# Designing and Evaluation of Washing Machine Base Stand Using Quality Function Deployment and Ergo-Fellow

Mahmoud Z. Mistarihi[1,2]*, Ghazi M. Magableh[1], Abdullah M. Alsarraj[3]

[1]*Department of Industrial Engineering, Hijjawi Faculty for Engineering Technology, Yarmouk University, Irbid 21163, Jordan*
[2]*Department of Mechanical and Industrial Engineering, Faculty of Engineering, Liwa College, Abu Dhabi P.O. Box 41009, United Arab Emirates*
[3]*Aqaba International Industrial Estate, Aluminum Light Solutions, Aqaba 787, Jordan*
** Correspondence: mahmoud.m@yu.edu.jo*

**Abstracts:** Currently, many of the discomforts that washing machine users experience in the back, hands, and shoulders are caused by the wrong way of the static and/or dynamic body positions as they bend to the level of the machine, move clothes, and return to the moderation stand. Data was collected through surveys and interviews to explore the common problems with washing machines and whether they comply with the current safety and ergonomic requirements. Data analysis showed that most of the available washing machine bases were not made according to ergonomic considerations as users experienced different discomforts in the shoulders and lower part of the spine. This paper introduces an improved ergonomic design for a washing machine base stand based on customers' needs and integrates customers’ requirements and desires with the new product using the Quality Function Deployment (QFD) technique. The proposed design of the Flexible Washing Machine Base Stand (FWMS) has been developed to make the washing process safer and help users work more comfortably, efficiently, and effectively. The research methodology includes three research tasks: Firstly, a 3-D model for evaluating and improving the ergonomics quality of the comprehensive conceptual design drawings was formed using computer-aided design (CAD) to minimize modification time and to allow for flexible editing of the initial design. Secondly, analysis was conducted using the Ergo-Fellow software tool to obtain anthropometric data for ergonomic ends and to evaluate and improve workplaces. Thirdly, a rapid prototype (RP) was developed to analyze the conceptual perception of FWMS features and assess its functionality. The prototype of the FWMS concept design was fabricated by a 3D printing machine using Fused Deposition Modelling (FDM) technology. Analysis of the results using different tools and techniques showed that the improved design of the Flexible Washing Machine Base Stand could protect users and prevent workplace-related injuries along with the considerations of safety and ergonomics issues with additional competitive attractive features at a reasonable cost.

**Keywords:** Washing Machine Base Stand, Rapid Prototyping, Quality Function Deployment, Ergo Fellow Software, Anthropometric Measurement, Ergonomic Design.

## 1. INTRODUCTION AND LITERATURE REVIEW

Due to the high discomfort among washing machine users, many designers and manufacturers developed and introduced newly designed washing machine bases to meet the users' needs and health requirements and reduce suffering. FWMS takes advantage of the existing designs in the marketplace and provides an improved solution to make the washing process safer, simpler, and more accessible and to help users avoid wrong-performing status when performing their tasks. Based on the Quality Function Deployment (QFD) results, FWMS has significant advantages compared to related products. The research study takes the Ergo Follow outputs. It analyzes the data collected from hospitals, health centers, surveys, interviews, experts’ and sellers’ opinions, and currently available washing machine bases and stands. The collected information is used to develop an improved FWMS design with additional features according to customers' needs and requirements, considering the ergonomics concerns that help users work more comfortably, efficiently, and effectively.

The rapid-prototyping (RP) technique fabricates a scale model using three-dimensional Computer Aided Design (CAD) data and the additive process. Fused Deposition Modelling (FDM) uses simple machines and is considered a primary type of 3D printing technology [1]. FDM is one of the most common printing methods with low consumption of materials and costs. It jets fuse material through the nozzle of layers to shape the prototype, depending on adding material layer-by-layer with the help of adhesion, and is characterized by low accuracy compared to other methods. QFD tool was used to evaluate the new conceptual design by incorporating customer needs and requirements, comparing it with other products in the market, and using SWOT analysis to identify and understand the main factors affecting the design. Computer Aided Design (CAD) tool was used to create the first conceptual design drawings. SolidWorks software was used to make the FWMS virtual design and prepare the final e-drawings for the RP machines. The model was built by RP machine using Fused Deployment Modeling technology to analyze FWMS improvements, evaluate the impact of the new features, and assess the value added by the developed washing machine bases. Then, results were shared with key users, and the QFD was used to evaluate the new conceptual design. The process was repeated with incremental improvements until the final FWMS design of the targeted washing machine base was achieved.

FWMS is an improved design for washing machine bases. Based on the analysis of the output results from Quality Function Deployment, the FWMS design features showed a great response to the voice of customers compared to other products available on the market with reduced ergonomic risk factors. The FWMS model is a high-quality multi-functional movable adjustable base characterized by rigidity, lightweight, easy to manage, safety and ergonomics considerations, and easy to move and handle with additional desirable features at a reasonable price. In addition, it decreases the lifting distance and the load while feeding the washing machine, reduces stooping, eliminates carrying loads while moving from one location to another, utilizes the available spaces beneath the washing machine, and works on both sit-stand positions. The bottom is a specially designed anti-skid noise reduction pad, effectively reducing the washing machine’s vibration and noise. Moreover, FWMS can be used for both washers and dryers as well. A flexible Washing Machine Base Stand is a design with unique features and accessories to help users of washing machines carry and move clothes and other staff safely. The device is proposed for frequent users and those who have problems with bending their bodies or carrying loads. The base is used to carry the washing machine and consists of two main separate parts: the fixed upper part is used to rise and hold the washing machine tightly, and the mobile lower part is used to carry and transfer clothes safely and has an adjustable vertical slide to adjust the suitable elevation for the user.

