Ergonomics Analysis of Luggage Trolley for Airport Using Posture Evaluation Index (PEI) in Virtual Environment Modelling

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Abstract. On the science of ergonomics, pushing trolley activity is the type of pushing tasks. Pushing the trolley activities with a given number of loads on it raises the risk of musculoskeletal disorders and discomfort in the body. This study tried to study a series of movements of pushing trolleys and study the ergonomic aspects that affect the posture of the trolley user using simulation in virtual environments. The study was conducted on five types of trolleys with the differences on size dimensions. The goal of this study is to get the kind of trolley which is ideal the operators. Valuation of the work posture done by evaluate the Posture Evaluation Index (PEI) for each trolley. PEI will integrate the assessment results of Rapid Upper Limb Assessment (RULA), Ovako Working Posture Analysis (OWAS), and the Lower Back Analysis (LBA) from the task analysis toolkits contained in the Jack 6.1 software into a score that can give you the actual condition of a person while using the trolley. The results of this study can be used as consideration in choosing trolleys with types and dimensions that really exists in this world that according to the ergonomic aspects of the Indonesian human body.

1. Introduction
Ergonomic problems in the material handling pushing task, in this case the airport trolley, influenced by body posture and operator movements that is not precise enough. Airport trolley operator pushes with a certain amount of load and with a wrong body posture while pushing, very susceptible to injury problems called musculoskeletal disorders or WMSD (Work-Related Musculoskeletal Disorder). Musculoskeletal disorder is an injury or physical issue that attack parts of the human body such as nerve, muscle, tendon, ligament, joints, and also the human spine [1]. Beside the unnatural postures and repetitive movements, WMSD is also caused by excessive energy expenditure and length of working time [2]. In addition, environmental factors and design workstations that are not appropriate can also triggered to the emergence of the injury musculoskeletal in the operators.

The main problem that will be discussed in this research is the need for ergonomic analysis of body posture when pushing airport trolleys. This analysis aims to identify the level of injury and fatigue that occurs in these activities. Preliminary studies conducted by involving 30 men to find out complaints when pushing the trolley, and the results is depicted on figure 1. The analysis will also be the basis of the proposed design of an ergonomic trolley according to the best value of Posture Evaluation Index (PEI). The selection of the best trolley design expected to reduce the occurrence of possible injury
(musculoskeletal disorders) and fatigue that may be experienced by the operator of airport trolley, especially passenger airport.

![Pain Report](image)

**Figure 1.** Pain position complaint by operator.

Results from this study are to obtain the output of simulation model-making work and working posture score for the airport trolley operator using a virtual human model and virtual environment that include in JACK™ version 6.1 the ergonomics software. Then the result is a recommendation design that operator of airport trolley has met the standard ergonomics posture, and give the comfort sensation to Indonesian body, and is expected to be the solution for any inconvenience when airport pushing trolleys especially for porter or operator.

### 2. Research Methodology

This research was conducted by taking a few examples of trolley to the actual airport of some of the existing airport in the Asia region. This study tried to see the impact of the airport trolley designs due to operators trolley ergonomic conditions in the airport area. The operator posture while pushing the trolley is the standing posture. Variables such as dimension, trolleys, trolley weight, and weight of baggage is the variables used to assess the condition and operator comfort. Assessment then made to the design of different trolleys and operators working posture when pushing adjusted with these trolleys. To create a posture similarly to the actual work, done by taking photos and video data in the form of movement when pushing airport trolleys. So, the data needed in this study are anthropometry data of Soekarno-Hatta airport porter, operator posture and movement data, trolley measurement data and passenger baggage weight data.

As an initial step of research, a normality test was carried out on the porter height measurement data obtained as a measurement database. If valid (p-value > 0.05), the data can be used for further research. P-value of 0.636 is obtained so that the porter anthropometric data is valid and can be used. This trolley in ergonomics study used 95% percentile because it represents majority of the population and in the anthropometry data table based on Indonesian Ergonomics Association, 95% percentile percentages are relatively small as represented in Table 1.

| Percentile | Operator | Height (cm) |
|------------|----------|-------------|
| 5%         | 162      | 144.95      |
| 50%        | 171.4    | 159.5       |
| 95%        | 176.75   | 172         |

| Table 1. Measurement comparison on Indonesian Ergonomic Association |

However, considering that porter measurements at Soekarno-Hatta airport only involve 30 men, then the difference can be understood so that the anthropometric data from the Indonesian Ergonomics Association can be used to represent the anthropometric data of Indonesian people as airport passengers. So, the following measurements are used in data processing using JACK software [3].
Table 2. Anthropometric measurement

| Percentile | SH   | EYH  | ELH  | FL   | FB   | EEB  | HL   | HB   | SB   | HIB  | KH   | PH   | EP   |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 95         | 172  | 160.55 | 109.07 | 27   | 12   | 49.06 | 83   | 176.7 | 46   | 40   | 52   | 46   | 39   |

