Design for Human Modelling

ME 599

Project: Flight Trolley Hauling

Student Name: Raj Oak

Student ID: 933 603 185

Table of Contents

Introduction of Design Problem

There are several working conditions associated with the day to day activities of a flight attendant that induce workload. These conditions include poor lighting, time limitations, poor access to flight inventory, helping passengers load the baggage, sleep deprivation which are few among other working conditions. As a part of the daily work operations, FAs have to serve passengers with food and amenities which are stored in heavy metal carts and are hauled several times during the flight. While operating these trolleys, the FA's may not always be in the optimal posture which can pose a threat to their lower back muscles.

Problem Summary: According to the U.S. Bureau of Labor Statistic, air transportation workers had 6.7 cases associated with nonfatal workplace injuries and illnesses per 100 full-time equivalent workers (2016) which is more than twice the rate of 2.9 cases taking into consideration all private industry workers [1]. The study conducted on Indian male and female flight attendants (FAs) accounted that 72.65% FAs reported back pain [2] which can be associated with several tasks ranging from pulling, pushing, lifting, working in flight galleys, etc. One of the studies mentions the pushing and pulling of the cart and the difference between the two when operating the trolley/cart [3], it can be analyzed using jack the practical application of this study.

Core Problem: Complaints about physical workload from maneuvering trolleys by flight attendants [4].

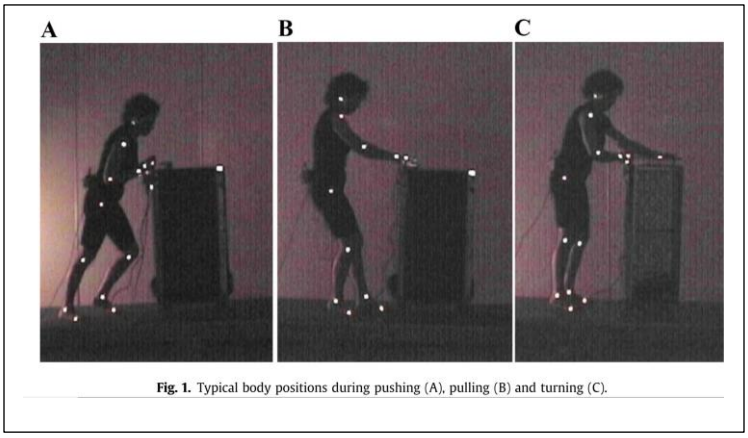


Fig. 1. Typical body positions during pushing (A), pulling (B) and turning (C).

Credit: J.Sandfeld et al [5]

Credit: Sachaporche

These images [5] depict the various postures that are taken while operating the cart. It can be inferred that no specific posture is optimal and it is necessary to study this subject in more detail. The references for the research papers and articles are mentioned in the footnotes.

Discussion of the HoQ process

Determination of Customers: Flight trolley have a different set of customers and different set of users. Flight trolleys are usually purchased by major airline like Southwest, Delta, United, etc. in bulk quantities and then are deployed in the respective aircraft that these airlines own. The flight attendants who host the passengers are the main users of these trolley system.

Customer Needs: The project tries to address the primary user, the flight attendants as well as the direct customers of the product that comprise of the major airlines discussed above. The project tries to put more focus on the primary users since the objective is to reduce the work load of flight attendants. The project has also identified key requirements form the direct customers view while designing the trolley system. The main needs of flight attendants are ease in handling, safe to operate and self-powered operation. The main needs of direct customer are durability of the product, cost effective and having maximum storage capacity. The following tables show customer needs and relative importance, engineering characteristics with related units of measure, competition benchmarking, raw and relative weight.

Customer Needs and Relative Importance

Sr. No.	Customer Needs	Relative Importance
1	Ease in handling	4
2	Safe to operate	5
3	Self Powered	3
4	Durable	3
5	Cost Effective	4
6	Maximum storage capacity	2

The customer needs were captured by thoroughly reviewing the research mentioned in the papers mentioned above. Along with this, different conditions that make the flight attendants feel strained were studied. The direct customer needs were extrapolated from the normal purchasing behavior of the airline industry in general.

House of Quality can be found in the appendix at the end of the report. Using house of quality raw weight and relative weight is calculated shown in the table below.

