight on the necessary areas of observation.

2.2 Video Observation

The selected video to be observed was:

Jory Dion. April 16th, 2019. *Maclean Bolting Practices.* Retrieved from:

https://www.youtube.com/watch?v=hxKmld1_Iks&t=1256s

This video is extremely in depth on current practices in the mining industry, while also focusing on equipment operation and human factors.

Activity Number	Description	Analysis notes
1	Navigate to area of interest	Uses a small control panel to navigate
2	Extrude scissor lift to appropriate height	
3	Load bolt into drilling mechanism	
4	Begin drilling into rock formation	Controlled from the same panel
5	Install support bolts by putting resin or stick powder tubes into the drill hole	Done by hand

6	Drape screen over drilling mechanism	Done by hand
7	Feed rebar through screen and drill	
8	Spray paint the exposed bolt for visibility.	
9	Navigate machine to next drilling location.	

From this video analysis four activities can be further identified as candidates for discussion. In the case of this video some of the areas that could be extremely helpful to have more knowledge of, especially areas where it seemed the primary user in the video had difficulties. The following activities are chosen for further analysis by the professional.

1) Navigation of the bolting rig machine.
2) Initial development drilling
3) Support bolt installation
4) Screen installation.

3.1 Chronology

Using still images from the video the key activities will be further analyzed. The video was analyzed in part with a primary user (opted to redact name) to get a professional take on all of these key activities.

1) Navigation

The first key activity analyzed in the navigation and movement of this specific Maclean Bolting Rig. All navigation is done using the control panel near the rear end of the machine platform. It is seemingly difficult to navigate the machine while looking at the controls. This means that the user must be familiar with the many buttons and knobs prior to movement.

The user who assisted with the video analysis points out as well that the control panel is in an awkward position requiring the user to kneel down when faced with overhead rock formations like shown above. The user also points out that visibility can be problematic when higher up on the scissor lift.

<u>2) Initial Development Drilling</u>

The second key activity being analyzed is the initial drilling operation to clear a passage for the securing bolt and subsequent screen installation. This is extremely important and is mostly controlled using a small handheld control box. In the video itself the machine does shake quite violently, and also subsequently jams, causing the user to have to run back to the other panel to override and stop the drill.

The analyst also notes that this was handled very well, to safety standards despite having difficulties. The user then states the main safety concern here is the lack of guard rails on the sides of the machine. When the machine is shaking as violently as it does this can be a serious hazard. The analyst was quite surprised that this went unnoticed when operating this rig.

3) Support Bolt Installation

The third major key activity being analyzed is the installation of the support and receiver bolts to hold the screen and rebar in place. The user often sets up the tubes to be placed while the drill is still doing the initial development drill These resin/stick powder tubes are rigid and get pushed into the hole with assistance from the head of the drill bit.

The user assisting with the video analysis states that it is extremely risky to do other work while the drill is in full motion, as if it stalls or jams it can easily deteriorate, or shake the machine further.

4) Screen Installation

The final major key activity under further analysis is the installation of the metal screens. These screens offer protection against falling debris and cave-ins and are crucial to underground mining operations. The screen is fed over the drill

unit and rebar with capped head is inserted and fed through the negative space in

the screen. As shown above the screen is handled haphazardly by hand.

The professional user once again states the importance of guard rails. In image 2 the user nearly falls from an approximately 15 foot drop due to the lack of rails. The user does state that this is a professional standard. He also says that besides the guard rail situation, the user handles this task well, and admits that this is extremely challenging.

User Persona

Gender: Male (McWilliams et.al)

Age: 43 (McWilliams et. al)

Location: Southwest Ontario

Income: 80,000 (Bureau of labour statistics)

Working hours: 47/wk (McWilliams et.al)

Education: High school diploma (Mcwilliams et. al)

Technical skills: Hands on, team player

Appendix iii

Benchmarked Products:

Item 1: BBC 16 WS Pneumatic Rock Drill, Atlas Copco

https://www.atlascopco.com/en-ca/construction-equipment/products/handheld/rock-drills/pneumatic-rock-drills/BBC16WS

Description:

Portable drilling unit powered by compressed air. Used for small scale drilling and bolting operations. Has a retracting arm to allow for ease of use in awkward environments.