Explanation:

- SH : Stature height
- EYH : Eye height
- ELH : Elbow Height
- FL : Foot length
- FB : Foot breadth
- EEB : Elbow to elbow breadth
- HL : Hand length
- HB : Hand breadth
- SB : Shoulder breadth
- HIB : Hip breadth
- KH : Knee height
- PH : Popliteal height
- EP : Elbow to palm

The normal mass used for Jack’s simulation is the average luggage mass of departing passengers, which is 9.77 Kg. Then it will also be used in the load simulation with the maximum mass of baggage allowed for passengers on the flight, which is 20 kg. This maximum mass is referred to as the extreme mass. Extreme mass is needed to test the validity of the simulation being carried out, whether the simulation is correct and valid to do or not [4].

A methodology for this research is developed based on the application of the Task Analysis Toolkit (TAT), included in the JACK software [5]. JACK is an ergonomics and human factors software which facilitates users to simulate how a human model (virtual human) in a virtual environment can interact with these objects and environments and get the right feedback from the objects they manipulate. The bio-mechanically virtual human is precise with various body sizes, aimed to visualize occupations when assigning the jobs and analyse their performance in a real time [6].

![Figure 2. Simulation of pushing trolley](image1)

![Figure 3. Virtual environment in JACK software](image2)
The assessment is defined from several working activity analysis tools that are available on the JACK software on TAT section such as the Static Strength Prediction (SSP), Low Back Analysis (LBA), Ovako Working Posture Analysis (OWAS) and Rapid Upper Limb Assessment (RULA). Among the provided assessment tools, there is no single method that can provide comprehensive solutions that enables user to determine the optimal solutions between one and other. Therefore, an ergonomics index measurement called Posture Evaluation Index (PEI) is used [2]. PEI can give the overall assessment score of several tools used in research. PEI-based assessment will be utilized in every configuration of work carried out on four workstations in the sewing division to select the ideal combination. PEI-based assessment will be used on each model airport trolley with different dimensions and a different posture because the effect of height of each trolley [5]. Some of the stages passed in the determination of score PEI is:

- Analysis of the activities and working environment
- Static Strength Prediction (SSP) analysis
- Low Back Analysis (LBA)
- Ovako Working Posture (OWAS) analysis
- Rapid Upper Limb Assessment (RULA) analysis
- PEI evaluation

In the first stage, a series of observations conducted on the activities of work performed by trolley operator. Observation was conducted to determine the series of movements that will be simulated in the virtual environment in JACK software. The series of movements observed included working postures, the movement to reach the object, and the execution of the pushing activities. Regarding to determine the specified configuration for a virtual design of trolley models, measurements were done on the actual condition.

![Figure 4. Biomechanics model for predicting load and force in joints](image)

At the next stage, an evaluation conducted on the percentage of the workers entire population who have ability to perform a series of jobs that have been examined previously, by using the Static Strength Prediction. Static Strength Prediction (SSP) was used to identify certain work postures that require strength characteristics which exceed the ideal load or exceed the worker's ability. A series of work that is done in a certain period of time by workers of a different criterion such as height, gender, and age,
can be analysed by PEI only if the work could be done by all workers in a population [7]. Nevertheless, it is very rare for work activities to have a perfect percentage to be done by all workers. Therefore, a limitation is made to determine the percentage of workers who have a requirement to perform these activities. In this study, the minimum limit of work capabilities is 90%. So, if the operation is below the capabilities limit, it should not be included. In the calculation of the SSP method, figure 4 is an illustration of a human biomechanical model used to calculate the force on a joint when performing an activity.

Evaluation of the forces that work in the virtual human’s spine is carried out under certain load and posture conditions is then carried out using Low Back Analysis tools at the next stage. The condition of the force received by the workers in the virtual environment is analysed in real time by comparing the results obtained to the standard value that is issued by the National Institute for Occupational Safety and Health (NIOSH). The conditions analysed are the loads received by the L4 and L5 sections of the human spine because the compression and cut strength are mainly received on its points, with the maximum compression limit 3400 Newton [8].

The fourth stage is using Ovako Working Posture Analysis to evaluate comfort level of working posture on difference position for each operator. OWAS score which consists of four-digit code number can define the need for a repair action of a working posture. It also indicates the consecutive postures score experienced by the back, arms, legs, and the load received by the body in a certain work. In OWAS assessment, score of 1 to 4 is applied to determine the level of risk. Where the score 1 to 4 respectively indicates normal posture, slightly harmful, distinctly harmful, and extremely harmful. [9].

