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Vehicle Interior Access Deployable Worksurface Mechanism Concept Product Design

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VEHICLE INTERIOR ACCESS DEPLOYABLE WORKSURFACE MECHANISM

CONCEPT PRODUCT DESIGN

by

Premchand Gunachandran

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ABSTRACT

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Under the Supervision of Professor Mohammad Habibur Rahman

Easy access and adjusting the vehicle interior configuration to a variety of situations and uses is the general desire for any vehicle user. To meet such desire an attempt has been made in this study to conceptualize a design to develop a new mechatronic product called re-configurable vehicle interior console mechanism to deploy a worksurface (DWS), which will provide flexible use of the vehicle's interior of both partial and fully autonomous vehicles. This re-configurable vehicle interior console will deploy the DWS using a power sliding mechanism concept enabled by electrical and electronic control unit circuits. This DWS will have 2 degrees of freedom (DOF) in its operation. Each user can access a DWS by pressing the nearby button. The console will move towards the center of the leg space and the electrical motor actuator and lead screw inside the console will drive the DWS by sliding it up and the DWS will down fold over the lap level of the user to offer a convenient individual worksurface. The inner side of the console body is designed to accommodate four DWS units, two each on its right and left sides, to cater to four users in a vehicle. The DWS power sliding mechanism concept product design will address the problems faced by the extreme users in the carpooling group of office goers, business travellers, family and friends going on a long road travel vacation trips. This DWS mechanism product's performance and size can be customized, re-designed and modified to assemble inside the console body for the user's accessibility, personalized and sharing experience in vehicle interiors of SUV, minivan and autonomous vehicles as well.

Keywords: Vehicle Interior Access, Deployable Worksurface (DWS), Re-configurable Console, Original Equipment Manufacturer (OEM)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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1. INTRODUCTION

The future of the vehicle's interior look will be completely transformed because of the upcoming autonomous and driverless vehicle technology. Figure 1 depicts a lofty presentation as to how the automotive designers and vehicle manufacturers are intending to bring in a completely new and radical approach to the way in which vehicle interiors are to be designed and operated. New technology will relieve the passengers free from the burden of driving and cruising maneuvers and will instead offer them access to more facilities so that they can spend the journey time in doing other useful routines. Interior designs offering such access and facilities could radically change vehicle choosing and buying decisions of the consumers. As the automotive industry prepares for the era of autonomous vehicles, more attention than ever is focused on designing the vehicle interior facilities to attract and satisfy the users to have a comprehensive engagement on useful activities during their journey on office travel or business travel or pleasure trip.

Figure 1. The future of vehicle interior in an autonomous vehicle [1]

1.1 Background and Motivation

Premchand Gunachandran is a graduate study student at the University of Wisconsin - Milwaukee and he is an Industrial Designer of Automotive mechatronic security & access products. Since 2008 he has been working for the client STRATTEC Security Corporation, Milwaukee which is having a track record of more than 110 years of existence in the automotive business of designing, developing, manufacturing and marketing automotive access control products including mechanical locks and keys, electronically enhanced locks and keys, steering column and instrument panel ignition lock housings, latches, power sliding side door systems, power lift gate systems, power deck lid systems, door handles and related products. These products are marketed in North America, and on a global basis through a unique strategic relationship with WITTE Automotive of Velbert, Germany and ADAC Automotive of Grand Rapids, Michigan. Under this relationship, STRATTEC, WITTE and ADAC market STRATTEC's products to global customers under the brand name "VAST".

This association with STRATTEC has kindled the research desire in Gunachandran and has driven him to endeavor into the automotive mechatronic new product development arena.

1.2 Problem Statement

The current vehicle interior design is associated with certain inherent problems like non-configurable, inflexible system usage, non-retractable assembly and non-deployable surfaces. Thus the present interior design may not be suitable to meet the demands of the future generation vehicle design. This insufficiency, a potential impact on the social and economic front, needs to be properly addressed by kindling the design thinking process.

It is seen that few automotive original equipment manufacturers (OEM's) like Tesla, Google, Mitsubishi, Fiat, Chrysler, Toyota, Honda, BMW, Yanfeng, GM, Nissan, Ford, Volkswagen etc. are actively working on the autonomous vehicle design.

Reconfigurable vehicle interior design and development is a potent new research area. The autonomous vehicle designing OEM's research groups are primarily focusing on overall autonomous driving technology that comes under deep learning/machine learning technology and is mostly concentrating on the vehicle exterior design outlook. Thus the reconfigurable vehicle interior design development is attracting less attention to the OEMs.

An attempt is made in this study to alleviate some of the challenges in the interior design front and to evolve a "sustainable new product development" that can provide more flexible use of the vehicle interior. Retractable steering wheel, retractable pedal assembly, deployable worksurface, flexible seating systems etc. have been identified as some of the interior facilities requiring design and development research and innovation. It is expected that such new product designs will enable the user to adjust the interior configuration to meet a variety of situations and such design technology can also be readily incorporated into both the partial and fully autonomous vehicles of the future generation.

Hence designing and developing a new vehicle interior product is undertaken in this study by exploiting the power control motion mechanism. This methodology and approach will make the advancement of science and technology knowledge into the field of automotive interior product design and development engineering and this new product design development is sought to be achieved by integrating the mechanical and electrical-electronic systems knowledge.

1.3 Research Goals and Objectives

The long term research goal would be to focus on vehicle interior product design for the front driver side area, wherein the development of a new product will provide the passengers with more flexible use of the vehicle interior accessibility involving retractable steering wheel, retractable pedal assembly and overall flexible front seating systems.

The short term research goal has focused on this study is on a vehicle interior product concept design for the driver rear side. The necessary inputs for kindling the new product design thinking concept are developed based on the customer discovery process. Interviews conducted with potential automotive users and automotive interior product design engineers have helped to understand their empathy on vehicle interior problems and their needs. Thus the research concentration has been aimed at developing a new product design concept mechanism that is deployable, flexible and reconfigurable use of the vehicle's interior console body.

Thus the present objective has been limited to develop a new concept product design called deployable worksurface (DWS) mechanism for the vehicle interior console body that will deploy the worksurface using the power sliding mechanism concept and this DWS mechanism can be used in partial and fully autonomous cars. This new product design mechanism will be a solution to address the following problems enumerated by the potential automotive users.

- Non-configurable,
- Inflexible system usage,
- Non-retractable assembly,
- Non-deployable surfaces.

The specific feats required to accomplish the aims of this research are:

1. To create a new product proof of concept based on the Design Thinking approach,
2. To develop a new DWS mechanism product design concept using 3D CAD,
3. To build a functional prototype for a DWS mechanism product design concept,
4. To test and validate the results for the DWS mechanism product design concept.

Concept testing results have revealed that the DWS mechanism can be efficiently used as a reconfigurable, flexible, retractable and deployable worksurface for the passengers to have a comfortable accessibility inside the vehicle to perform individual or group activities like using for writing, to accommodate an in-built surface embedded computer screen, inbuilt tablet which can be flipped to use, for dining, as a personal laptop mount etc.

The inputs, outcomes, the engineering solution, future needs etc. derived while undertaking this research, with the above objective and aims, are detailed in Chapters 2 to 7. The summary for each of these chapters would be as follow:

Chapter 2: Autonomous Vehicle Overview

Chapter 2 outlines the technological overview and market overview of the autonomous vehicle sector. The reader can understand the end-user views as well as geographic perspectives on autonomous vehicle market. This chapter also outlines certain details on the key player OEM's (Original Equipment Manufacturers) and other agencies that are involved in the autonomous vehicle sector.

Chapter 3: Vehicle Interior Market Overview

Chapter 3 describes specifically the Vehicle's Interior domain. This also explains the interiors of the future, the market and the resistance. This will also give an understanding of the market segmentation and the key players in the interior domain.

Chapter 4: Vehicle Interior Product Design Thinking

Chapter 4 analyzes the user needs and their problems in the access and usage of the vehicle interior and outlines how an interior design concept was derived as a solution to address the user empathy as well as their expectations in the interior designs.

Chapter 5: DWS Mechanism Concept Product Design

Chapter 5 describes the CAD Development and Assembly Structure of the DWS Mechanism evolved in this research. It also outlines the Architecture, Motor, Microcontroller and Sensor Mechanisms behind the DWS.

Chapter 6: DWS Mechanism Concept Product Design Testing & Validation

Chapter 6 outlines the Testing objectives, Methodology and Testing Results. It also speaks about the Validation of the DWS mechanism test results and data points.

Chapter 7: Conclusions and Recommendations

This chapter summarizes the research findings, outcomes and suggests follow-up directions for further research in vehicle interior design concepts.

2. AUTONOMOUS VEHICLE OVERVIEW

The innovation of self-driving cars, also known as autonomous vehicles, is revolutionizing the transportation and commutation sectors. An autonomous vehicle can cruise in the midst of the busy road traffic without a driver operating the vehicle. These vehicles are enabled with various safety features like electronic blind-spot assistance, crash avoidance, lane assistance, parking assistance and adaptive cruise control. A version of this vehicle, variously called as a driverless car, self-driving car, robotic car etc. is shown in Figure 2. An autonomous system in combination with other systems enables these vehicles to be driven without the active control or monitoring by a human operator.

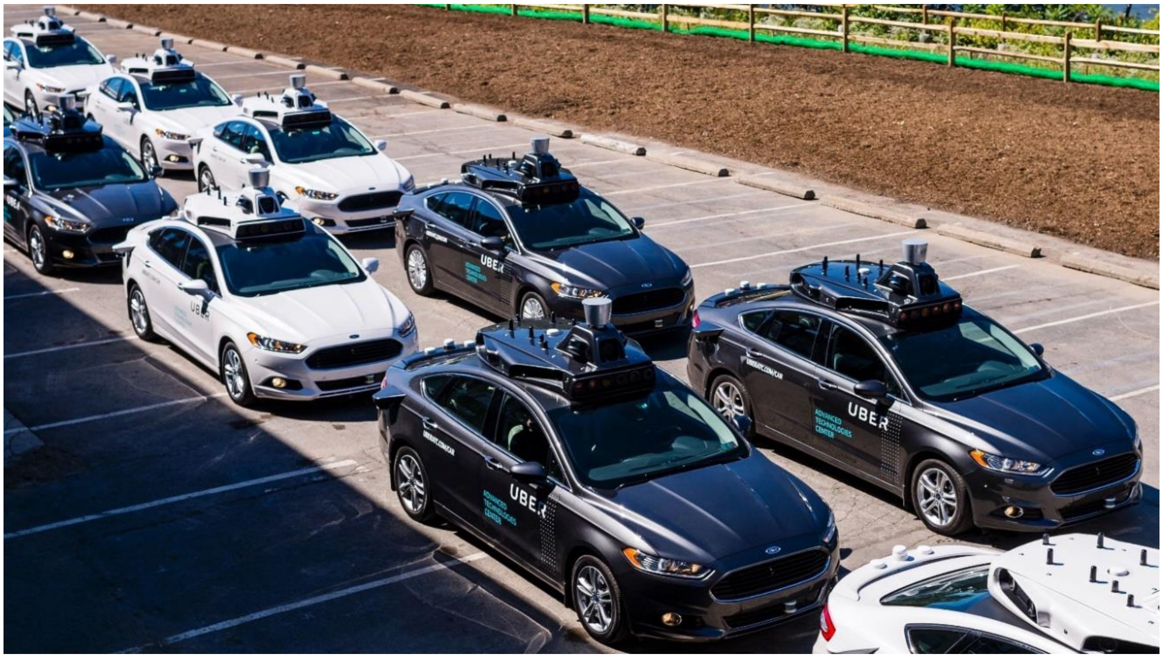


Figure 2. Uber autonomous taxi cars [2]

2.1 Technological Overview of Autonomous Vehicle

Autonomous cars or driverless cars, as the name implies are the vehicles that have the transportation and cruising capabilities of a conventional car and can navigate by electronically sensing the surrounding using the techniques such as RADAR (Radio Detection and Ranging), LIDAR (Light Detection and Ranging), GPS (Global Positioning System) and computer vision. Advanced Control Systems mounted into these cars can interpret the sensory inputs to detect the signboards or to avoid any impediment and collision. Different products like the advanced driver assistance systems (ADAS), 5G network and other advanced technology innovations have entered into the automobile market. Figure 3 shows the technologies, namely RADAR and LIDAR instruments, and their contributions to the development of advanced self-driving vehicles.

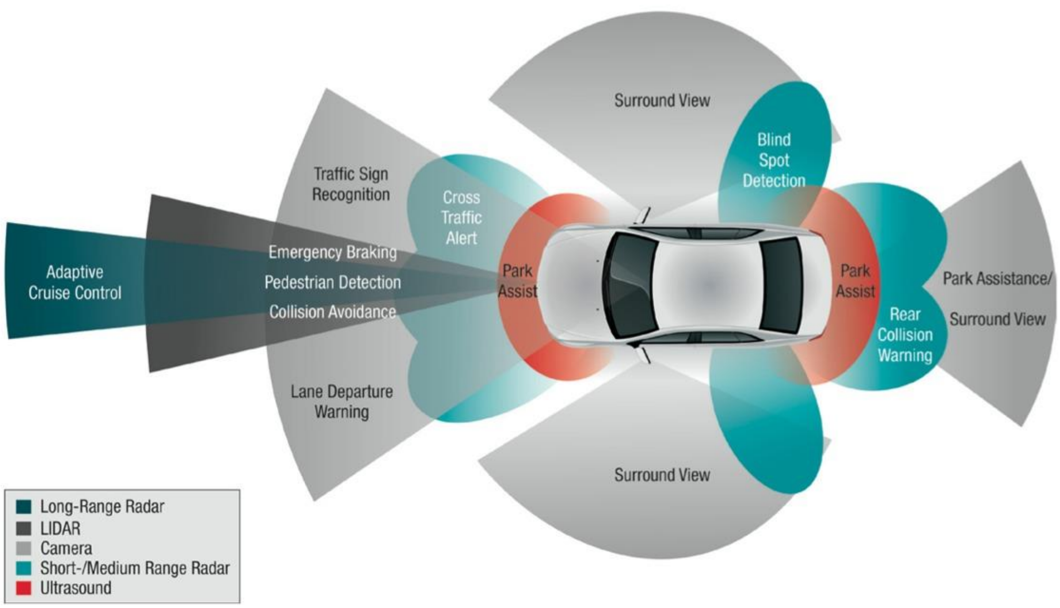


Figure 3. LIDAR emits laser signals and RADAR emits radio waves [3]

2.2 Autonomous Vehicle Market Overview

The global autonomous car market is expected to register a strong growth during the period from 2017 to 2025 [4]. Some of the prominent trends that were assessed from the market are given below:

- Increasing demand for semi-autonomous technologies,
- Rising demand for comfort and convenience in developing countries,
- Rising technological developments in autonomous cars/driverless cars,
- Growth of investment opportunities in the automotive sector.

2.2.1 Autonomous Cars/Driverless Cars Market, By End User

The global autonomous/driverless market is expected to register a compound annual growth rate (CAGR) of 36.2% during the period 2017 to 2025 to meet the demand from the following sectors and end-users:

- Healthcare
- Third-party or law firms
- Government
- Transportation

The advent of increased levels of autonomy is not only foretelling a revolution in mobility but is also forcing the manufacturers to rethink and accept a change in the car ownership approach of the customers in the future.

Once we enter into an era wherein autonomous vehicles could be summoned on demand, then we can visualize the notion of shared vehicle access becomes more real. Currently car sales are for a single transaction, but under a shared ownership notion the revenue per mile traveled for an average US$30,000 [5] car would be five or six times the amount that would be achieved from a current single transaction mode.

In the near future, the customer is expected to travel approximately 12,000 miles a year [5]. Thus the revenue for every mile of such travel and the other revenue for serving the other needs of the customer needs would witness a phenomenal growth and this revenue will register a further hike during the weekends.

2.2.2 Autonomous Cars/Driverless Cars Market, by Automation Level

The different classifications of autonomous driving are shown in Table 1. These classifications are the adopted standards: J3016 of the international engineering and automotive industry association, SAE, and in Europe by the Federal Highway Research Institute [6].

According to these *standards*, based on the levels of automation, the cars are classified as below:

- Level 0: Driver only: the human driver controls everything independently, steering, throttle, brakes, etc.
- Level 1: Assisted driving: assistance systems help the driver during vehicle operation (Cruise Control, ACC).
- Level 2: Partial automation: the operator must monitor the system always. At least one system, such as cruise control and lane centering, is fully automated.

- Level 3: Conditional automation: the operator monitors the system and can intervene whenever necessary. Safety-critical functions, under certain circumstances, are shifted to the vehicle.
- Level 4: High automation: no monitoring by the driver, Vehicles are designed to operate safety-critical functions and monitor road conditions for the entire trip. However, the functions do not cover all and every driving scenario and are limited to the operational design of the vehicle.
- Level 5: Full automation: operator-free driving.

Table 1. Gradation of automated driving [6]

SAE Level	SAE Name	SAE Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System capability (driving modes)	BASt Level	NTHSA Level
Human Driver monitors the driving environment								
0	No Automation	the full-time performance by *the human driver* of all aspects of the *dynamic driving task*	Human Driver	Human Driver	Human Driver	N/A	Driver only	0
1	Driver Assistance	the *driving mode-specific* execution by a driver assistance system of either steering or acceleration/deceleration	Human Driver and Systems	Human Driver	Human Driver	Some Driving Modes	Assisted	1
2	Partial Automation	Part-time or driving mode-dependent execution by **one or more driver assistance systems** of both steering and acceleration/deceleration. Human driver performs all other aspects of the *dynamic driving task*	**System**	Human Driver	Human Driver	Some Driving Modes	Partially Automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	*driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* - *human driver* **does** respond appropriately to a *request to intervene*	System	**System**	Human Driver	Some Driving Modes	Highly Automated	3
4	High Automation	*driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* - *human driver* **does not** respond appropriately to a *request to intervene*	System	System	**System**	Some Driving Modes	Fully Automated	3/4
5	Full Automation	**full-time** performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	**System**	Some Driving Modes		

As of today, no car manufacturer has achieved level 3 or higher in production, although many have produced demonstration vehicles. The legislatures of some countries are also working on a possible admission of "Level 3" vehicles under their law and these exercises are expected to be completed in 2020/21 [6].

As mentioned already three main groups of sensor systems: camera, radar, and LIDAR based systems are essential for autonomous cars of Level 5. For parking, ultrasonic sensors are already available and are in wide use, but they are of minor importance for autonomous driving. Camera and radar systems are used in Level 1 and 2 vehicles today and they will continue to be the prerequisite for all further higher levels of automation [6].

Although Level 4 and Level 5 autonomous cars are unlikely to reach wide acceptance by 2025 [6], there would be a rapid growth for Level 2 and Level 3 autonomous cars, which will be housed with advanced driver assistance systems like collision detection, lane departure warning, and adaptive cruise control.

2.2.3 Automotive Cars Global Market Overview

An analysis of the market estimates and forecasts for all the given segments on global as well as regional levels is shown in Figure 4 [7]. It provides global market data for the year 1990-2017 with respect to vehicle sales. The data on international annual car sales for 2018 is shown in Table 2.

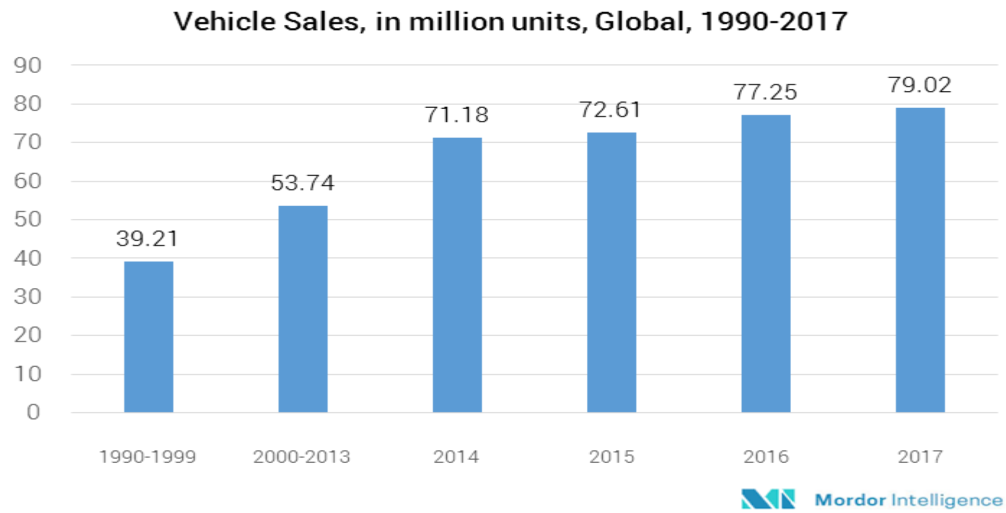


Figure 4. Vehicle sales, in million units, global, 1990-2017 [8]

Table 2. Annual car sales in various major markets [8]

Region	2018	2017	2016	2015	2014	2013
Europe (EU+EFTA)	15,624,500	15,631,700	15,131,700	14,201,900	13,006,500	12,308,200
Russia*	1,800,600	1,595,700	1,425,800	1,601,200	2,491,400	2,777,400
USA*	17,215,200	17,134,700	17,465,000	17,386,300	16,435,300	15,531,600
Japan	4,391,200	4,386,400	4,146,500	4,215,900	4,699,600	4,562,300
Brazil*	2,475,400	2,176,000	1,988,600	2,480,500	3,333,400	3,579,900
India	3,394,700	3,229,100	2,966,600	2,772,700	2,570,500	2,554,000
China	23,256,300	24,171,400	23,693,400	20,047,200	18,368,900	16,303,700
*Light vehicles	–	–	–	–	–	–
Combined:	68,157,900	68,325,000	66,817,600	62,705,700	60,905,600	57,617,100

2.2.4 Global Autonomous Vehicle Market

The available data suggests that the Asia-Pacific region is dominating the market. The technology for manufacturing the autonomous cars is readily available, but the concerns about liability and legislation are acting as constraints on the market. It is also felt that a fully autonomous car segment cannot command a wide customer base unless it is secured from possible cyber attacks. However an assured built-in backup systems and the option to take over the control of the car by the driver, in case of such need, are some of the factors that may act as promoters to capture the future market.

Once these concerns are addressed, the autonomous car market is estimated to reach the US $60 billion by 2030 [9]. Increased safety assurance, lower insurance and fuel costs, and friendly interior design to facilitate multitask by the traveling user are expected to boost the market. North America is expected to lead the market in the first phase however the Asia-Pacific region, with the presence of fastest adopters like China and Japan, is expected to garner a woofing 35% share by 2025 [10].

The statistics in Figure 5 projects the type wise size of the global autonomous vehicle market in 2025 [11]. It is estimated that the market for fully autonomous vehicles will reach 6 billion U.S. dollars by 2025 while the market share for partially autonomous vehicles would be 36 billion U.S. dollars [11]. This sounds that the scope for semi-autonomous and even non-autonomous sectors are not going to be drastically affected or vanished.

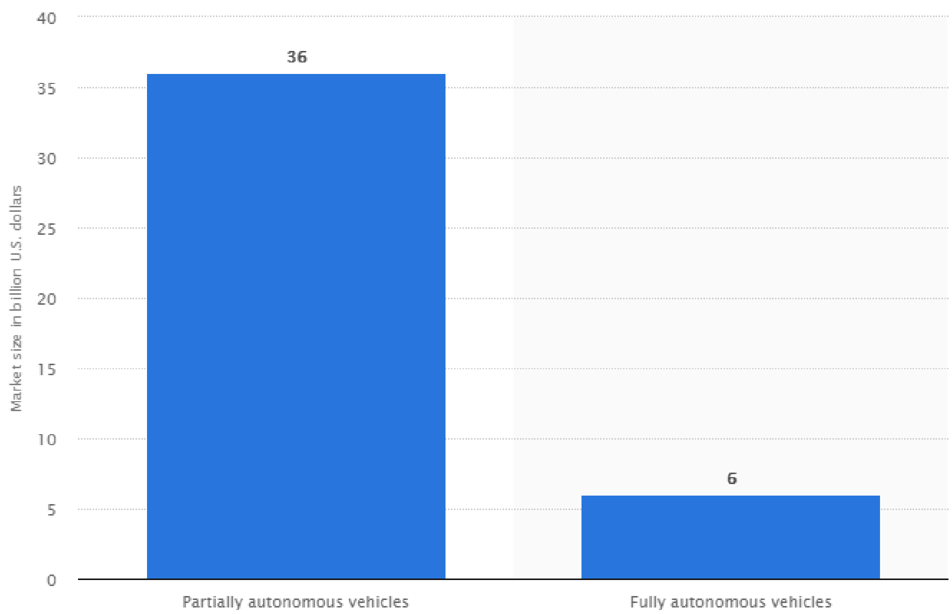


Figure 5. Market size for autonomous vehicles [11]

2.2.5 Autonomous Cars Key Player Activities

Apart from the data on market trends, supply chain trends, technological innovations, key developments, and future strategies etc., the following activities of the existing players, new entrants and the future investors seem to be an effective factor to influence the market share for the autonomous vehicles:

- January 2018: Waymo strikes a deal to buy thousands of self-driving minivans from Fiat Chrysler
- January 2018: GM started testing autonomous technology on Cadillac cars in Israel.
- December 2017: Ford patents autonomous police car to hand out tickets

- Apple is partnering with Hertz to test its in-house developed autonomous software in some of the company's rental cars.
- Waymo has developed Phoenix that lets people use its autonomous cars for their daily transportation needs.
- Microsoft has several partnerships with automotive manufacturers developing internet-connected and autonomous vehicles including Ford, BMW, Renault-Nissan, Toyota, and Volvo. It is latest deal in this new market is with the Chinese company Baidu, to develop an open-source platform dubbed Apollo.
- Nissan Alliance will spend $225m a year for the next five years to increase the automotive autonomy and that figure is likely to ramp up after the US$1.1bn allocation has been spent.[5]
- CISCO and IBM are also in the fray as major players.

2.2.6 Leading Autonomous Vehicle Manufacturing Companies

The following are the leading manufacturers of autonomous vehicles at present.

- Uber
- Mercedes-Benz
- Alphabet Inc. (Google)
- Nissan
- Toyota
- Volvo Car Corporation

- Tesla Motors
- General Motors
- Honda Motor Corporation
- Audi
- Bayerische Motoren Werke AG (BMW)

3. VEHICLE INTERIOR MARKET OVERVIEW

Till a few years ago, Tesla's built-in display was perceived as big and overpowering with its cockpit little bit sparse, but now companies such as Byton are rewriting the rule book in terms of how one will travel and interact with our cars. In 2025, there won't be a unison trend, instead the car industry might flip upside down and OEMs will be offering the customers a wide range of choice, whether it is an autonomous car or a little city car and both will have very different interiors. However technology will play a key role in moving forward all such segments.

Something we are currently encountering very closely is how people feel when driving or traveling in their cars, particularly about the access to the surrounding, health, well-being and motion sickness and other technological needs. It is felt that the digital model has just as much a place as an analog, and tactile elements are perceived just as important as touch displays.

The new technology and innovation have made the interior designing easier with the use of amazing new tools in the studio. The virtual reality does a lot more to produce the most amazing virtual images for the designers. However, make clay and memory foam models are still resorted to by the designers to simulate physical properties.

3.1 Vehicle Interiors Market Assessment

The autonomous vehicles are arriving with dramatic interior implications and are perceived with the following notions:

- Safer,
- Lower cost of ownership,

- New found time

These notions may have the potential to boost the interiors market. However China continues to make a global impact on the luxury market for the following reasons:

- World's biggest luxury goods market since 2012.
- Luxury consumption market of US$106 billion in 2014 i.e. 46% of global consumption
- World's 2nd largest market for luxury cars from 2016

The Urban SUV segment may hold the global market battleground for the following reasons:

- SUV/CUV is the fastest-growing segment in EU, NA and Asia-Pacific
- Urbanization from 54% to 70% in 2050, causing driving congestion and pollution

3.1.1 Vehicle Interior of the Future

As the market is going to be in favour of SUVs, the interiors of the first generation of automated SUVs may offer better life on board, if it could provide the following:

- Solutions to enhance the ambiance
- Solutions to increase practical functionality
- Solutions to engage the driver in other activities after enabling automated driving

Thus the future of vehicle interiors will necessarily take a complete transformation as seen in Figure 6. This means that the designers have to be ready with a new and radical approach to offer better solutions to satisfy the demands of the customers. Such a new approach will facilitate the passengers to spend less time on driving but more time for doing other routines, this approach could also radically change the way the consumers would make their buying decisions. Currently the automotive industry is gearing up for the emergence of autonomous vehicles, hence more attention than ever is required to be focused on vehicle interiors.

Figure 6. Interiors concepts feature seating designed for conversation [12]

3.1.2 The Millennials and Resistance

The Millennial population, i.e. those born between 1982 and 2004, presently a vexatious buyer group, is largely disinterested in car ownership. This group forms a big chunk of the population. Hence there is a reasonable apprehension for the millions of Americans living in large cities that the next vehicle they purchase may be the last car they ever own. However there is a solace that a growing number of US buyers are evincing eager for the advanced technology.

The UK based Juniper Research has predicted that there would be around 20 million autonomous vehicles on road worldwide in 2025 [12]. At that time the present millennial group would be in the age range of 20 to early 40s and they would be the potential user of vehicles. Thus it would be ironical to see that the present car ownership resisting millennial group would be the owners or users of the autonomous vehicles in 2025. Hence it is going to be an added burden on the automotive designers to adapt to the expectations of this group.

In a recent survey [12] by consultant Deloitte, 43% of respondents have expressed a desire for limited self-driving capability while 39% evinced interest in fully autonomous vehicles. The Boston Consulting Group has predicted that more than 5 million conventional cars per year could be replaced by fully autonomous electric vehicles for urban fleets and by partially autonomous cars for personal use.

Although eager for it, the younger buyers remain wary of autonomous-vehicle safety. In a survey [12] of 158,000 consumers, most of them millennials, the driving-tests.org has found considerable angst over the possibility of riding in a driverless car. When asked to gauge their level of concern on a scale of 0-10, 38% rated it as 8 or higher while 24.0% felt that the benefits of autonomous vehicles will not be worth the risk and 20.5% believed it as good [12].

3.2 Automotive Interiors Market Overview

The global automotive interior market size for the years 2014 and 2020 is shown in Figure 7. This market is expected to reach $236.2 billion by 2022 by registering a CAGR of 6.5% during the period 2016-2022 [13].