Specs:

Hole range - 27-41mm

Weight - 29.5 kg

Length - 710 mm

Air consumption - 69 l/s

Impact rate - 2340 blows/min

Piston diameter - 70 mm

Stroke length - 55 mm

Item 2: Maclean 928 Scissor Bolting Rig, Maclean Engineering

https://macleanengineering.com/products/mining/ground-support-equipment/scissor-bolters

Description:

The MacLean Series 900 Bolters, the 928 (eight foot-wide deck) and 946 (seven foot-wide deck) provide a complete ground support system for underground hard rock mines. The benefits of safety, productivity, versatility and quality of installation combine to provide the ideal tool for the mine development cycle and rehabilitation operations.

Specs:

Length - 9.7 m

Width - 2.5 mm

Turning radius (inside) - 5.49 m

Turning radius (outside) - 8.39 m

Feed travel - 1.32 m

Weight - 22000 kg

Item 3: BBD 12 DCS Freehand Pneumatic Rock Drill, Atlas Copco

https://www.atlascopco.com/en-ca/construction-equipment/products/handheld/rock-drills/pneumatic-rock-drills/BBD12DCS

Description:

Equipped with a D-type handle, it is used for horizontal drilling, plug hole drilling, and drilling in concrete to a maximum depth of one meter. Equipped with T-handles, the BBD 12T is designed for vertical drilling of up to two meters.

Specs:

Hole range - 17-29 mm

Weight - 10.5 kg

Length - 560mm

Air consumption - 22 l/s

Impact rate - 2580 blows/min

Piston diameter - 45 mm

Stroke length - 41 mm

Item 4: BBC 34-DSI Vehicle Mounted Drill, Atlas Copco

https://www.atlascopco.com/en-ca/construction-equipment/products/handheld/rock-drills/pneumatic-rock-drills/BBC34-DSI

Description:

When you see the DSI designation on a drill, you'll know it's made for bigger operations. DSI stands for Dimension Stone Industry and these well-proven pneumatic rock drills can be mounted on a drill column to make you really productive. The BBD and BBC-models can drill holes of up to 27-41 mm in diameter and they come equipped with an H22 chuck and air flushing as standard. You can get water flushing as an option and the machines can be equipped with both cable or chain feeds.

Specs:

Hole range - 27-41 mm

Weight - 31 kg

Length - 774 mm

Air consumption - 88 l/s

Impact rate - 2280 blows/min

Piston diameter - 80 mm

Stroke length - 70 mm

Item 5: Sandvik DD422iE Electric Development Drill Rig, Sandvik Group

https://www.rocktechnology.sandvik/en/products/underground-drill-rigs-and-bolters/mining-jumbos/dd422ie-development-drill-rig/

Description:

Sandvik DD422iE is an electric mining jumbo designed to drive down production costs while reducing the environmental impacts of drilling and tunneling. Major benefits of this innovative electric drill rig include zero emissions during tramming and improved productivity. The drill rig's well-designed, structures and proven components ensure a reliable workplace for both operators and maintenance crews.

Specs:

Hole length - up to 5270 mm

On board battery - Sodium-Nickel-Chloride technology

Max. battery energy - 75 kw/h

Weight - 27500 kg

Impact frequency - 95 hz

Stabilizer - hydraulic

Upgradeable automation levels

Percussion power - 2 kw

Item 6: Sandvik DU412i ITH Production Drill Rig

https://www.rocktechnology.sandvik/en/products/underground-drill-rigs-and-bolters/in-the-hole-longhole-drills/du412i-articulated-in-the-hole-production-drill-rig/

Description:

Sandvik DU412i is a highly versatile and compact in-the-hole (ITH) longhole drill fitted with an onboard booster and designed for underground mining in 3.2 x 3.2 m or larger production drifts.