Engineering characteristics with related units of measure, raw and relative weight

Sr. No.	Engineering Characteristic	Measurement Unit	Raw Weight	Relative Weight
1	Weight	Kg	457.1	17.4
2	Braking Feature	N	442.9	16.9
3	Electric Actuation	W	642.9	24.5
4	Material	Strength/Weight	347.6	13.2
5	Strength	MPA	433.3	16.5
6	Shape	m^3	300	11.4

The engineering requirements mentioned in the table above are obtained based on the requirements of the two customer segments. The engineering requirements were identified which will be crucial in determining and fulfilling the needs of the product. Here the weight of the trolley which is an important property is measured in kilograms to select the optimum material. The braking feature is assumed to be fully acting when brakes are applied and can be measured in Newton for the amount of force applied by the brake pads. It is assumed that the trolley will be locked in all conditions on the application of the brakes. The electrical actuation is done by providing electrical power and the units is watt (W). For the material consideration the unit or strength to weight ratio can be used to determine the most appropriate material and compare several different material families. For strength mega pascals is used and volume in m^3 for shape.

Competition Benchmarking

Attribute	Proposed Design (Our Company)	Competitor 1 (ATLAS) [6]	Competitor 2 (KSSU) [7]
Ease in handling	5	3	3
Safe to operate	4	4	3
Self powered	5	0	0
Durable	4	4	4
Cost effective	2	4	5
Maximum storage capacity	3	4	4

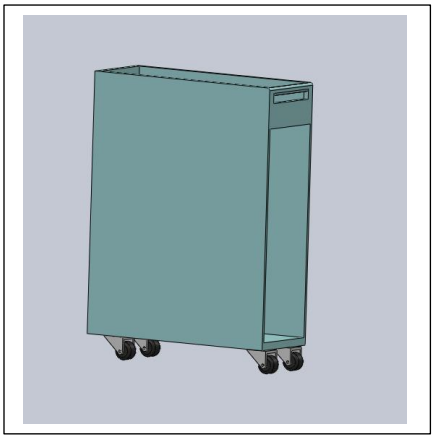
ATLAS and KSSU are the major players in the flight trolley industry and provide trolleys to major airlines in the world. The proposed design is the only design with electrical actuation and scored highest in this sector. The proposed design scores less in cost effective and storage capacity due to the electrical actuation which increases the cost and takes some storage space.

Developing CAD Models

For the sake of comparing the proposed design with the commercially available trolleys, two separate CAD models are developed shown below.

Commercially Available Trolley

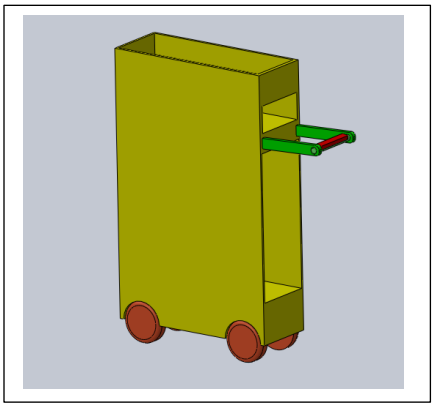
CAD model seen on the right depicts commercially available flight trolley. It is CAD model of ATLAS trolley of similar specifications. The total height of the trolley is about 1 meters, width 301mm and breadth 810 mm. As it can be observed from the figure, the handle of the trolley is not well formed and does not provide a comfortable grip. Along with this, hands need to stretched completely for pushing or pulling the trolley as there is no space for the free movement of legs if the hands are held close to the body.



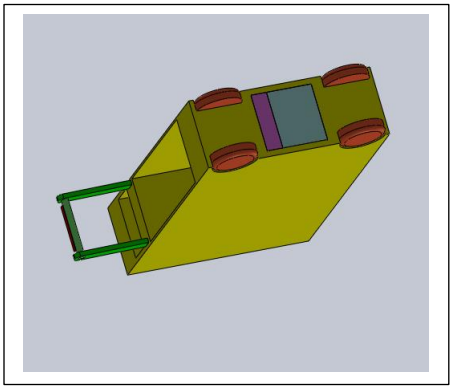
Larger images can be found in appendix.

Proposed Design Trolley

The two figures on the right depict the proposed model for the flight trolleys. The design is made using the result of the House of Quality which can be found in appendix of the report. According to the set conditions, ease in operation and safe to operate parameters are given considerable weights and hence the design is made keeping these requirements in mind.

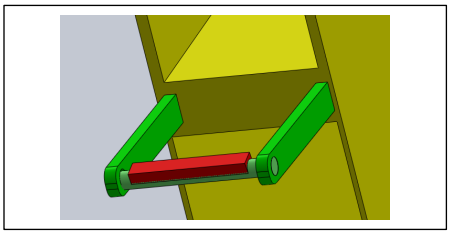


One of the prominent feature of this design is the elongated handle that is more comfortable to operate as it provides ample of space for legs while the hands are close to the body. This posture is much comfortable as compared to the earlier consideration.