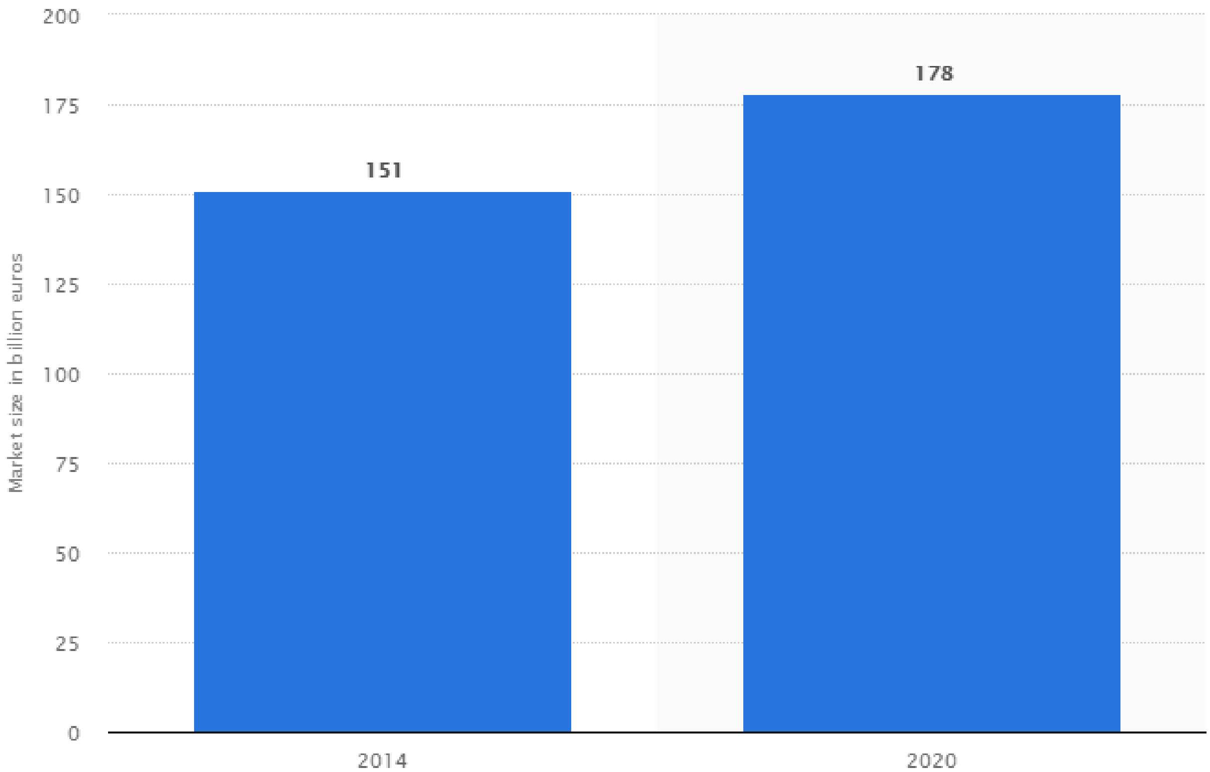


Figure 7. The global automotive interior market size in 2014 and 2020 [13]

Automotive interiors include the interior components and systems in a vehicle that are specifically designed to provide comfort, grip, sound insulation etc. in the vehicle cabin. Thus headliners, cockpit modules, consoles, vanity mirrors, door panels, flooring, automotive seats, safety devices, interior lighting, electrical and electronic gadgets and access facilities are all fall under interiors. Since automotive interiors are perceived as an indicator of overall vehicle comfort and quality, they play a critical role to influence the buying decision of the buyers. Hence the desire of the customers to enhance driving and travel experience warrant innovations for new features and incorporation of technologically advanced systems. Thus the growing customer demand for new features and sophistication drives the growth of the interior market.

Geographically, the automotive interior market has been divided into North America, Latin America, Western and Eastern Europe, Asia Pacific without Japan, Middle East & Africa and Japan as shown in Figure 8.

China is likely to be the biggest user of leather for automobile insides thereby increasing the growth and development of the international automotive interior leather market segment. Retrieval of the automobile interior segment in the U.S. and Western Europe is expected to stimulate the progress of the international automotive interior leather market.

Figure 8. Global automotive interior market, by region forecast [14]

The Asia Pacific region is, at present, the major marketplace for automotive interior materials as shown in Figure 9. China is the prime shopper of automotive interior materials in this region. Speedily developing the automobile industry, modest cost of manufacturing, and great financial development rate are the encouraging market powers for automotive interior materials market growth in this region. These issues help in the growth of businesses in the Asia Pacific.

The worldwide market for automotive interior material is growing due to features such as an increase in the call for automobiles in North America and Asia Pacific, Cool materials attaining curiosity in established markets, and OEM's emphasis on dropping vehicle weightiness to achieve fuel efficiency. Hence the international automotive interior material market has grown up manifold in the past few years.

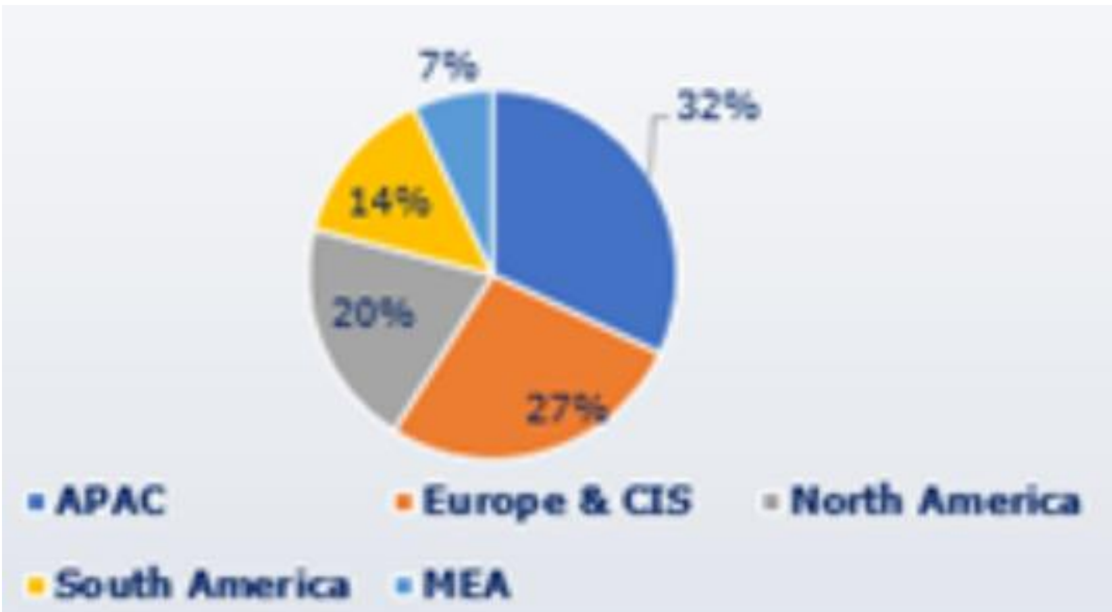


Figure 9. Global automotive interior market share by region, 2022 forecast [14]

The Asia Pacific is the major customer of automotive interior materials in the world. Japan, China, South Korea, and India are the chief markets for interior materials in the Asia Pacific. The call-in these markets are driven by the increasing automobile manufacturing, lesser conveyance and labor charges and plentiful availability of raw supplies.

3.2.1 Automotive Interiors Market Segmentation

The interior market segmentation by vehicle type-wise will include the following [15]:

- Passenger Car
- Commercial vehicles
- Light Commercial Vehicles
- Heavy Commercial Vehicles

The interior market segmentation by component-wise will include the following [15]:

- Cockpit Module
- Infotainment
- Instrument cluster
- Telematics
- Flooring
- Door Panel
- Automotive Seat
- Interior Lighting
- Others (sun visors, headliner, overhead and acoustic systems)

The interior market segmentation by Geography-wise will include [15]

- North America
- The U.S.
- Canada
- Mexico

- Europe
- Germany
- Russia
- U.K.
- France
- Asia-Pacific
- China
- India
- Japan
- Australia
- Rest of Asia-Pacific
- LAMEA
- South Africa
- Brazil
- U.A.E.
- Rest of LAMEA

3.2.2 Vehicle Interior Key Players

The major key players in the interior market are [16]

- Grupo Antolin
- Faurecia Interior System
- Johnson Controls Inc.
- Calsonic Kansei Corp.

- Visteon
- Lear Corporation
- Delphi Automotive LLP
- Hyundai Mobis Company, Ltd.
- IAC Group
- TACHI-S CO., LTD

4. VEHICLE INTERIOR PRODUCT DESIGN THINKING

Empathize, Define, Ideate, Prototype, and Testing are the essential stages in the Design Thinking process as shown in Figure 10. Mentally perceiving the problem of the user is the Empathize stage of the Design Thinking process. Then the thinking process is taken further by attempting to define the problem of the user. The problem definition will open up many thinking and ideas as a solution to the problem and any such feasible idea may result in a product concept.

The vehicle interior product concept design envisaged in this research requires a collaborative thinking and deeper understanding of the customer's requirements and their problems in the usage of vehicle interior access. The concept of design activity will encompass more collective brainstorming and reflective thinking before making a full product design. A planned interaction and discussion with the users will help in identifying the problem. Creating and learning by doing, thinking it through an organized process and visualizing a prototype that would certainly need future iterations will be the correct process to reach a successful solution to the problem as mentioned in Figure 10.

4.1 Vehicle Interior Users Challenges

Vehicle users include school/college goers, office goers, business travellers, scientific and technical professionals etc. These users face multifarious challenges during their travel time. These challenges are mostly related to access to the vehicle interior facilities. Thus there is a need to accomplish a concept product design for better managing the vehicle interior utility by the users.

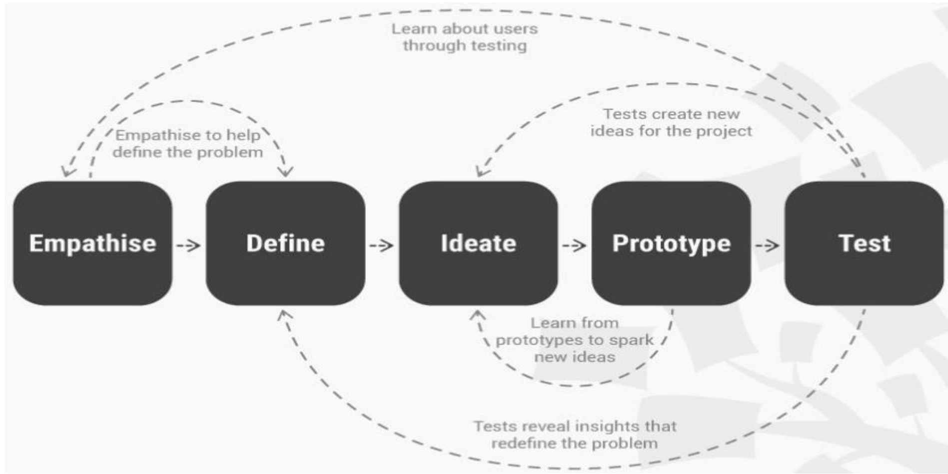


Figure 10. Design thinking: A non-linear process [17]

An idea or suggestion to a problem may be ridiculous; however it should also be encouraged as they can serve as a building block in the ideation process of the design thinking process aimed to address the user's challenge as mentioned in Figure 11. The new concept product design for a vehicle interior need not have to happen with the actual vehicle interior space, it can also happen with a vehicle interior console body, if it helps to repurpose the space as a better solution to user's problem. Prototypes can be very vague but still they may clearly represent an idea.

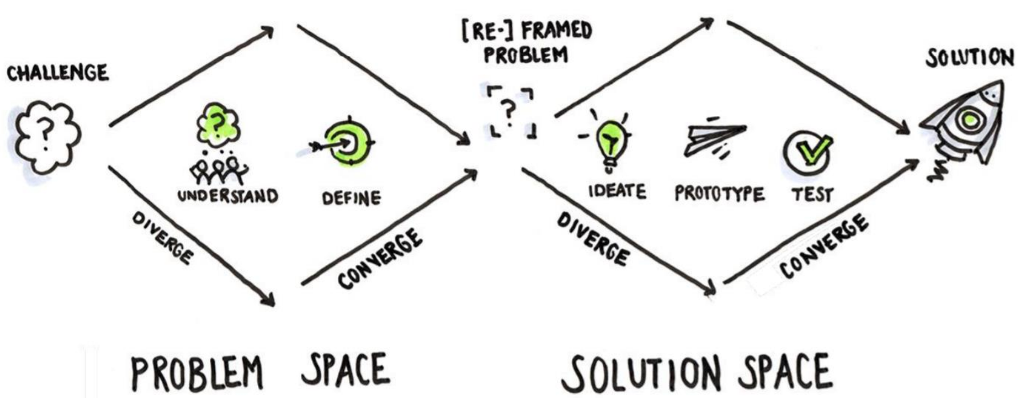


Figure 11. Design thinking process [17]

4.2 Vehicle Interior User - Empathy Findings

Empathy is all about understanding the user's problem as mentioned in Figure 12. Empathy requires mental alertness to correctly perceive and understand the problems encountered by the users. To get correct empathy we have to identify the proper users. There are two extreme user groups (right and left) with a moderate user group in the middle of the bell curve as shown in Figure 14. We have to pick one user group to probe the issues faced by them. This approach may bring forth both sensible and non-sensible issues. The broader perspective of the issues related to the interior access has to be analysed to correctly understand the challenge and to find a solution to the problems faced by the selected user group.

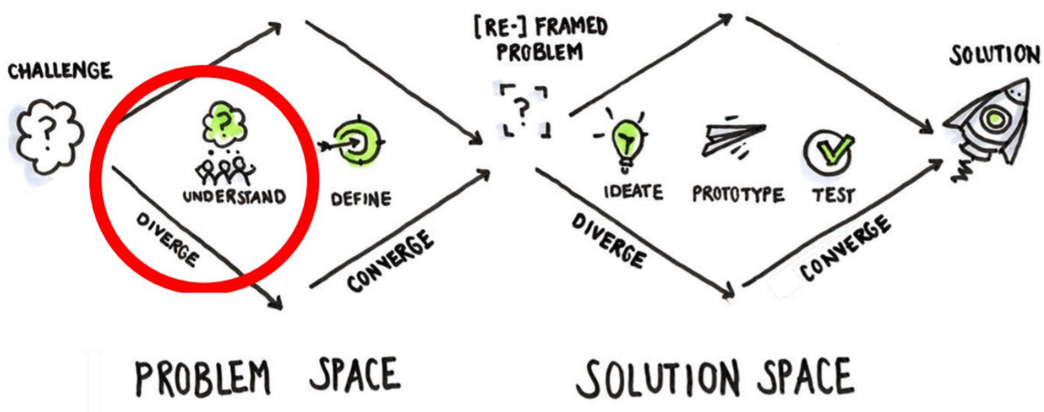


Figure 12. Empathy = Understand the problem [17]

4.3 Vehicle Interior User Interviews

The problems faced by the user customers on the performance or utility of a product are made known generally through customer feedback, appraisal rating or complaint etc. However the issue taken for this research is not on the running performance of the vehicle as such but is limited to the difficulties faced by the users inside the vehicle while on a trip. Such difficulties or expectations can be obtained only by personal interaction. Discussion or interviews with the users will bring out all their problems.

The interview process with the users is shown in a graphical format in Figure 13. The customer interview process includes the introduction of an interviewer, introduction of the project, building rapport, evoke stories, explore emotions, question statements, thank & wrap-up. This process requires the interviewer to keep the user in a free mental state to extract all their concerns and expectations either on their own volition or by posing pertinent questions to get their explanation or answers on the issues faced by them and their expectations. The interviewer should exhibit a certain degree of behavioural modulation while seeking information from the users. He should not get bored but should be ready to capture the pertinent responses of the user. Extreme users as shown in Figure 14 are important for the user interviews.

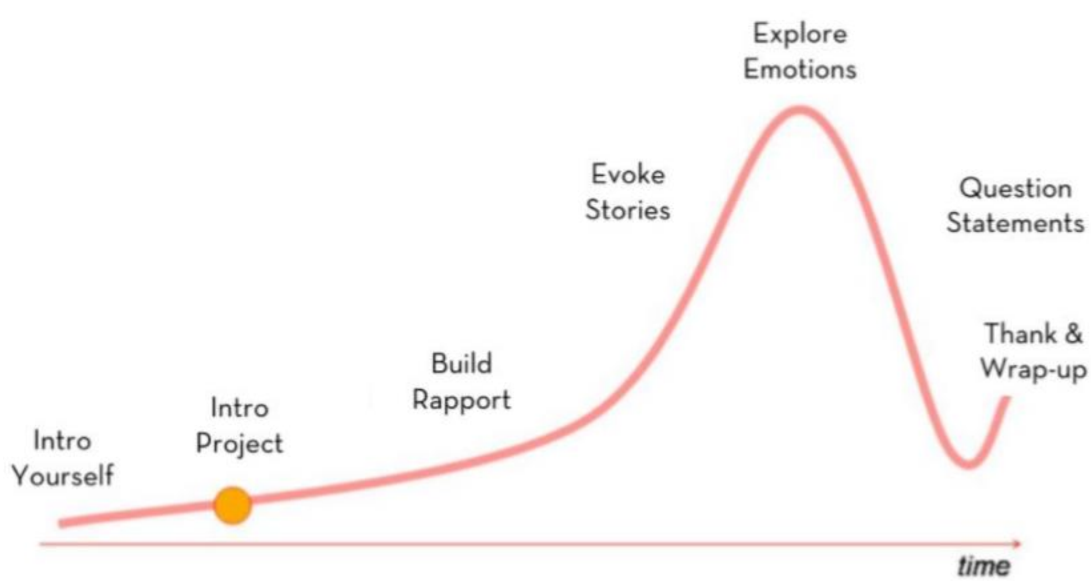


Figure 13. Interview graph [18]

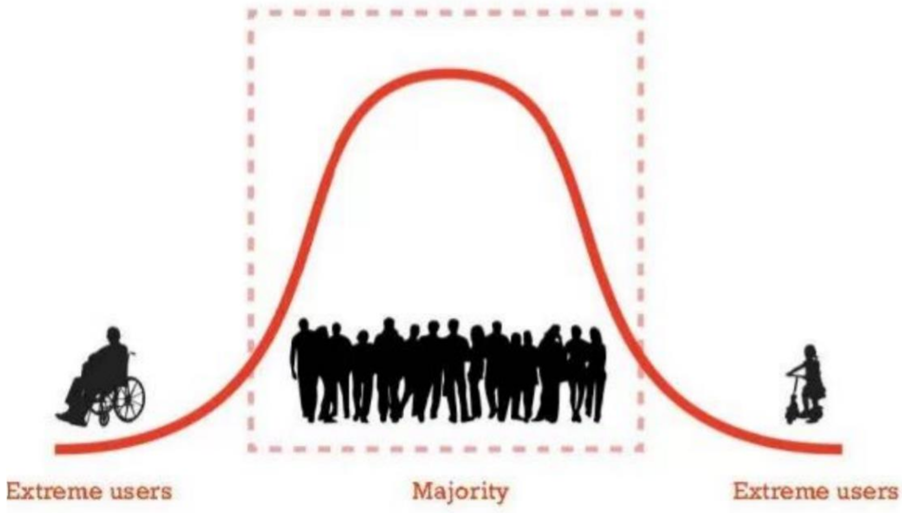


Figure 14. Example graph of extreme user [18]

4.3.1 Extreme User Interview- 1:

Figure 15. Interview with Zak Husz

Zak Husz, seen in Figure 15, is an automotive advanced product industrial designer at Strattec Security Corporation, Milwaukee. He goes on long road travel of 12 - 24 hours on business trips as a carpooling user along with his other group of colleagues. His interview was to understand the problems related to the vehicle interior.

Zak Husz says that the USB port in the vehicle is few in number and are not enough for the group of people traveling in a vehicle. He wishes to have multiple USB ports and 3 port plug-in adapters at the rear side passenger's area for charging the cell phones. He also needs a mini refrigerator inside a vehicle to store the vegetables etc. while on a long road trip for camping.

He desires to share music and play music using Bluetooth while on travel and desires to have trouble-free Bluetooth pairing. He also desires to have a turning display screen to show and share a display with the co-passengers.

He desires to have a system to record the cost/expenditure incurred during the travel with time and location details and with the facility to retrieve the data at the end of the travel and this facility should permit each user to access it for his expenditure monitoring.

He needs a tray or something to keep the book, coffee, food and water and he even desires to read the book while eating and says that reading and eating is highly discomforting presently. He also needs a safe box other than a glove box to store few valuable items.

He says that the rear seat is not having enough legroom and headroom and is uncomfortable for sleeping during travel. He also desires to have separate GPS display on the rear side to follow the route map during the travel.

4.3.2 Extreme User Interview- 2:

Figure 16. Interview with Adam Pirkey

Adam Pirky, seen in Figure 16, is an automotive advanced product development engineer at Strattec Security Corporation, Milwaukee. He used to travel to different companies with the technical team to gather inputs and to develop business in various ways. His major transportation means of commutation is carpooling along with his colleagues.

As a rear seat passenger he faces difficulties in reaching any of the electronic accessories and ports, for example he was not able to reach the ports of the phone charger.

Adam experiences a great problem in viewing and following the GPS Navigation System from the rear side and wishes to have a duplicated or replicated Navigation display access to the rear-seated users.

He has also felt inconvenience in accessing the coffee mugs, eating, drinking and leg space constraints.

He has also felt the strain on his shoulders due to immobility during travel as a carpooling user and faces seat belt issues causing neck pain and desires motion sickness control for rear users.

He experiences difficulty in sharing the information from his mobile or media with his colleague while traveling and desires to have multiple independent media access.

He specifically feels for the lack of desk access for his tablet or PC or while reading books and making notes and also feels for lack of reading light.

He thinks that it would be useful to have a visual screen to project the contents of email or presentation.

He needs intuitive and adjustable workspace and sleeping adjustments for the rear seat passengers as well.

He also wants emergency exit for the third-row passengers as a safety measure.

Adam needs a heart rate monitoring inside the vehicle.

He thinks water cooling and refrigeration access will make the travel better, He also thinks heating options like coffee may make the travel interesting.

He needs access to share landmark pictures instantly with the co-passengers. He also feels that the parking location of the car needs to be saved automatically.

He needs enough safe storage facility as he has to carry a lot of prototypes during his travel.

He also feels that the driver or the front passenger should be able to monitor the activities going on in the rear seat area.

4.3.2 Extreme User Interview- 3:

Figure 17. Interview with Nicole Barker

Nicole Barker, seen in Figure 17, is an automotive advanced product development technical lead at Strattec Security Corporation, Milwaukee. Nicole, also a product patent attorney, used to travel to different companies with the technical team to gather inputs and to develop business in various ways. Her major transportation means is carpooling with her colleagues across US mid-west region.

She as a driver feels that the pedal touch distance is in a way too close to the steering wheel, and she thinks this as a seat related issue.

She has issues in sharing the media files with her co-passengers.

She always feels it difficult to share music and display works with her front seated colleague. She demands seat reclining facility should be leveraged to the rear passengers as well to relieve her from motion sickness.

She believes a coffee warmer inside the car will keep her feel better and refreshed during travel.

She expects a refrigerator to store her home brought food and a smaller box for safekeeping other items.

4.4 Vehicle Interior Users empathy- Synthesis

Research empathy notes gathered during customer interviews and communications have to be put into consideration by employing certain tools known as a point of view (POV) and "how might we" (HMW) for defining and framing the designer's design challenge.

4.4.1 POV in Design Thinking

Defining a designer's design challenge is probably one of the most important steps in the design thinking process. It sets the tone and guides all other activities coming under the design thinking process. In the define mode, the designer should come up with a clear actionable problem statement which is commonly known as the point of view (POV) in design thinking. The designer should always base his point of view on a deeper insight to understand the specific users, their needs. In the design thinking process, the designer will gain insights from his research and fieldwork in the empathize mode. POV is designer's unique design vision created by the designer based on discoveries during the empathy work. This will serve as a guiding statement that focuses on specific users, and insights on their needs that the designer has unearthed during the empathize mode. The designer's POV will not or never contain any specific solution, nor will contain any indication as to how to fulfill the user's needs but it should provide a wide enough scope for the designer and his team to start thinking about various solutions which may even go beyond the status quo.

Thus the designer's understanding of a meaningful challenge that needs to be addressed is fundamental for the creation of a successful solution.

4.4.1.1 Point of View Template

Table 3. Point of view template

User	Need	Insight
Zak Husz, a carpool traveler of long road trips with colleague and friends	To provide flexible use of the interior during his 12-24 hours of travel on business and technical meetings twice a week.	Zak needs a safe storage box other than the front glove compartment. He needs a phone charger and 3 plug-in adapter, refrigerator, navigation sync from rear side passenger to front driver side,

		display and sharing media screen, photos and music. He needs turn around display, storing and retrieval of expenditure during travel, reading books, drinking water and coffee mug holder near the display, eating food while reading in rear side, pillow head and arm resting in the rear side and refrigerator to keep vegetables during travel on camp. He is looking for personalized accessibility in the vehicle interior
Adam Pirkey, a carpool user on business trips along with colleagues	To provide flexible use of vehicle interior for more than 4-12 hours during his official business and technical product prototype demonstration trips twice a week.	He is uncomfortable with the limited leg space in the rear; He needs facilities for eating, drinking hot coffee, reading, writing and mounting tablet. He feels difficulty in using the

		back seat, coffee holding, eating and drinking water. He needs turn around tablet or screen display during business and technical discussions. He needs a surface to keep the laptop, read books and to eat. He needs sleeping adjustments in the rear seat to avoid motion sickness. He expects a quick exit during prevention, quick exit during emergency. He wants GPS navigation display for the rear passengers also. He is wary of the comfortless back seat. He needs reading lights for reading at night. He needs Heart monitoring inside the interior. He needs refrigerator and coffee warmer. He needs

		slide and data screening with multiple displays. He needs recording of parking location. He needs safe box for keeping tool kits and product prototypes.
Nicole Barker, car user on business travel with colleagues across mid-west region	To provide flexible use of vehicle interior for 4-8 hours of official business travel with her technical group twice a week.	Nicole would not prefer car pool for business trips because she feels that the interior is too inflexible and inconvenient to fulfill her needs. She wishes to have a turnaround screen display to share business related information with other users during her travel. She is annoyed over the short distance between the pedals and the steering wheel and considers it as a seat issue. She likes to share music with other users and aspires for a

		reclining seat. She likes to have a tray for eating food, keeping water bottle and coffee cup near the driver area apart from a laptop mount. She also needs a bigger glove compartment in the vehicles used in cold states like Milwaukee. She needs a storage box for small items, a refrigerator, coffee warmer, display screen sharing, laptop mount and not to have motion sickness. Nicole truly needs access to a food tray with a laptop mount.

4.4.1.1 POV Madlib

The designer can articulate the POV as a problem statement by considering the designer's information about the users, their needs and designer's deep insights on their issues. Thus the problem statement arrived at in this study is as follow:

- Carpooling professional users traveling 4-24 hours twice a week, along with their colleague, on business or for technical meetings, require flexible and personalized interior access facilities to accomplish effective work productivity.

4.4.2 Generate HWM questions

Once the design challenge is correctly defined from the POV, the designer can start opening up for ideas to solve the designer's design challenge. This design thinking will explore new ideas and solutions to a specific design challenge.

The designer can start using the designer's POV by asking a specific question starting with, "how-might-we?" or "in-what-ways-might-we?". How might we (HMW) questions are the best way to open up brainstorm and other ideation sessions. Thus HMW opens up into the ideation session where the designer can explore ideas that can help him to solve the designers' design challenge. By framing designers' challenges in how might we question format, the designer will enter to explore an innovative solution to the challenge. The how might we method is constructed in such a way that it opens the field for many new ideas, though the designer admittedly does not know the answers, but it encourages a collaborative approach to solve the challenge.

The challenge defined in the problem statement is dealt with under the HWM format in a human-centered manner as follows:

- How might we make a better vehicle interior access product suitable for carpooling professionals?
- How might we inspire carpooling professionals towards effective work productivity inside the vehicle?

- How might we make an integrated vehicle interior accessibility to meet the aspirations of the carpooling professionals?
- How might we make it an affordable personalized interior accessibility product?

4.5 Vehicle Interior Access Ideation

The designer, having crossed the empathy and definition stages with his deep insight understanding of the profile of the users and their issues, is now entering in to the ideation stage of the design thinking process wherein he can start exploring and generating ideas and innovative thinking to answer the identified and defined problem faced by the user group. In this process he can even think outside the box, as an alternative way of looking at the problem, in his pursuit of a solution to the problem.

There are plenty of ideation techniques such as Brainstorm, Brain writes, Worst possible idea, and Scamper etc. However brainstorm and worst possible idea sessions are typically used to stimulate free thinking and to expand the problem space. It is important to get as many ideas or problem solutions as possible at the beginning of the Ideation phase. The designer should pick some other Ideation techniques by the end of the Ideation phase to help the designer to investigate and test the designers' ideas so that the designer can find the best way either to solve a problem or to provide the elements required to circumvent it.

4.5.1 Access Product Design Ideations

The new console design is proposed to be positioned in between the rear seats and upon actuation it would move forward to provide individual workstations to all the 4 passenger seats as shown in Figure 18.

Retractable trays for four passengers are mounted on the console as shown in Figure 19 and this console can be operated by pressing the push-button for release of the console using spring push-pull self-locking mechanism.