Currently, engineers use many techniques to make proper design specifications. Quality Function Deployment (QFD) is one of the best and most popular methods as it is structured to develop the significant information necessary to understand the factors of concern [2]. QFD is used to identify and focus on meeting the voice of the customers, help plan and sequence the focus points of the designer selection, provide the designer with the means of design functionality, shape, and features, evaluate the design in contrast to other competitors, and identify the strengths and weaknesses points of the design [3]. If applied correctly, QFD is considered one of the contributing factors to success [4]. The QFD Technique uses a chain of matrices called a house of quality to link inputs to outputs in various stages of development [5]. QFD is a suitable method to convert customer needs into technical parameters [6]. The individual customer needs must be weighed based on decisions on preference between two criteria [7]. Designers should follow many systematic sequences to build the (QFD) model. A step-by-step methodology can define the product, and the house of quality diagram can be used to understand and identify the target customers, recognize the customers’ needs and requirements, classify the importance and weight of each need, determine the features and characteristics of the design, define the benefits and weight of each feature or improvement, match the best features of the design with the factors of focus, match voice of the costumers to the voice of the manufacturer (design features), identify the competitors and evaluate how they reflect the customer needs on their design [8]. The results of such an approach will clear up the best features that satisfy most customers' needs and requirements. Evaluations of the results based on the maximum benefits (highest score) to the designers will lead to the best choice of design features and improvements [9].

A rapid prototype (RP) is a means to build a prototype to evaluate the functionality of the design and to get a complete impression of the shape and performance of the model. A rapid prototype is characterized by high technology, faster and more accurate prototyping, reduced losses and minimized manufacturing steps, more accessible and more uncomplicated modifications, and increased ability to improve at low costs compared to other traditional methods [10]. RP uses layer-by-layer fabrication of 3-D models directly from a computer-aided design, and it applies a group of techniques used to fabricate a scale model quickly [11]. RP utilizes a wide range of materials and speeds up the development process of the products in an unprecedented way. Competitive products should be functional with improved quality at low cost, and it is hard to get such products quickly. However, RP is a method to minimize time and effort since the development time can be minimized by making early process corrections to the products [12]. Several steps should be followed to build and reach the final prototype using Rapid Prototype machines. These steps include drawing a 3-D model using Computer-Aided Design software/ SolidWorks [13], converting the file into ". stl" format or uploading the CAD file to any external service provider to execute the prototype such as 3-D HUBS, printing the model, perform the surface processing operations, and assemble the parts to build the final model.

Fused Deposition Modeling (FDM) depends on three basics: surface chemical reactions, thermal energy to melt the plastic, and adding materials layer-by-layer until the prototype is complete. Many types of technology are used depending on the raw material extrusion methodology, such as the two-material extrusion method and material filament extrusion through a heated nozzle [14]. Materiality parameters affecting the quality of the printed prototype, such as the heat needed to raise the temperature to the melting point, quality and characteristics of raw material used, diameter of the nozzle, material extrusion and compression ratio, density and thickness of material extruded along one path on the layer, thickness of the layer, feeding rate, and cooling method and the efficiency of the cooling system. FDM is considered one of the best RP methods. It is a computer-controlled, clean process with no waste, can produce products relatively quickly, and employs different types of materials. FDM technology can create prototypes using a desktop manufacturing process that can be run in an office with a clean environment [15]. It requires no laser and is a relatively simple process, and parts can be produced accurately using CAD applications. The materials used are less expensive and easy to manage. The material is fed and heated above its melting point before deposition, then fills in the two-dimensional profile of each slice in two directions. The material solidifies, creating a laminate of each slice and keeping the optimal temperature to allow fusion with the next layer. The platform then lets the product down to add the next layer, repeating the process for each slice until the 3-dimensional object is entirely built. Once the product is finished and removed from the FDM, the final part is sanded to enhance the surface finish [16].

### 1.1. Problem Statement

Many of the discomfort washing machine users suffer in their backs, hands, and shoulders are caused by incorrect static and/or dynamic body positions. Many of these problems can be decreased by raising the washing machine to a suitable level and by using a specially designed cart to transport laundry back and forth to the washing machine. The most repeated procedure experienced by the users of washing machines, especially in laundry shops (dry cleaning shops or washing machine shops), is the transfer of clothes to and from washing machines and dryers. Usually, users experience static bending while putting the clothes inside the machine or removing them. In addition, users carry and hold clothes to transfer them from one location to another in a dynamic movement until reaching the state of moderation stand. Currently, the body of the washing machine user' is subject to the static and dynamic state and relies on the bones of the vertebrae and the forearms as they bend to the level of the machine, moving clothes, carrying, and walking with the load, and returning to the moderation stand. The repetition of standing, bending, and carrying things incorrectly led to arthritis pain and harm in the spine, arms, neck, and/or shoulders. The following components were considered to understand the current design problems, essential improvements, and related injuries: Data were taken from a public hospital and other health centers in the Hashemite Kingdom of Jordan (HKJ). Users who experienced significant discomfort or injuries were interviewed, and a survey was given to randomly chosen users. Analysis was conducted using the Ergo-Fellow software tool to obtain anthropometric data for ergonomic ends and to evaluate and improve workplaces. Finally, a QFD process using HOQ techniques was utilized to investigate customer needs and market requirements, allowing for direct comparison to the competition in meeting the customer's needs, reducing the possibility of development time, and preventing wasted resources. The remainder of this paper is organized as follows. In section 2, the research methodology is illustrated, the required data is collected, and a conceptual design of the FWMS is introduced and analyzed. Performance evaluation and comparison are provided in Section 3. Finally, remarkable conclusions and future work are given in the conclusion.

## 2. MATERIALS AND METHODS

The research methodology went through several steps, as shown in Figure 1. Initially, the problem was recognized as many users complained about health problems caused by the repeatable usage of the washing machines. The initial investigation of the problem among users realized that an improved design of washing machine bases could protect users and prevent workplace-related injuries, taking into consideration safety and ergonomics issues with additional attractive features at a reasonable cost.