Other important feature is the addition of the electrically powered wheels. The hub motor is in built in each wheels and can deliver up to 250 watt combined for the ease of locomotion.

The next figure on the right describes the bottom section of the trolley which carries the battery and electronic control unit.



The last figure represents a unique brake mechanism that operates automatically when hand is removed from the red bar. When the red bar is pushed electrical assist helps in trolley maneuvering.

Assessment of the Human Factors Issues

The project will make use of predominantly Occupational Packaging Task Analysis Toolkit. The proposed design is compared with the commercially available flight trolley for which CAD models are shown above. Following analysis are being conducted: comfort assessment, lower back analysis, static strength prediction, OWAS posture evaluation. For the purpose of study a maximum force of 215 N is being applied equally on both the hands from the data in the research [4]. For the modified version the electric assist mode reduces 60% of effort, thus the net force exerted is 86N.

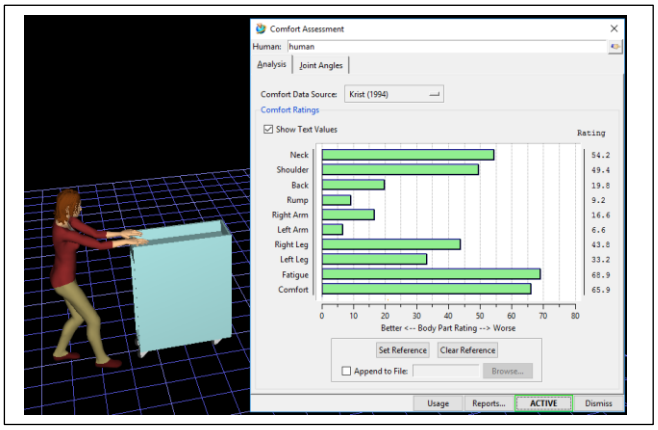
Comfort Assessment

This assessment is done as a graphical guide to compare the relative comfort level as experienced by the manikin in alternative designs. This originally used for drivers can be effectively used in this scenario as the flight attendants may be in the shown posture for extended amounts of time.

Commercially available design

In the multi joint analysis show in the figure on right it can be seen that no joint displays a yellow colored bar indicating that the posture is not very uncomfortable.

However, it can be seen that the comfort score for neck, shoulder and right leg have worst comfort score and can become uncomfortable after prolonged period of operation.

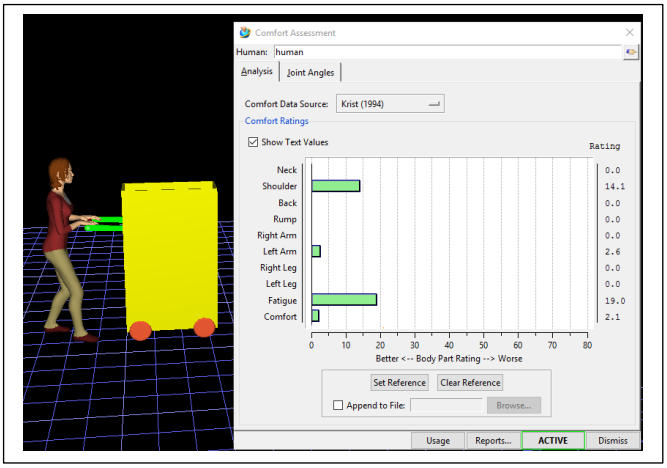


New proposed design

In the multi joint analysis shown in the image for the new proposed design of the trolley the comfort score is much higher than the previous condition.

Here, shoulder is showing some minor discomfort but much lower than in case of the commercial trolley.