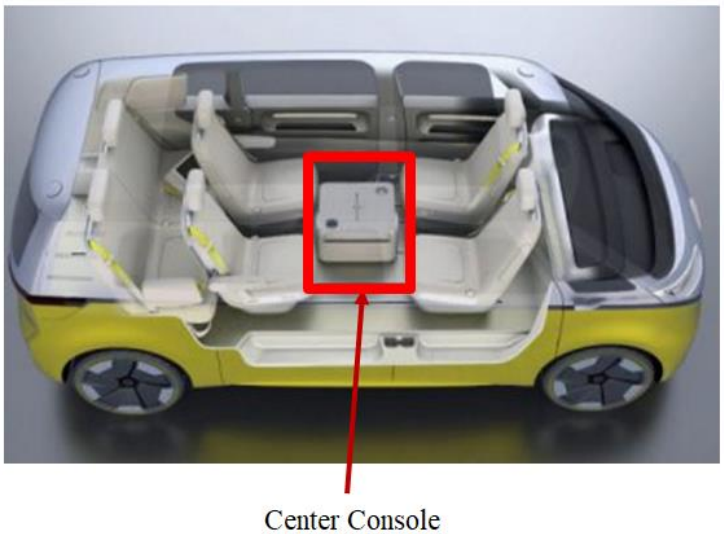


Figure 18. Moving console concept ideation [19]

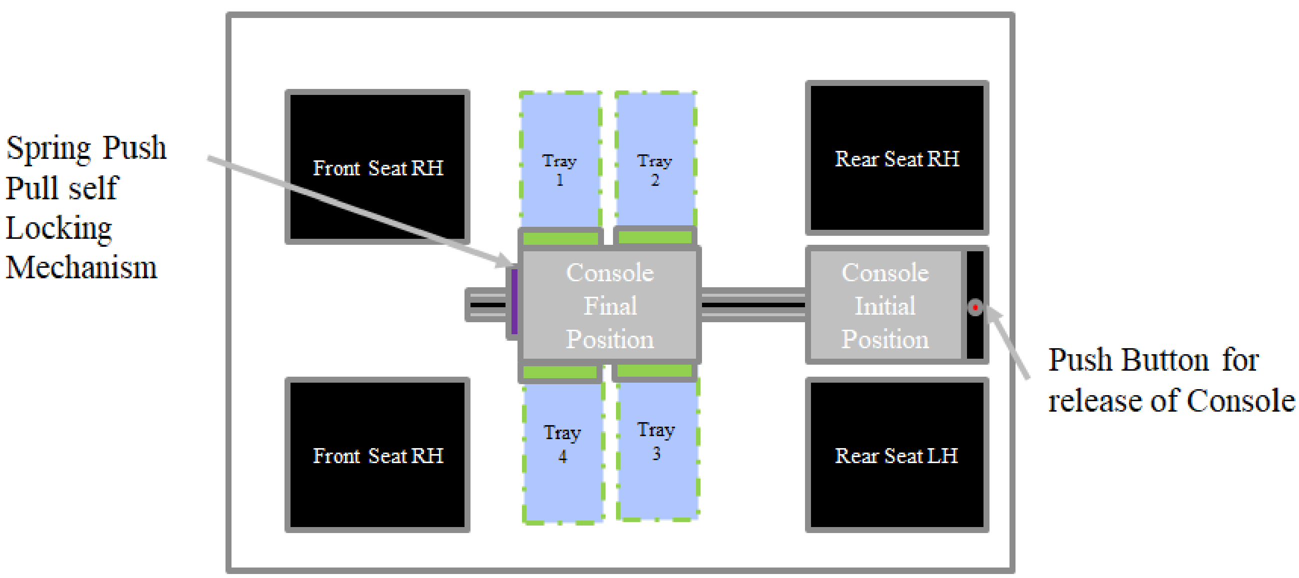


Figure 19. Console with deployable trays ideation

Our goal is to address the user problem through ideation to accommodate the concept console having retractable trays or re-configurable console as shown in Figure 20. The vehicle floor dimension is essential to provide a better access product. The overall floor dimensions may vary and it is depending on the prototype design and manufacturing implementation in vehicle-level testing and feedback for further improvements. In this study the overall measurement for interior floor has been taken from Honda Pilot to understand the basic measurements of the console which is intended to be housed inside the current spacious SUV segment in the market.

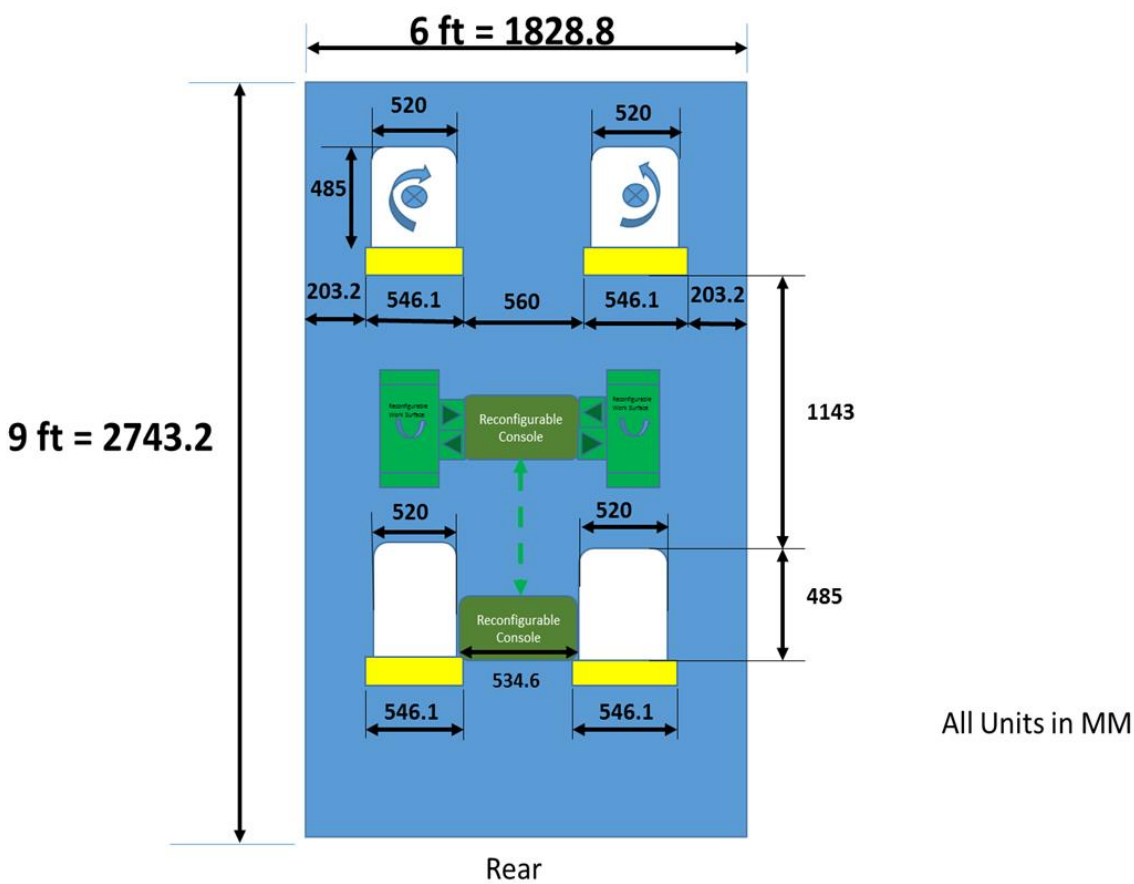


Figure 20. Interior floor dimensions of an SUV vehicle Honda Pilot for ideation

4.5.2 Basic Design Approach

- The console would be designed to be housed within the rear seats and locked in place through a push spring lock mechanism
- Once the button is pressed for the console release, it can be manually pushed to lock in the final position. The guided track will be provided for swift movement as shown in Figure 21
- Once it reaches the final position it will be locked through another push-pull spring lock mechanism
- The trays will be actuated manually or through mechanisms to lift and then placed in position without any obstructions to the user as shown in Figure 22.
- trays / Individual worksurface can stay at the position via gas struts or mechanical locks to ensure retain the ability
- Once used, the whole system can be retracted and reverted to the original position and locked

Figure 21. Track wheels for console motion forward

Figure 22. Retractable trays in an airline

4.5.3 Over All Deployable Worksurface Environment Free Hand Sketches

A hand sketch of the deployable worksurface environment with all the user needs is shown in Figure 23.

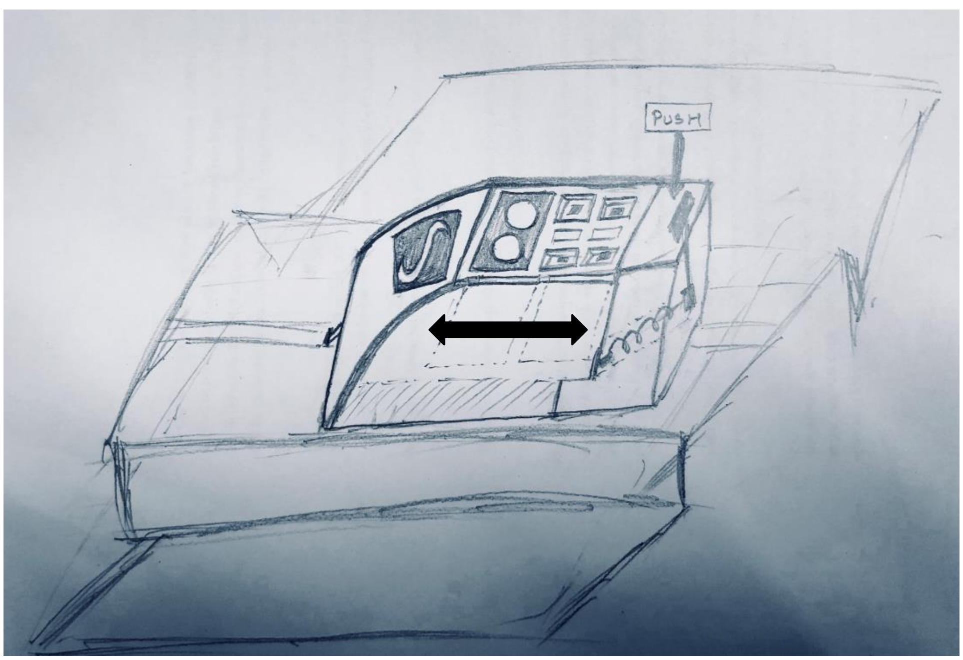


Figure 23. Initial freehand sketch-1 for deployable worksurface console ideation

The user’s needs such as worksurface, eating tray, display sharing screen, laptop mount, phone charging ports, cup holders, storage box etc. can be provided into the console as shown in Figure 24.

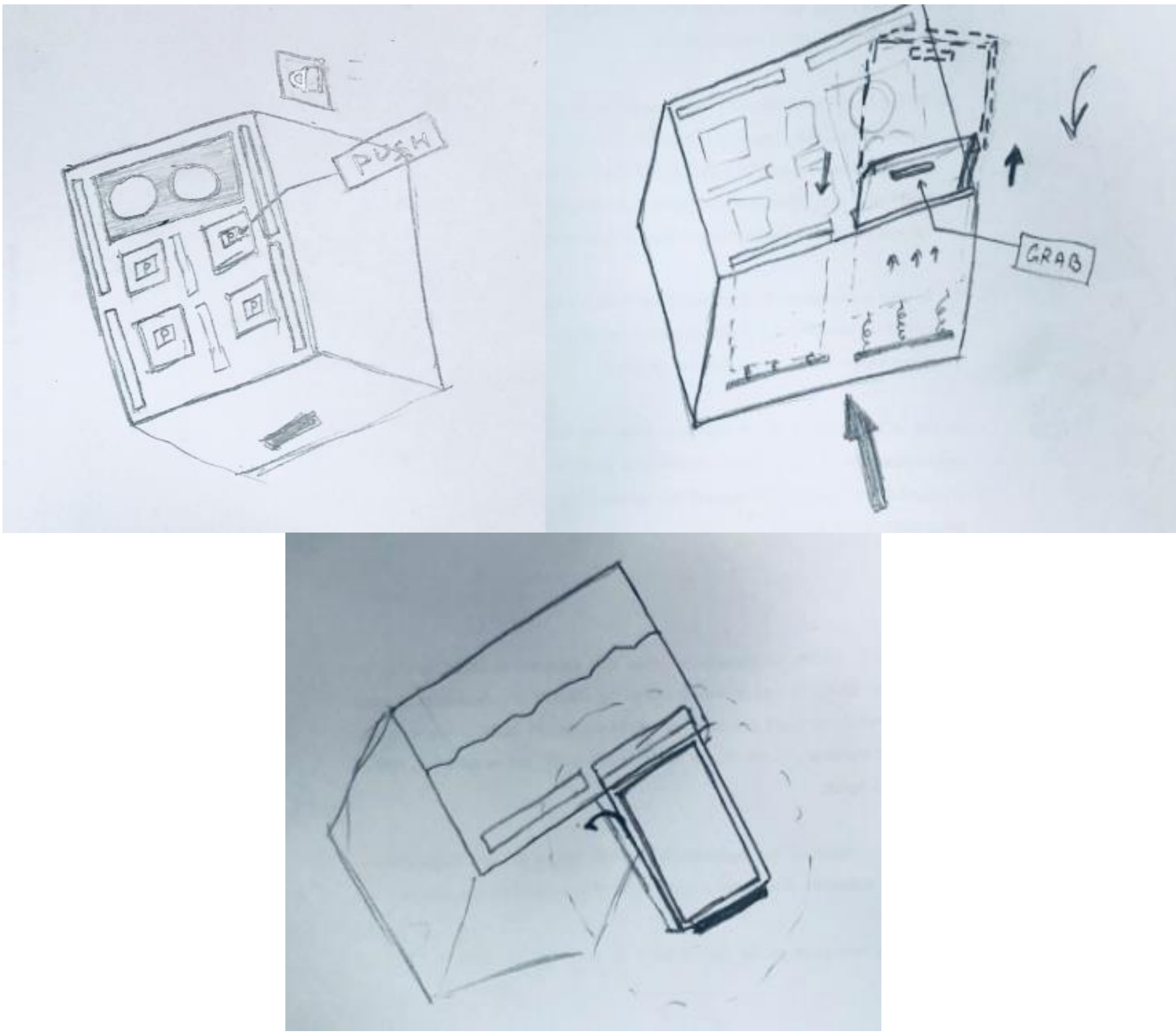


Figure 24. Console deploys worksurface ideation

The deployed surface has all features for comfortable eating with coffee holder and built-in screen display with keyboard for the users need as show in Figure 25.

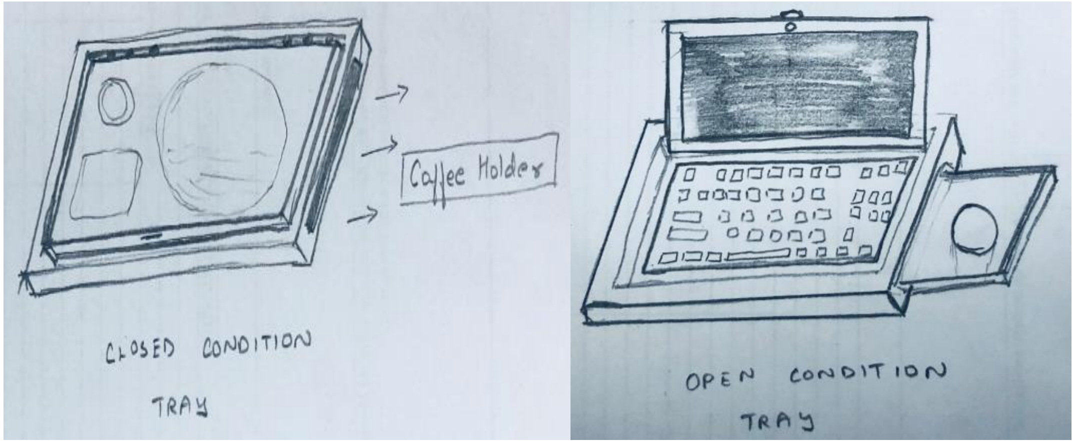


Figure 25. Worksurface platform proposed design ideation

The freehand sketch in Figure 26 shows the ideation for the user needs with respect to vehicle interior access product environment using external deployable worksurface console.

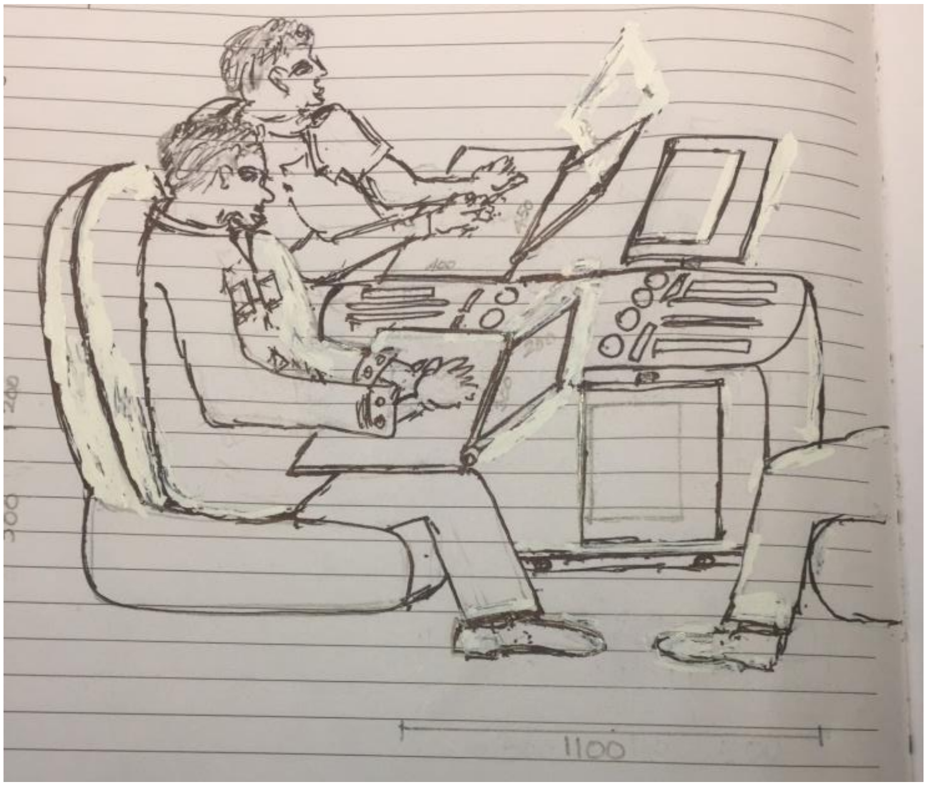


Figure 26. Overall deployable worksurface vehicle environment ideation

Hand sketches showing the measurements, mechanisms and exploded views that were ideated for external retractable worksurface are shown in Figures 27 to 31.

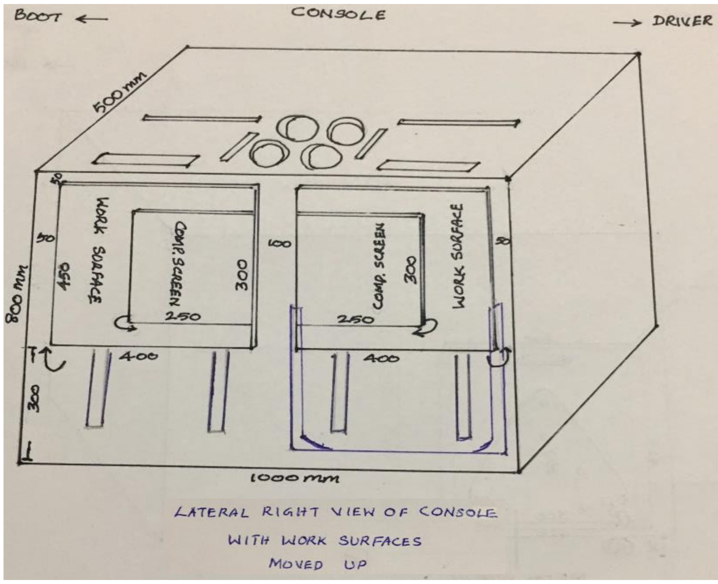


Figure 27. Overall external DWS console dimension ideation

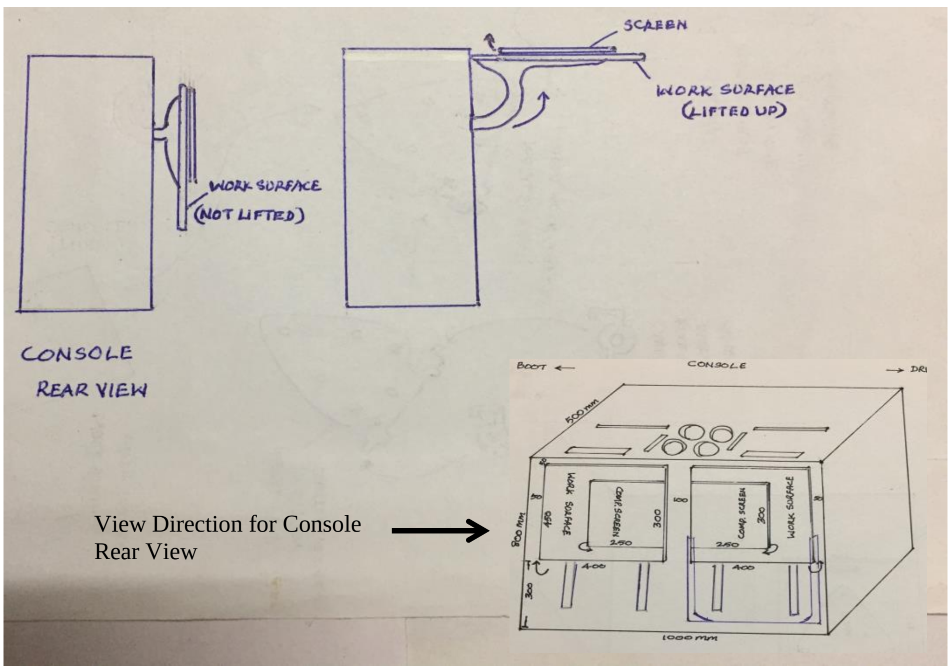


Figure 28. External deployable worksurface general mechanism ideation

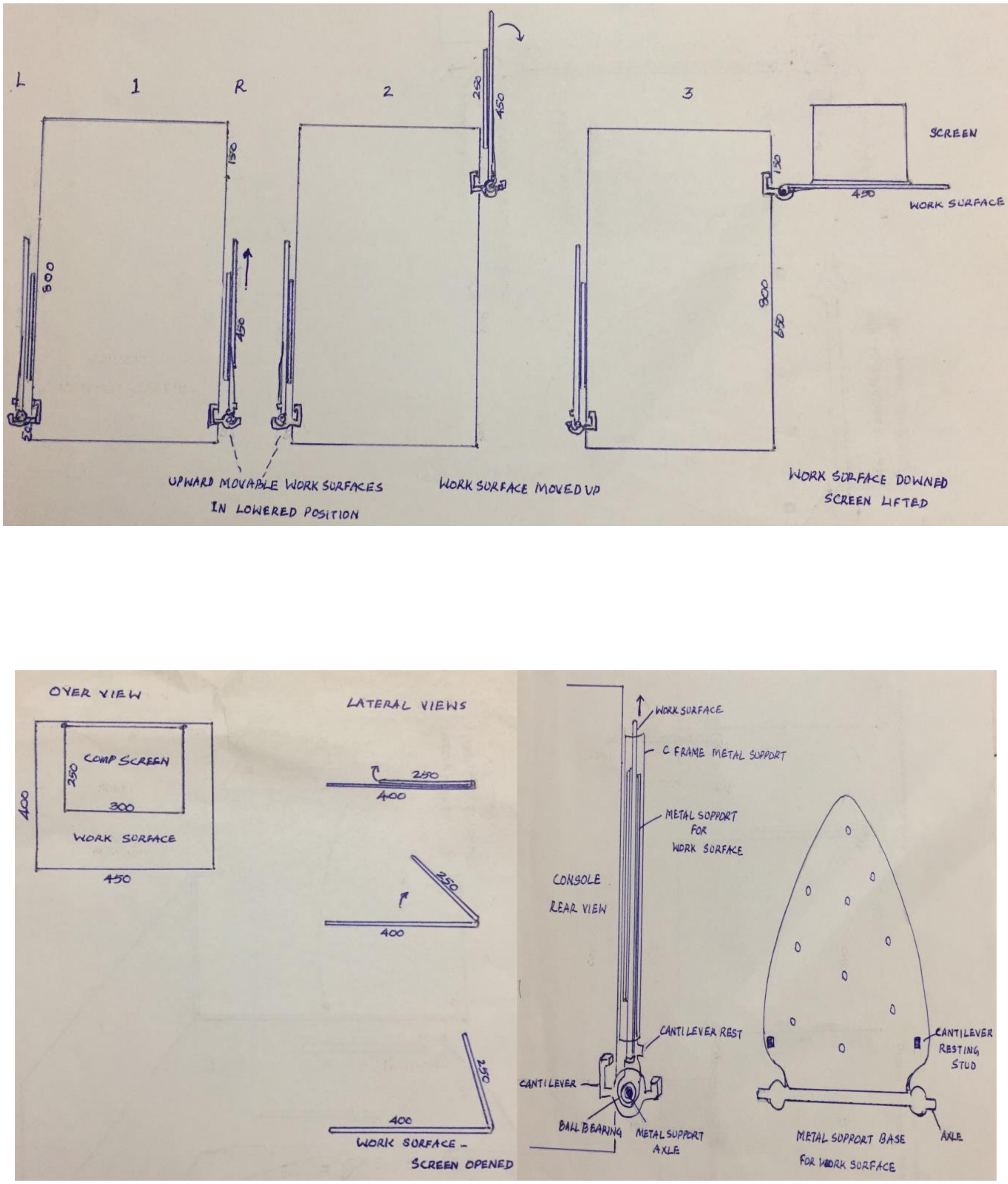


Figure 29. External deployable work mechanism ideation with dimensions

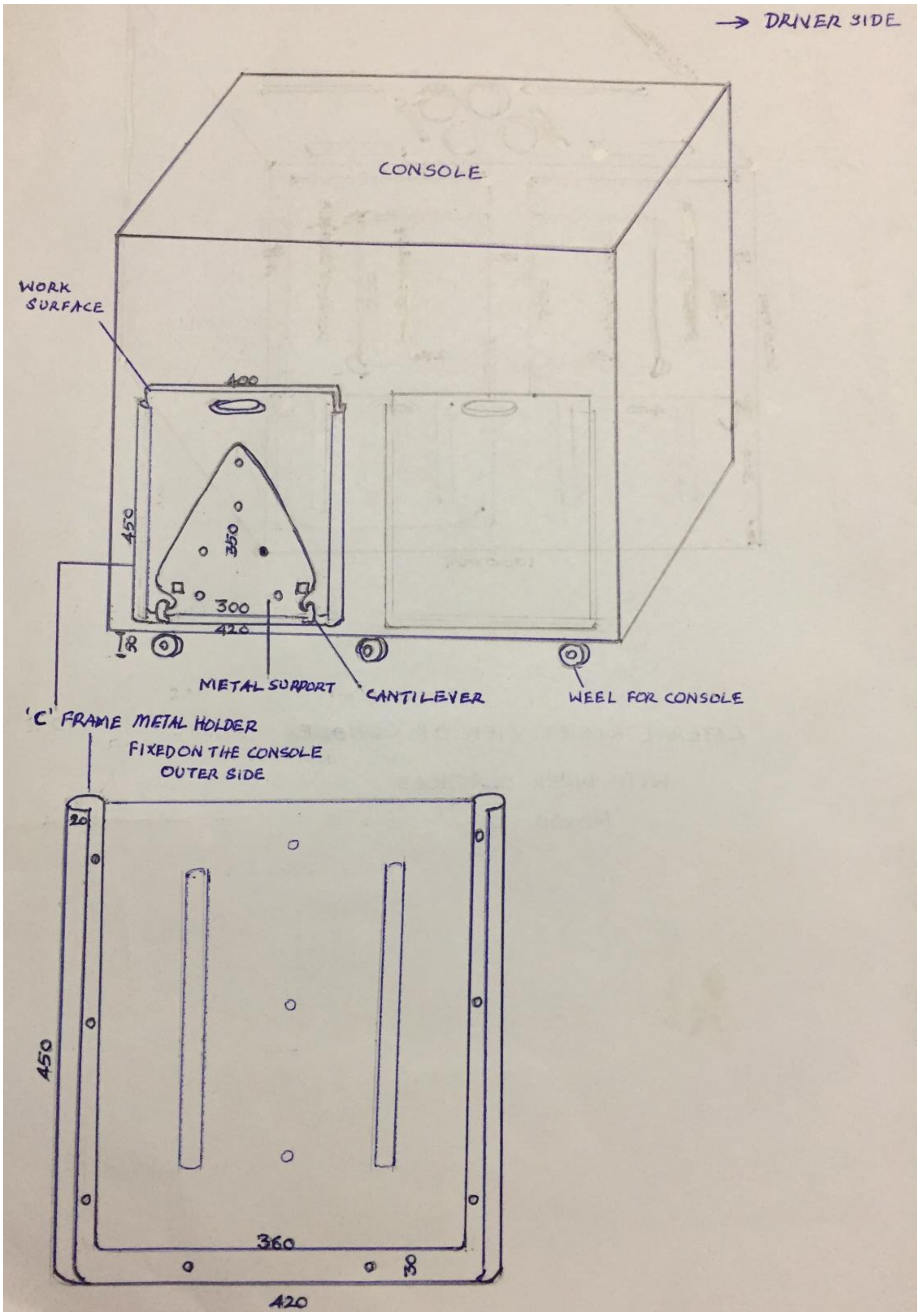


Figure 30. External deployable worksurface mechanism ideation detail

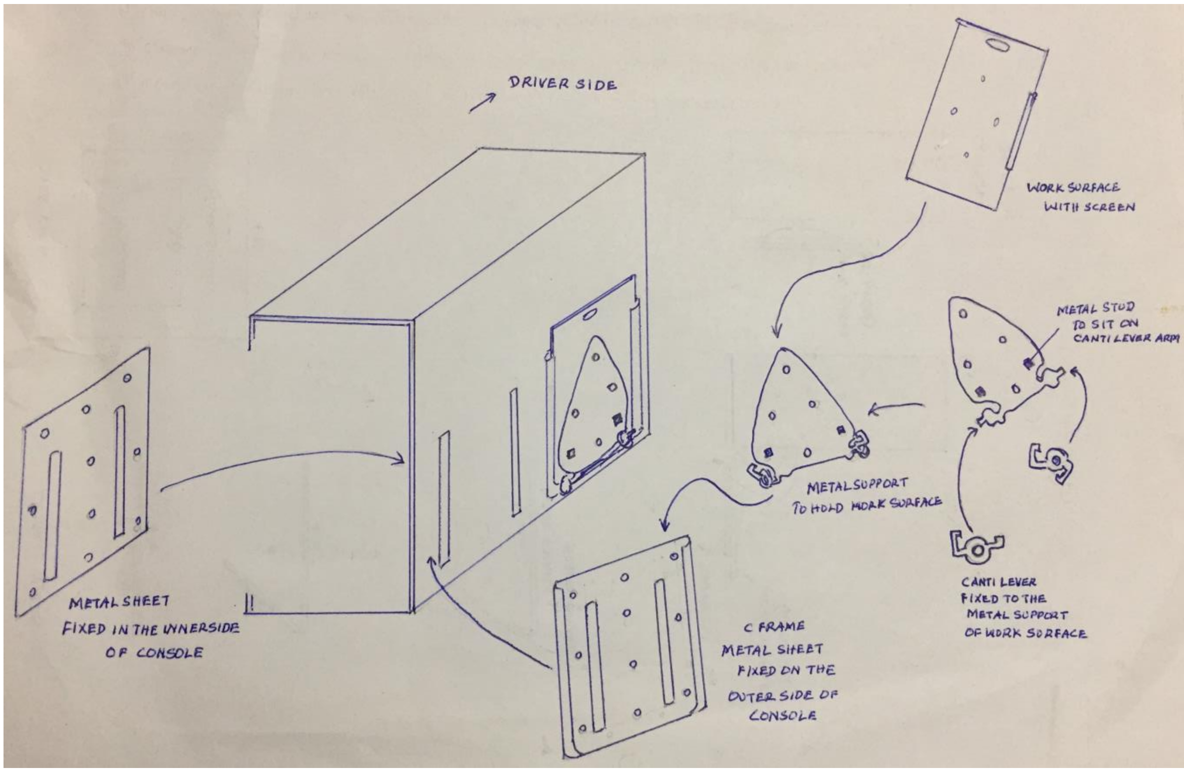


Figure 31. An exploded mechanism for external deployable worksurface ideation

4.6 Console External Deployable Worksurface Model Proof of Concept

The Console proof of concept is a quick prototype using foam board material. Using foam board prototype construction is an art of building a conceptual model to express the design features from the freehand sketches derived in the ideation process. The goal is to address the user needs in a 3D model of actual physical size. This proof study requires certain measurements in relation to the body parts of the user. H-Point (or hip-point) is the theoretical, relative location of an occupant's hip, specifically the pivot point between the torso and upper leg portions of the human body, as shown in Figure 32, is usually considered during vehicle design, and vehicle regulation as well for other disciplines including furniture designs as shown in the Figures 88-90 in Appendix-A.