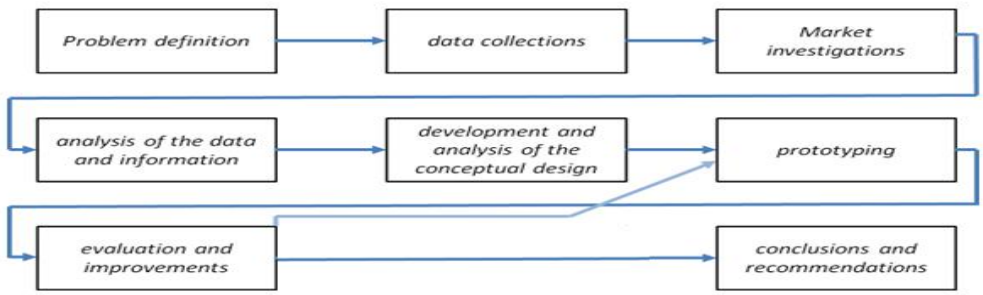



**FIGURE 1.** RESEARCH METHODOLOGY STEPS

Data was collected from Princes Raya Hospital and other health centers in the HKJ during the years 2021-2023 to understand the related injuries. As shown in Figure 2, the statistical analysis shows that 14750 patients have bone or joint injuries that prevent them from carrying loads. The primary injuries were caused by staying for a long time on the same wrong static status or wrong dynamic moving while carrying loads.

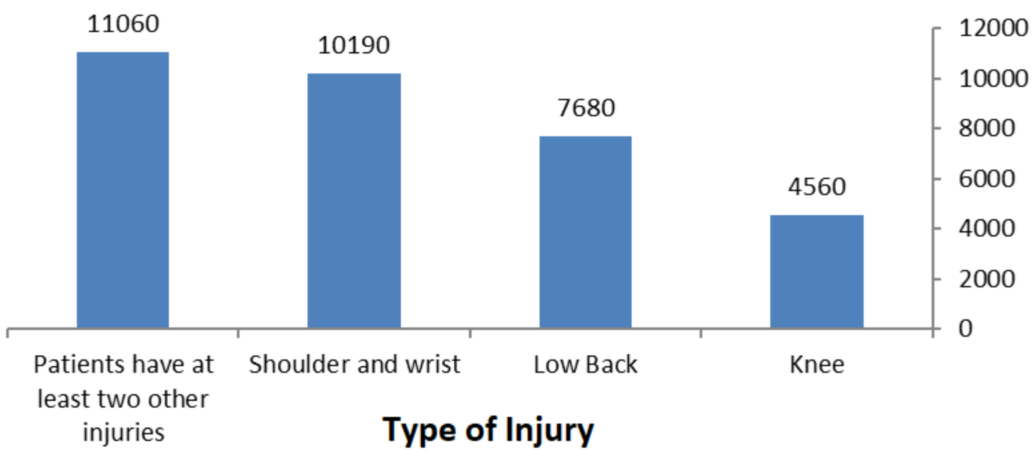



**Figure 2.** Data about bone and joint injuries from Princes Raya Hospital

A survey was designed and distributed to repeated users, including housewives who frequently use washing machines (1-5 times a week) and employees who work at laundry shops (dry cleaning shops or cloth washing shops) in HKJ. Then, an interview was arranged with many users who use the washing machines more frequently (several times a day) and users who suffered pain or significant discomfort from using the washing machines. Interviews and survey analysis showed that most of these washing machines were not designed according to ergonomic considerations, as users experienced different discomforts at the lower part of the spine and shoulders. The survey was distributed to users between the ages (18-55) years old. The study sample includes 300 users (200 individual users and 100 laundry shop employees). Detailed information was collected from more than ten women and 20 workers based on personal interviews. The survey questions focus on (1) general information such as age, gender, weight, and career of the users, in addition to the number of weekly operation hours. (2) Washing machine information such as type, capacity, dimension, location, and position, and whether they use the base stand, pedestals, or risers installed underneath front-loading door washers and dryers. (3) Health discomforts and problems experienced by the users at the lower part of the spine and shoulders. (4) Diagnostic information such as type of injury, if any, the disease's seriousness, and the treatment cost. Data and information about the available washing machines, bases, and stands were collected. The research team shared the information with 30 users to get their opinions and analyze the pros and cons of each product released on the market. The research considers the advantages and tries to solve or avoid the disadvantages of the proposed design.

Additional information was collected from health centers and doctors specializing in bone, joint, and neurology diseases. Furthermore, the research studies the connections between diseases and the careers of employees or individuals who use washing machines frequently. Ergo Fellows software is used to evaluate the fitting of the task and working environment to the user and discuss the differences between washing machine bases and anthropometric characteristics of the users. On the other hand, PEI and WEI techniques were used to compare various products based on the forces affecting the human's lower back.

A conceptual design of the FWMS was introduced based on Ergo-Follow outputs and the analysis of the data collected from hospitals, health centers, surveys, interviews, and currently available washing machine bases and stands. An improved design with additional features according to customers' needs and requirements was developed, considering the ergonomics concerns that help users work more comfortably. The new FWMS design was analyzed after determining the features, the core functionality, and the evaluation of the critical competition factors to determine the value added of FWMS compared to other similar products in the market. SWAT analysis was used to compare FWMS with comparable products, the QFD tool was used to integrate the "voice of the customer" into the design [13], and the house of quality technique (HOQ) was used to link the users' needs to the new design. Design process and prototype building after reflecting modifications and improvements on the FWMS design. The design drawings were prepared using the CAD Software – SolidWorks, exported to CAM, and implemented by rapid prototyping using an FDM 3D printing machine [16].