Specs:

Transport length - 10000 mm

Weight - 30000 kg

Pipe length - 4-6’

Feed force - 70 kN

Front stinger extension - 1386 mm

Hole depth - 1830 mm

Item 7: Maclean MDA-8 Excavator Drill, Maclean Engineering

https://macleanengineering.com/products/mining/drilling/excavator-rock-drills

Description:

The MacLean MDA Excavator Rock Drills are a valuable addition to your fleet. From quarrying operations, to secondary breaking, to construction drilling, the MDA Excavator Rock Drill can do it all. Mounted on a Mini-Excavator or Tractor Loader Backhoe, the MDA drill is a value-based unit.

Specs:

Drill hole diameter - 33-51 mm

Drill saddle travel - 2.3 m

Air requirement - 225CFM @90psi

Hydraulic requirement - 2-4GPM @3600psi

Electric requirement - 12v

Weight - 295 kg

Item 8: Epiroc Boomer E2 Battery, Epiroc

Specs:

Length - 15069 mm

Weight - 36000 kg

Protective roof -Manual spotlights

ROPS certified cabin - <80db

Min. hole diameter - 38 mm

Air conditioned

Operator assistance functions

Item 9: Atlas BBD 12 T-01 Pneumatic Jackhammer, Atlas Copco

https://www.atlascopco.com/en-ca/construction-equipment/products/handheld/rock-drills/pneumatic-rock-drills/BBD12T-01

Description:

Equipped with a D-type handle, it is used for horizontal drilling, plug hole drilling, and drilling in concrete to a maximum depth of one meter. Equipped with T-handles, the BBD 12T is designed for vertical drilling of up to two meters.

Specs:

Hole range - 24-34 mm

Weight - 11.1 kg

Length - 505 mm

Air consumption - 824 l/s

Impact rate - 2580 blows/min

Piston diameter - 45 mm

Stroke length - 40 mm

Hose connection - 19 mm

Penetration rate - 150 mm/min

Item 10: Stennick BBAS 60p Pneumatic Crawler, Stenuick International

https://www.stenuick.com/en/machines/pneumatique/bbas-micropiles-crawler

Description:

Drilling rig for ground/rock reinforcement and micropiling.

Specs:

Rotation motor - F574FB

Torque - 60 m/kg

Rotation speed - 75 tr/m

Lift force - 1300 kg

Rod length - 0.5-1 m

Oil lubrication

4 manual stabilizers

Crawler chassis

Weight - Around 500 lbs

Features and benefits

FEATURES		Sort #1	Sort #2
rom Promotional Material	Re-order: NOUN first	DATA [On Menu Bar] →	Group like categories
Electric motor	Motor: electric	Motor: electric	Hydraulics 4
Hydraulic	Hydraulic:	Automated	Drill:Hydraulic
hydraulic drill	Drill:Hydraulic	Drill: automated	Hydraulic:
electro-hydraulic	Hydraulic: Electro	Drill:Hydraulic	Hydraulic: Electro
zero emmission	Emmissions: zero	Drilling: automated	Suspension: hydraulic
electric power	Power:Electric	Emmissions: zero	
storage bed	Storage bed	Hydraulic:	
high capacity storage bed	Storage bed: high capacity	Hydraulic: Electro	
high capacity storage unit	Storage Unit: High capacity	Interior: Noise reduction	
automated	Automated	Noise reduction	
automated drilling	Drilling: automated	Noise:low	
Noise reduction interior	Interior: Noise reduction	Power:Electric	
low noise	Noise:low	Semi-automated	Automation 4
noise reduction	Noise reduction	Storage bed	Automated
semi-automated	Semi-automated	Storage bed: high capacity	Drill: automated
automated drill	Drill: automated	Storage Unit: High capacity	Drilling: automated
hydraulic suspension	Suspension: hydraulic	Suspension: hydraulic	Semi-automated
			Low noise 3
			Interior: Noise reduction
			Noise reduction
			Noise:low
			Storage 3
			Storage bed
			Storage bed: high capacity
			Storage Unit: High capacity
			Electric motor 2
			Motor: electric
			Emmissions: zero