While sitting on a car seat the H-Point for Large man = 343mm and Small woman = 241mm. The average of 292mm is taken as the H-Point and this measurement taken from the vehicle floor level is applied in adjusting to match the height of the console deployable worksurface. Similar measurements for leg stretching, hand stretching, torso and neck twisting and flexing also have to be considered to design the position of all utility features on the Console or on the worksurface to allow a comfortable bodily maneuvers for the user to access such features provided on the deployable console.

Some of the steps in the construction of a quick around proof of concept using foam board material are shown in Figures 32 to 34.

Figure 32. Foam board construction for proof of concept build

Figure 33. Foam board build based on ideation trials

Figure 34. Foam board model for console external deployable worksurface

Based on ideation, the foam board model for the console deployable external worksurface was created, constructed and critically studied for its suitability. It is learned that the external deployable worksurface may pose user safety issues to the user. However the foam board model construction has at least proved the practicability of the concept of a deployable worksurface. Hence it has been decided to package all the deployable external parts into the inner side of the console body to assure safety and a good Human-machine interface (HMI).

Having decided to package and place all the external components of the deployable worksurface mechanism a revised deployable worksurface mechanism has been conceptualized. After a detailed study and assessment of the requirements for the internally housed deployable worksurface mechanism, it has been decided to implement the revised concept based on 3D CAD software application with necessary mechanism bill of materials and by integrating both mechanical and electronic-electrical systems and thus a functional prototype has also been developed for the revised DWS mechanism.

5. DWS MECHANISM CONCEPT PRODUCT DESIGN

This chapter focuses on DWS concept design Mechanism development based on the design thinking process to address the extreme user needs by finding and understanding their needs through in-person interviews. Empathy on their issues has been gained after a deep insight understanding of their issues. Employing HMW format their issues have been identified and defined as a problem statement to search for a solution to the problem. This exercise has given rise to the DWS mechanism concept product. The foam board modeling of the concept prototype with the DWS concept mechanism mounted externally on the console has revealed certain safety issues. Hence the DWS mechanism concept product design has been revised by shifting the DWS mechanism to the inner side of the console. It was decided to import 3D CAD software and necessary machinations for the DWS concept.

5.1 DWS Mechanism Concept Mechanical Design Technical Overview

Feasibility studies with respect to space constraint for positioning the DWS mechanism inside the console, generation and studying multiple concepts to meet the exact defined point of view, basic calculations of the motor torque and speed of the mechanism, listing of required engineering items, identification of suppliers for the required standard bought out items, CAD application for designing the concept DWS, necessary drawings for the components of the DWS mechanism, and determining the assembly line were all carried out as shown in Figure 35.

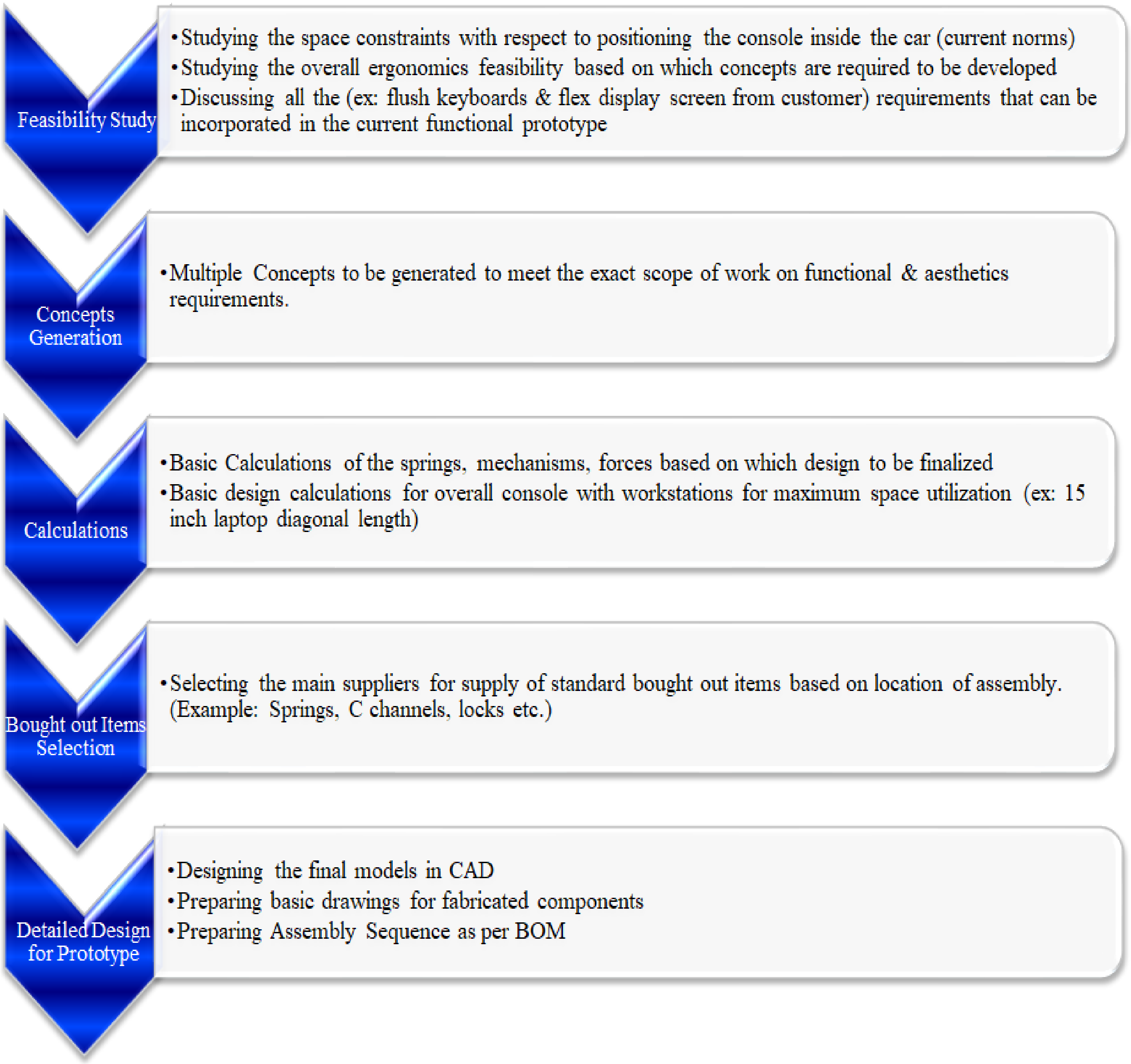


Figure 35. DWS mechanism design flow chart

5.2 Mechanical CAD Initial Conceptualization

3D CAD development is crucial for concept design visualization. Using Creo 4.0, the entire CAD assembly model has been developed by performing feasibility studies to derive the suitable console height for fitting into the spacious vehicles as shown in Figure 36-38. This DWS mechanism concept is designed for accommodating the DWS mechanism both in the current model of SUVs and the future generation of autonomous versions.

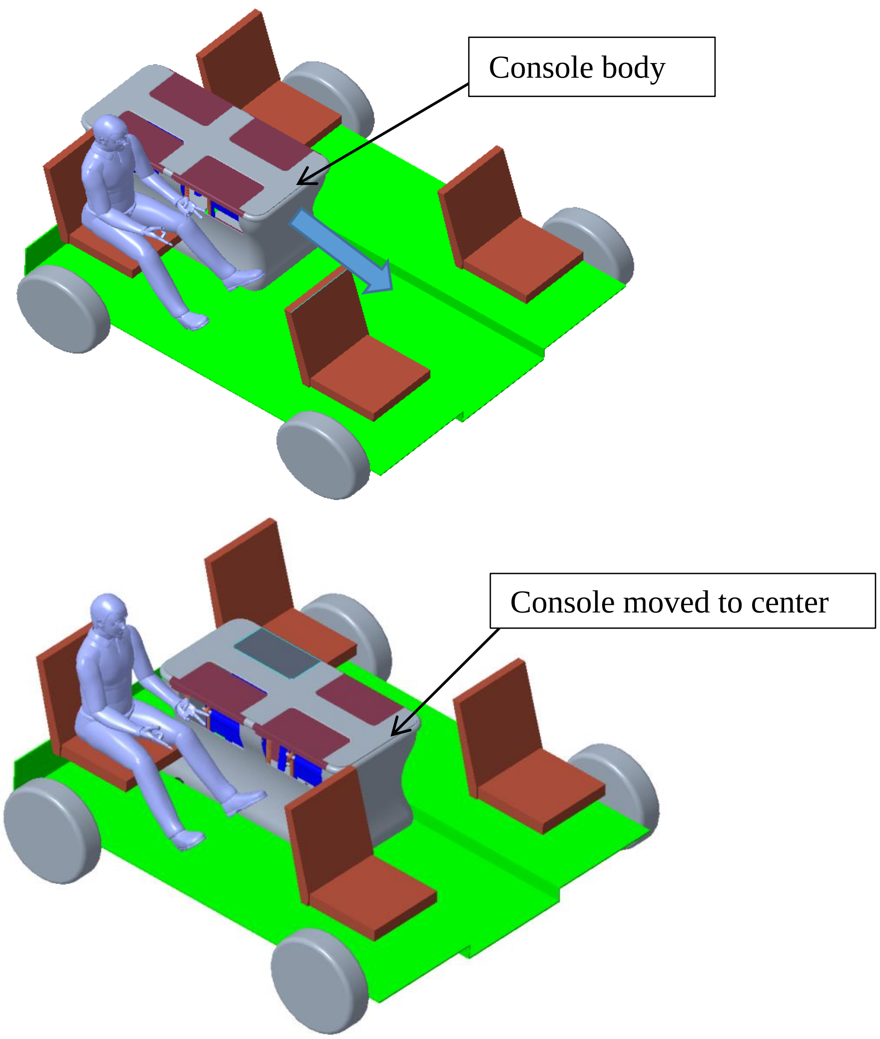


Figure 36. Console space feasibility analysis using CAD Creo 4.0 modeling

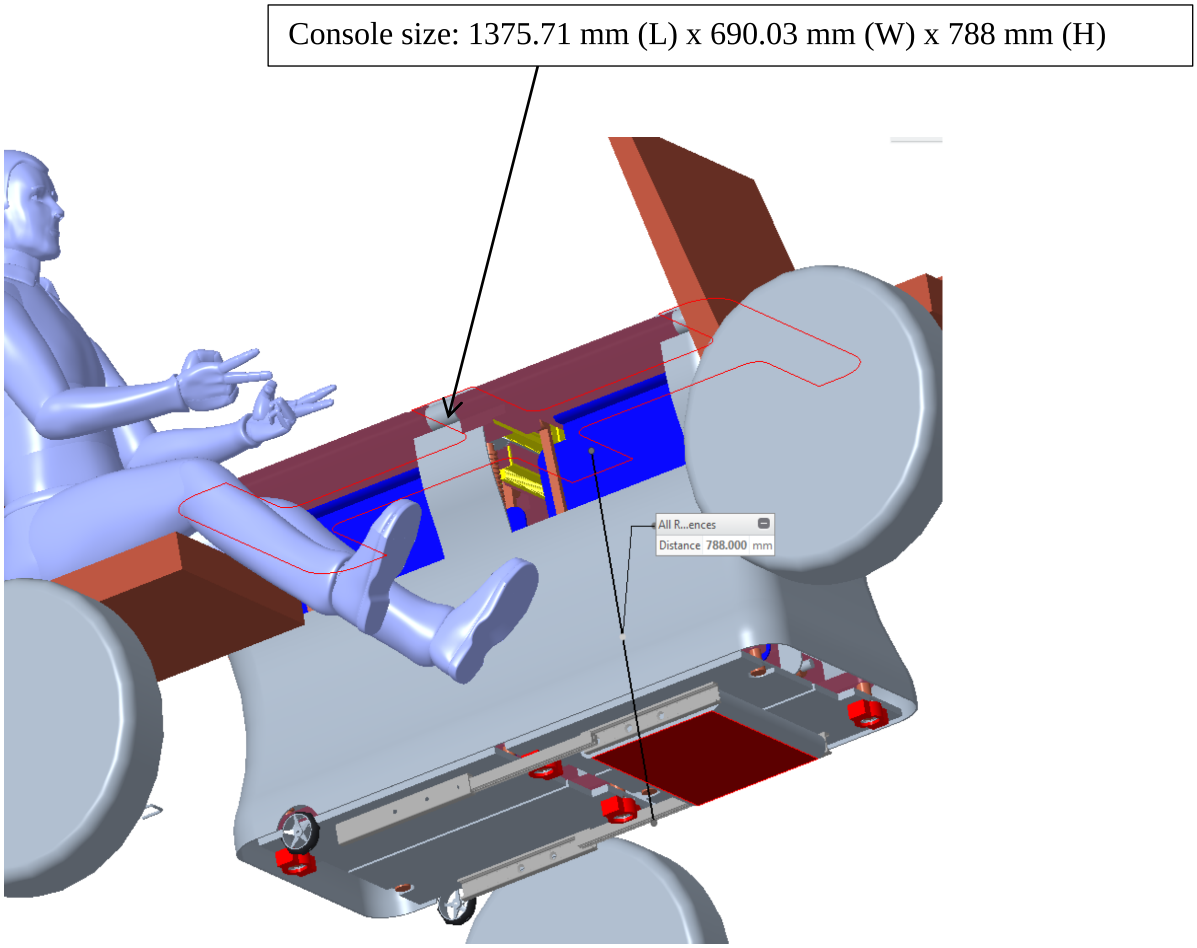
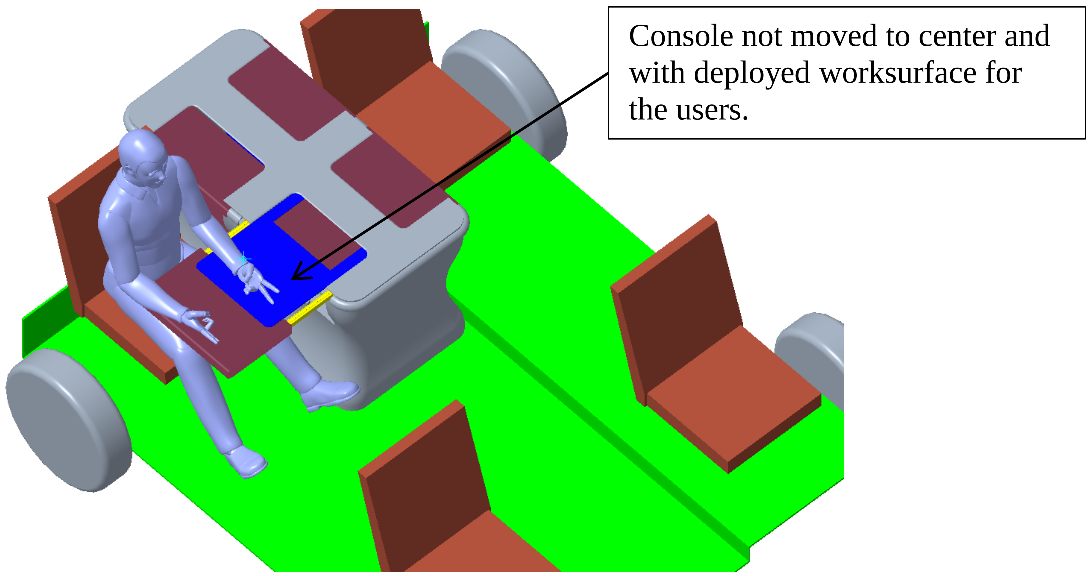


Figure 37. Console size positioning using 3D CAD modeling



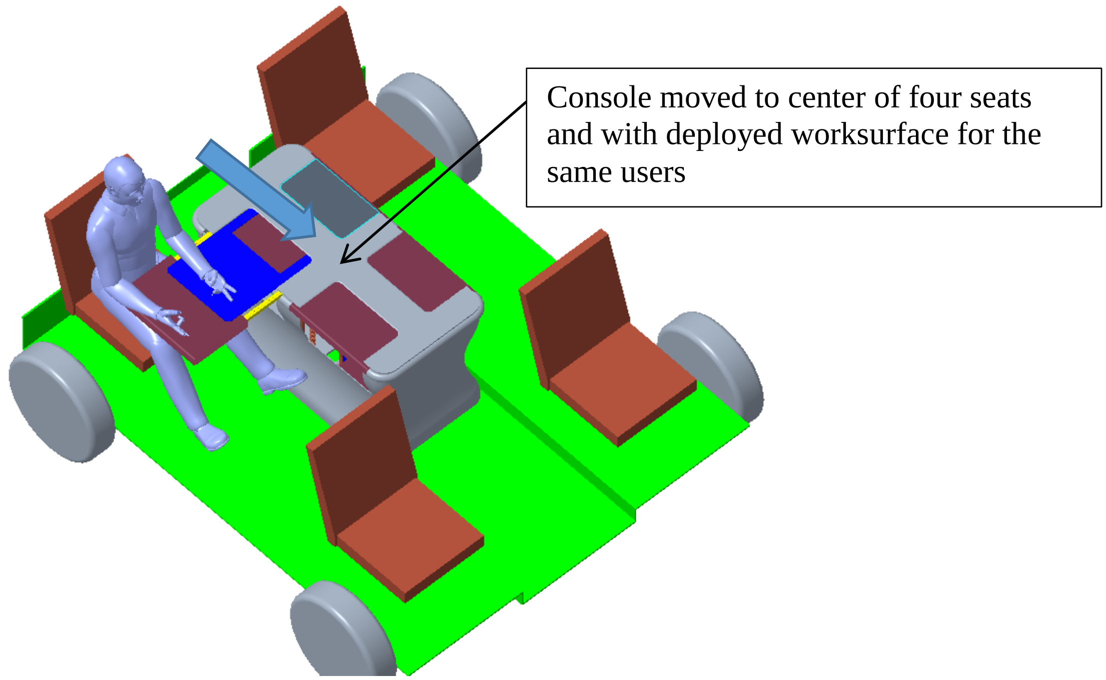


Figure 38. User easy access for the deployed worksurface

Space constraints studies with respect to positioning the console inside a vehicle was made by considering a spacious SUV type vehicle wherein around 6 passengers can travel as shown in Figure 39. CAD modeling of DWS mechanism and positioning of various features on the console were generated after detailed ergonomics feasibility studies. These ergonomics concerns were addressed based on the measurements shown in Figure 40-41. Some of the user required features have been incorporated in the DWS mechanism prototype as shown in Figure 42.

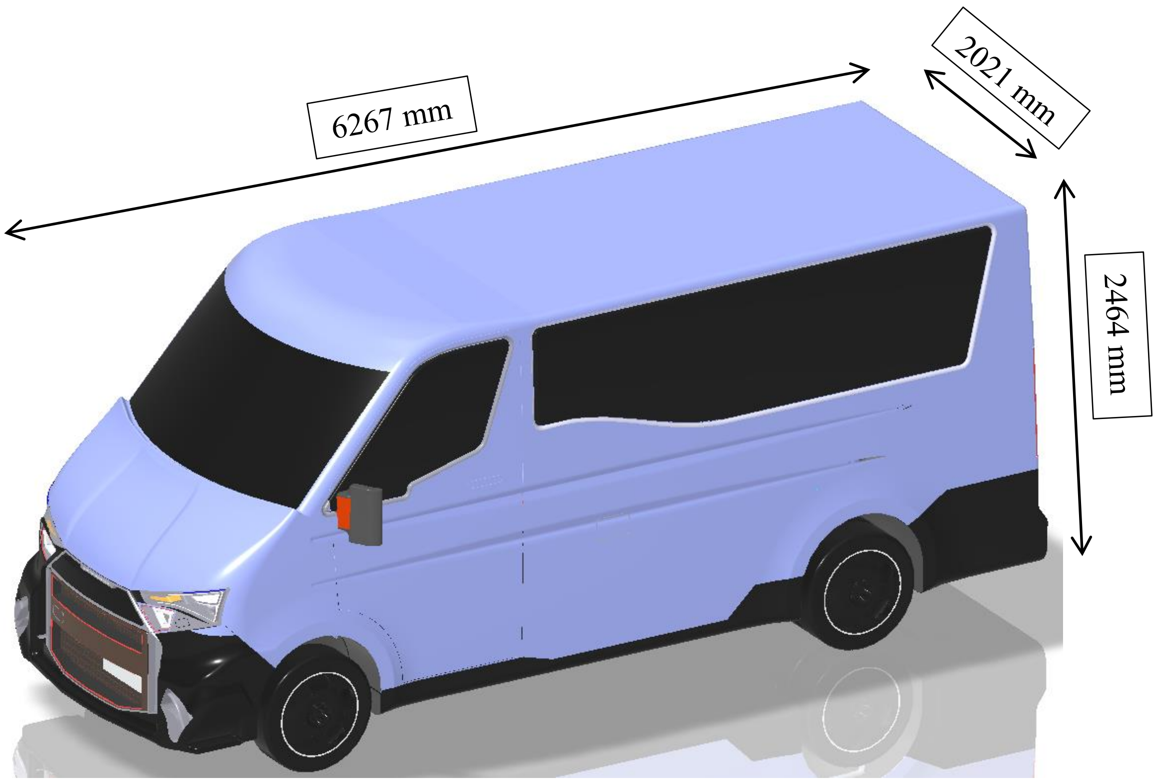


Figure 39. Vehicle 3D CAD modeled after feasibility studies

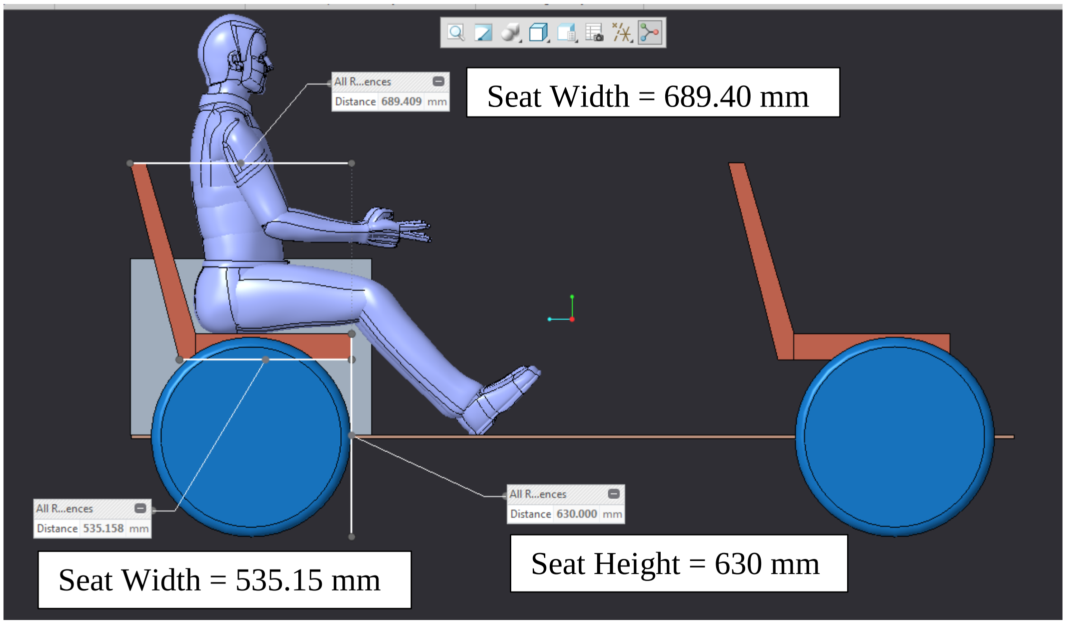


Figure 40. Ergonomic 3D CAD model dimensions for seat height & H-Point [20]

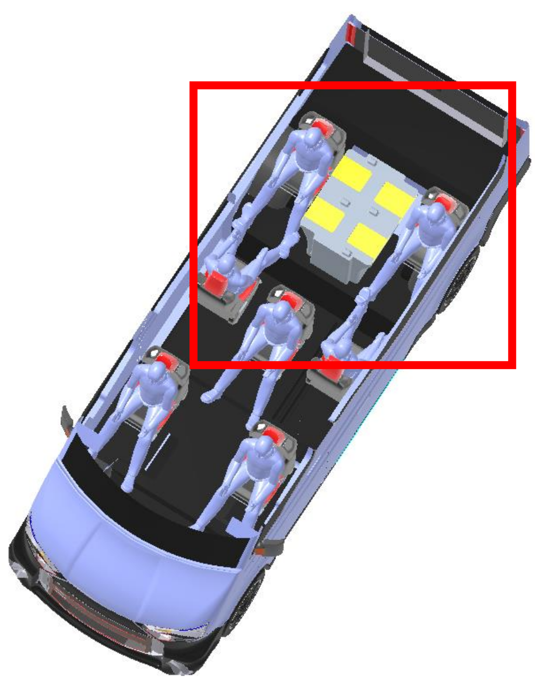


Figure 41. Rear side console with worksurface mechanism concept model location

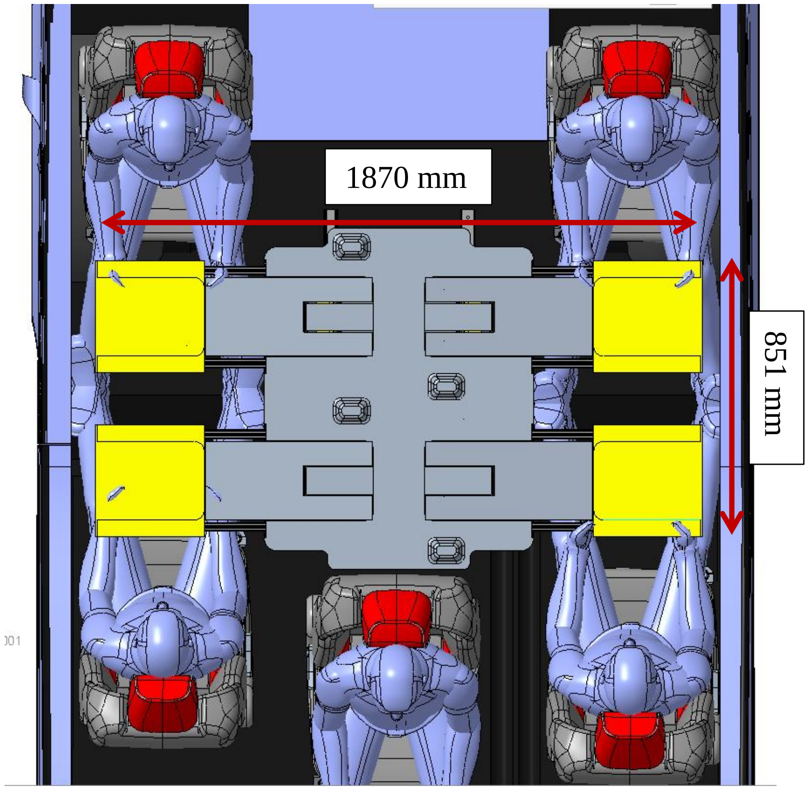


Figure 42. 3D CAD model Console with deployed worksurface for user's access

5.3 DWS Mechanism Product Concept Design & Development

Deployable worksurface mechanism concept has been designed using the 3D CAD application software Creo 4.0 for its modeling, assembly and kinematic motion. The initial focus is to complete the feasibility study for the DWS mechanism, for its proper fit, form and function. A sliding power motion product called the deployable worksurface, shown in Figure 43, has been conceived for use in the feasibility studies.

This sliding power motion worksurface was mounted inside the concept console as part of the DWS concept product. This DWS mechanism is provided with many connecting parts to accomplish the sliding mechanism. A power sliding deployable worksurface sketch has been developed using CAD modeling techniques. An optimized sliding mechanism sketch was derived and further the sketch has been extruded to make the 3D CAD assembly model, as shown in Figure 44.

Figure 43. DWS power sliding mechanism assembly concept product design

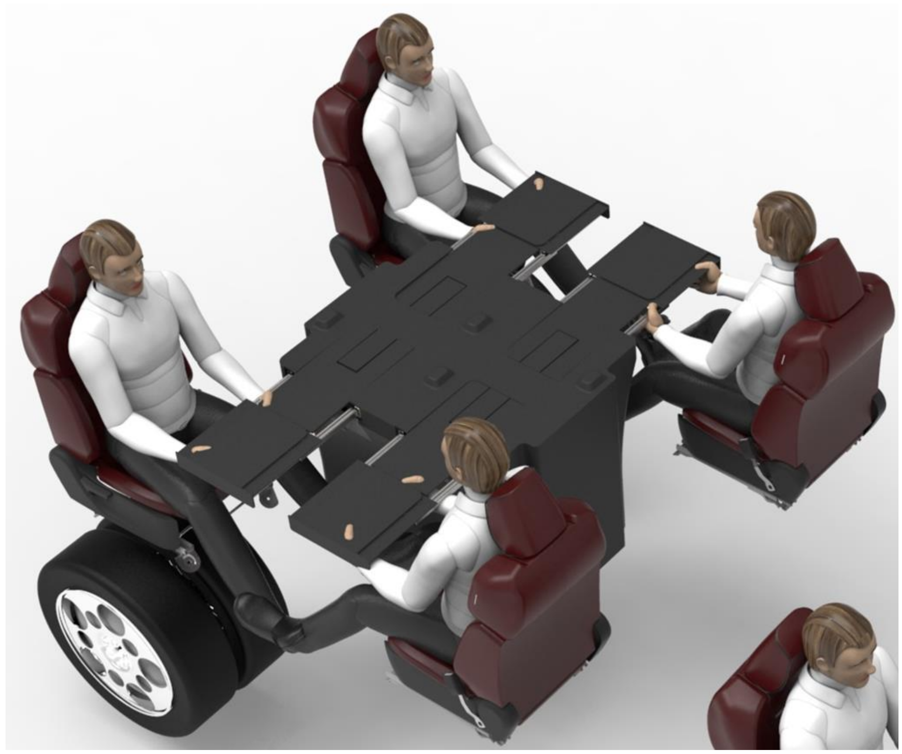


Figure 44. 3D CAD model developed for the console with DWS mechanism product

5.3.1 DWS Mechanism Product CAD Concepts

Multiple concepts have been generated to meet the exact user needs, with functional and aesthetic requirements, for better interior access for with the following criteria and features:

- The initial position of the console is located between rear seats.
- The console is kept locked in its initial position
- The console is moved electrically on rails towards the center of the vehicle
- Center of the vehicle is the final position and the console is locked in this position
- 4 Coffee mugs holders, mobile holders, pen stands are provided on the top of the console

- 4 Individual trays or worksurfaces are provided for each seat user
- Each tray is designed for variable height
- The trays are positioned inside the console and electrically opened by the user
- Each tray has a turnaround display screens for viewing by other users
- The display screen is collapsible
- The screen on collapsed will be a flat tray for food serving, reading etc.
- USB ports & charging ports are also provided on the tray

5.3.2 Console Initial Positioning & Movement – Concept Approach

One of the concepts generated was to regulate the movement of the console. The console has to be kept locked in between the rear seats and on releasing the lock it will move to the center of the vehicle where it will be locked again till this lock is released to allow it to return to its initial place. Hence a study on such locking mechanisms was conducted on various types of door latches in the market and on their mechanism to identify suitable latches as shown in Figures 45.