After finalizing the prototype design and reaching the complete (CAD) design, the final design for each part of FWMS was uploaded to 3D-HUBS to perform the rapid prototype (RP). Choosing the base for printing is a crucial step as each part of the product should be built on its surface to decrease the number of supporting substrates, and then the machine should be chosen to take its zero-coordination point. The 3D printing parameters were determined by the thickness of each layer, melting material used, and size of the injection nozzle [17]. Printed product accuracy depends on the quality of raw material used, the number of printed layers, the dimension of nozzle diameter, the choice of melting temperature, and the machine feed rate. All previous factors build up the time needed to manufacture the parts of the product. Most of the processing time came from machine parameters preparation, data entry, and software setup; once the machine begins fabrication, any prototype part can be created in a single run. Surface processing operations include cleaning, surface treatment, and finishing using a liquid polisher and sandpaper (P1200 standard) to make the final product smooth, shiny, and easy to handle and assemble. The final production stage is assembling the ready parts using different fitted materials and tools [18].

## 2.1. The Proposed Design Overview

FWMS consists of two main parts, as shown in Figure 3. First, the fixed upper part raises and holds the washing machine tightly. The fixed base stands are designed with suitable adjustable height to allow feeding of the clothes without bending the lower back.  Second, the mobile lower part is fitted underneath the fixed part and used to carry and transfer clothes safely. It is equipped with a portable basket to hold clothes and an adaptable vertical slide to adjust the suitable elevation for the user. It also has four double small wheels, allowing smooth movement in all directions. FWMS design allows the user to adjust the fixed stand according to his/her height or body anthropometry and to change the height of the mobile cart accordingly. The design allows the users to feed the clothes into the washing machine or dryer without bending and moving the clothes without carrying them. FMWS is a flexible design since it considers serviceability, maintainability, body positions/ postures, safety, utilization of the available space, and ergonomic considerations of the product. The foot is a specially designed anti-skid noise reduction pad that reduces the washing machine's vibration and noise. FWMS is a lightweight product, as the system's total weight is less than 17 kg.

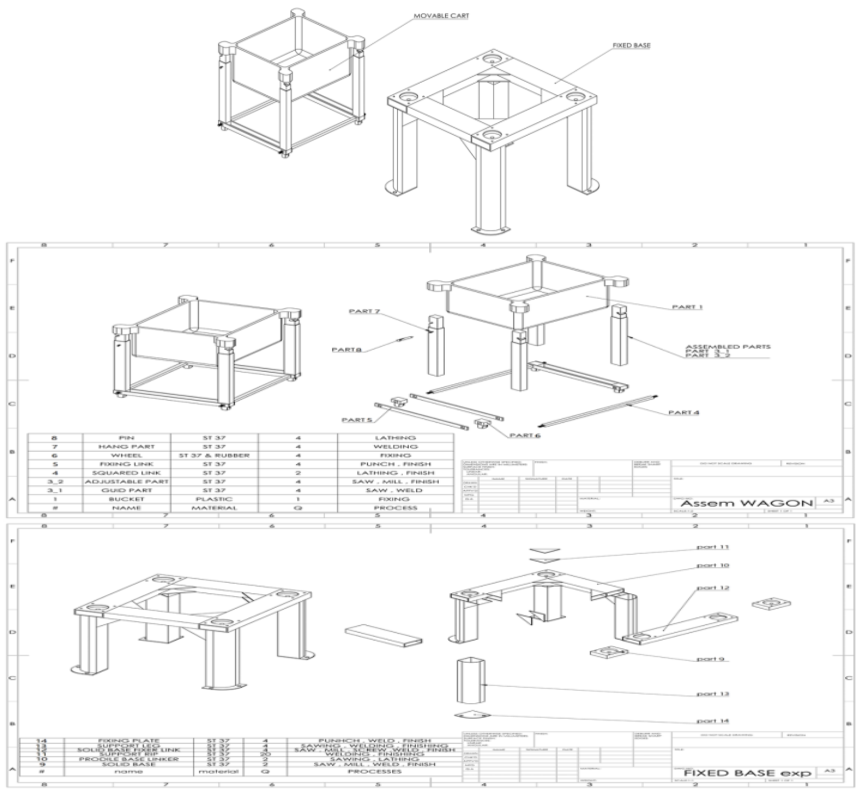



**Figure 3.** FWMS breakdown parts

Additional Figures and Tables are prepared to clarify the design drawings, product components both assembled and exploded the designing dimension of each part, and information about each part such as the material used, made, or bought, required number of parts, type of machines and equipment used, and the manufacturing processing sequence. The product dimensions depend on the human dimension's measurements in static at rest conditions and the functional dynamic dimensions based on the anthropometry and workplace design method. The dimensions help consider human variability and implement the required adjustments that should be made because one size doesn't fit the population (adjusting the workstation, adjusting the tool, adjusting the human position relative to the workstation, etc.) and user's requirements such as design for the extremes, design for adjustable range, or design for the average.

## 3. RESULTS AND DISCUSSION

The design process started with identifying the customer's needs and requirements and determining the current washing machine problems. SolidWorks software was used to do the required drawings and make improvements before building the prototype. QFD tool was used to evaluate the design and do the benchmarking. The first model was created using a 3-D printing process using Fused Deposition Modeling rapid prototyping technology. After assessing the initial model and implementing several modifications and improvements, a pre-production model was built using a conventional manufacturing process to reduce costs [7]. SolidWorks drawing software was used to create an integrated design for the finished product after product sketches were developed [19]. Product dimensions are based on human dimensions' measurements of structural (static) and functional (dynamic) dimensions and the anthropometry and workspace design method. Those dimensions support the consideration of human variability, such as age, gender, and user height, as the FWMS design uses adjustable height [20-21]. Sit-stand work positions are based on work conditions, as in both cases, and all workers need to take frequent breaks and move around for refreshment and to protect their bodies. All dimensions of FWMS are designed according to human bodies' dimensions.