BENEFITS	Sort #1	Sort #2
From Promotional Material	DATA [On Menu Bar] → Sort	Groups like categories
comfort	comfort	***Lightweight*** ***5***
efficiency	compact	Lightweight
compact	ease of use	Light
ergonomic	efficiency	low weight
versitility	ergonomic	weight reduction
versitile	light	not as heavy
Useable in a variety of environments	Lightweight	
quick	low weight	
Mobile	Mobile	
ease of use	Not as heavy	
reliable	quick	
light	reliable	
low weight	small scale	***Versitility*** ***4***
small scale	Useable in a variety of environments	versitility
weight reduction	versitile	versitile
wide array of uses	versitility	easy to use
Lightweight	weight reduction	usable in a variety of environments
Not as heavy	wide array of uses	
safe		
safety		
reliability		
		Safety ***3***
		Safe
		Safety
		comfort
		Reliability ***2***
		Reliability
		Reliable
		Compact *2*
		mobile
		compact

Appendix iv

Needs statement

Table: Benefits and Corresponding Fundamental Human Needs
Mining Safety

	Benefit	*Possible Corresponding Fundamental Human Needs (FHN)*	*Relationship between Benefits and FHN*
1	Comfort	Control, security, self-esteem (mastery)	STRONG
2	Style	Esteem, belonging, aesthetically pleasing	MODERATE
3	Efficiency	Accomplishment, autonomy, self-esteem	STRONG
4	Ease	Accomplishment, autonomy, protection, security, control, self-esteem (mastery)	STRONG
5	Fun	Leisure (excitement), Participation, Belonging (shared fun)	SLIGHT

Comfort in this context is increasing the sensory experience for the infant of being protected, connected with the caregiver and the outside environment, with some freedom to move safely)
Comfort also includes the harshness of the ride (ride harshness would contribute to a feeling of a *loss of control*, increasing possibility of injury (risk), both of which decrease one's sense of protection)

Security is the major fundamental human need met.

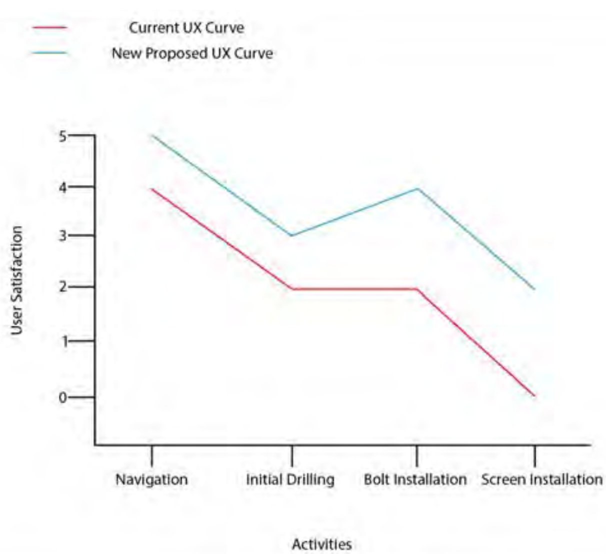
Style is an important expression of individuality. What is considered by the group as stylish increases **self esteem**.

Efficiency is defined as the effort required to perform at a particular level. This is related to **control** the user has during the activity (**autonomy**)