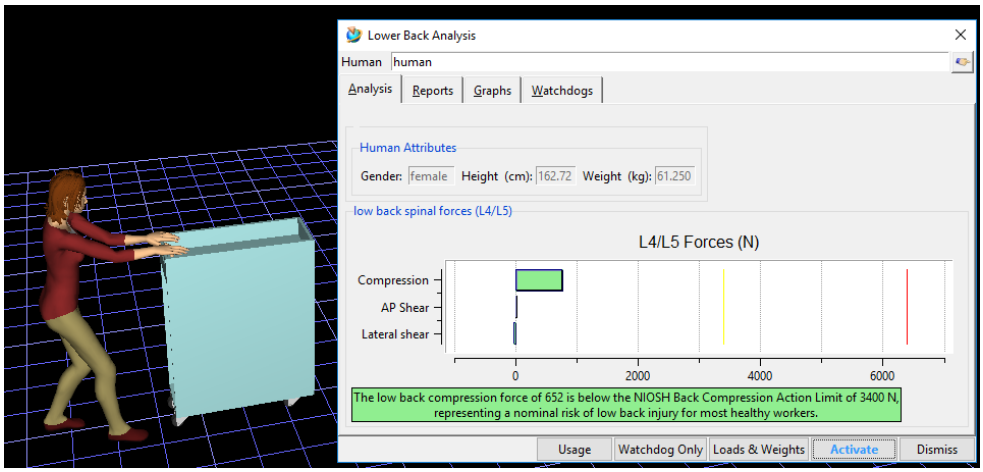
This can largely be attributed due to the extended handle which allows the manikin to keep the hands neat torso, thus increasing the comfort level.



Lower back analysis

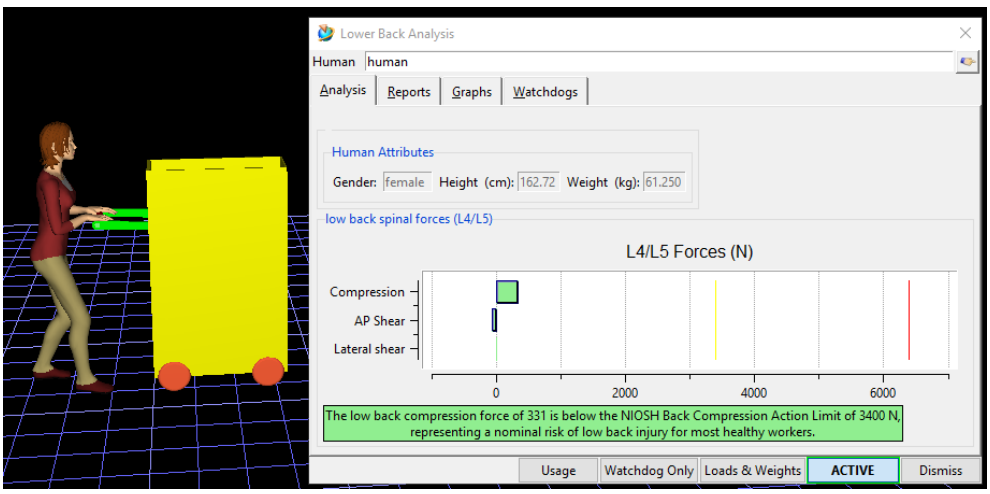
Lower back analysis is one of the most common and important assessment that is required to find the actual force as experienced by the L4/L5 musculoskeletal structure.

Commercially available design



Here, it can be seen that the lower back force is much lower than the NIOSH force limit and we can say that this process may not cause any harm of significant magnitude. However, with repeated motion this can result in some discomfort as it was proved from the comfort assessment.

New proposed design



For the new proposed design, it can be seen that the forces on the lower back are significantly lower. The compression forces, here are about 250 N and for the commercial trolley the force is about 850N. The proposed model performs better than the commercial.

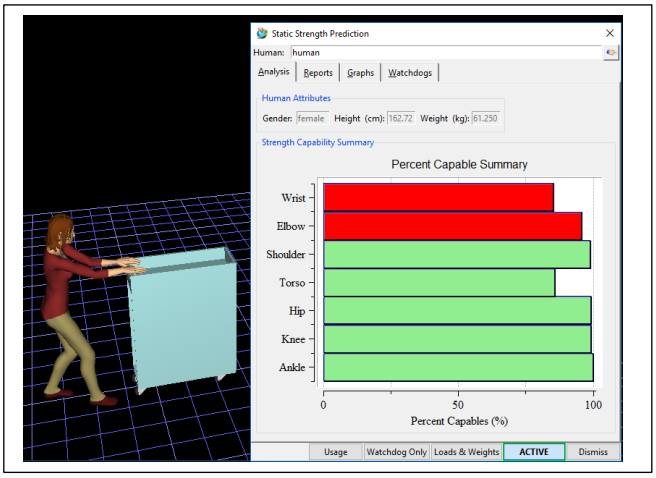
Static Strength Prediction

Commercially available design

The static strength prediction for the commercial trolleys indicated that there is extensive loading on wrist and elbow joints while starting the trolley.