The next stage is investigation of received load and overall posture experienced by the neck, torso, limb, and other upper body part using the Rapid Upper Limb Assessment. RULA gives information about the use of body part (static or repetitive) and the load received in each body part in a score according to level of risk, then determine the final postural risk of 1 to 7. Posture with acceptable risk if the score is 1 and 2 and requires further investigation and change may be needed if the score is 3 and 4. It requires further investigation and changes in design or environment if the score is 5 and 6 and the most severe if the score is 7 which must be changed as soon as possible [10].

The last stage is to calculate PEI value comparison to analyse each configuration can be done by calculating the PEI value with following equation:

\[
\text{PEI} = I_1 + I_2 + m_r, I_3
\]

Where: \( I_1 = \frac{\text{LBA}}{3400 \text{ N}}, I_2 = \frac{\text{OWAS}}{4}, I_3 = \frac{\text{RULA}}{7}, m_r = \text{amplification factor} = 1.42 \)

In theory, PEI define uncomfortable level of work postures examined which depends on result of three methods those are LBA, OWAS, and RULA. LBA, OWAS, and RULA is summarized into three dimensional variables respectively: \( I_1, I_2 \) and \( I_3 \). Variable \( I_1 \) shows the evaluation of LBA value which considers the limit compression strength of NIOSH standard (3400 N). While the variable \( I_2 \) and \( I_3 \) indicate the OWAS index divided by its cut-off value ("4") and the RULA index divided by its cut-off value ("7"). The higher uncomfortable level of a working posture, the greater the value of \( I_1, I_2 \) and \( I_3 \) and automatically the larger value of PEI. Specifically, PEI shows the quality of working postures with a minimum value indicating better results than maximum value.

In addition, model verification is carried out to determine whether the model that has been created is successfully simulated or not. It turns out that during the simulation, changes in posture that occur cause changes in the scores for LBA, OWAS, and RULA. Meanwhile, model validation is done to find out whether the results of the model simulation are correct by manipulating the load carried by the trolley which exceeds the normal load. The additional burden should affect the LBA score obtained. Thus, the model simulation is valid and verified on all four trolleys.
3. Result and Investigation
The results seen from the values of PEI on the figure 5, the most ergonomic trolley design for the body of Indonesia is the trolley 5 with PEI the lowest value among the four other design that is equal to 1.477. Why trolley 5 can get the lowest value of PEI. Data processing results is summarized on the table 3.

![Image of chart showing PEI scores for trolley configurations]

**Figure 5.** Chart of PEI score for trolley configurations

As seen from the table 5, two types of trolleys with the largest PEI score, both have a value of more than two, namely a trolley 1 (Indonesian airport trolley) and trolley 4 with successive value of 2.035 and 2.045, respectively. If viewed in terms of the trolley dimensions, length x width x height (p x l x t), then those two trolleys are generally higher than other trolley, the height of trolley 1 and the trolley 4 in a row was 1038 and 1050. For the variable dimensions, length and width of the trolley design does not affect a person's body posture when pushed. Then apart from the dimension, it can also be seen the difference in terms of the weight trolleys. Trolleys 1 and 4 are a type of trolley which has a greater weight than any other trolley, the weight of trolley 1 and the trolley 4 in a row are 25 kg and 23 kg.

| Configuration | Manufacturer | Origin | Distribution |
|---------------|--------------|--------|--------------|
| Trolley 1     | PT. X1       | Indonesia | Indonesia Airport |
| Trolley 2     | PT. X2.      | Jiangsu-China | Southeast Asia, Africa, Mid East, Western Europe |
| Trolley 3     | PT. X2.      | Jiangsu-China | Southeast Asia, Africa, Mid East, Western Europe |
| Trolley 4     | PT. X2.      | Jiangsu-China | Southeast Asia, Africa, Mid East, Western Europe U.S.A., Japan, South Korea, Russia, Philippines, and Middle East Region |
| Trolley 5     | PT. X5       | Hubei-China |

**Table 3.** Recapitulation of PEI value calculation

| Configuration | Manufacturer | Origin | Distribution |
|---------------|--------------|--------|--------------|
| Trolley 1     | PT. X1       | Indonesia | Indonesia Airport |
| Trolley 2     | PT. X2.      | Jiangsu-China | Southeast Asia, Africa, Mid East, Western Europe |
| Trolley 3     | PT. X2.      | Jiangsu-China | Southeast Asia, Africa, Mid East, Western Europe |
| Trolley 4     | PT. X2.      | Jiangsu-China | Southeast Asia, Africa, Mid East, Western Europe |
| Trolley 5     | PT. X5       | Hubei-China |