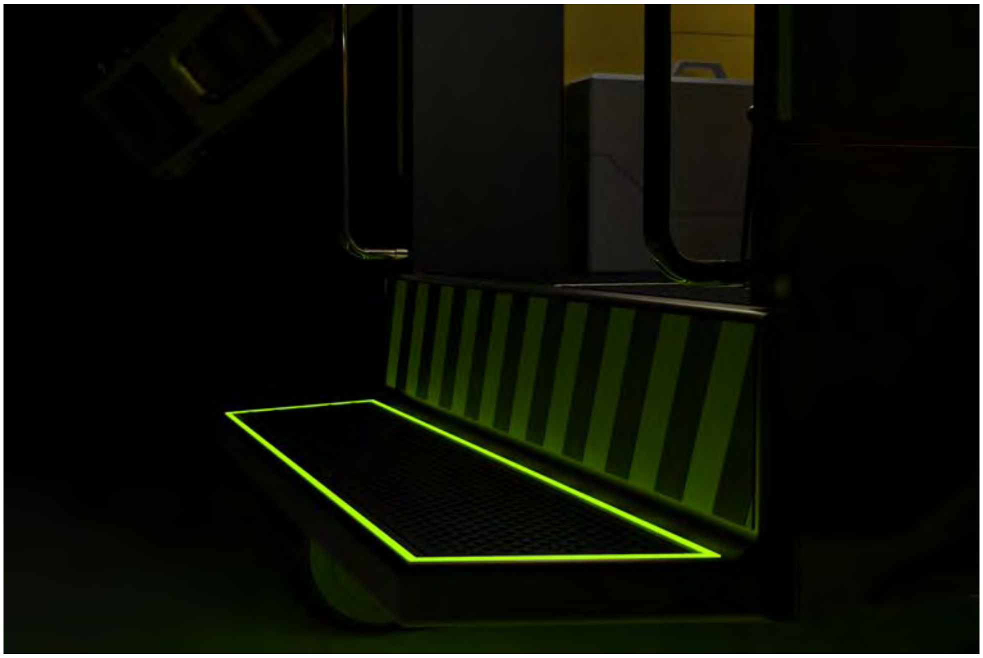
Ease is in many ways related to efficiency in terms for fundamental human needs (i.e. **control, autonomy**).

Fun related to **leisure** ('travel' to new interesting environments) and **belonging** (**shared fun, participation** between infant and caregiver).