### 3.1. FWMS Compared with Other Products Based on (QFD) Total Weighted Score

FWMS design improvements are based on the results from the QFD tool, comparison between different products and features using SWOT analysis, and user feedback after sharing the design information with 30 users, experts, and sellers. Additional features and modifications were added to prevent users from squatting and reduce the bending of the back while loading or unloading clothes from the washing machine, minimize the number of movements, utilize the space under the washing machine fixed base, and use a mobile cart with adjustable elevation and portable basket to eliminate carrying cloths or moving with a carrying load. Having defined customers' needs and other design requirements, generating and evaluating multiple design concepts, the design team chose a small set of concepts for further development. It used 3 steps evaluation procedures: screening, comparison, and decision-making. The FWMS design considers four significant aspects to rank the alternative designs in order. These aspects include performance with three factors and a total weight of 25, features with six factors and a total weight of 41, product quality with four factors and a total weight of 24, and competitiveness with a prices factor and a total weight of 10 taking into consideration of the availability of the raw material in the market.

The analysis considers a comparison between six types of washing machine bases, pedestals, or stands that are available in the market, including the new FWMS design, VidaXL washing machine pedestal stand, Xavax universal stand with base, Electrolux 74-un-04 pedestal and drawer unit, Washer and dryer pedestal, and the case of not using any base or stand. The results were shared and discussed with selected users (the 30 interviewed users) to get their feedback and comments about different designs, factors, and weights of each factor. QDF total weight scores are used to compare different designs, as shown in Table 1. Fourteen factors were used for comparison purposes, including safety, efficiency, effectiveness, type of the base or stand (fixed or mobile), ergonomics considerations, utilization of the available space, serviceability, reliability, body position/ postures, durability, moisture resistance, rigidity, maintainability, and prices. Each factor gives a specific weight based on the opinion of the experts, sellers' judgments, and users' interview results. The cost weights were calculated using the formula (cost weight = 10-(IC/AC) where IC is the individual cost and AC is the average cost of the six alternatives in euros). Information about the available products was taken from the internet (Amazon), electrical appliance shops, local markets, and users. SWOT analysis, house of quality (NIOSH and rating), and Excel sheet were used to make the required calculations and recommend features and characteristics of the proper FWMS design. Decisions are based on the highest score of the alternatives. Results show that FWMS got the highest score (88.27) while the rest of the products were ranked as follows: Xavax (74.36), VidaXL (72.78), no base or stand (66), Electrolux (67.28), and Pedestal with score (59.31).

**Table 1. FWMS compared with other products based on (QFD) total weighted score**

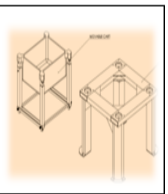
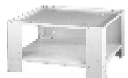
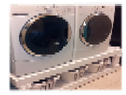
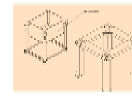
| Factor | | WEIGHT (WI) | |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| | | | NO RISING BASE £ 0 | Electrolux 74-UN-04 Pedestal and Drawer Unit £ 81.46 | VidaXL Washing Machine Pedestal Stand Dryer White with Drawer £ 58.01 | Washer and Dryer Pedestal £ 128.00 | Xavax Universal Stand with Base Division for Washing Machine and Dryer £ 77.94 | W M F B £ 130 |
| | | | RATING(rij) | RATING(rij) | RATING(rij) | RATING(rij) | RATING(rij) | RATING(rij) |
| Performance | Effectiviness | 8 | 5 | 6 | 5 | 4 | 5 | 7 |
| | effecincy | 8 | 3 | 4 | 5 | 4 | 5 | 6 |
| | Safety | 9 | 8 | 4 | 5 | 4 | 6 | 7 |
| Features | Type of base | 7 | 2 | 6 | 6 | 6 | 6 | 7 |
| | Ergonomic Consideration | 8 | 2 | 3 | 2 | 2 | 4 | 7 |
| | Utilization of the available space | 6 | 4 | 2 | 6 | 4 | 6 | 5 |
| | Reliability | 7 | 5 | 5 | 5 | 4 | 5 | 6 |
| | Serviceability | 5 | 6 | 4 | 5 | 1 | 4 | 5 |
| | Body Positions/ Postures | 8 | 1 | 4 | 5 | 5 | 6 | 8 |
| Product Quality | Durability | 6 | 5 | 5 | 5 | 6 | 5 | 6 |
| | Moisture resistance | 6 | 5 | 5 | 5 | 5 | 4 | 6 |
| | Rigidity | 6 | 5 | 5 | 5 | 5 | 5 | 6 |
| | Maintainability | 6 | 5 | 5 | 5 | 2 | 5 | 5 |
| competitivness | Price | 10 | 10 | 8.28 | 8.78 | 7.31 | 8.36 | 7.27 |
| Website link | | | | https://goo.gl/cGawBt | https://goo.gl/63NqVz | https://goo.gl/WnVprw | https://goo.gl/Ju7mfz | |
| TOTAL SCORE | | 100 | 66 | 66.28 | 72.78 | 59.31 | 74.36 | 88.27 |
| RANK | | | 4 | 5 | 3 | 6 | 2 | 1 |