The design proposition for choosing such a latch is to have a lock that will release the console once the user presses the console motion switch as shown in Figure 46. This motion control switch will allow the user to command a forward or return movement of the DWS mounted console.

The DWS mounted console will be making its movements on concealed rails as shown in Figure 47.

Figure 45. Mini lockings for the interior [21]

Figure 46. Console forward and backward motion switch [22]

Figure 47. Proposed rails for console movement

5.3.3 Deployable Worksurface Opening – Concept Approach

Once the console is moved to the desired location and locked the individual worksurface tray can be accessed by the user through a power windows switch as shown in Figure 48. This switch will enable the user to command a sliding up or down movements of the tray worksurface as shown in Figure 49.

Figure 48. Power window switch actuator

This power window switch was chosen for its potential that it could deploy the trays up and down and could also keep the tray staying at the required position as shown in Figure 50.

Figure 49. Power window switches for worksurface opening

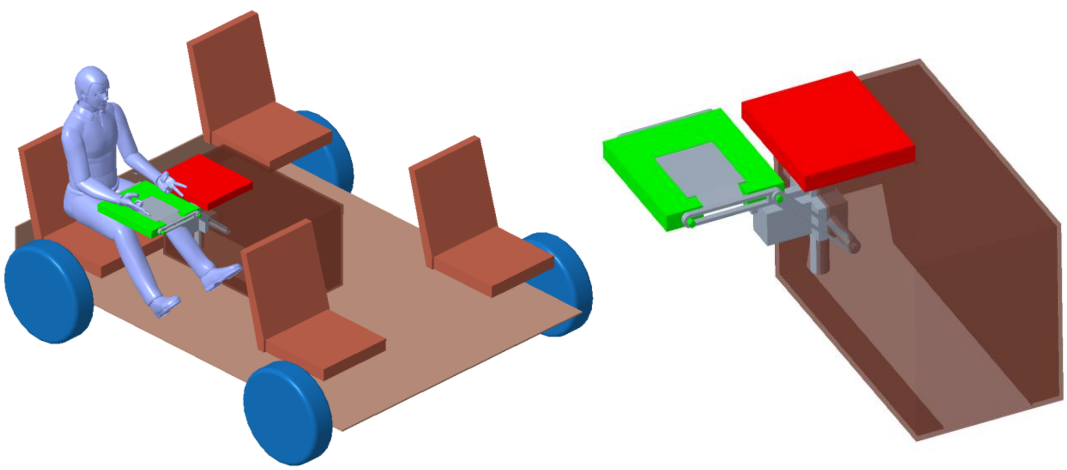


Figure 50. Initial deployable worksurface opening concept

The finalized 3D CAD concept model has been rendered to reflect the actual console outlook as shown in Figure 51. Inside the consoled four deployable work mechanism power sliding mechanism products are assembled as shown in Figure 52. These worksurfaces in an extension position are shown in Figure 53 and Figure 54.

Figure 51. Console with DWS mechanism 3D CAD model concept product developed

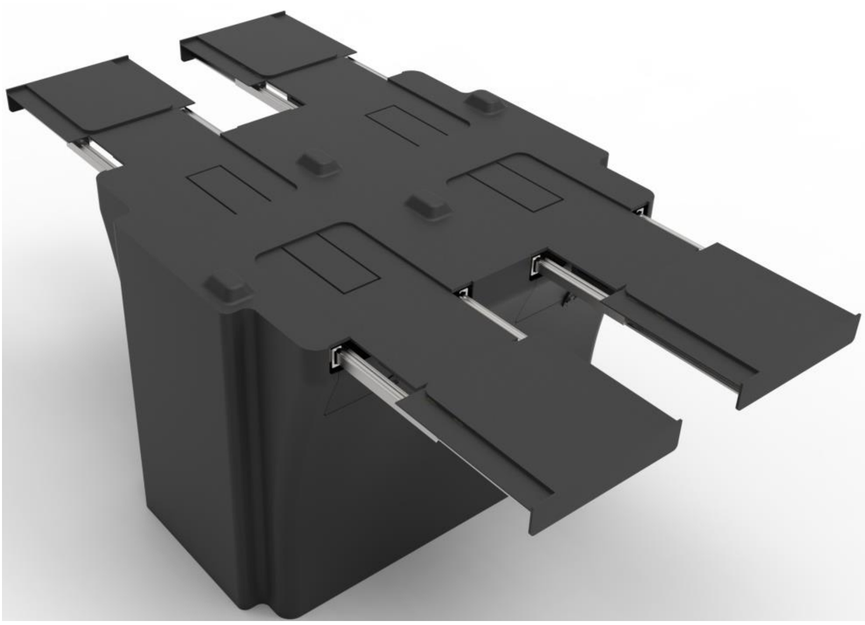


Figure 52. Reconfigurable and deployable worksurface console model

Figure 53. DWS mechanism concept product design model - bottom view

Figure 54. Power sliding mechanism deploying worksurface position

5.4 DWS Mechanism Product Concept Design Assembly Structure

The reconfigurable and deployable worksurface mechanism concept designed model contains 22 mechanical components as shown in Table 10 under Appendix- B.

The creation of the parts of the sliding worksurface was the initial step in the mechanical system design concept for the re-configurable DWS followed by integration with electrical and electronic systems for closed feedback control. The detailed part numbering call out for the mechanism's main assembly structure bill of material is as shown in Figure 55-56 and the exploded view of the complete mechanism structure is as shown in Figure 57.

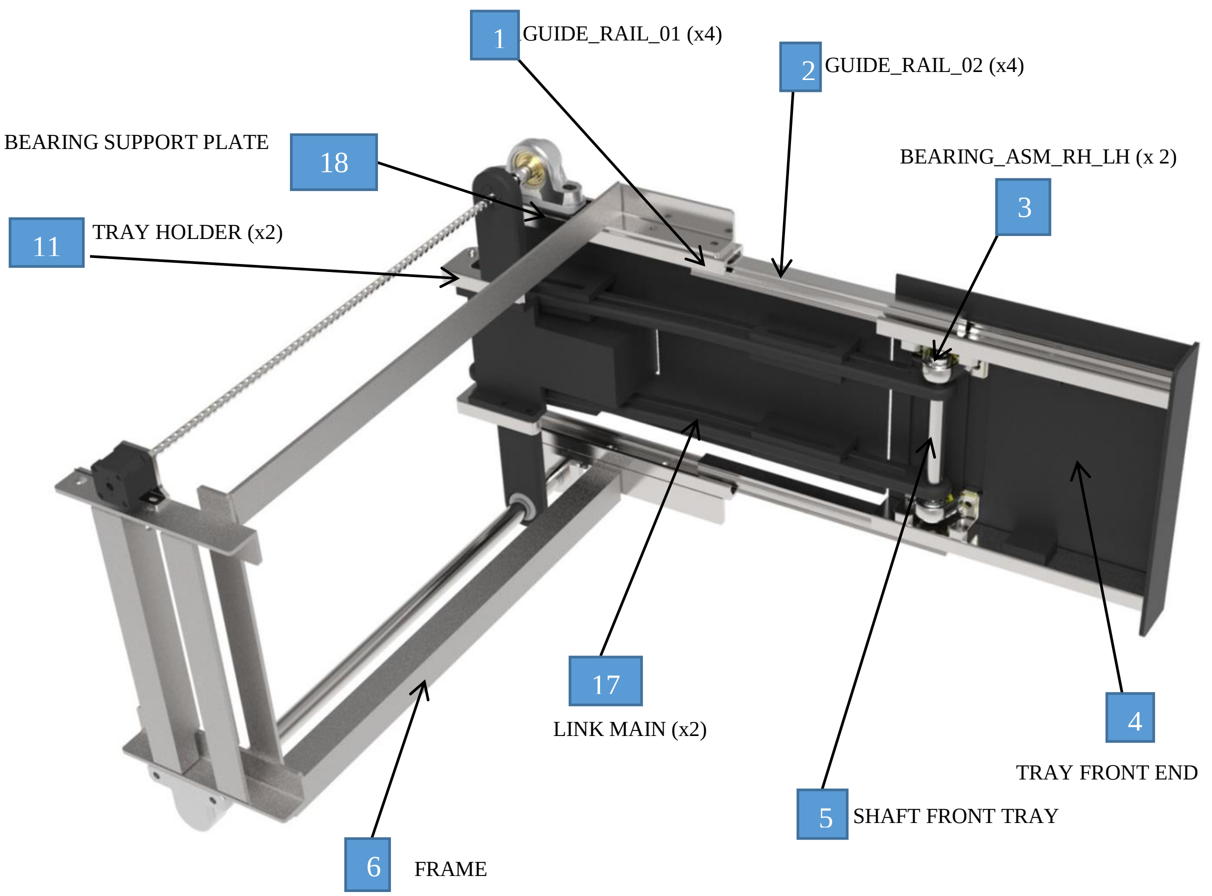


Figure 55. Component detail for DWS mechanism assembly bottom view

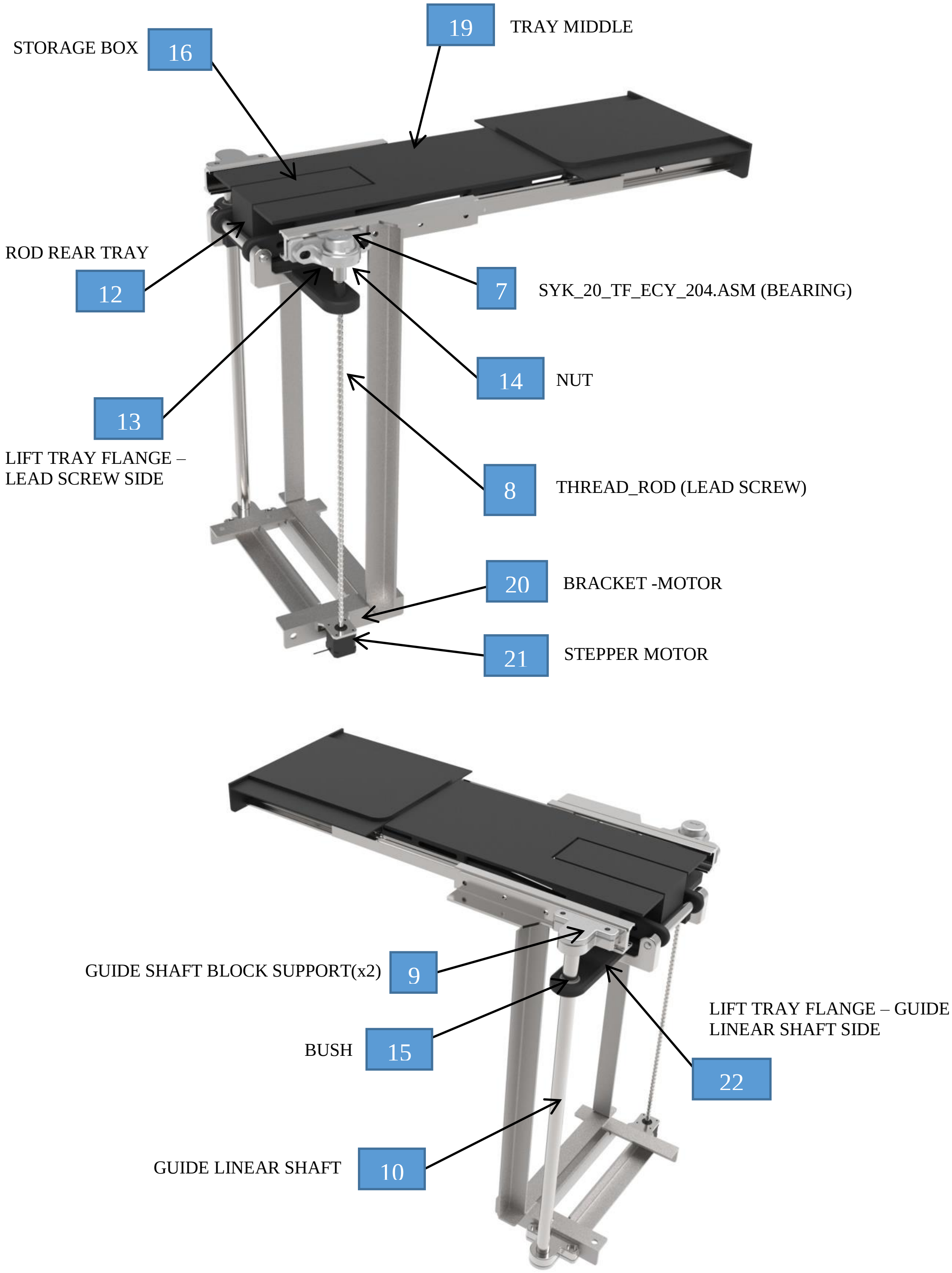


Figure 56. Component detail for DWS mechanism assembly isometric views

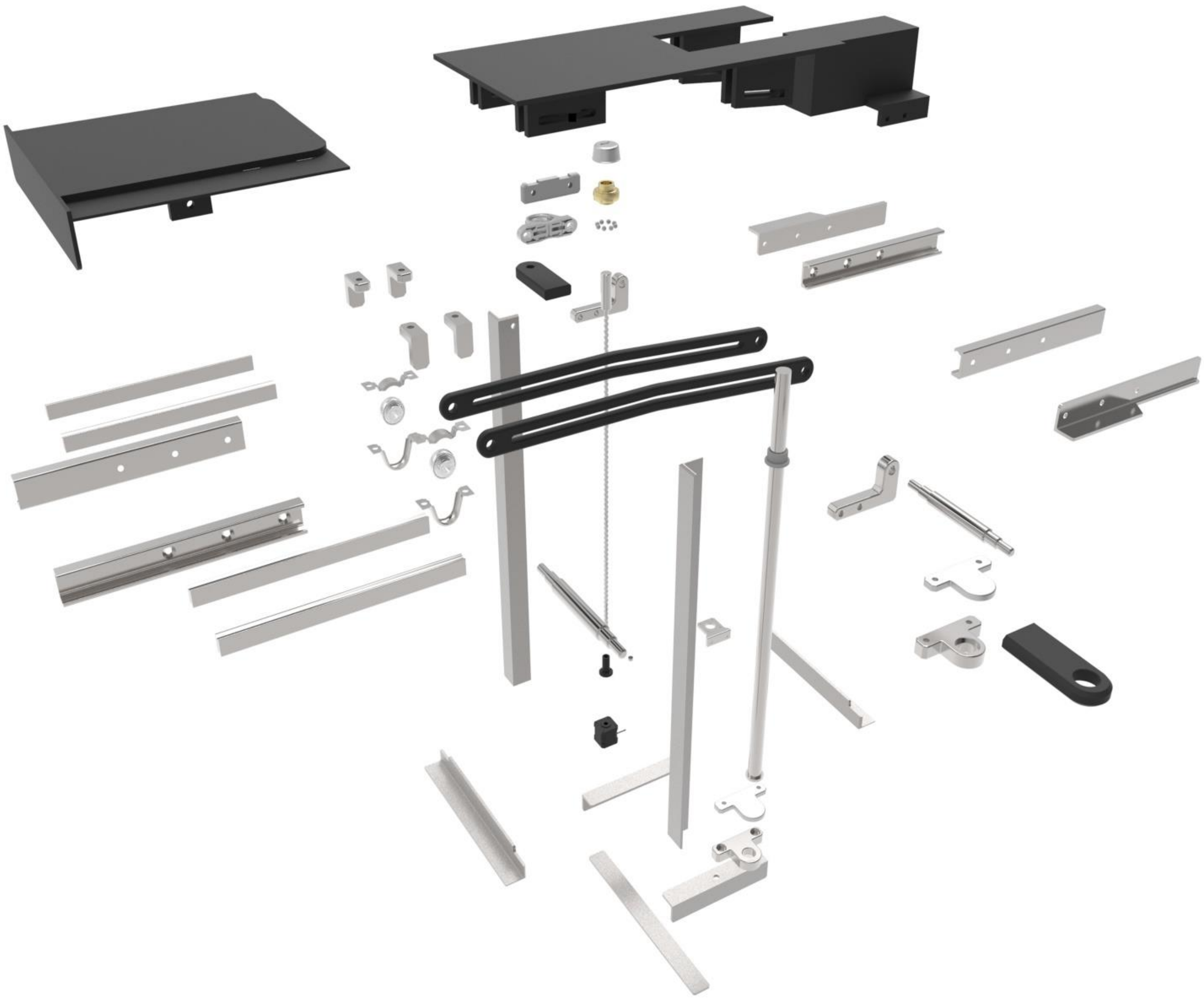


Figure 57. DWS mechanism assembly exploded view

5.5 Mechatronic Concept Design Technical Overview

The completed deployable worksurface (DWS) mechanism is a mechanical system concept designed model having an actuator (stepper motor) and sensors (limit switches). The stepper motor produces motion and causes some action; the limit switches detect the state of the DWS mechanical system parameters, inputs, and outputs; the digital devices (Arduino microcontroller) control the system; conditioning and interfacing circuits (Schmitt trigger inverter Filter IC and motor driver) provide connections between the control circuits (Arduino microcontroller) and the input/output devices; and graphical displays provide visual feedback to the users.

5.5.1 DWS Mechanism Product Concept Mechatronic Architecture

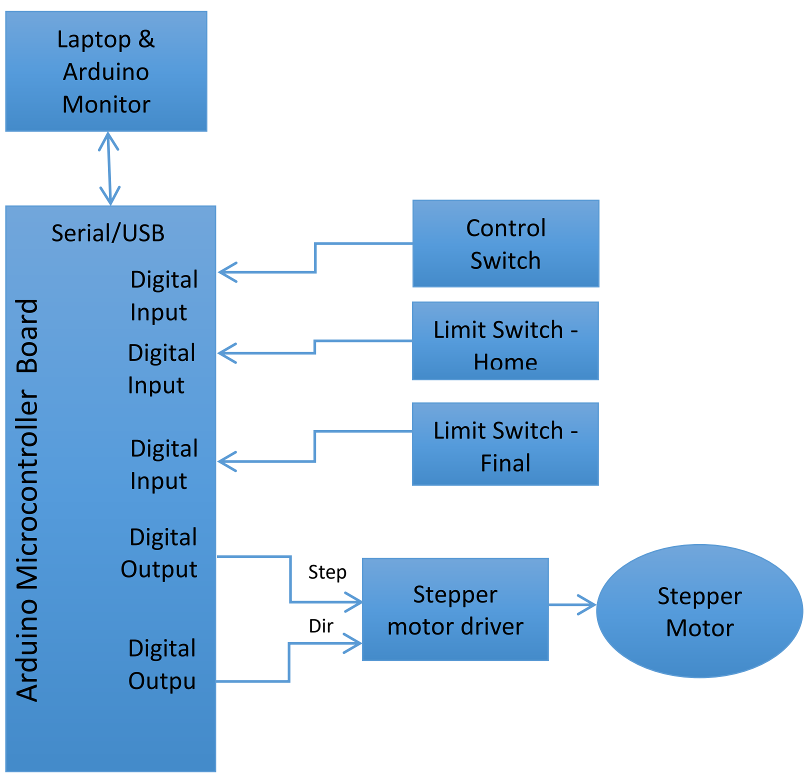


Figure 58. DWS mechanism mechatronic block diagram

5.5.2 DWS Mechanism HW Wiring Schematics

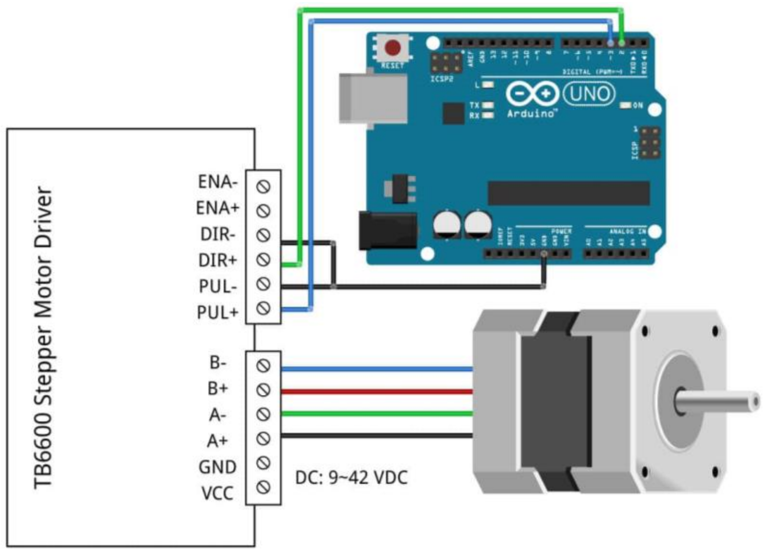


Figure 59. Wiring schematics for motor driver, motor and microcontroller

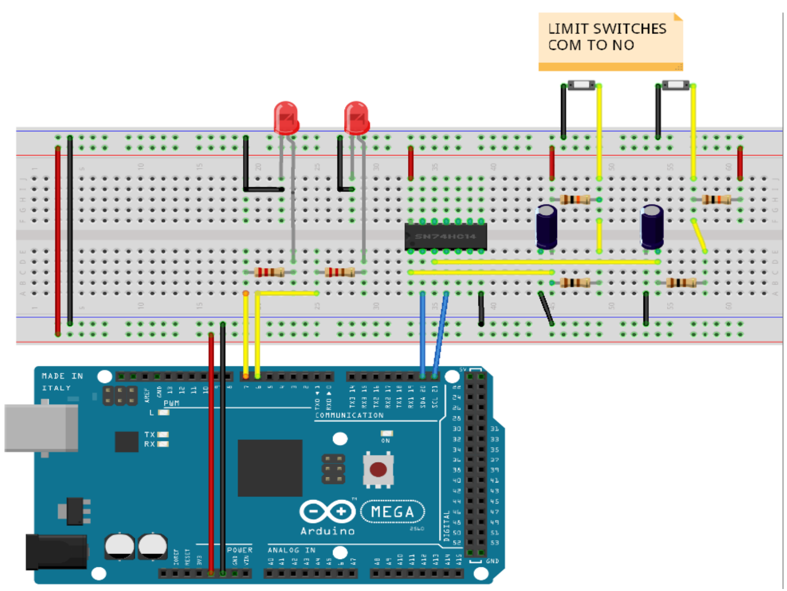


Figure 60. Wiring connections for limit switches with debouncing circuit

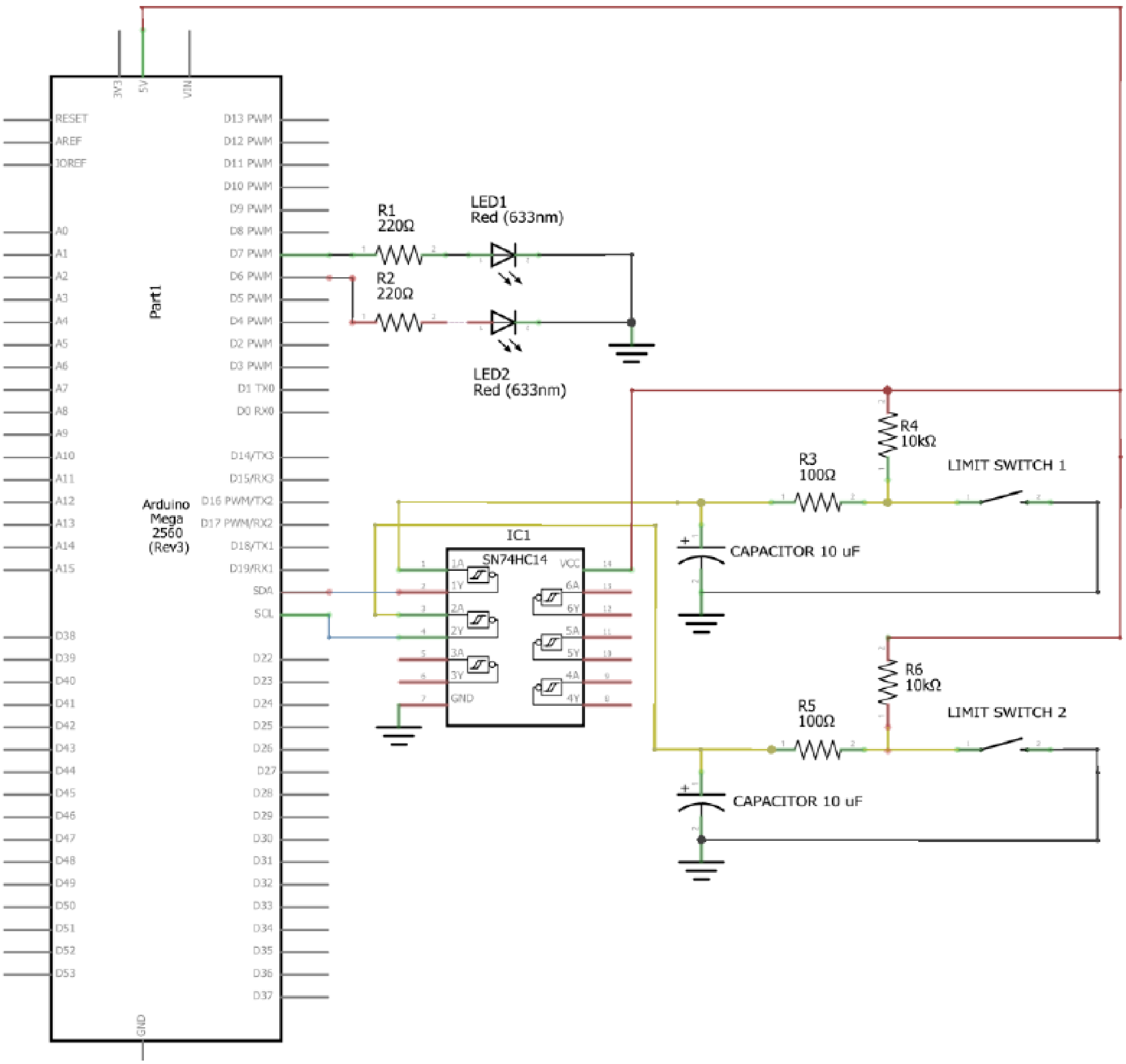


Figure 61. Wiring schematic for limit switches with debouncing circuit

5.5.3 DWS Mechanism Motor selection

Finding a suitable motor for this DWS mechanism is an important task because it is an advanced development product (ADP) used in an automotive vehicle interior. For this prototype a compact linear stepper motor has been chosen for its compact size, lightweight, low cost, high torque up to 22 oz-in at low speed, low vibration, accurate in positioning and actuation, high step accuracy and high resolution than other DC brushless motor types of 12 Volt DC in the market. The stepper motor selected from LIN Engineering for this concept would be subjected to testing and validation to qualify fit for the automotive product DWS mechanism. The stepper motors generally do not include a lead screw shaft position sensor for the internal feedback of the rotor position. Instead a stepper controller will rely on a sensor to detect the position of the driven DWS mechanism because it is frequently stopped with the rotor in a defined angular position while still producing torque.

The stepper motor size should be fit into the available room space of 84 mm (L) x 65 mm (W) x 65 mm (H) of the DWS mechanism product as shown in Figure 62. The lifting torque = 192.805 N-mm has been calculated for the DWS mechanism concept product. A suitable stepper motor has been considered. Considering the mass of the worksurface a design torque = 385.610 N-mm was arrived using the mass calculation as shown in Table 5. The design is having a Lead screw of 10mm dia. The stepper motor will rotate the Lead screw to perform the function. The torque calculation for the DWS mechanism lifting lead screw is shown in Table 6.

The selected motor specification is 4118M-06P stepper motor features 63 oz-in of Holding Torque, NEMA 17 Frame Size, and 1.8 degree step angle as shown in Figure 63. This motor is manufactured by Lin Engineering in the United States. The specification weight in lbs. of the motor is listed in Table 7. If this stepper motor 4118M-06P cannot generate the torque at the speed required as shown in Figure 64, then other stepper motor 4118L-06P, which is 48mm long vs. 40.1mm length can be used as shown in Figure 65.