Activity data

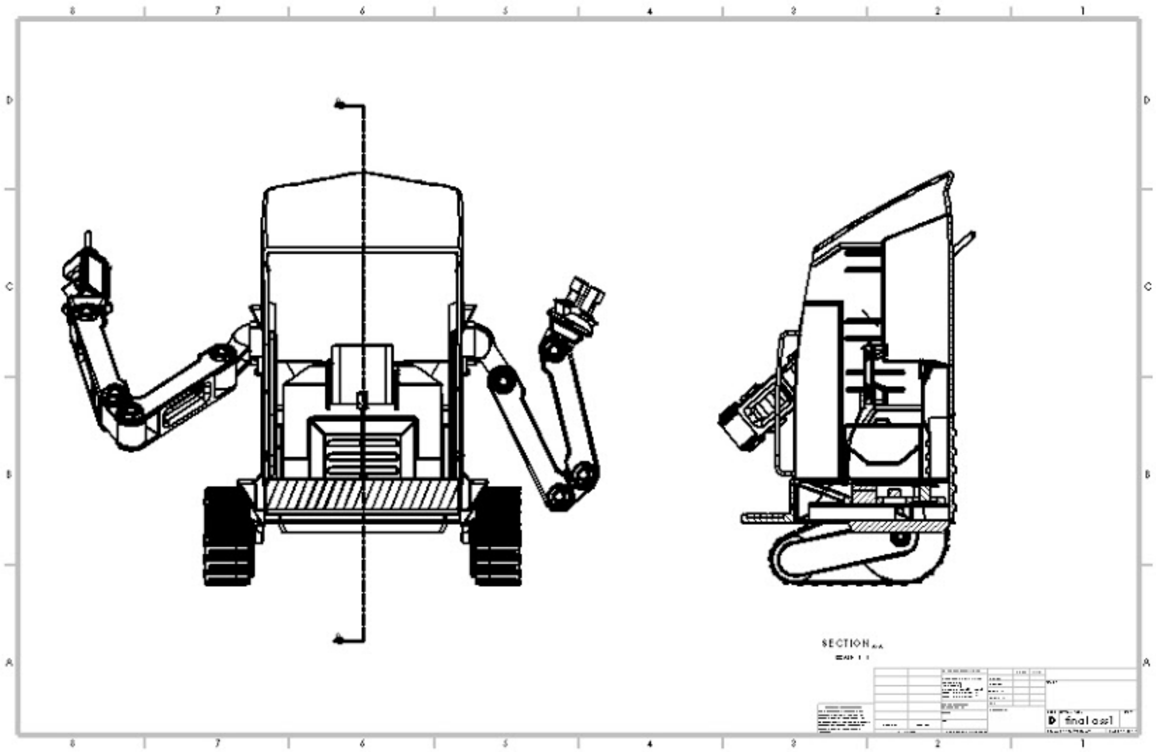


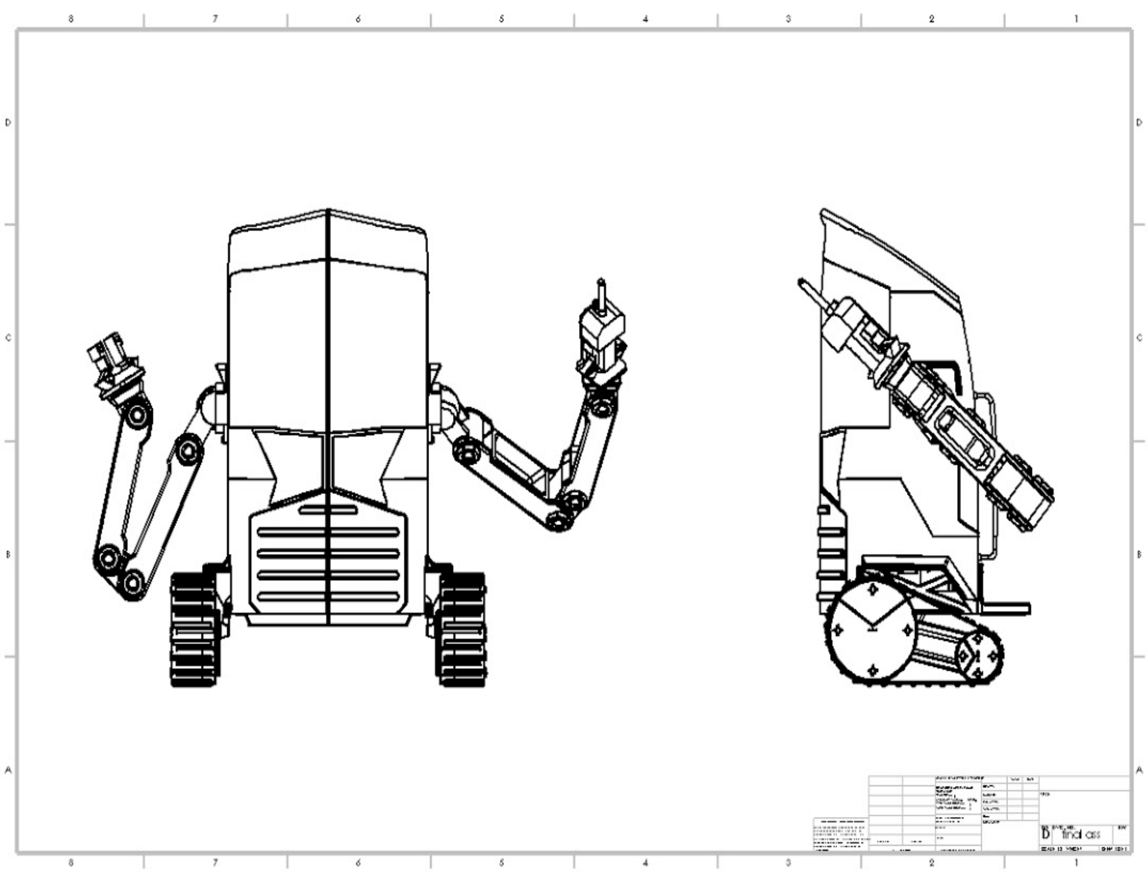
Appendix vi



Appendix vii

Appendix viii





Appendix ix

Manufacturing cost report

Chassis	Steel	Main frame	Stamping, assembly	9000	A
Main panels	Steel	Outer shell	Stamping, break pressing	16000	A
Main arms	Steel	Main lengths	Cast	8000	A
Arm linkages	Aluminum	Elbow parts	Extrusion	1000	C
Shoulders	Aluminum	Main body connection	Machining	950	C
Hands	Aluminum	Fingers and receiver	Cast	2700	B
Step	Steel	Exterior safety step	Stamping	2000	B
Textured mat (step)	Natural rubber	Exterior mat	Injection molding	750	C
Textured mat (Interior)	Natural rubber	Interior cabin mat	Injection molding	1950	B
Environmental lights	Polycarbonate	Exterior lighting front, side, environmental	Injection molding	2500	B
Drive wheels	Aluminum	Small and large	Machining	5100	A
Tracks	Butadiene rubber	x2	Injection molding	2700	B
Axle	Steel	Centre axle and suspension receiver	Extrusion, bending	2500	B
Suspension springs	Aluminum	x2	Bending	500	C
Drive wheel spacer	Steel	Connection between wheels	Cast	1500	B
Electric components	Various	Various motors and supporting components	Outsourced	80000	A
Tools	Various	For drilling, cutting, scanning tools. Cost will vary	Outsourced	9500	A
Interior wall	Makroblend	Housing and handrail connection	Blow molding	5000	A
Handrails	Aluminum	Exterior	Bending, extrusion	300	C
Interior lighting	Apec	Large and small lights	Thermoforming	1750	B
Centre console	Bayblend	Top and bottom	Blow molding	2250	B
Medical kit	Makroblend	Including supplies	Blow molding	1750	B
Tool kit	Makroblend	Including hand tools	Blow molding	2500	B
Window	Polycarbonate	Impact resistant	Thermoforming	10000	A
Panel screen	Makrolon	Screen in centre console	Extrusion	1000	C
Control sticks	Aluminum, Makrolon, Texin	x2	Extrusion, injection molding	300	C
Batteries	Various	Supporting components for charging	Outsourced	6500	A
Seat	Bayblend	Frame only	Thermoforming	175	C
Cushions	Medium density PU foam	Including fabrics	Molding, stitching	100	C

Seat adjustment	Aluminum	Including metal bars and locking mechanism	Cast, extrusion	150	C
Control systems	Various	Systems for measuring arm/movement control	Various	17000	A