**Table 2. Ranking based on NOISH equation calculations**

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | | | |  | | | |  | | | |  | | | |  | | | | | |
| vidaXL Washing Machine Pedestal Stand Dryer White with Drawer Disabled Elderly Raiser | | | | Xavax Universal Stand with Base Division for Washing Machine and Dryer. White | | | | Electrolux 74-UN-04 Pedestal and Drawer Unit | | | | Washer and Dryer Pedestal | | | | W F M S | | | | Assumbtion | |
| Design Dimensions (cm) | | W=63<br>D=54<br>H=31 | | Design Dimensions (cm) | | W=60.3<br>D=60.3<br>H=40 | | Design Dimensions (cm) | | W=61.5<br>D=55.5<br>H=30.6 | | Design Dimensions (cm) | | W=120<br>D=55<br>H=35 | | Design Dimensions (cm) | | W=63<br>D=64.63<br>H=60.6 | | | |
| | | LC (kg.f) | 23 | | | LC (kg.f) | 23 | | | LC (kg.f) | 23 | | | LC (kg.f) | 23 | | | LC (kg.f) | 23 | Measured part | The measure in (cm,g,min) |
| H (cm) DRY | 40 | H M | 0.63 | H (cm) DRY | 40 | H M | 0.63 | H (cm) DRY | 40 | H M | 0.63 | H (cm) DRY | 40 | H M | 0.63 | H (cm) DRY | 40 | H M | 0.625 | Laundry's door height from ground | 30 (cm) |
| H (cm) WET | 40 | H M | 0.63 | H (cm) WET | 40 | H M | 0.63 | H (cm) WET | 40 | H M | 0.63 | H (cm) WET | 40 | H M | 0.63 | H (cm) WET | 40 | H M | 0.626 | Basket dimensions | 50 Φ * 30 (cm) |
| V (cm) DRY | 0 | V M | 0.78 | V (cm) DRY | 10 | V M | 0.81 | V (cm) DRY | 15.6 | V M | 0.82 | V (cm) DRY | 10 | V M | 0.806 | V (cm) DRY | 55 | V M | 0.94 | Human's body depth | 18 (cm) |
| V (cm) WET | 61 | V M | 0.96 | V (cm) WET | 100 | V M | 0.925 | V (cm) WET | 60.5 | V M | 0.96 | V (cm) WET | 55 | V M | 0.94 | V (cm) WET | 90.5 | V M | 0.9535 | No of Washing Machines In a work satation | 20 unit |
| D (cm) DRY | 61 | D M | 0.89 | D (cm) DRY | 60 | D M | 0.895 | D (cm) DRY | 45.5 | D M | 0.92 | D (cm) DRY | 55 | D M | 0.90 | D (cm) DRY | 46 | D M | 0.92 | Feeding in and out duration in minute | 2.5 (min) |
| D (cm) WET | 43 | D M | 0.92 | D (cm) WET | 25 | D M | 1 | D (cm) WET | 19.7 | D M | 1.00 | D (cm) WET | 89 | D M | 0.87 | D (cm) WET | 0 | D M | 1.00 | L I > = 3 | Need system redesign |
| F | 1 | FM | 1 | F | 1 | FM | 1 | F | 1 | FM | 1 | F | 1 | FM | 1 | F | 1 | FM | 1 | 1 = < L I < 3 | At least one part need redesign |
| A (degree) | 90 | A M | 0.712 | A (degree) | 90 | A M | 0.712 | A (degree) | 90 | A M | 0.712 | A (degree) | 90 | A M | 0.712 | A (degree) | 0 | A M | 1 | L I < 1 | Good to go |
| C | from recommend ation table | C M | 1 | C | from recommenda tion table | C M | 1 | C | from recommend ation table | C M | 1 | C | from recommend ation table | C M | 1 | C | from recommend ation table | C M | 1 | | |
| | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR DRY CLOTHES | 7.089 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR DRY CLOTHES | 7.374 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR DRY CLOTHES | 7.726 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR DRY CLOTHES | 7.430 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR DRY CLOTHES | 12.432 | | |
| | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR WET CLOTHES | 9.066 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR WET CLOTHES | 9.467 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR WET CLOTHES | 9.790 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR WET CLOTHES | 8.376 | | | R W L (kg.f) RECOMANADED LOAD LIMIT FOR WET CLOTHES | 13.707 | | |
| | | Actual weight (kg.f) for dry clothes | 8 | | | Actual weight (kg.f) for dry clothes | 8 | | | Actual weight (kg.f) for dry clothes | 8 | | | Actual weight (kg.f) for dry clothes | 8 | | | Actual weight (kg.f) for dry clothes | 0 | | |
| | | Actual weight (kg.f) for wet clothes | 13 | | | Actual weight (kg.f) for wet clothes | 13 | | | Actual weight (kg.f) for wet clothes | 13 | | | Actual weight (kg.f) for wet clothes | 13 | | | Actual weight (kg.f) for wet clothes | 0 | | |
| | | L I (dry clothes) L I = ( Actual weight) / (RWL) | 1.128 | | | L I (dry clothes) L I = ( Actual weight) / (RWL) | 1.085 | | | L I (dry clothes) L I = ( Actual weight) / (RWL) | 1.035 | | | L I (dry clothes) L I = ( Actual weight) / (RWL) | 1.077 | | | L I (dry clothes) L I = ( Actual weight) / (RWL) | 0.000 | | |
| | | L I (wet clothes) L I = ( Actual weight) / (RWL) | 1.434 | | | L I (wet clothes) L I = ( Actual weight) / (RWL) | 1.373 | | | L I (wet clothes) L I = ( Actual weight) / (RWL) | 1.326 | | | L I (wet clothes) L I = ( Actual weight) / (RWL) | 1.552 | | | L I (wet clothes) L I = ( Actual weight) / (RWL) | 0.000 | | |
| | | Recommendation | At least one part need redesign | | | Recommendation | At least one part need redesign | | | Recommendation | At least one part need redesign | | | Recommendation | At least one part need redesign | | | Recommendation | Good to go for each statuse | | |

### 3.2. Evaluation of The Proposed Design

#### 3.2.1. Evaluation of The Physical Material Handling Risks

The NIOSH lifting Equation is an instrument used by occupational health and safety (OHSAS) specialists to evaluate the physical material handling risks related to lifting and lowering tasks in the workplace. The main product of the NIOSH lifting equation is the Recommended Weight Limit (RWL), which defines the maximum acceptable load under certain conditions. RWL is an ergonomic tool that evaluates the entire load to perform tasks under specific circumstances. A Lifting Index (LI) calculation estimates the physical stress and musculoskeletal disorders and considers whether the product or part of the product needs redesign. Table 2 shows the Recommended Load Weight (RWL) and Load Index (LI) comparison results based on NOISH equation calculations. Results assure the effectiveness and safety of FWMS design.