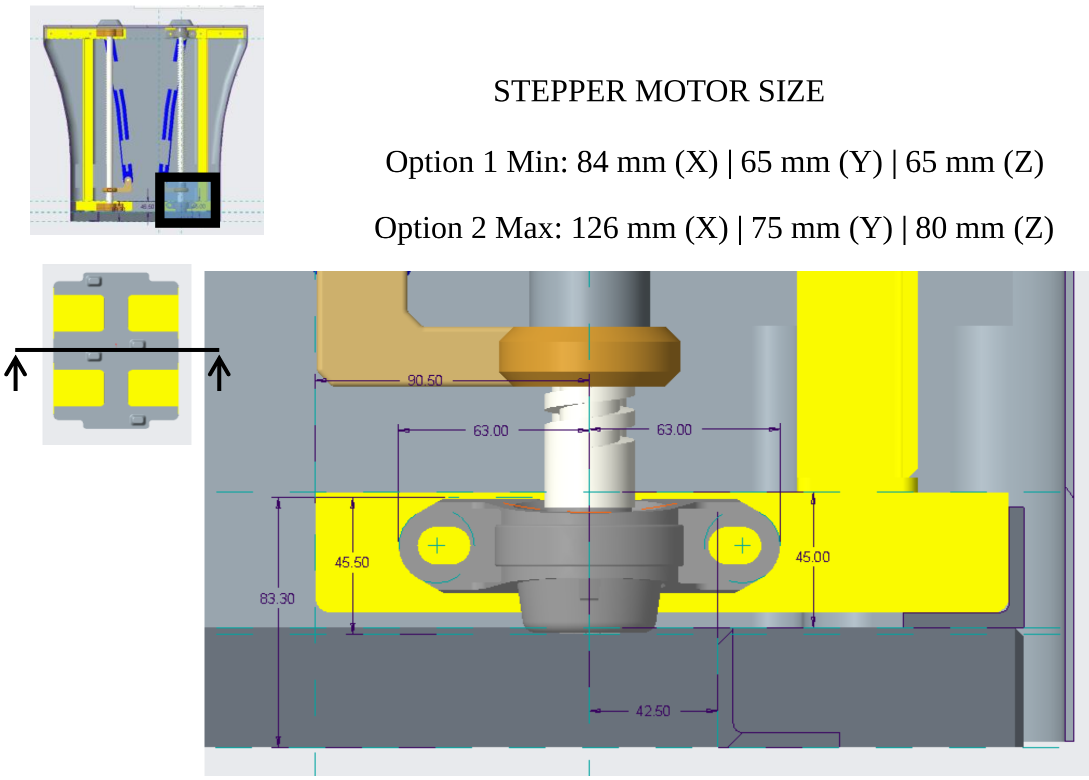


Figure 62. Stepper motor size study for assembly and mounting into DWS mechanism

The parameters of the selected Stepper Motor 4118M-06P is mentioned below:

- Torque = 0.385 N-mm (54.5 oz-in)
- Speed = 120 RPM (2 Revs per Sec)
- Lead Screw= 10mm pitch and 700 mm length
- Meeting automotive required shock and vibration standards (LIN Engineering manufactured stepper motors meets military shock and vibration standards)

Table 4. DWS lifting mass calculation

Model Info	Material	Density (kg/mm^3)	Mass (Kg)	Qty.
LIFT_NUT	Nylon6 GF40	1.35E-06	0.19262	1
GUIDE_BUSH	SAE 841 Bronze	8.85E-06	0.08001	1
TRAY_O3_HOLDER	Nylon6 GF40	1.35E-09	0.09125	1
TRAY_O3_HOLDER	Nylon6 GF40	1.35E-09	0.09125	1
ROD_01	6061 Aluminum	2.71E-06	0.13827	1
LIFT_NUT_02	Nylon6 GF40	1.35E-06	0.19262	1
THREAD_BUSH	SAE 841 Bronze	8.85E-06	0.20991	1
TRAY_03_NEW	Nylon6 GF40	1.35E-06	2.39789	1
LINK_MAIN	Nylon6 GF40	1.35E-06	0.3749	1
LINK_MAIN	Nylon6 GF40	1.35E-06	0.3749	1
TRAY_02_NEW	Nylon6 GF40	1.35E-06	1.40752	1
		Total	5.35852	

The Leadscrew Lifting Torque equation is:

$$T_R = F \cdot \frac{d_m}{2} \left(\frac{l + \pi \cdot \mu \cdot d_m}{\pi \cdot d_m - \mu \cdot l} \right)$$

Load (F) =(M+Mo)*g

The lead screw will be integrated with the selected stepper 4118M-06P as shown in Figure 63. The standard lead accuracy for lead screw is .0006 in./in. (mm/mm). Lead accuracy is available up to .0001 in. / in. (mm/mm).

This is the rotational speed at which a screw may experience vibration or other dynamic problems. See Figure 66 for the critical speed chart to determine if DWS mechanism parameters result in speed approaching critical. To minimize critical speed problems we have to use a longer lead, choose a larger diameter or increase bearing mount support as shown in Figure 66.

Table 5. DWS mechanism lifting screw torque design calculation details

DWS Mechanism Design Details	**where**	**value**	**Unit**
Total weight / Mass	M	5.35852	kg
Speed	V	0.5	m/s
Gravity	g	9.81	m/s2
Friction coefficient (Lead Screw-Steel)	μ	0.15	-
Lead Screw pitch	l	10	mm
Lead Screw Major Dia	Dmajor	30	mm
Lead Screw Minor Dia	Dminor	20	mm
Lead Screw Mean Dia	d_m	25	mm
Mean Lead Screw Color Dia	Dc	25	mm
Other forces(Load on tray)	Mo	2	N
Safety factor	SB	2	-
Time for deploying worksurface	t	30	Sec
Distance lifted for DWS	d	700	mm
Pi	π	3.14286	-

Load	F	54.5671	N
Lifting Torque	T_R	**192.805**	**Nmm**
Design Torque	Td	**385.611**	**Nmm**

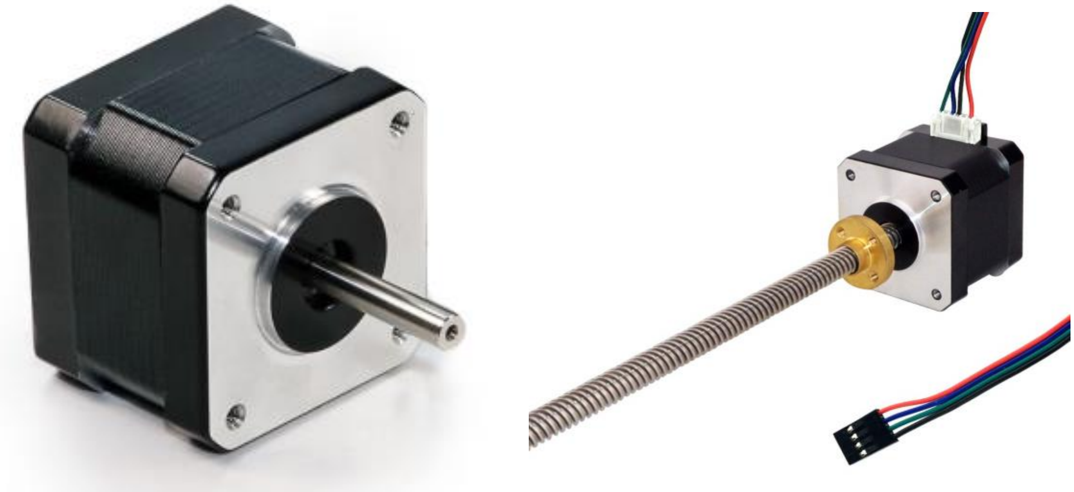


Figure 63. DWS mechanism stepper motor 4118M-06P with lead screw integrated

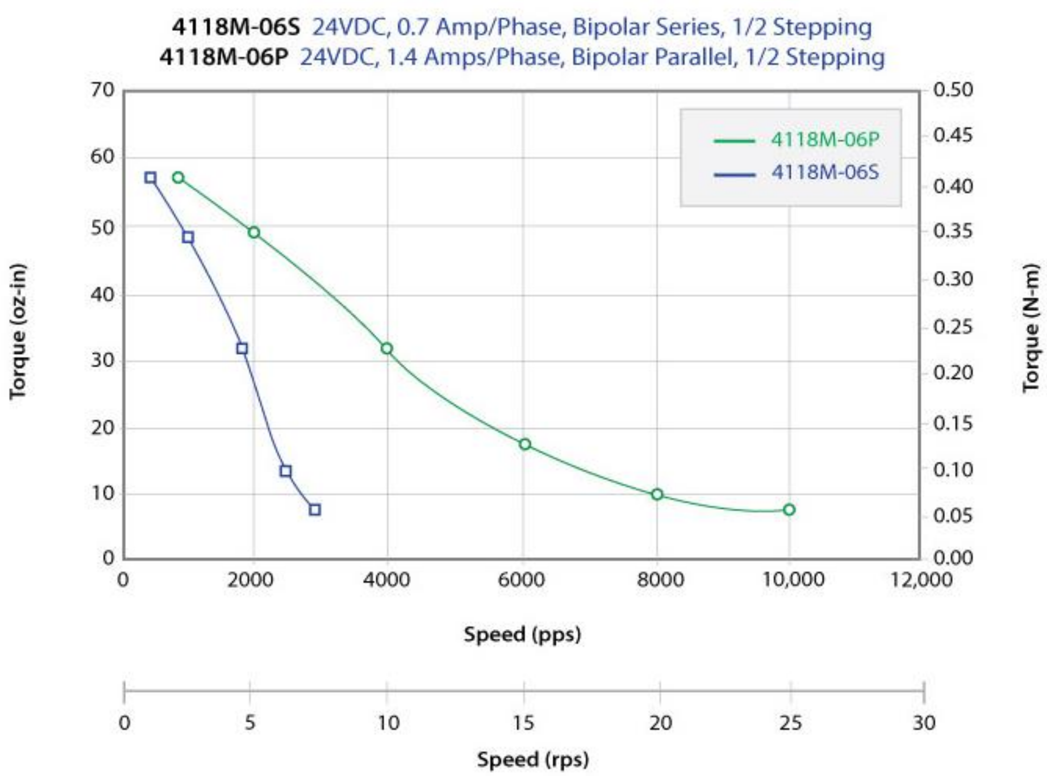


Figure 64. Torque curve details of selected stepper motor 4118M-06P

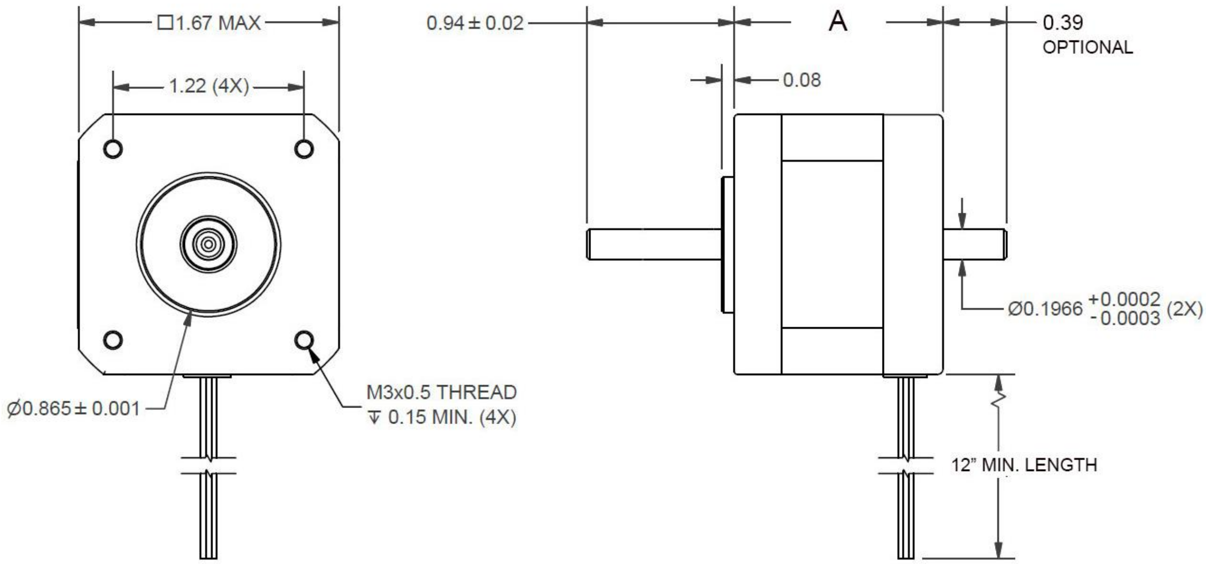


Figure 65. Selected Stepper motor 4118M-06P dimensions

Table 6. Stepper motor 4118M-06P design specifications

Selected Stepper Motor Specifications	
Step Angle:	1.8 Degree
Frame Size:	NEMA 17
Body Length (in):	1.58
Body Length (mm):	40.1
Current (AMP):	1.4
Holding Torque (oz-in):	63
Holding Torque (N-m):	0.44
Resistance:	2.7
Rotor Inertia (oz-in2):	0.28
Number of leads:	4
Connection:	Parallel
Weight (lbs):	0.6
Branding:	PowerStep High Torque
Vacuum Rating:	Yes

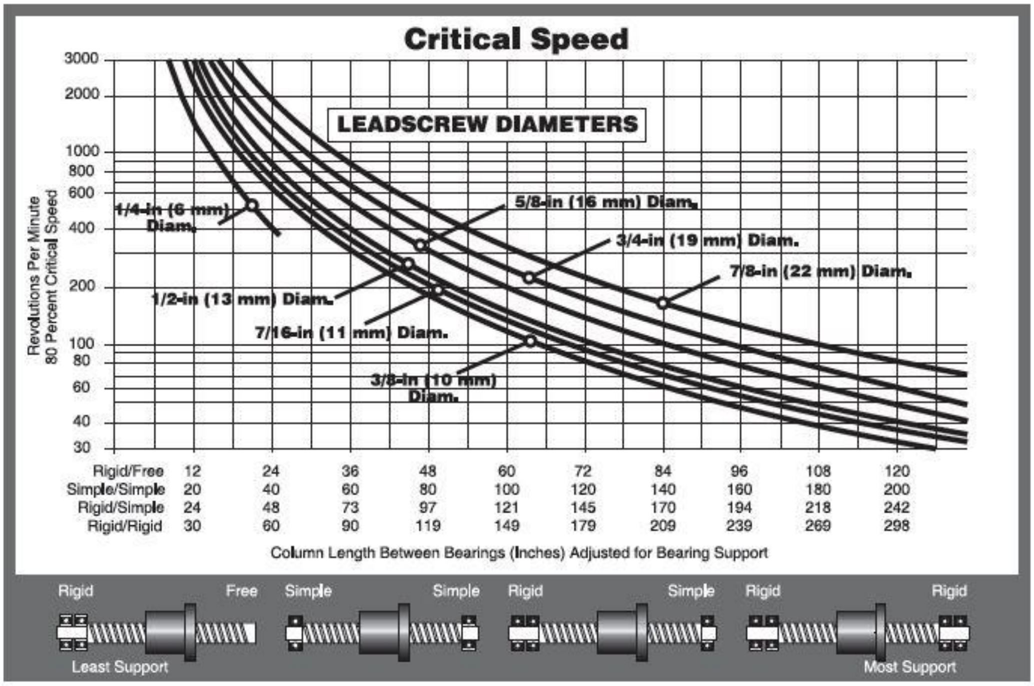


Figure 66. Critical speed chart for DWS mechanism speed approaching critical

5.5.4 DWS Mechanism Microcontroller

The Arduino UNO or Mega 2560 is the most commonly used microcontroller board for any advanced product development mechatronic functional prototypes proof of concept as shown in Figure 67. The stepper motor electromagnets are energized by an external drive circuit called microcontroller. This microcontroller is used to activate the drive transistors in the right order. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

Figure 67. Example of Arduino Mega 2560 microcontroller

5.5.3 DWS Mechanism Sensors

The Momentary hinge metal roller lever micro switch AC 5A 125 - 250V Single Pole Double Throw (SPDT) 3 Pins have been used only for functional proof of concept DWS mechanism because it is not an automotive-qualified microswitch as shown in Figure 68.

Figure 68. Momentary hinge metal roller lever micro switch SPDT 3 Pins

It is commonly used as Limit Switches to indicate that a part of a DWS mechanism has reached the limit of its travel of 700 mm. This is an important component because it is needed to prevent the DWS mechanism from jamming and damaging itself. This micro switch is used as bumpers to physically detect contact, when the user accesses the re-configurable console to use the DWS. The switches have already been installed on the DWS mechanism assembly product. Each microswitch is a single pole double throw (SPDT) switch with a common contact (C), a normally open (NO) contact and a normally closed (NC) contact. Pressing the lever causes the common contact to break its connection to the NC contact and connect to the NO contact; releasing the lever switches the C contact back to the NC contact. It requires very little force is to actuate the switching DWS mechanism. The switch is momentary (like the pushbutton), when not touched it springs to its lever not pressed state with the common connected to the NC contact. Only two contacts of the microswitch will be used (C and NO) thus using it as an SPST or ON/OFF switch.

Each switch is wired with a 10K pull-up resistor so a switch closure causes the switch output to go from +5V to ground. Releasing the switch causes the output to go back to +5V. The switch output is connected to a switch debouncing circuit consisting of a 100W resistor, 10mF capacitor and a 74HC14 Schmitt trigger inverter. The 74HC14 integrated circuit contains six Schmitt trigger inverters but only two will be used, one for each limit switch.

5.5.6 Schmitt trigger inverter 74HC14

One of the major disadvantages to using interrupts with mechanical switches, thus debounce the input signal, otherwise the interrupt can trigger multiple times during a hardware input as shown in Figure 69. This can be done through software by essentially rejecting any inputs within a certain time frame after the initial input, or through hardware by implementing a debouncing circuit.

Mechanical switches do not make perfect contact when they change state (open to closed or closed to open). This vibration in the connection, called Switch Bounce, can make the output a series of pulses instead of a single transition. The debouncing circuit removes this chatter from the switch signal by filtering out the high-frequency switch bounce pulses. Hence using a

74HC14 Schmitt trigger inverter, so the switch signal polarity gets flipped or inverted. When the switch is untouched the output of the debouncing circuit is 0V, and when the switch is closed the output is +5V. During a switch closure the output transitions from 0V to +5V, this is known as a rising edge. Conversely, when the switch opens the output transitions from +5V to 0V is called a falling edge.

Figure 69. Schmitt trigger inverters 74HC14 IC

5.5.7 TB6600 Upgraded Driver

TB6600 upgraded one is a kind two-phase hybrid stepping motor driver which suitable for 57/42 phase current below 4.0A as shown in Figure 70. Through 6 digit DIP switch, set 7 subdivisions and 8 level output current. The best application target torque is 1.8N.m and below 57 stepping motor, 42 stepping motor.

Figure 70. Stepper motor driver

TB6600 driver product features are listed below:

- DC 9-42V power supply, 12-30V is the best power supply.
- Control signal input voltage 3.3-24V universal (do not need series resistance).
- Interpolation precision, 1-32 optional.
- Output peak current 4.0A.

5.5.8 DWS Mechanism SW Programming Algorithm

Step 1: Start

Step 2: Definition of Variables

Define Stepper Motor Variables

Define Switch Control Variables

Step 3: Declaration of Variables

Declare Move_Speed

Declare Switch_Initial //Boolean Value

Declare Switch_Final //Boolean Value

Declare Control_Switch //Boolean Value

Step 4: Set up, Configure & Write Values

//The pinMode() function is used to configure a specific pin to behave either as input or output.

pinMode Stepper Motor Variables

pinMode Switch Control Variables

pinMode Switch_Initial

pinMode Switch_Final

pinMode Control_Switch

//The digitalWrite() function is used to write a HIGH or a LOW value to a digital pin If the pin has been configured as an OUTPUT with pinMode()

digitalWrite Stepper Motor Variables

Step 5: Move the DWS

// The digitalRead() function is used to read the status of any digital Pin

digitalRead Switch Control Variables

If Control_Switch == true

If Switch_Initial == false

Move DWS up

If Control_Switch == false

If Switch_Final == false

Move DWS down

Step 6: Stop or Repeat above in loop

5.5.9 DWS Mechanism SW Programming Flowchart

Figure 71. DWS mechanism SW programming flowchart

5.5.10 DWS Mechanism SW Programming

```
# define X_ENgnd  2 //ENA-(ENA) stepper motor enable , active low Gray

# define X_EN_5v  3 //ENA+(+5V) stepper motor enable , active low Orange

# define X_DIRgnd 4 //DIR-(DIR) axis stepper motor direction control Blue

# define X_DIR_5v 5 //DIR+(+5v) axis stepper motor direction control Brown

# define X_STPgnd 6 //PUL-(PUL) axis stepper motor step control Black

# define X_STP_5v 7 //PUL+(+5v) axis stepper motor step control RED

# define SW_Ctrl 10

# define SW_Fin 11

# define SW_Init 12

int MoveSpeed = 600;

boolean FinalPosSW;

boolean InitPosSW;

boolean CrtlSW;

void setup() {

  // put your setup code here, to run once:

pinMode (X_ENgnd ,OUTPUT); //ENA-(ENA)

pinMode (X_EN_5v ,OUTPUT); //ENA+(+5V)
```

```
pinMode (X_DIRgnd,OUTPUT); //DIR-(DIR)

pinMode (X_DIR_5v,OUTPUT); //DIR+(+5v)

pinMode (X_STPgnd,OUTPUT); //PUL-(PUL)

pinMode (X_STP_5v,OUTPUT); //PUL+(+5v)

pinMode (13,OUTPUT);

pinMode (SW_Ctrl, INPUT);

pinMode (SW_Fin, INPUT);

pinMode (SW_Init, INPUT);

digitalWrite (X_ENgnd,  LOW); //ENA-(ENA)

digitalWrite (X_EN_5v, HIGH); //ENA+(+5V) low=enabled

digitalWrite (X_DIRgnd, LOW); //DIR-(DIR)

digitalWrite (X_DIR_5v, LOW); //DIR+(+5v)

digitalWrite (X_STPgnd, LOW); //PUL-(PUL)

digitalWrite (X_STP_5v, LOW); //PUL+(+5v)

Serial.begin(115200);

}


void move (){
```

```
FinalPosSW = digitalRead(SW_Fin);
InitPosSW = digitalRead(SW_Init);
CrtlSW = digitalRead(SW_Ctrl);
if(CrtlSW == true)
{
 if(InitPosSW == false)
 {
   digitalWrite (X_DIR_5v,LOW);
   digitalWrite (X_EN_5v, LOW);
   digitalWrite (X_STP_5v, HIGH);
   delayMicroseconds (MoveSpeed);
   digitalWrite (X_STP_5v, LOW);
   delayMicroseconds (MoveSpeed);
 }
 }
if(CrtlSW == false)
 {
  if(FinalPosSW == false)
```

```
    {
    digitalWrite (X_DIR_5v,HIGH);
    digitalWrite (X_EN_5v, LOW);
    digitalWrite (X_STP_5v, HIGH);
    delayMicroseconds (MoveSpeed);
    digitalWrite (X_STP_5v, LOW);
    delayMicroseconds (MoveSpeed);
    }
   }
   }
void loop() {
  // put your main code here, to run repeatedly:
  move ();



}
```

5.5.11 DWS Mechanism Prototype Build

The DWS mechanism functional prototype has been built after completing the 3D CAD development activities as shown in Table 11 and Figure 91 under Appendix-B for the CAD assembly structures.

6. DWS MECHANISM PRODUCT DESIGN TESTING AND VALIDATION

This chapter focuses on the DWS concept design Mechanism development testing and results to demonstrate reconfigurable console having deployable worksurface mechanism withstanding load and vibration.

6.1 DWS mechanism Concept Product Testing & Validation Overview

The DWS is tested with respect to the product. The prototype has been tested and validated using FEA – Finite Element Analysis which is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed. Any FEA Method follows the below steps:

- Discretization or subdivision of the domain - The discretization of the domain is the first and perhaps the most important step in any finite element analysis because the manner in which the domain is discretized will affect the computer storage requirements, the computation time, and the accuracy of the numerical results. The subdomains are usually referred to as the elements.
- Selection of the interpolation functions (to provide an approximation of the unknown solution within an element)
- Formulation of the system of equations
- The solution of the system of equations (once solving completed for the system of equations, then compute the desired parameters and display the result in form of curves, plots, or color pictures, which are more meaningful and interpretable.)

6.1.1 DWS Mechanism Testing Objectives

Since the DWS system is placed inside the vehicle there are certain objectives that would need to be considered in order to fulfill the purpose of the design and the product. The main objectives are the following:

- To check the structural integrity of the Console mechanism and capable of withstanding a peak load of 350N is applied on Console extended tray top surface (500 mm x 240 mm area surface) in –ve Y-direction.
- To check the structural integrity of the Console mechanism, when Console mechanism assembly in an extended tray position is subjected to vibration frequency of 100 Hz in +Y direction.
- To check the binding, when the lead screw rotates, it may cause deflection because of binding force in guide linear shaft.

6.1.2 Scope of Testing & Validation Analysis-1

Linear Static analysis would be performed for the below-mentioned condition:-

- The peak load of 350N applied on console extended tray top surface (500 mm x 240 mm area surface) in –ve Y-direction and find the capability of withstanding a peak load, assembly stress and displacements observed for the applied load as shown in Figure 72.

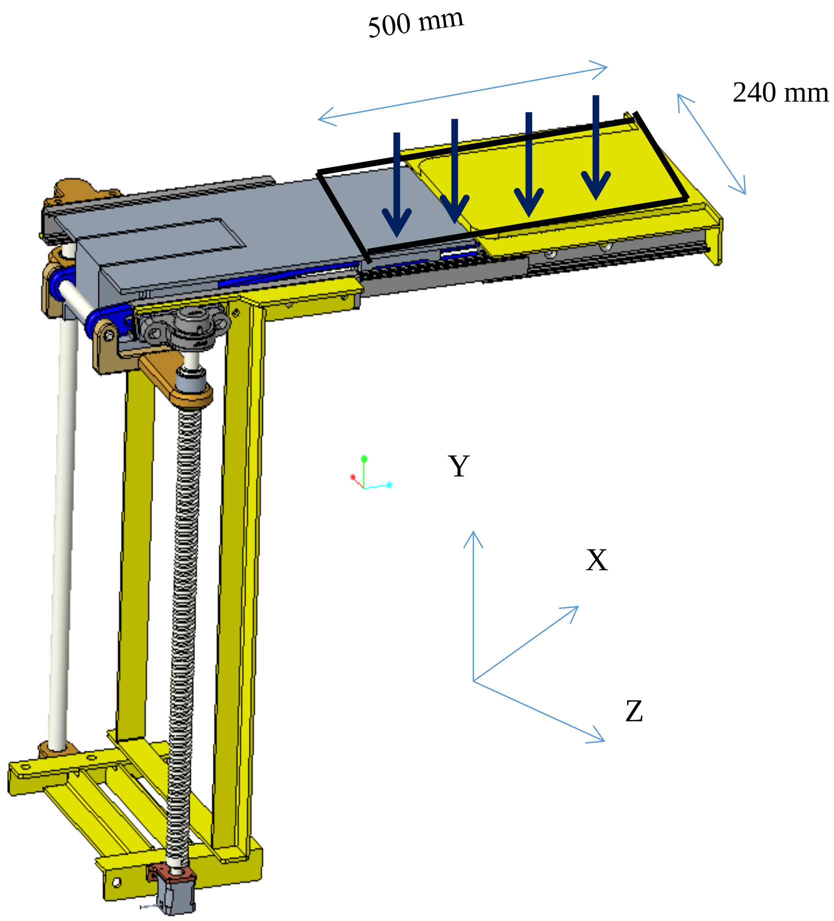


Figure 72. Product in deployed worksurface loading applied

6.1.3 Scope of Testing & Validation Analysis-2

Linear Static analysis would be performed for the below-mentioned condition as shown:-

- When console mechanism assembly in the extended tray position is subjected to a vibration frequency of 100 Hz in +Y direction as shown in Figure 73.

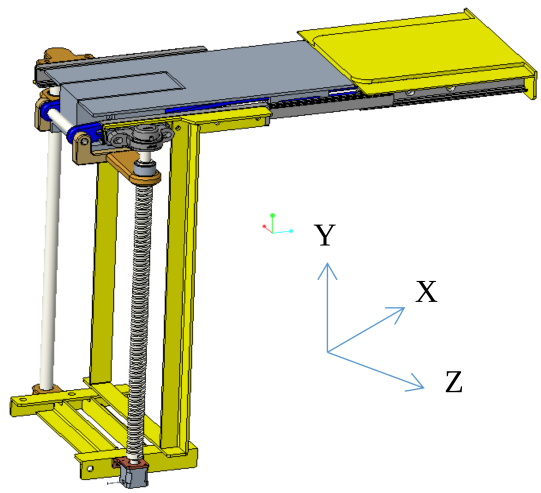


Figure 73. Product in deployed worksurface for vibrational analysis

6.1.4 Scope of Testing & Validation Analysis-3

GD&T dimensional analysis would be performed for the below-mentioned condition:- Whether the lifting tray mechanism may deflect because of binding force in guide linear shaft, when the lead screw rotates as shown in Figure 74.

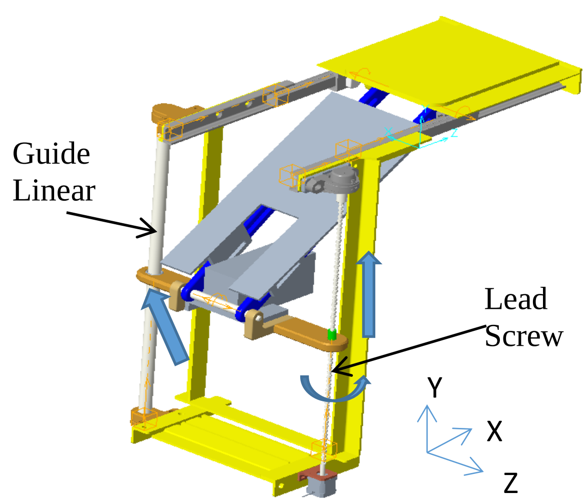


Figure 74. DWS Product in mid position condition analysis

6.1.5 Material Properties and Units Followed

Table 7. DWS mechanism concept product material properties

Component Name	Material name	Young's modulus (MPa)	Poisson's ratio	Yield Strength (MPa)	Ultimate Strength (MPa)
1 GUIDE_RAIL_01(x4)	STAINLESS STEEL 1.4034	190000	0.28	730	900
2 GUIDE_RAIL_02 (x4)	STAINLESS STEEL 1.4034	190000	0.28	730	900
3 BEARING_ASM_RH_LH(x2)	BEARING STEEL CARBON CHROMIUM (100Cr6)	210000	0.29	530	690
4 TRAY FRONT END	PA6-50%GF	18000	0.36	240	250
5 SHAFT FRONT TRAY	STAINLESS STEEL X90CrMoV18	200000	0.28	430	750
6 FRAME	COLD ROLLED HIGH STRENGTH STEEL	210000	0.28	740	1020
7 SYK_20_TF_ECY_204 .ASM (BEARING)	BEARING STEEL CARBON CHROMIUM (100Cr6)	210000	0.29	530	690
8 THREAD ROD(LEAD SCREW)	STAINLESS STEEL X30Cr13 -Quenched and Tempered	190000	0.28	730	930
9 GUIDE SHAFT BLOCK SUPPORT	206.0-T7 Cast Aluminium	71000	0.33	350	440
10 GUIDE LINEAR SHAFT	STAINLESS STEEL X90CrMoV18	200000	0.28	430	750
11 TRAY HOLDER	PA6-50%GF	18000	0.36	240	250
12 ROD REAR TRAY	206.0-T7 Cast Aluminium	71000	0.33	350	440
13 LIFT TRAY FLANGE– LEAD SCREW SIDE	PA6-50%GF	18000	0.36	240	250
14 NUT	STEEL CARBON CHROMIUM (100Cr6)	210000	0.29	530	690
15 BUSH	STEEL CARBON CHROMIUM (100Cr6)	210000	0.29	530	690
16 STORAGE BOX	PA6-50%GF	18000	0.36	240	250
17 LINK MAIN	PA6-50%GF	18000	0.36	240	250
18 BEARING SUPPORT PLATE	COLD ROLLED HIGH STRENGTH STEEL	210000	0.28	740	1020
19 TRAY MIDDLE	PA6-50%GF	18000	0.36	240	250
20 BRACKET -MOTOR	COLD ROLLED HIGH STRENGTH STEEL	210000	0.28	740	1020
21 STEPPER MOTOR	STEEL - powercore® H 085-27 L	210000	0.28	360	-
22 LIFT TRAY FLANGE – GUIDE LINEAR SHAFT SIDE	PA6-50%GF	18000	0.36	240	250

Table 8. FEA units followed

Dimensions	Units
Force	N
length	mm
Stress	MPa

6.1.6 Boundary Conditions and Loads

- The bottom face of the Frame will be constrained in all degrees of freedom as highlighted in red as shown in Figure 75-77.
- For all 3 scope of analysis.