This can be attributed to the fact that hands are fully stretched to allow for the foot to start walking.

This is an uncomfortable posture and causes strain on wrist and elbow.



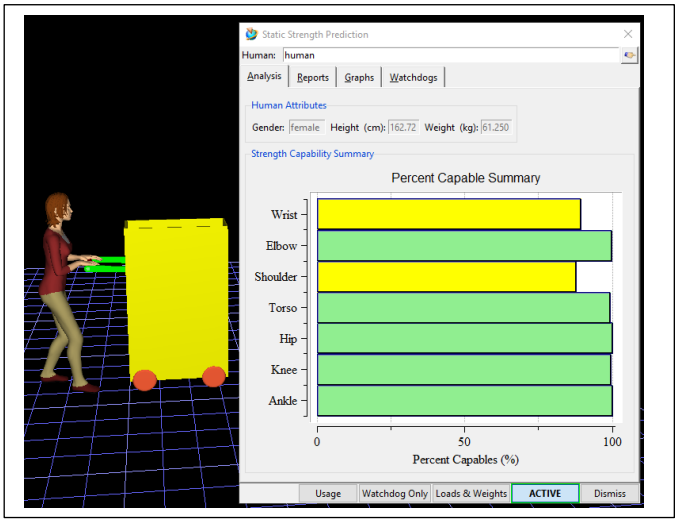
New proposed design

As seen in the graph on the right, the proposed design performs better that the commercial design.

This is majorly attributed to the elongated handle bar and the electrical assist.

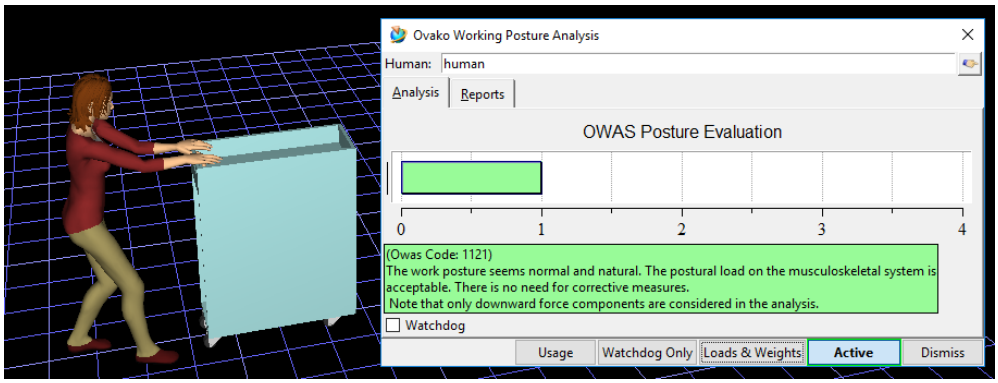
When ever the red bar on the handle is pushed (discussed in CAD models) the electrical assist is actuated and reduces the load of the trolley.

The elongated handle allows the manikin to place hands near the body, thus decreasing strain.



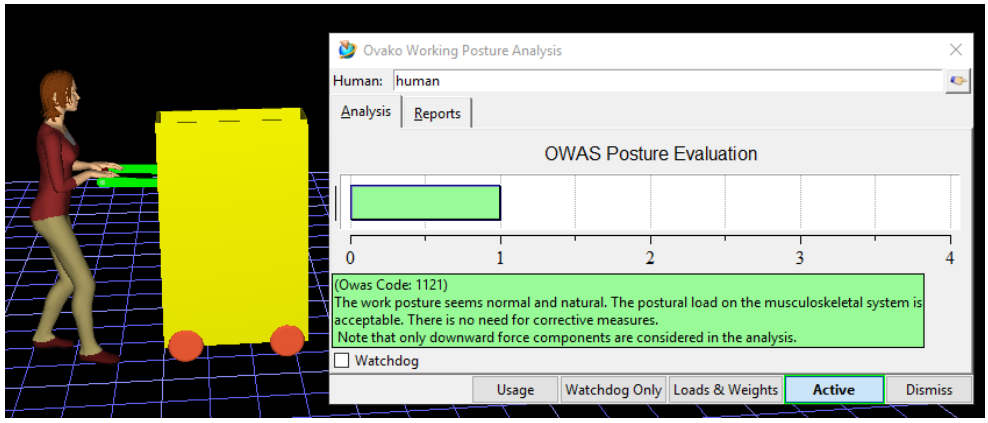
OWAS posture evaluation

Commercially available design



The OWAS postural analysis indicates that the normal operation is normal and natural and is acceptable.