**Table 4.** PEI Value differences for each design trolley

| Parameter | Length (mm) | Width (mm) | Height (mm) | Diameter (mm) | Mass (kg) | Weight (mm) | Percentile |
|-----------|-------------|------------|-------------|---------------|-----------|-------------|------------|
| Trolley 1 | 998         | 595        | 1038        | 180           | 25        | 9.77        | 95         |
| Trolley 2 | 1000        | 570        | 1080        | 180           | 17.5      | 9.77        | 95         |
| Trolley 3 | 930         | 660        | 1010        | 180           | 20        | 9.77        | 95         |
| Trolley 4 | 1040        | 670        | 1050        | 180 (back)    | 23        | 9.77        | 95         |
| Trolley 5 | 995         | 650        | 960         | 180           | 20        | 9.77        | 95         |
Looking at the ratio of the two types of trolleys (trolley 1 and trolley 4) with the three other trolleys can be concluded that the high initial weight trolleys affect the amount of PEI. The height of the trolley changes a person's body posture when using a trolley, and the weight of the trolley itself affect the load received by the body, in the calculation of this PEI is a burden especially for the back. For more details, the following table 4 to sort the PEI values of the types of trolleys starting from the highest to the lowest.

From table 5 shows that the value of the LBA is directly proportional to the value of PEI because of the value of RULA and OWAS each trolley the same, except for trolley number 5 which has the smallest RULA rating. The value of LBA is strongly influenced by how the shape of your posture and how big the load is received by the body that affect the resistance of the rear body.

| No. | Configuration | Height (mm) | Mass (kg) | SSP >90% | LBA (N) | OWAS | RULA | PEI   |
|-----|---------------|-------------|-----------|----------|---------|------|------|-------|
| 1   | Trolley 4     | 1050        | 23        | Yes      | 1643    | 1    | 5    | 2.045 |
| 2   | Trolley 1     | 1038        | 25        | Yes      | 1595    | 1    | 5    | 2.035 |
| 3   | Trolley 3     | 1010        | 20        | Yes      | 1492    | 1    | 5    | 1.988 |
| 4   | Trolley 2     | 1080        | 17.5      | Yes      | 1485    | 1    | 5    | 1.973 |
| 5   | Trolley 5     | 960         | 20        | Yes      | 1216    | 1    | 3    | 1.477 |

Trolley 4 with the largest value of PEI (2.045) has a combined weight and height which large enough, the weight of 23 kg and height of 1050 mm. For the second trolley, despite having the highest height compared to other trolleys which amounted to 1080 mm, but the weight of the trolley is the lowest among all of 17.5 kg, so although her posture a bit worse than trolleys 4 but loads will not overload the body because the trolleys that used lightly.

For the trolley 5, PEI has the lowest value because the trolley 5 has the lowest height that significant among all the other trolleys. It turns out the trolley with height (960 mm) yields the best posture when pushing trolleys among other trolleys. This can be seen from the scores of the smallest LBA, and concurrently RULA score is 2 points lower than others. From picture of the body posture when pushing trolleys 5 (figure 6), there is a difference on postures of the mannequin’ hand as he pushed. Compared with two trolleys mannequin trolley 1’s hand posture with the greatest height from surface, and posture on a mannequin trolley 4’ hand is lower and slightly bent.

![TROLLEY4](image1.png) ![TROLLEY1](image2.png)

**Figure 6. Chart of PEI score for trolley configurations**

Apparently, posture when pushing trolleys more comfortable if the lower hand on the shoulder and elbow angle of the curve is not too large, and the load or force exerted to push the trolley to a minimum in order to not overload the rear of the body as the support reaction force of encouragement. The driving force is one of them was influenced by the weight of the trolley itself, besides the weight of baggage carried. Therefore, we can conclude that the height and weight affect the value of trolleys Posture Evaluation Index (PEI) of the movement pushing trolleys.
4. Conclusion
The simulated trolleys are a representation of the actual model trolleys available at airports in Indonesia. The selection of the 95th percentile anthropometric data was carried out to find the specification of trolley dimensions (minimum extreme values) that can be used by majority of the population, in this case the body posture of Indonesians. The lowest PEI value was found in trolley 5 with the lowest height compared to other trolleys. PEI lowest trolleys produced by a high five with the lowest compared to other trolleys. So, the results of the simulation show trolley 5 is very suitable for the posture of the Indonesian human body. It provides a more comfortable posture when pushing the trolley because the hands are lower against the shoulders and the angle of the elbow is not too large compared to other trolley body postures, and the weight of the trolley is not too big compared to trolley 1 and trolley 4. In addition, it was concluded that the dimensions of the height of the trolley and the weight of the trolley are factors that greatly affect posture and the risk of musculoskeletal injury. In the activity of pushing a trolley carried out on standing conditions provide the number of forces (push force) from the arm to the trolley in order to move it. This puts a strain on the back of the body as a support force for the reaction from the push. Working to push repetitive trolleys can cause minor injuries. The factors that influence the posture simulation for this airport trolley are the height of the trolley handhold, the weight of the trolley, and the weight of the luggage.

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