#### 3.2.2. Evaluation of How Well the Work Fits the Performance using Ergo-Fellow

Ergo-Fellow is ergonomic software used to evaluate if the task or working environment is fitting for the performer. It checks all statutes of the tasks performed in all directions, analyzes the effects of external and internal factors on the normality of the task's conditions and environments, and displays the results and scores based on working conditions [22]. Ergo-Fellow consists of 17 tools, but only six are used in this research as it concerns carrying loads issues and the risks accompanying them. The six tools are used to determine RWL and LI using the NIOSH tool, postural load during work using the OWAS tool, ergonomic investigation of workplace-related upper limb disorders using the RULA tool, estimating the risks of work related to entire body disorders using REBA tool, muscles fatigue analysis depending on effort, duration, and frequency using SUZANNE RODGERS tool, and the six job risk factors using MOORE & GRAG (STRAIN INDEX) tool [23]. Ergo-Fellow comparison discusses the following tasks: carrying dry clothes to the washing machine, feeding the washing machine with dry clothes, taking out cleaned wet clothes from the washing machine, and carrying the clothes from the washing machine to the desired destination. The following assumptions are considered to complete the analysis as shown in Figure 4 [18]: 1) The anthropometry of the body is based on a person 167.6 (cm) tall, and all body dimensions are found using Ergo-Fellow software. 2)The washing machine door height from the ground is 30 cm. 3) The horizontal distance H equals 40 (cm) about the clothes' basket diameter. 4)The altitude from the ground to the arms is 104 (cm) calculated by Ergo Fellow dimensions. 5) The load carried while feeding the washing machine, including the clothes, basket weight, and other weights. 6) Effort exerted while carrying clothes is the same for the left and the right side. 7) Washing machines' doors open clockwise from the top view of the monitor so that the left hand will be dominant. 8) Process time is the summation of all tasks times and adds up to equal to (1 – 2) min.

Another ranking method using (PEI) and (WEI) techniques was used to compare various products based on the forces affecting the human's lower back. Low back Analysis LBA with OWAS and RULA's results are used to evaluate alternatives. The method calculates the Posture Evaluating Index (PEI) and then finds the Work Evaluation Index (WEI) to rank alternatives. Results from Ergo Fellow are shown in Table 3, which indicates the effectiveness and efficiency of FWMS Design. WEI values for the six alternatives are as follows: FWMS (1.137), VidaXL (2.346), Electrolux (2.489), Xavax (2.456), no base or stand (2.456), and Pedestal with score (2.456). The scores indicate that WFMS is 51% better than the second-best alternative. Results from Ergo-Fellow assure the effectiveness and efficiency of WFMS Design.

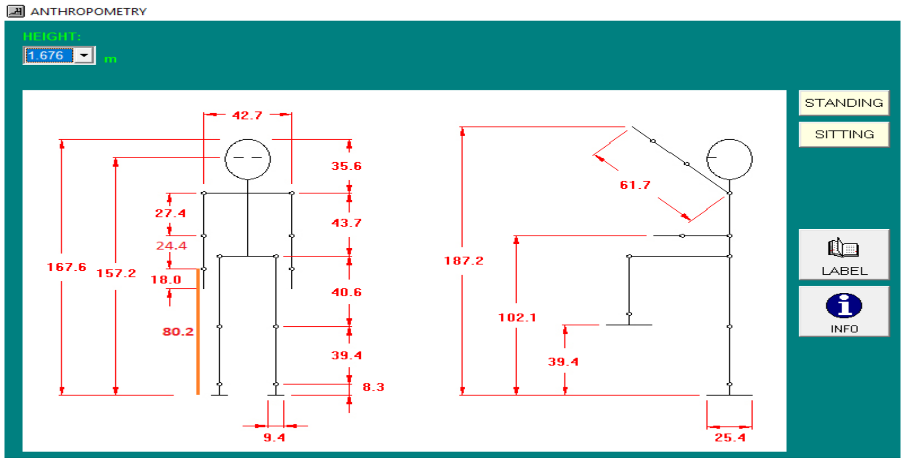


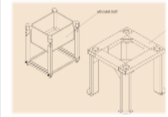

**Figure 4.** Ergo-Fellow anthropometry

## CONCLUSIONS AND FUTURE RESEARCH

This paper introduces a flexible washing machine base stand (FWMS) using QFD and rapid prototyping technology. The proposed contemporary design proved to compete with other products available in the market due to the consideration of ergonomics concerns, consideration of health and safety issues, involvement of the customers in the design and evaluation processes, and the addition of new features based on the voice of customers. Washing machine market analysis of the available bases and stands is used to identify the customer desires, determine the current washing machines' problems and their impact on the human body, and compare them with the new FWMS design. The research utilizes several available tools, techniques, and software to reach the final design of FWMS. QFD proved a valuable tool for getting the final conceptual design, connecting the customers' needs, facilitating SWOT analysis of competent products, and identifying factors the designer should focus on. The Ergo-Fellow software tool helps obtain anthropometric data for ergonomic ends and evaluate and improve workplaces. At the same time, PEI and WEI techniques are practical tools to compare various products based on the forces affecting a human's lower back. A Rapid Prototype is a valuable way to build the initial model quickly and efficiently to perform a primary product evaluation. Fused Deposition Modelling is considered one of the most common and popular technology methods to make (RP) at a low cost.