New proposed design



The OWAS postural analysis for the new proposed design indicates that there is not a significant difference in the posture that might be harmful in both the conditions.

There is no need for any corrective measures as only downward forces are considered in this analysis and the current postures do not have these forces.

Discussion

Some of the major improvements in the proposed design include the elongation of the handle to facilitate leg movement while hands are kept near the torso for increasing the comfort level. Along with this the electric assist provided by the hub motors help in reducing the pushing effort by almost 60% thus making the person less exert while applying force to move the trolley. The braking system is designed in such a way to be engaged when the hands are taken off the handle and get deactivated when the person starts applying force on the handle.

Following table summarizes the comparison of different tests conducted so far to better understand the advantages of proposed design.

Sr. No.	Analysis Type	Commercial Trolley	Proposed Trolley Design
1	Comfort analysis	Neck, shoulder and right leg in some discomfort	No significant discomfort observed
2	Lower back analysis	850N force exerted	250N force exerted
3	Static strength prediction	Wrist and Elbow under significant strength	No significant strain observed
4	OWAS posture evaluation	No change	No change

Limitations of the current design

- The current design is very comfortable to operate but poses some limitations. One of the biggest limitations in wide scale adoption of the design is the actual weight of the trolley. Due to the integration of electrical actuation system the actual weight of the trolley might increase up to 60% which may not be favorable for some airlines as this has a direct impact on the fuel usage of the aircraft.
- The cost of making such a trolley will be substantially higher that the conventional design, majorly due to the braking mechanism coupled with electric assist mode. The trolley was designed to offer highest safety and comfort while in operation as it does what it is intended for.
- These points need to be thoroughly considered before going forward with prototyping and are beyond the scope of this report.

Conclusion

The report successfully presents as an alternative design for flight trolleys used extensively by flight attendants for serving food and other accessories. The report then presents a House of Quality which is made to understand the design requirements and translate them in to usable engineering requirements that can help for further prototyping and manufacturing purposes. The report discusses the requirements that are needed while operating a trolley and presents CAD models of the proposed design with modification which is intended to provide high level of comfort over other factors.

Next, the report analyzes the proposed CAD models made using SolidWorks software which are imported in to Siemen's Jack software for Digital Human Modeling analysis. A 50^{th} percentile American female manikin is chosen to represent a flight attendant and various analysis as discussed in the report are carried out.

The result of the analysis clearly indicates that the proposed new model of trolley is much more comfortable to operate. For moving forward in to prototyping phase several other factors like cost and weight of the trolley need to be considered.

References

[1] U.S. Bureau Of Labor Statistics, TED: The Economic Daily (April 30, 2018); Air transportation workers had high rate of nonfatal workplace injuries and illnesses in 2016.

[2] Sharma (2007), JRSH, Lifestyles, flying and associated health problems in flight attendants.

[3] [Al-Eisawi et al.,1999]; Factors affecting minimum push and pull forces of manual carts.

[4] [Glitsch et al.,2007]; Physical workload of flight attendants when pushing and pulling trolleys aboard aircraft.