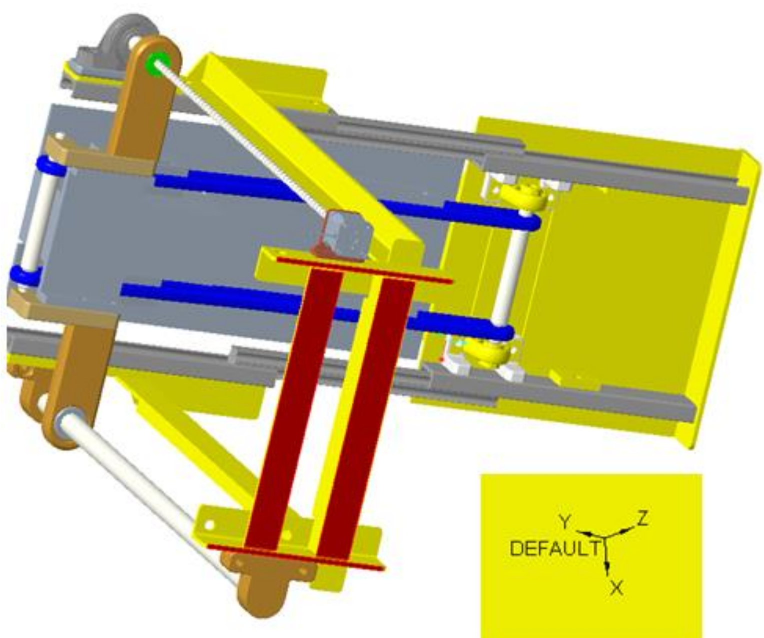


Figure 75. FEA boundary condition for DWS concept product

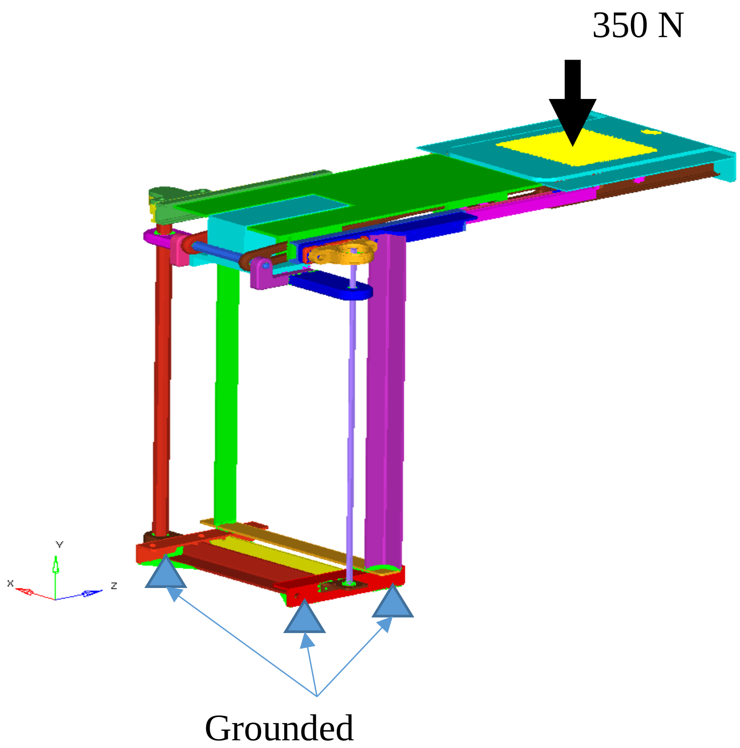


Figure 76. FE model and load description for scope FE analysis -1

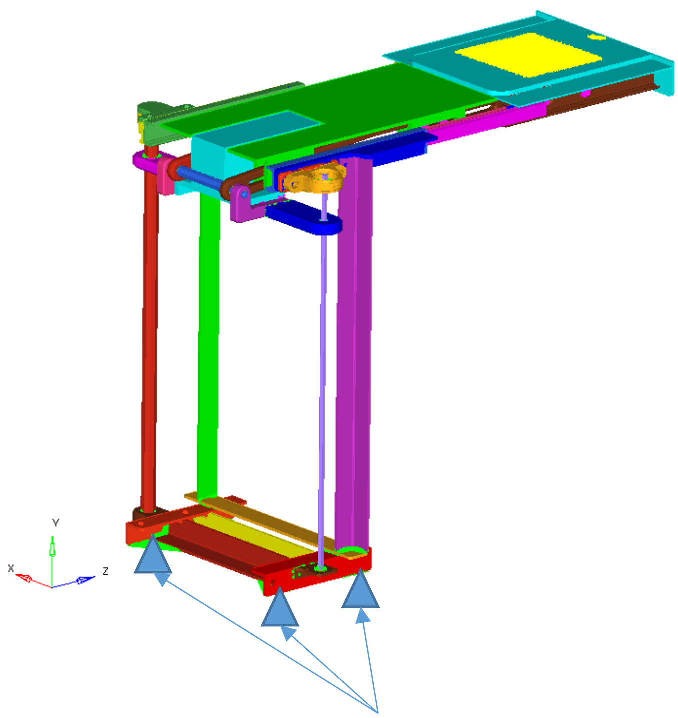


Figure 77. FE model and load description for scope FE analysis -2

6.1.7 Contacts Definition

Frictional contact will be defined between all mating interfaces (μ=0.15) and bonded contact defined example: Fasteners/ Screw joints, Lead Screw end with Motor and Link Main with Tray's bottom.

6.1.8 FEA Methodology

- Geometry cleanup will be done on the model de-featuring small fillets without compromising the interested region.
- First/second-order tetrahedral elements will be used to build the finite element model.
- Load test to see if the surface withstands enough load to find the capability of withstanding a peak load including the stress and the displacement. This load test would come under the linear static analysis and will help determine how much load the DWS can withstand.
- Vibration test in which DWS will be subjected to a high frequency which will also include the worst road conditions to see the withstanding capacity of the surface.
- Linear material properties considered for all the components.
- The finite element analysis report will be generated by reporting the peak stress and displacement plots for the applied load.
- Meshing Type & Steps - Meshed using second-order tetrahedral elements. The analysis was started with the geometry clean up. Then the material property is assigned, post which the components are connected by applying boundary

conditions. Once the boundary conditions are applied, then it is run in a solver post which is plotted.

- Software Used - Preprocessor Software - Mesh Hypermesh 14 Student Version, Analysis Solver– Nastran 2018, Postprocessor – HyperView 14 Student version.

6.1.9 Assumptions and Risks

- Linear material properties considered for the analysis.
- Springs will not be considered for the FE analysis.
- No temperature effects considered for analysis.
- Convergence issues, if faced.

6.2 DWS Mechanism Concept Product Testing & Validation Results

The Testing Results are completely based on the above testing methodology. Find the below test results based on the testing objectives and methodology.

6.2.1 DWS Mechanism Analysis Scope-1 Results

Linear Static analysis has been performed and test results of the peak load of **350N** applied on console DWS mechanism extended tray top surface (500 mm x 240 mm area surface) in –ve Y-direction and find the capability of withstanding a peak load, assembly stress and displacements observed for the applied load. The stress has been highlighted in the scale mentioned below, starting from low scale to the highest stress points as shown in Figure 78. The stress has been highlighted in the scale mentioned below, starting from low scale to the highest stress points.

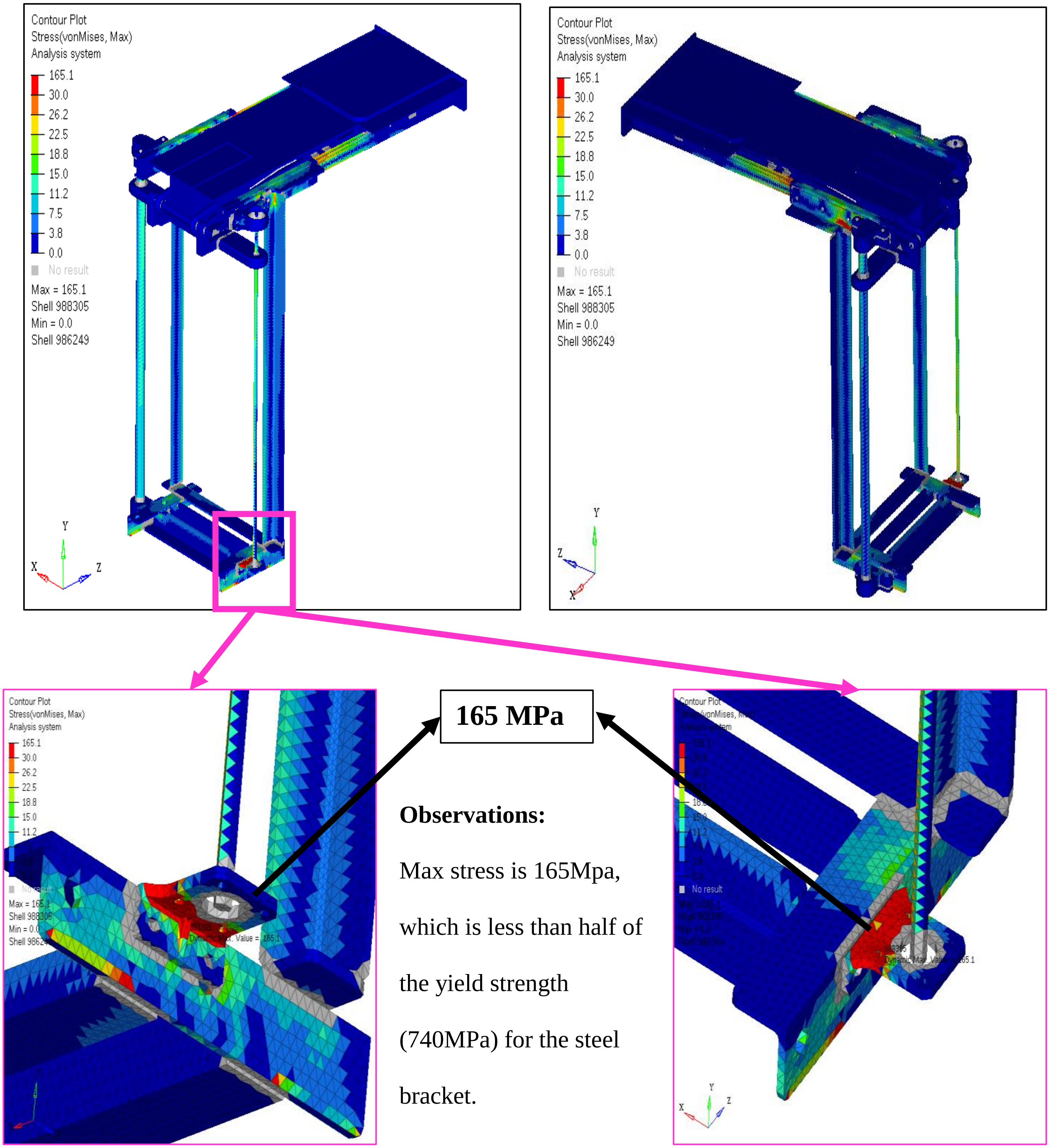


Figure 78. Stress contour plot for scope FE analysis-1

6.2.2 DWS Mechanism Analysis Scope-2 Results

Linear Static analysis has been performed and test results of FE analysis scope-2 are based on vibrational analysis studies of the moving vehicle. When the DWS mechanism assembly in extended tray position is subjected to the vibration frequency of 100 Hz in a minimum of three linear degrees of motion/freedom and finds the assembly stress and displacements observed for the applied vibrational frequency as shown in Figure 79-84.

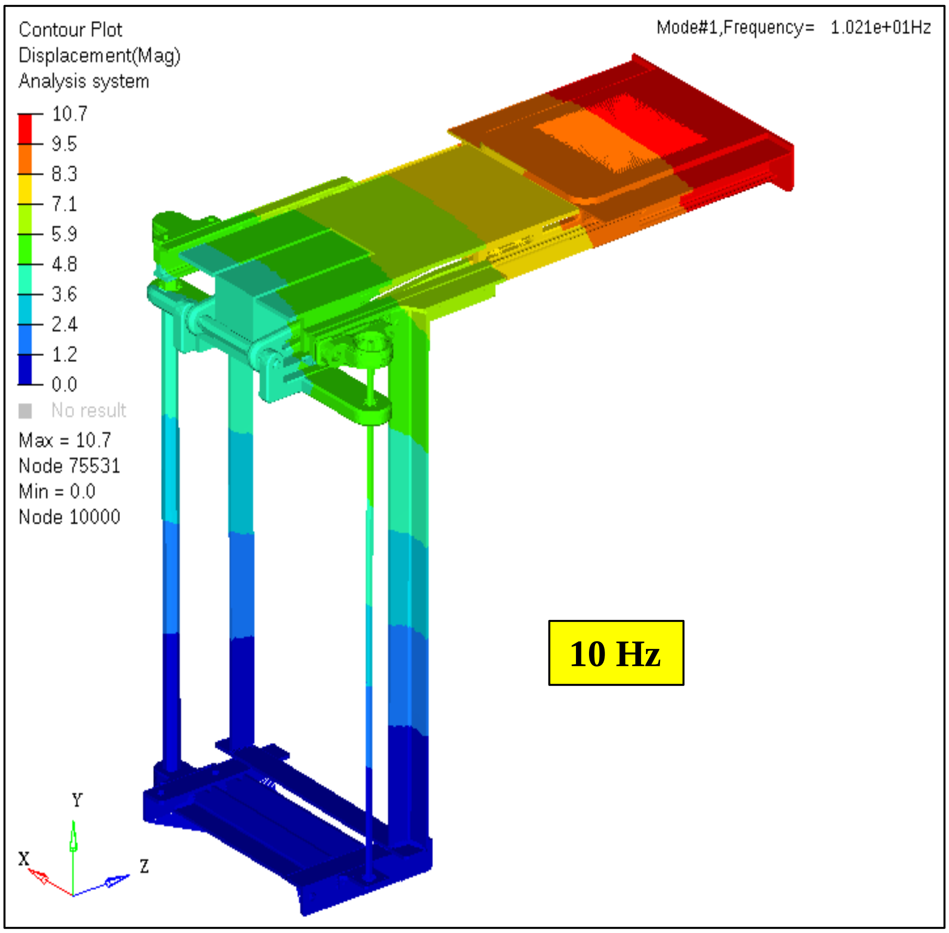


Figure 79. Normal modes of the assembly @ 10 Hz

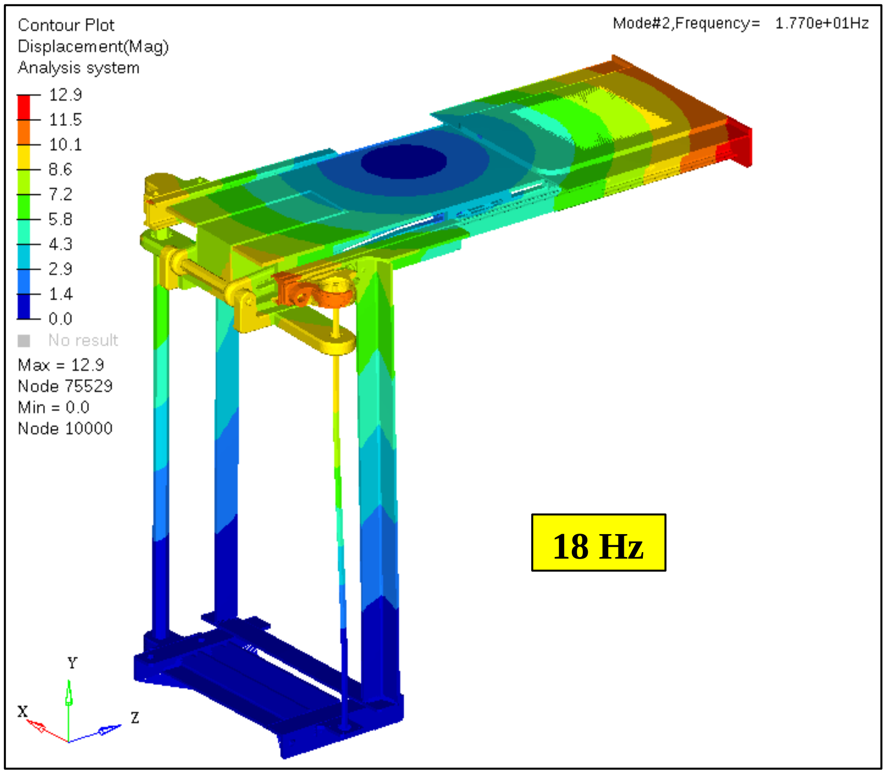


Figure 80. Normal modes of the assembly @ 18 Hz

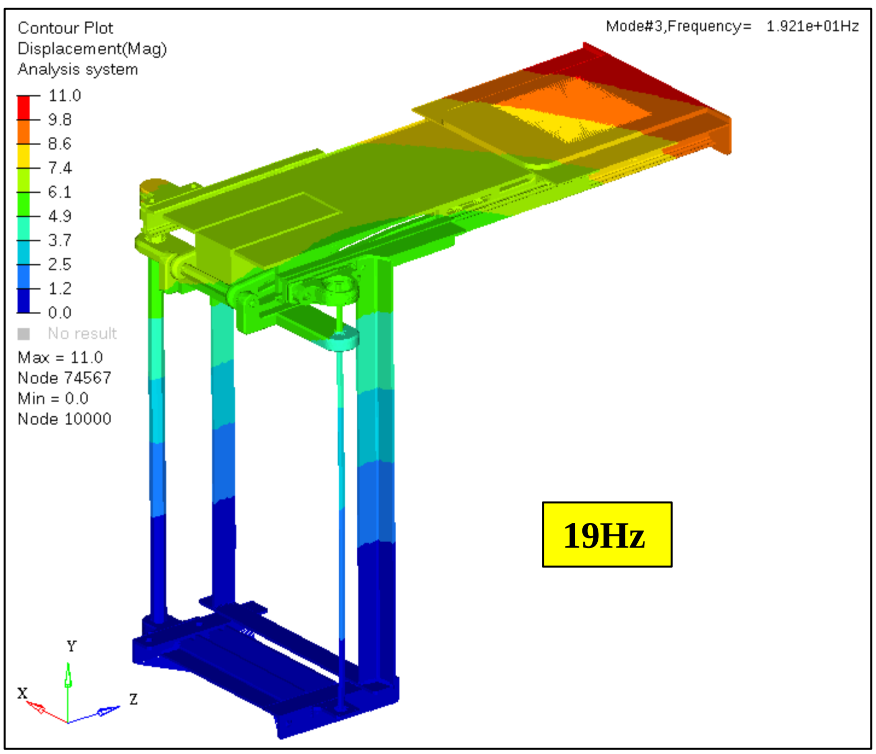


Figure 81. Normal modes of the assembly @ 19 Hz

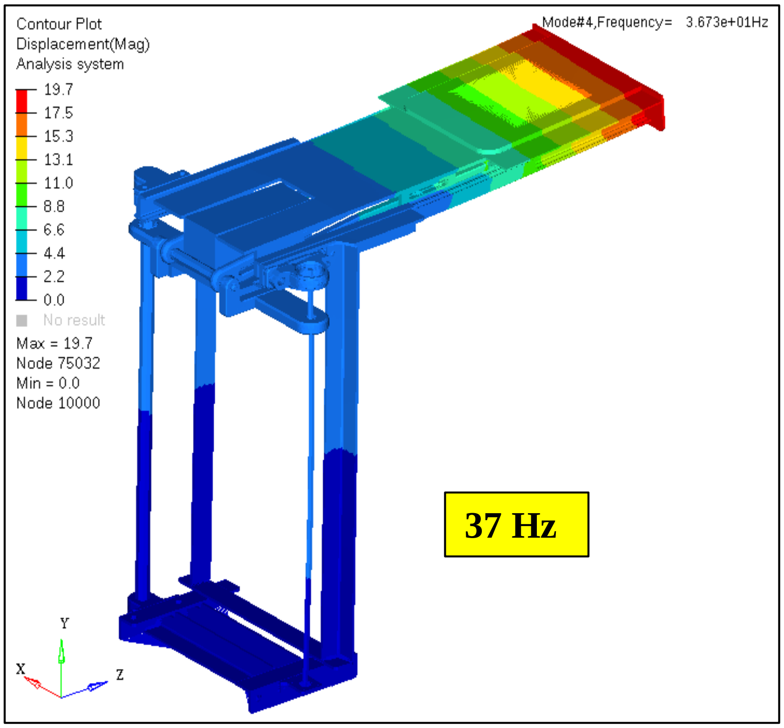


Figure 82. Normal modes of the assembly @ 37 Hz

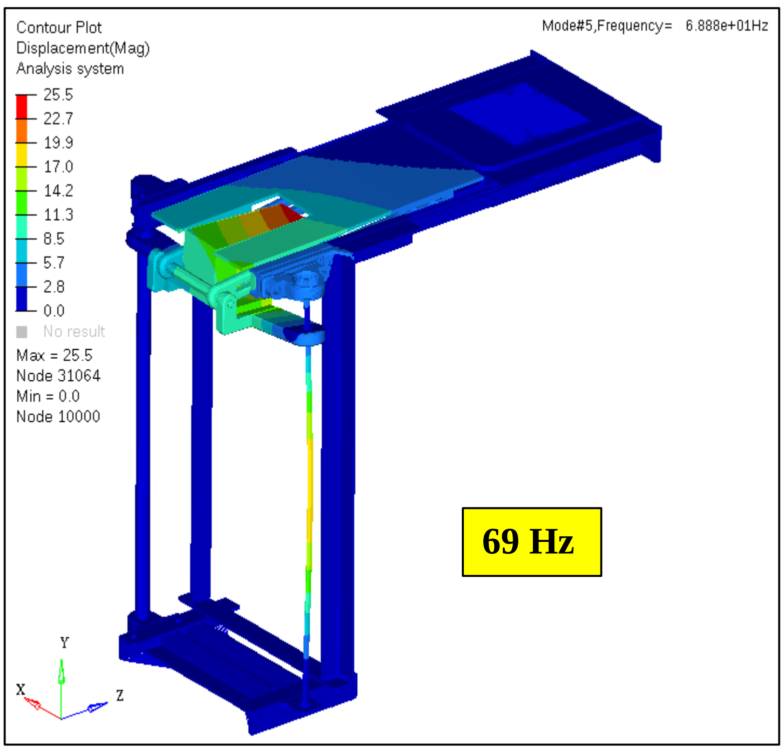


Figure 83. Normal modes of the assembly @ 69 Hz

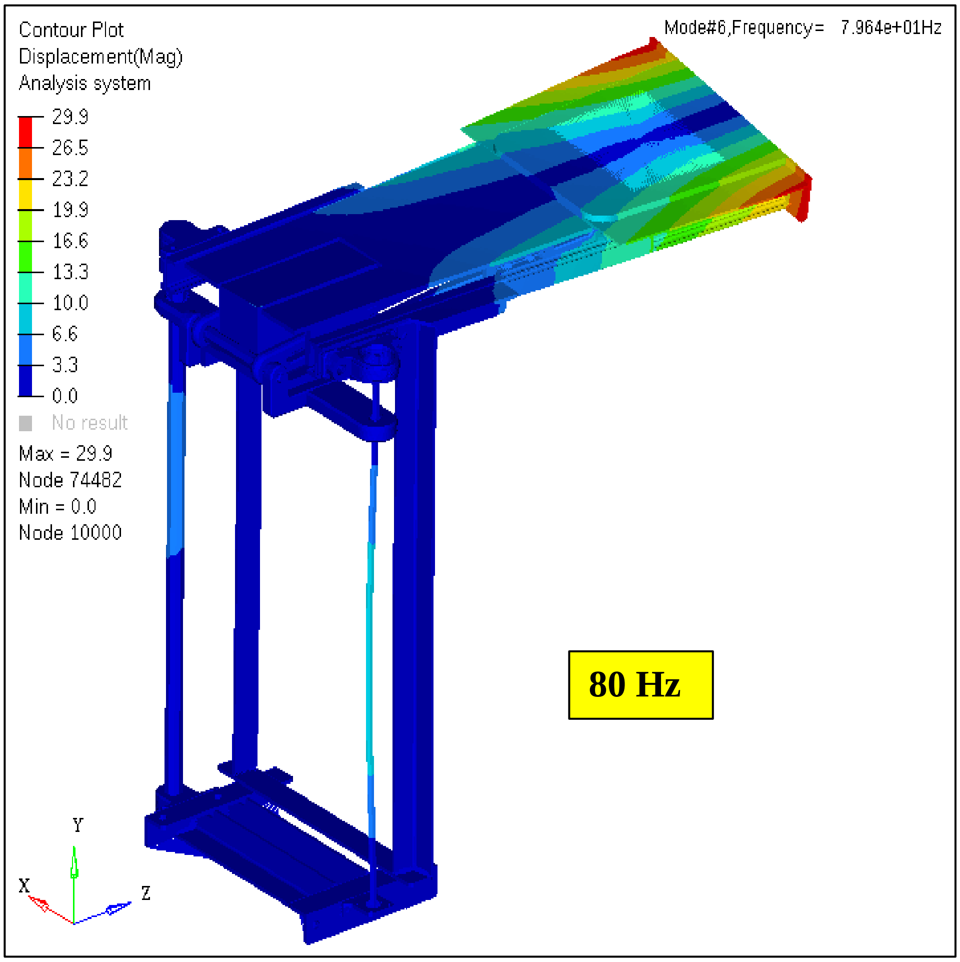
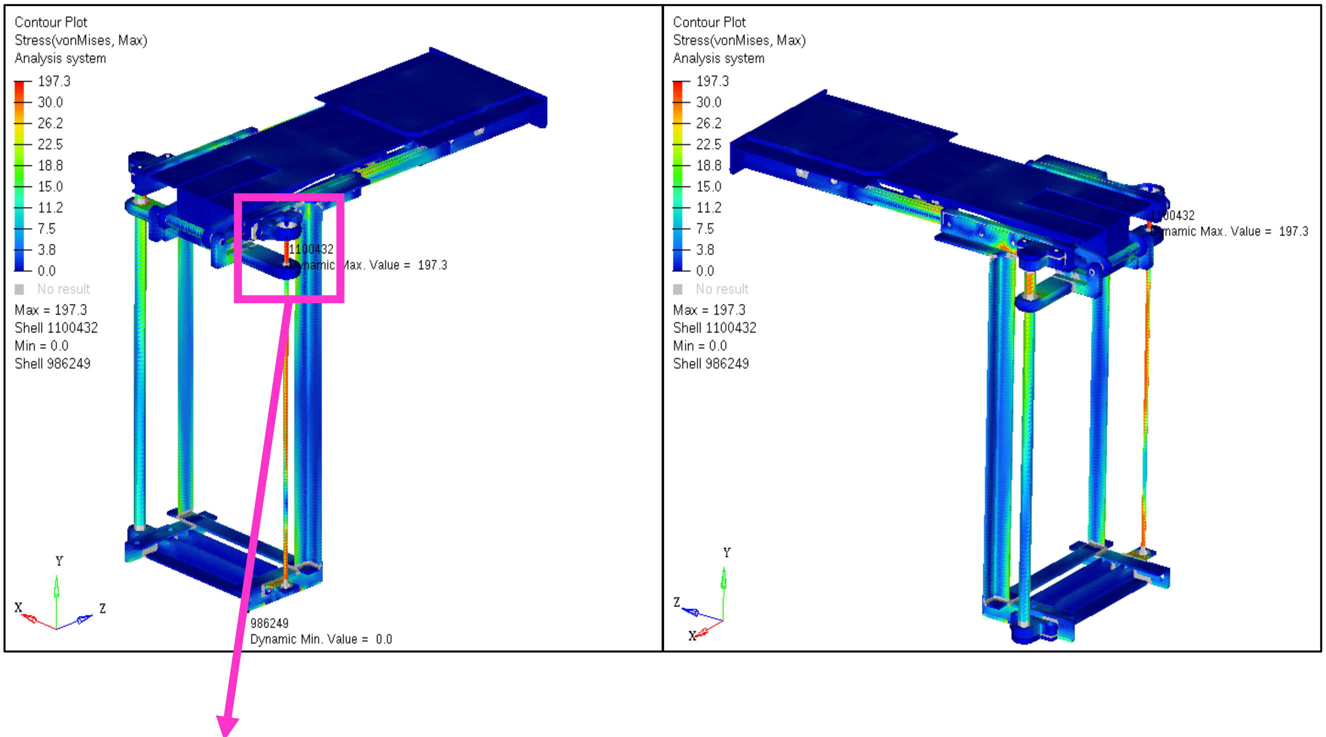
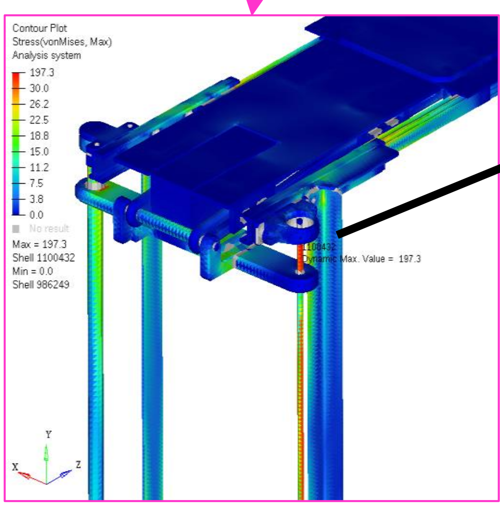


Figure 84. Normal modes of the assembly @ 80 Hz





197MPa

Observations:

Max stress is 197Mpa, which is less than half of the yield strength (730MPa) for the Steel Thread rod. Peak Stress Contour plot @ Normal mode frequency of 69 Hz

Figure 85. Stress contour plot for scope FE analysis-2

The stress has been highlighted in the scale mentioned in Figure 85 shown above and below, starting from low scale to the highest stress points.