Arm bolts	Steel, aluminum	x16	Cast	3000	A
Fasteners	Various	Various screws and bolts	Various	1875	B
Various internal components	Various	Internal wiring, reinforcement, and computer systems	Various	1900	B

Appendix x

Technical Report - Sustainability

Sustainability

Sustainable initiatives in the underground mining sector are a growing trend when designing new pieces of equipment and vehicles. These vehicles are built for extreme conditions as well as a long product life cycle. Simple construction and deconstruction methods ensure that service and repairs can often be performed on site, or in a worst case, new parts can be sourced or repaired with ease. Due to the amount of hazardous situations and environments that these vehicles are used in, they must be built to withstand the elements. Sustainable initiatives in this regard revolve around ensuring an extremely long life cycle with maintenance and good construction. These elements mean that the product is manufactured and handled in the most efficient way possible.

Due to the increase in sustainable development in the mining industry, some companies are opting to begin the development of hybrid or fully electric vehicles for this environment. One critical example of this is the Boomer E2 by Epiroc. This vehicle is a large scale drilling rig that is fully battery powered. The Boomer E2 has an onboard charging port and a large battery that can withstand long work hours and long tram distances. Furthermore, when the vehicle is being charged it does not affect usability, thus streamlining the drilling process. The capability to produce zero emissions while working coupled with the drastic cost savings when fuel purchases are not required offer an unprecedented level of sustainable elements to this design. The cost savings on diesel fuel compensate for the generally higher cost of the electrically powered vehicles. The carbon output of traditional diesel powered drill rig models has a negative impact on the environment on a micro to macro scale. The emissions created in the mines can often affect the mining personnel with a variety of respiratory diseases and cancerous diseases (Ristovski et.al, 2012).