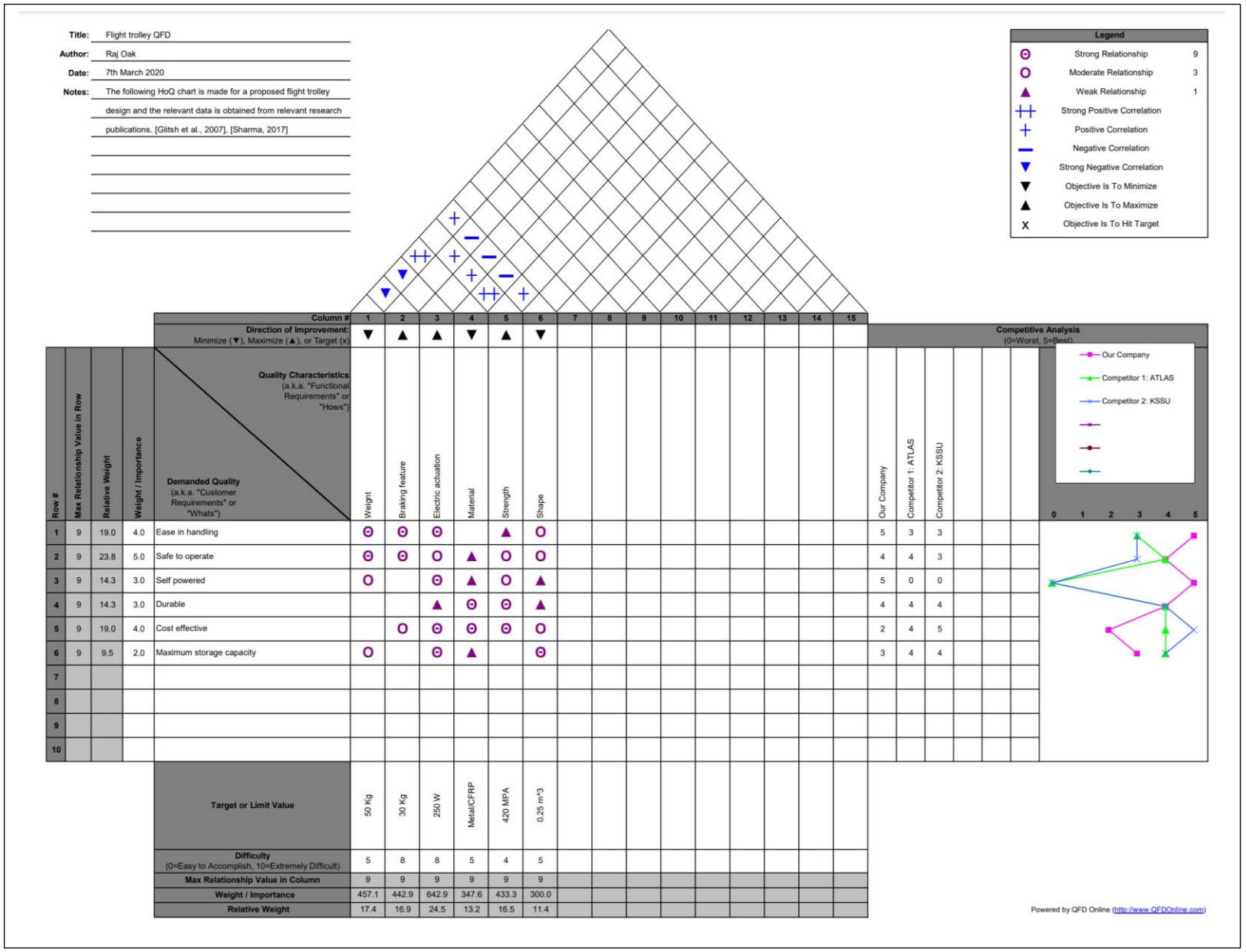
[5] [Sandfeld et al., 2014]; L4eL5 compression and anterior/posterior joint shear forces in cabin attendants during the initial push/pull actions of airplane meal carts.

[6] Global Sources; Wuxi Lanji Aviation Kitchen Equipment Co. Ltd
Find here: https://www.globalsources.com/si/AS/Wuxi-Lanji/6008845070062/pdtl/Atlas-Aviation-Meal-Trolley---Aircraft-Meal-Cart---Airplane-Cart---Atlas-Meal-Cart/1064453266.htm

[7] Made-in-China; Transportation-Barrow, Trolley & Cart
Find here: https://egret-aviation.en.made-in-china.com/product/CXGQHOxYfwVN/China-Atlas-Kssu-Aircraft-Inflight-Full-Size-Meal-Beverage-Cart-Trolley-TF0001-.html

Appendix

a) House of Quality



Title: Flight trolley QFD
Author: Raj Oak
Date: 7th March 2020
Notes: The following HoQ chart is made for a proposed flight trolley design and the relevant data is obtained from relevant research publications. [Glitsh et al., 2007], [Sharma, 2017]