Analysis of the results using different tools and techniques showed that the improved design of the Flexible Washing Machine Base Stand could protect users and prevent workplace-related injuries along with the considerations of safety and ergonomics issues with additional competitive attractive features at a reasonable price. Future research may use remotely controlled adaptable elevation for the fixed base stand to be adjusted according to the users' height, use electrical motors to move the lower part instead of manual pushing, equip the mobile part with a fixed or foldable hand, and incorporate intelligent systems.

**Table 3. Ergo-Fellow Results, PEI, and WEI Evaluation.**

| Factor | | | |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| | | | Without Base or Stand | Electrolux 74-UN-04 Pedestal and Drawer Unit | vidaXL Washing Machine Pedestal Stand Dryer White with Drawer | Washer and Dryer Pedestal | Xavax Universal Stand with Base Division for Washing Machine and Dryer | FWMS |
| | | | VALUE | VALUE | VALUE | VALUE | VALUE | VALUE |
| NIOSH | RWL | DRY | 7.694 | 7.726 | 7.089 | 7.43 | 7.374 | 12.431 |
| | | WET | 7.694 | 9.79 | 9.066 | 8.376 | 9.467 | 13.707 |
| | LI | DRY | 1.04 | 1.035 | 1.129 | 1.077 | 1.085 | 0.724 |
| | | WET | 1.69 | 1.328 | 1.434 | 1.552 | 1.373 | 0 |
| OWAS | TASK #1 | | 2 | 2 | 2 | 2 | 2 | 1 |
| | TASK #2 | | 4 | 4 | 4 | 4 | 4 | 2 |
| | TASK #3 | | 4 | 2 | 4 | 4 | 4 | 2 |
| | TASK #4 | | 3 | 3 | 3 | 3 | 3 | 1 |
| RULA | TASK #1 | | 5 | 6 | 6 | 6 | 6 | 2 |
| | TASK #2 | | 7 | 7 | 7 | 7 | 7 | 3 |
| | TASK #3 | | 7 | 7 | 7 | 7 | 7 | 3 |
| | TASK #4 | | 5 | 6 | 6 | 6 | 6 | 2 |
| REBA | TASK #1 | | 6 | 6 | 6 | 6 | 6 | 1 |
| | TASK #2 | | 11 | 7 | 9 | 9 | 9 | 4 |
| | TASK #3 | | 11 | 7 | 7 | 7 | 7 | 4 |
| | TASK #4 | | 6 | 6 | 6 | 6 | 6 | 1 |
| SUZANNE RODGERS | TASK #1 | | 1 3 3 3 3 1 1 | 1 3 3 3 3 1 1 | 1 3 3 3 3 2 2 | 1 3 3 3 3 1 1 | 1 3 3 3 3 1 1 | 1 1 1 1 1 1 1 |
| | TASK #2 | LEFT | 2 4 4 4 4 4 2 | 1 2 2 2 2 1 1 | 2 4 4 4 4 4 2 | 2 4 4 4 4 4 2 | 2 4 4 4 4 4 2 | 1 1 1 2 2 1 1 |
| | | RIGHT | 2 2 4 2 2 4 2 | 1 1 2 1 1 1 1 | 2 2 4 2 2 4 2 | 2 2 4 2 2 4 2 | 2 2 4 2 2 4 2 | 1 1 1 1 1 1 1 |
| | TASK #3 | LEFT | 2 4 4 4 4 4 2 | 1 2 2 2 2 1 1 | 2 4 4 4 4 4 2 | 2 4 4 4 4 4 2 | 2 4 4 4 4 4 2 | 1 1 1 2 2 1 1 |
| | | RIGHT | 2 2 4 2 2 4 2 | 1 1 2 1 1 1 1 | 2 2 4 2 2 4 2 | 2 2 4 2 2 4 2 | 2 2 4 2 2 4 2 | 1 1 1 1 1 1 1 |
| | TASK #4 | | 1 3 3 3 3 1 1 | 1 3 3 3 3 2 2 | 1 3 3 3 3 1 1 | 1 3 3 3 3 1 1 | 1 3 3 3 3 1 1 | 1 1 1 1 1 1 1 |
| MOORE & GRAG (STRAIN INDEX) | TASK #1 | | 3 | 3 | 3 | 3 | 3 | 0.25 |
| | TASK #2 | | 6.75 | 6.75 | 6.75 | 6.75 | 6.75 | 0.56 |
| | TASK #3 | | 6.75 | 6.75 | 6.75 | 6.75 | 6.75 | 0.56 |
| | TASK #4 | | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 0.25 |
| COMPRESSIV E FFORCE (N) | UPPER BIDY WEIGHT | | 400 | 400 | 400 | 400 | 400 | 400 |
| | LOAD WEIGHT | | 100 | 100 | 100 | 100 | 100 | 10 |
| | LOAD MOMENT | | 500 | 500 | 500 | 500 | 500 | 100 |
| CT ( Total Compressive ) (N) , (LBA) | | | 1000 | 1000 | 1000 | 1000 | 1000 | 510 |
| PEI (EVALUATION) = (LBA/3400 + OWAS/4 + RULA/7) | TASK #1 | | 1.508403361 | 1.651260504 | 1.651260504 | 1.651260504 | 1.651260504 | 0.685714286 |
| | TASK #2 | | 2.294117647 | 2.294117647 | 2.294117647 | 2.294117647 | 2.294117647 | 1.078571429 |
| | TASK #3 | | 2.294117647 | 1.794117647 | 2.294117647 | 2.294117647 | 2.294117647 | 1.078571429 |
| | TASK #4 | | 1.758403361 | 1.901260504 | 1.901260504 | 1.901260504 | 1.901260504 | 0.685714286 |
| WI = $T_{op}$ / $T_{cycle}$ (min) | TASK #1 | | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | TASK #2 | | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | TASK #3 | | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | TAASK #4 | | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| WEI (EVALUATION) ( min is the best ) | | | 2.488655462 | 2.345798319 | 2.545798319 | 2.545798319 | 2.545798319 | 1.137142857 |

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