Safety, Health, and Environment

Most mining vehicles are still operated with large diesel engines, this is problematic for the health and safety of the workers, and the environment as a whole. The traditionally large diesel engines used to power these vehicles causes a large amount of carbon monoxide emissions. Furthermore, another issue with large internal combustion diesel engines is diesel particulate matter (DPM). DPM is the solid matter formed from diesel exhaust. According to OSHA, DPM is considered a group 1 carcinogen for humans. This means that if not handled or disposed of properly that it can cause a plethora of diseases including lung cancer and silicosis. Diesel particulate matter creates an airborne chemical compound that can be difficult to detect and deter in underground mining environments. DPM is especially troublesome in underground environments because the off gasses coupled with DPM particles create a viciously toxic environment for the mining personnel (Ristovski et. al 2012). By minimizing the usage of diesel engines and thus the DPM it creates, it would create a much healthier workplace and environment.

Conclusion

To conclude, further sustainable initiatives in the underground mining industry are a growing need. This would help the earth by reducing the already large carbon footprint that the mining industry holds. Furthermore it creates an opportunity for improved, environmentally conscious design that helps the users and the environment. By creating a design that can minimize the emissions caused, it will therefore create a positive environmental impact to combat the reputation that underground mining already withholds. This will create a significantly improved workplace by reducing the risk of respiratory diseases such as cancer anc silicosis. By improving the sustainability of mining vehicle designs, the industry and the users all benefit.

Appendix xi

Humber Institute of Technology & Advanced Learning
Bachelor of Applied Technology – Industrial Design
IDSN 4002 Senior Level Thesis 1
Catherine Chong, Dennis Kappen, Sandro Zaccolo

School of Applied Technology
Fall 2019

THESIS TOPIC APPROVAL

STUDENT NAME: Sean Platek

TOPIC TITLE:

How might we mitigate the effects of occupational hazards associated with ore mining operations.

TOPIC DESCRIPTIVE SUMMARY

This thesis proposal explores the effects of occupational hazards in underground ore mining operations. Multiple factors are apparent in this environment such as physical trauma, respiratory issues, and long term damage from repetitive stress injuries. This has a negative effect on the workers, as well as the industries that require the effective procurement of ores such as refineries and manufacturing plants. Current solutions to the problem include generic PPE items such as hard hats, small respirators, and reflective vests; as well as small scale mining vehicles. These solutions do not provide a cohesive experience for mitigating occupational hazards in mining operations due to the lack of depth in their design. This thesis proposes in-depth studies about the mining personnel and their interaction with the equipment that is common throughout the workplace; using various research methods such as product benchmarking, user interviews, and user observation. Detailed evaluation of user data and benchmarking is aimed to influence better standards for equipment in the workplace. The evaluation data will be reflected in a one-to-one scaled ergonomic buck to effectively map out user experience and ergonomics for a full-bodied human interaction design. The ethnographic data from these evaluations will influence the ergonomics, user experience, and sustainability of mining equipment in the future.

Student Signature(s) ______________________ ______________________

Instructor Signatures ______________________ ______________________

Date ______________________

Date ______________________

Appendix xii

Sun, Dec 8, 2019, 9:08 PM

to me

Hi Sean,

Thanks for your email. Certainly, I'll be glad to assist if I can. Perhaps we can have a quick chat tomorrow evening. In the meantime let me know if there are specific topics or areas you you wish to explore.

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Ergonomics literature review

Introduction

Ergonomics are a consideration that must be taken into account when designing solutions for equipment that people are going to use daily. The purpose of this section is to analyze current ergonomic flaws in the mining industry.

Result

Citation: McPhee, B. (2004). Ergonomics in mining. *Occupational Medicine*, *54*(5), 297-303.

Key Findings:

- Ergonomic considerations in mining have not been addressed from many aspects such as vehicle cab designs, to the consideration of manual labour.
- Little recognition of health problems in the industry
- Slips, trips, and falls are only some of the issues faced with poor ergonomic considerations.
- Whole-body vibration exposures.
- Ergonomics are a side consideration beside fatality reduction.
- It is difficult to address because there are so many considerations

Appendix xiv

PANEL ON RESEARCH ETHICS

Navigating the ethics of human research

TCPS 2: CORE

Certificate of Completion

This document certifies that

Sean Platek

has completed the Tri-Council Policy Statement:
Ethical Conduct for Research Involving Humans
Course on Research Ethics (TCPS 2: CORE)

Date of Issue: **30 September, 2019**