6.2.3 DWS Mechanism Analysis Scope-3 Results

Geometric dimensional & tolerance stack analysis has been performed for the lifting tray mechanism tilting or deflection towards one side because of binding or catching of two components namely guide linear shaft diameter size with sliding component guide bush internal diameter size, while the lead screw in rotation takes place in opposite side of the mechanism.

The dimensional tolerance stack-up analysis performed based on Shaft and Hole feature of size (FOS) with tolerance Class fit as shown in Figure 86.

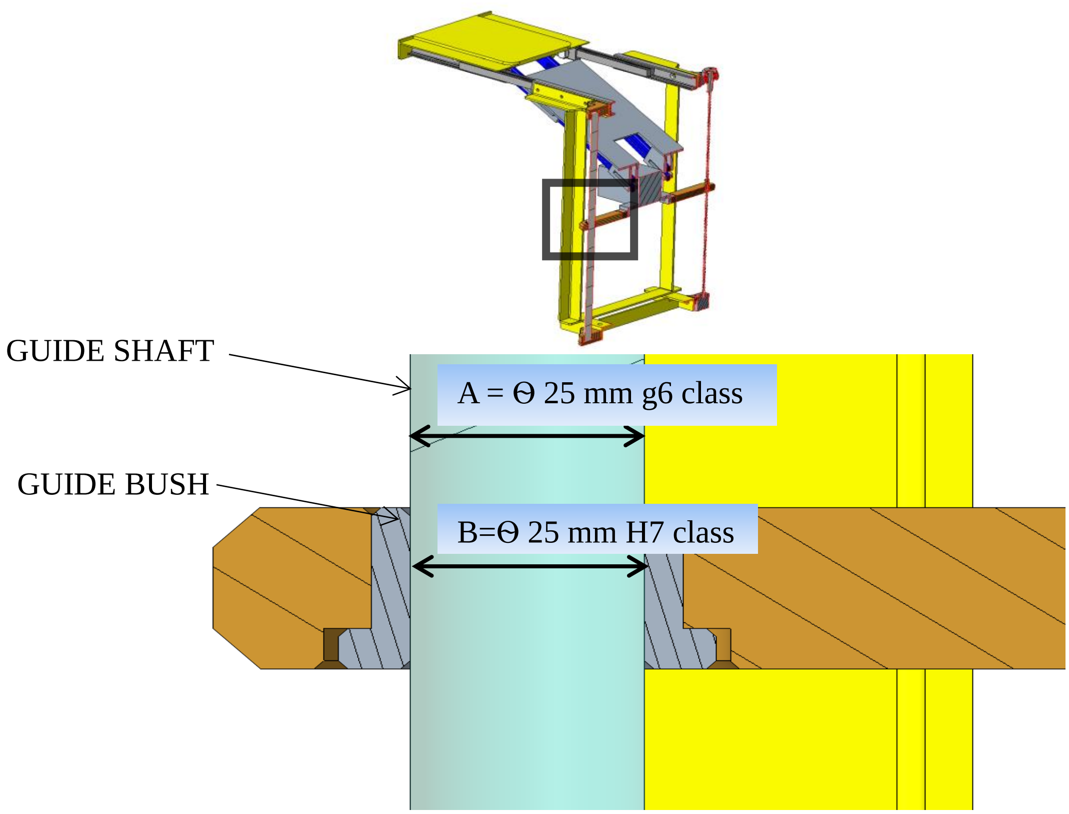


Figure 86. Guide shaft and bush GD&T details

Tolerance Stack 1D Analysis Report

Guide Shaft Sliding Fit

Observations: At worst case condition, there is a minimal clearance of 0.03 mm (min) for high accuracy requirements. The Guide shaft can be easily assembled and will turn and slide freely and there is no deflection or tilting failures of deployable worksurface or trays, when the lead screws in rotation.

Table 9.Tolerance analysis calculation for Guide Shaft sliding fit (All units in mm)

Loop/Vector	Component Name	Contributors	Nominal Dimension	Tolerance Plus	Tolerance Minus	Dimension (A)add or (S)subtract	Upper Limit Value	Lower Limit Value	Maximum Stack Up Total	Nominal Stack Up Total	Minimum Stack Up Total	Statistical Tolerance Value	Sigma Value	Cp Value
A	GUIDE SHAFT	Dia FOS	24.98	0.00	0.00	S	24.98	24.98	-24.98	-24.98	-24.98	0.00	0.04	0.00
B	GUIDE SHAFT	GD&T sliding fit g6 class	0.00	0.00	0.01	S	-0.01	0.00	-24.97	-24.98	-24.98	0.00	0.04	-0.09
C	GUIDE BUSH	Internal hole dia FOS	25.00	0.00	0.00	A	25.00	25.00	0.03	0.02	0.02	0.00	1.04	0.00
D	GUIDE BUSH	GD&T sliding fit H7 class	0.00	0.00	0.02	A	0.00	-0.02	0.03	0.02	0.00	0.00	2.04	0.00
		Results:		0.00	0.03					sum of sqrs=		0.00		
		Minimum worst case per side (Clearance) =	0.03							square root(RSS)=		0.01		
		Nominal per side (interference) =	0.02											
		Maximum worst case per side (interference) =	0.00			Negative means interference or no gap								
		Statistical Interference lower side =	0.01			Positive means air gap / no compression								
		Statistical Interference upper side =	0.03											

Results:	
Minimum worst case per side (Clearance) =	0.03
Nominal per side (interference) =	0.02
Maximum worst case per side (interference) =	0.00
Statistical Interference lower side =	0.01
Statistical Interference upper side =	0.03

7. CONCLUSION AND FUTURE WORKS

7.1 Conclusion

Based on the interviews with extreme users of carpooling, empathy on their issues in vehicle interior accessibility issues has been perceived. A problem statement has been defined with a deep insight understanding of their problems and needs. This problem statement was taken to ideation process where many hand sketches were made as part of ideation to arrive at a suitable concept product design for DWS mechanism. The outcome of this ideation process has been taken into a model construction as proof of concept which was carried out using foam board material to simulate a concept DWS.

On critically evaluating this foam board model proof of concept, it was learned that the concept design for DWS is practicable. However it was observed that the positioning of the deployable worksurface externally on the sides of the console body may be a possible safety issue for the users. Hence it was felt necessary to position the DWS inside the console body, so that the revised DWS concept will ensure a good human-machine interface (HMI) environment, once the concept DWS is assembled inside the console.

3D CAD model development has been chosen to incorporate in the revised concept product design. After taking due care for the ergonomics aspects of the users with reference to their H-point various design factors of the DWS like position and degree of freedom, locations for other DWS access features have been decided and incorporated into the product concept design by integrating mechanical, electrical and electronic engineering after following design approach norms. Thus a functional DWS mechanism has been developed as a workable mechatronic product prototype.

This prototype has been subjected to rigorous testing protocol and the test results were encouraging without any failures on static load test, vibration test and geometric dimensional & tolerance stack aspects.

This DWS mechanism concept product is presently designed for SUVs of current market segment models and for the future generation of autonomous versions as shown in Figure 87.

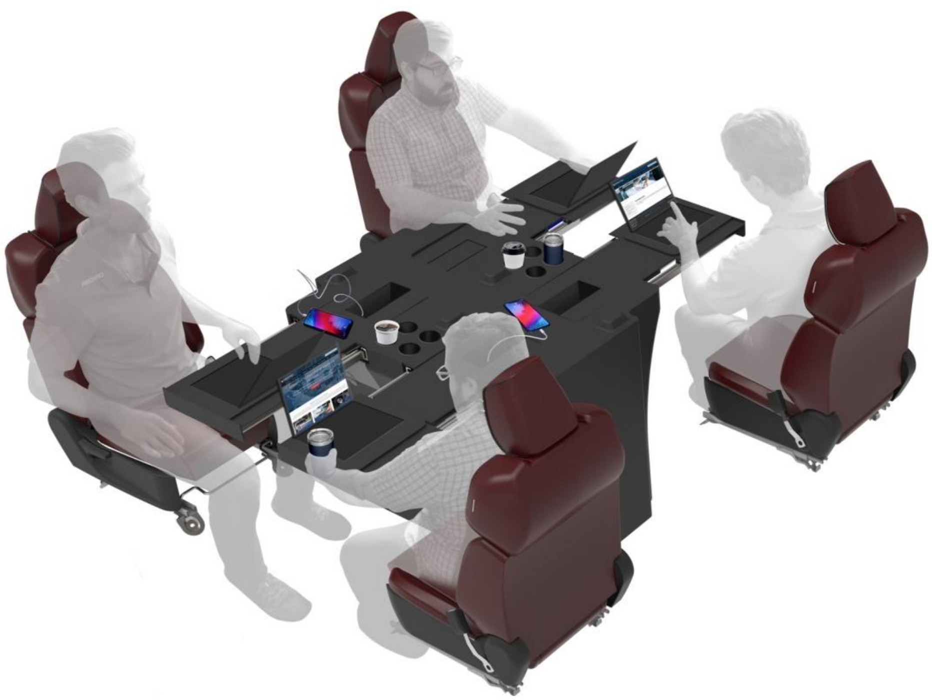


Figure 87. Users in the vehicle interior accessing the reconfigurable console

This DWS mechanism concept product can be customized with necessary modifications on size factors and can be assembled into any vehicle interior of any segment in both autonomous and non-autonomous vehicles. Hence this DWS mechanism product has got a good marketing potential in the automotive vehicle interior global market.

7.2 Future Scope

This DWS mechanism product concept requires further studies on further design improvement to make the product safety compliance for ISO 26262 Automotive Safety Integrity Level (ASIL). Further improvement on this product concept with noiseless motors, smooth retractability, durability, latching & locking selection, better sensors, less weight, cost-effective etc., will attract the users. Further studies on improving the reliability and sustainability of this DWS mechanism concept product design are also required.

This DWS mechanism concept with suitable modifications may also be used in aviation, railways and waterways transportation.

Though autonomous vehicles will be having an influence on the market, semi-autonomous or non-autonomous and other luxurious vehicles will still attract a large portion of the customers particularly in the developing countries. These customers may have inclination for an advanced interior access product like DWS.

With suitable modifications this concept product design can be adapted as a mobile, portable console providing access for worksurface for the system work environment in educational institutions, home, office, editing desk for media production units, business conference etc.,

Thus this concept product will have market potential in the furniture segment also.

Thus this DWS mechanism concept product will have the potential to induce the growth of the automotive interior access product market and furniture market globally.

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APPENDIX-A

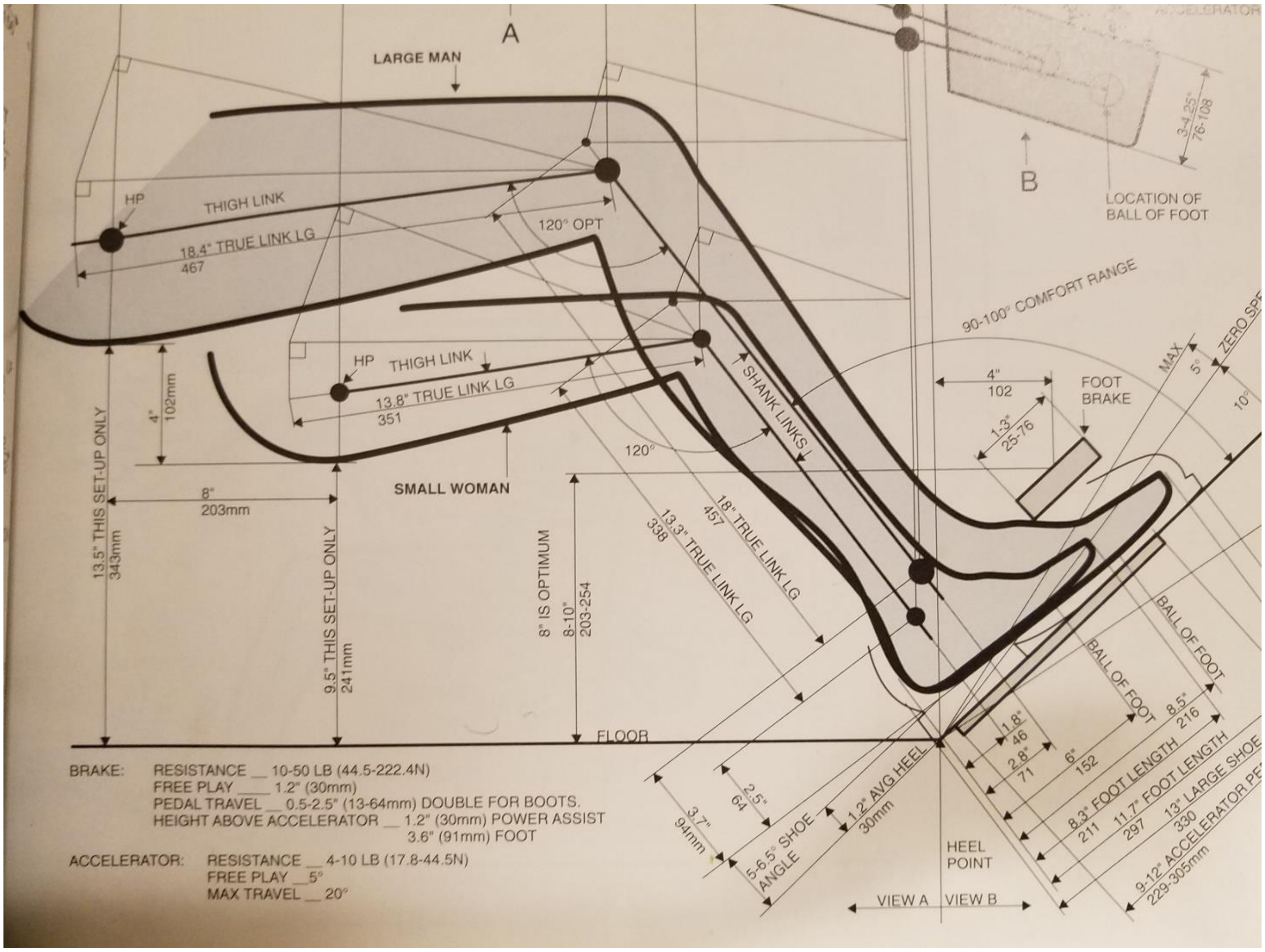

Figure 88. H-Point for large and small woman in vehicular accommodation [20]

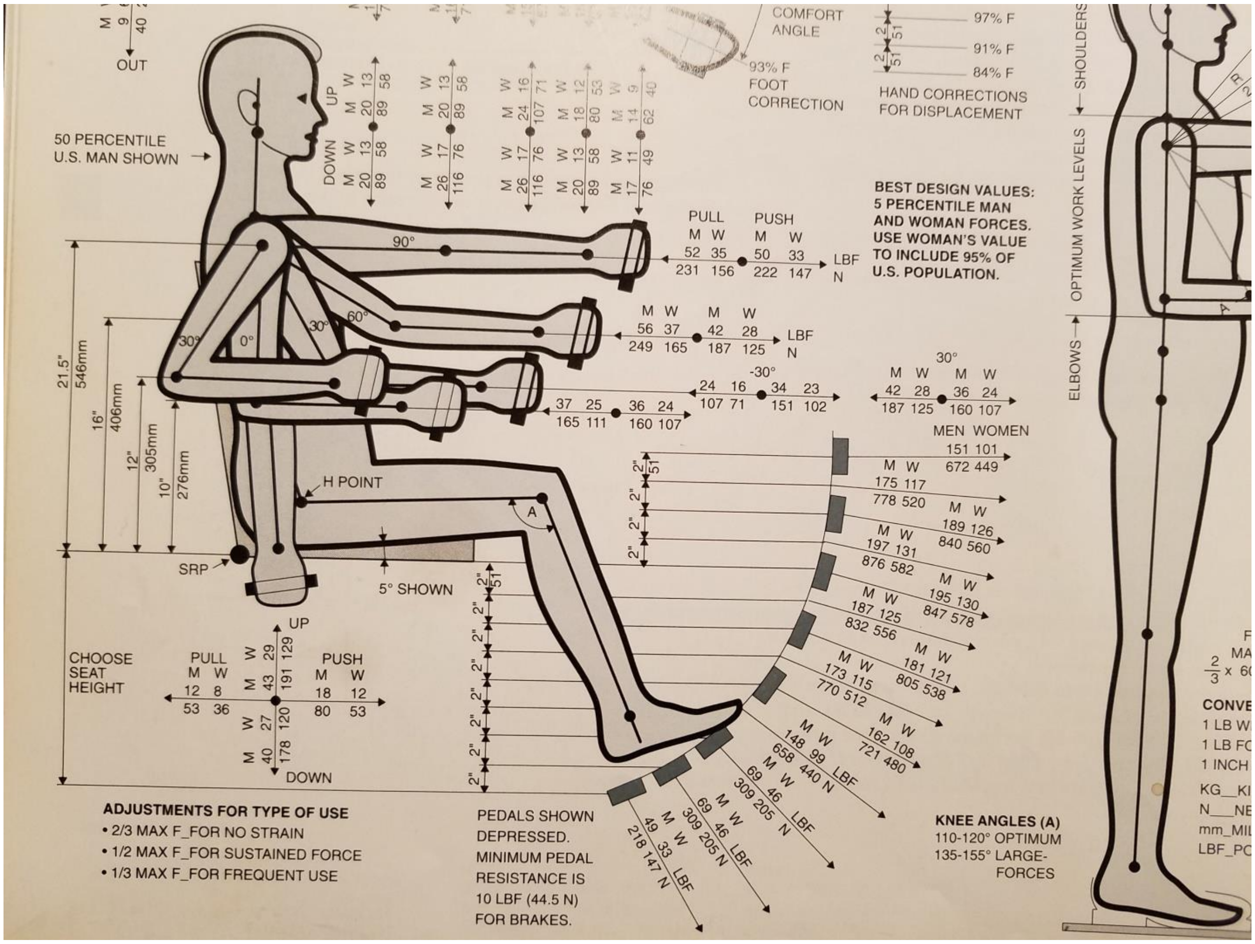

Figure 89. H-Point for resting foot in vehicular accommodation [20]

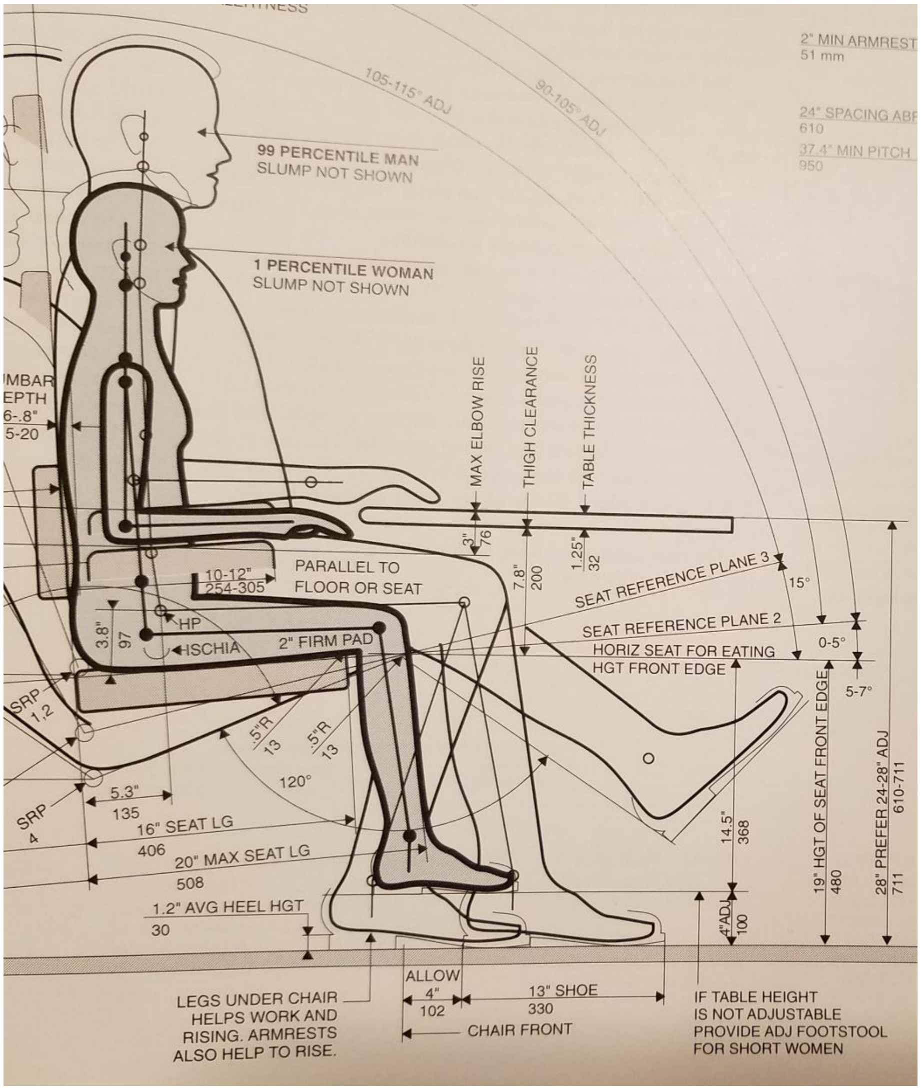

Figure 90. H-Point for accessing worksurface in seating condition [20]

APPENDIX-B

Table 10. Reconfigurable DWS mechanism CAD structure

Model	CAD Structure	Name	Part Numbers
RECONFIGURABLE DWS MECHANISM	ASM	RECONFIGURABLE_WORK_CONSOLE	X00001365867
	ASM	FRAME_ASM	X00001365868
	PRT	FRAME_TOP_LEFT	X00001365869
	PRT	FRAME_TOP_RIGHT	X00001365870
	PRT	FRAME_VERTICAL_RIGHT	X00001365871
	PRT	FRAME_VERTICAL_LEFT	X00001365872
	PRT	FRAME_HRZ_BACK	X00001365873
	PRT	FRAME_HRZ_FRONT	X00001365874
	PRT	FRAME_BOTTOM_RIGHT	X00001365875
	PRT	FRAME_BOTTOM_LEFT	X00001365876
	PRT	FLAT_PALTE	X00001365877
	PRT	LIMIT_SWITCH_BRACKET	X0000136710
			X00001365878
	ASM	LEAD_SCREW_ASM	X00001365879
	PRT	LEAD_SCREW	X00001365880
	PRT	SKF_BEARING	X00001365881
	PRT	SPACER_BRG	X0000136709
	PRT	MOTOR_BRACKET	X00001365884
	PRT	NEMA_17_DRIVE_NUT	X00001365882
	ASM	GUIDE_SHAFT_ASM	X00001365883
	PRT	GUIDE_SHAFT	X00001365885
	PRT	GUDE_POST_STOPPER	X00001365886
	ASM	MOVABLE_TRAY_ASM	X00001365887
	PRT	SHAFT	X00001365888
	PRT	LINK_BAR	X00001365889
	PRT	L-FLANGE	X00001365890
	ASM	TRAY_BEARING	X00001365890_01
	PRT	BEARING_HSG	X00001365890_02
	PRT	BRG_HUB	X00001365890_03
	PRT	BRG_CLAMP	X00001365890_04
	PRT	BALL RACE FOR BEARING	X00001365891
	PRT	TRAY_01	X00001365892
	PRT	TRAY_03_WGT	X00001365893
	PRT	BUSH_LEAD_SCREW_BRACKET	X00001365894

	PRT	BUSH_GUIDE_BRACKET	X00001365895
	PRT	BUSING_LEAD_SCREW	X00001365896
	PRT	BUSHING_GUIDE_POST	X00001365897
	PRT	TRAY_2	X00001365898
	ASM	SLIDER_STD_ASM	X00001365898_01
	PRT	SLIDER_01	X00001365898_02
	PRT	SLIDER_02	X00001365898_03
	PRT	SLIDER_03	X00001365898_04
	PRT	SLIDER_04	
	PRT	BEARING_HSG	
	PRT	BRG_HUB	
	PRT	BRG_CLAMP	
	PRT	BALL RACE FOR BEARING	
	PRT	BALL RACE FOR BEARING	
	PRT	BALL RACE FOR BEARING	
	PRT	BALL RACE FOR BEARING	
	PRT	BALL RACE FOR BEARING	
	PRT	BALL RACE FOR BEARING	
	PRT	BALL RACE FOR BEARING	
	PRT	BALL RACE FOR BEARING	
	PRT	TRAY_01	
	PRT	TRAY_03_WGT	
	PRT	BUSH_LEAD_SCREW_BRACKET	
	PRT	BUSH_GUIDE_BRACKET	
	PRT	BUSING_LEAD_SCREW	
	PRT	BUSHING_GUIDE_POST	
	PRT	TRAY_2	
	ASM	SLIDER_STD_ASM	
	PRT	SLIDER_01	
	PRT	SLIDER_02	
	PRT	SLIDER_03	
	PRT	SLIDER_04	
	ASM	SLIDER_STD_ASM	
	PRT	SLIDER_01	
	PRT	SLIDER_02	
	PRT	SLIDER_03	
	PRT	SLIDER_04	

Table 11. Prototype 3D CAD assembly structure

Item	CAD Structure	Assembly Name	Component Name	Part Numbers
1	ASM	**RECONFIGURABLE_WORK_CONSOLE**		X00001365867
2	ASM	**FRAME_ASM**		X00001365868
3	PRT		FRAME_TOP_LEFT	X00001365869
4	PRT		FRAME_TOP_RIGHT	X00001365870
5	PRT		FRAME_VERTICAL_RIGHT	X00001365871
6	PRT		FRAME_VERTICAL_LEFT	X00001365872
7	PRT		FRAME_HRZ_BACK	X00001365873
8	PRT		FRAME_HRZ_FRONT	X00001365874
9	PRT		FRAME_BOTTOM_RIGHT	X00001365875
10	PRT		FRAME_BOTTOM_LEFT	X00001365876
11	PRT		FLAT_PALTE	X00001365877
12	PRT		LIMIT_SWITCH_BRACKET	X0000136710
13	ASM	**LEAD_SCREW_ASM**		X00001365878
14	PRT		LEAD_SCREW	X00001365879
15	PRT		SKF_BEARING	X00001365880
16	PRT		SPACER_BRG	X00001365881
17	PRT		MOTOR_BRACKET	X0000136709
18	PRT		NEMA_17_DRIVE_NUT	X00001365884
19	ASM	**GUIDE_SHAFT_ASM**		X00001365882
20	PRT		GUIDE_SHAFT	X00001365883
21	PRT		GUDE_POST_STOPPER	X00001365885
22	ASM	**MOVABLE_TRAY_ASM**		X00001365886
23	PRT		SHAFT	X00001365887
24	PRT		LINK_BAR	X00001365888
	PRT		L-FLANGE	X00001365889
	ASM	**TRAY_BEARING**		X00001365890
	PRT		BEARING_HSG	X00001365890_01
	PRT		BRG_HUB	X00001365890_02
25	PRT		BRG_CLAMP	X00001365890_03
26	PRT		BALL RACE FOR BEARING	X00001365890_04
27	PRT		TRAY_01	X00001365891
28	PRT		TRAY_03_WGT	X00001365892
29	PRT		BUSH_LEAD_SCREW_BRACKET	X00001365893

30	PRT		BUSH_GUIDE_BRACKET	X00001365894
31	PRT		BUSING_LEAD_SCREW	X00001365895
32	PRT		BUSHING_GUIDE_POST	X00001365896
33	PRT		TRAY_2	X00001365897
34	ASM	**SLIDER_STD_ASM**		X00001365898
	PRT		SLIDER_01	X00001365898_01
	PRT		SLIDER_02	X00001365898_02
	PRT		SLIDER_03	X00001365898_03
	PRT		SLIDER_04	X00001365898_04

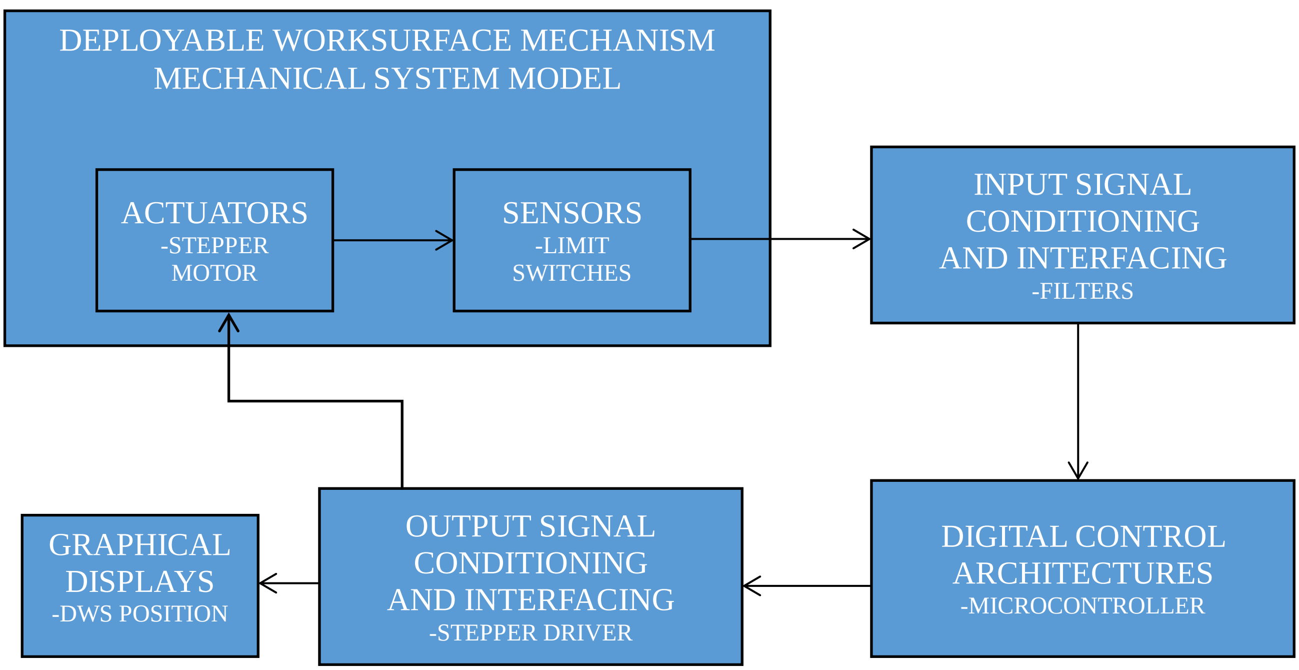

Figure 91. DWS mechanism mechatronic prototype operation