Legend

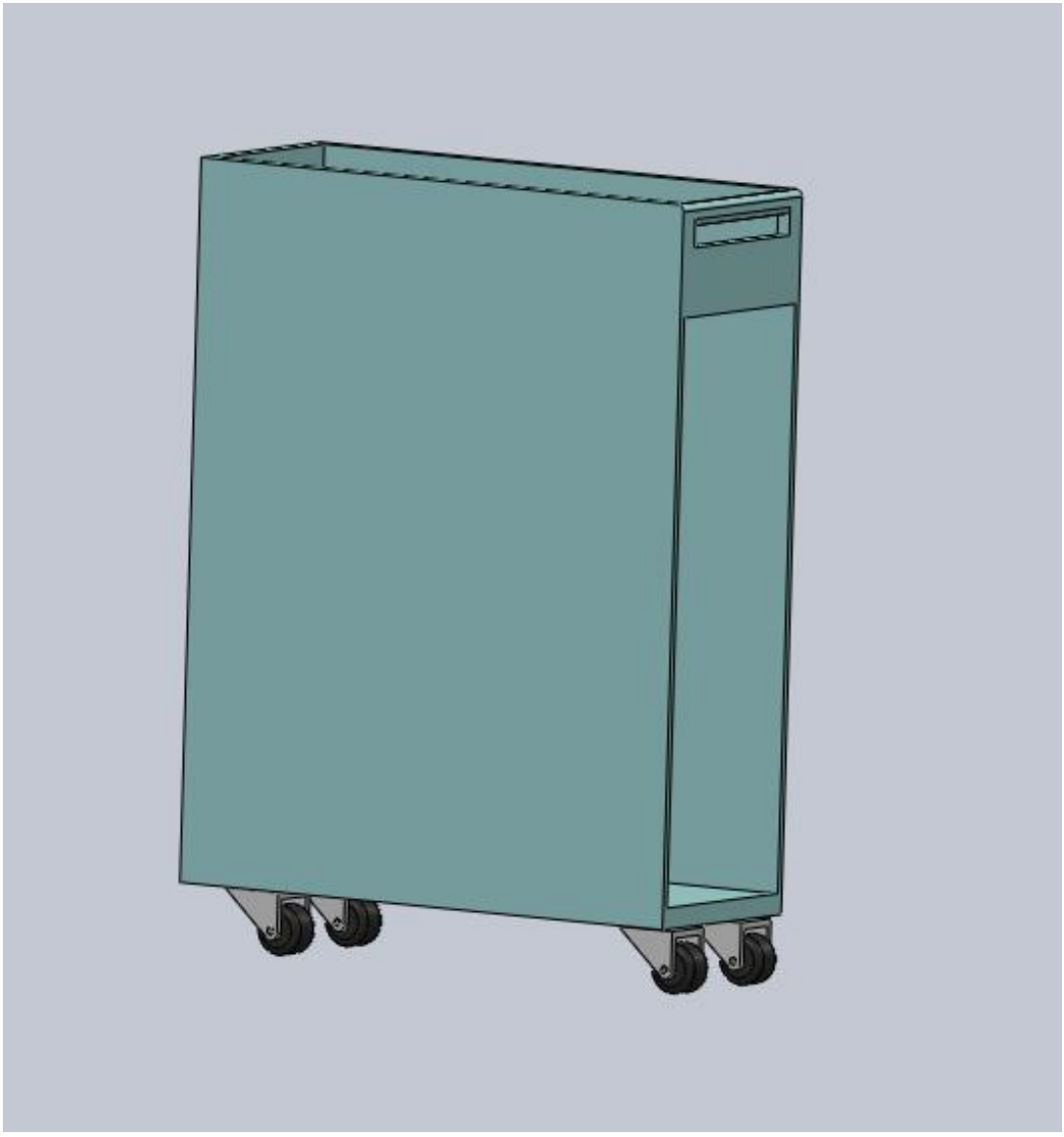
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Weight	2 Braking feature	3 Electric actuation	4 Material	5 Strength	6 Shape	Our Company	Competitor 1: ATLAS	Competitor 2: KSSU
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▲	▲	▼	▲	▼			
1	9	19.0	4.0	Ease in handling	Θ	Θ	Θ		▲	O	5	3	3
2	9	23.8	5.0	Safe to operate	Θ	Θ	O	▲	O	O	4	4	3
3	9	14.3	3.0	Self powered	O		Θ	▲	O	▲	5	0	0
4	9	14.3	3.0	Durable			▲	Θ	Θ	▲	4	4	4
5	9	19.0	4.0	Cost effective		O	Θ	Θ	Θ	O	2	4	5
6	9	9.5	2.0	Maximum storage capacity	O		Θ	▲		Θ	3	4	4
7													
8													
9													
10													
				Target or Limit Value	50 Kg	30 Kg	250 W	Metal/CFRP	420 MPA	0.25 m^3			
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	5	8	8	5	4	5			
				Max Relationship Value in Column	9	9	9	9	9	9			
				Weight / Importance	457.1	442.9	642.9	347.6	433.3	300.0			
				Relative Weight	17.4	16.9	24.5	13.2	16.5	11.4			

Competitive Analysis (0=Worst, 5=Best)

Powered by QFD Online (http://www.QFDOnline.com)

b) Commercially Available trolley



c) Proposed Design Trolley