Comparison of Commercial Stairchairs using Data Envelopment Analysis

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Abstract. Firefighters and Emergency Medical Services (EMS) personnel must perform a wide array of potentially hazardous emergency rescue procedures that often include the use of specially designed rescue and/or transport equipment. One common procedure involves transporting a victim down one or more flights of stairs using a stairchair. Since there are several stairchair models commercially available, the objective of this study was to analyze and compare the performance of six different models following a scenario-based study that involved EMS professionals carrying a patient down one flight of stairs and continuing 90? through a landing. Performance of the stairchairs was evaluated based upon subjective and quantitative measures. Stairchair performance rankings were then developed from the accumulated measures via mean cross-efficiency scores developed with the application of Data Envelopment Analysis.

INTRODUCTION

Emergency Medical Services (EMS) personnel perform many emergency and rescue tasks that put them at an elevated risk of incurring musculoskeletal injuries. One task frequently performed by EMS professionals involves transporting a patient down one or more flights of stairs using a piece of equipment called a stairchair. The objective of this paper is to compare and rank six stairchair designs (see Figure 1) based on data that measures the effort and relative risk of low back disorder (LBD) (Marras, et.al., 1993) involved in using the studied chair designs.

The comparison of a group of products, such as models of stairchairs, is frequently based on the numerical values of several attributes. In many cases, some products will score quite favorably with respect to one or more attributes, and poorly with respect to others. This can make it very difficult to compare product designs, especially if the designs are based on different usability tradeoffs. To define an overall performance (or efficiency) measure for each product design, one approach is to build an "engineering ratio" consisting of a weighted sum of a product's output attributes divided by a weighted sum of its input attributes (Doyle & Green, 1994). However, developing such ratios is often complicated by the absence of a natural or obvious way to weight the importance of each attribute toward overall performance. Data Envelopment Analysis (DEA) can be used to alleviate the difficulty in defining a set of weights for comparison. DEA is a linear programming technique that allows each product to choose its own set of weights so that it appears in the best possible light relative to the other products being considered. That is, each product selects the weights that maximizes its weighted output to input ratio (*simple efficiency score)*, subject to the constraints that the weighted output to input ratio of each product is ? 1, when subjected to the same chosen weights.

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MODEL 1 MODEL 2

MODEL 3 MODEL 4

MODEL 5 MODEL 6

Figure 1: Chair model designs studied.

In DEA, the maximum simple efficiency score of one (100% relative efficiency) identifies a product as a good performer relative to the other products being considered. However, Doyle and Green (1994) suggest that a simple efficiency score can be thought of as a measure of *self-appraisal*, which may be misleading in that it could be based on a product performing very well with respect to only one or a few desirable attributes. Doyle and Green (1994) also suggest that an alternative measure, based on *peer appraisal*, can be obtained from DEA in terms of a set of *cross-efficiency scores*. A cross-efficiency score for product A is obtained from product B by calculating the weighted output to input ratio for product A, based on the optimal weights chosen by product B. A high *mean* cross-efficiency score is an indication of a good overall performing product design. In this paper we calculate the simple efficiency and mean cross-efficiency score for each stairchair design via a DEA model in which there is only one "input", and several "outputs" (Caporaletti, Dulla, & Womer, 1999).

METHODS AND PROCEDURES

Subjects

Eight male EMS professionals volunteered to participate in the data collection portion of this study. The age range of these eight men was from 20 to 47 years, with a mean of 31 years and a standard deviation of 8 years. The mean height and weight of these eight individuals were 1.81 m (range: 1.71-1.98 m) and 101 kg (range: 58-123 kg), respectively. Before data were collected, all subjects were given an orientation that included a discussion of the experimental procedures and practice runs with each stairchair design studied.

Procedure

Six stairchair designs (Figure 1) were evaluated with respect to three different carrying positions (i.e., follower, leader facing backward, and leader facing forward). The task performed by the subjects included transporting a victim (weight 70 kg) down one flight of stairs and through a landing. The testing environment included an open staircase with 20 steps and a landing, which required a 90? turn. The staircase width was 840 mm with each step having a 180 mm rise and a 280 mm run. Four video cameras were positioned to provide the best orthogonal views to the sagittal and frontal planes of each subject. Trunk positions and motions were measured with the Lumbar Motion Monitor (LMM) manufactured by Chattanooga Group, Inc. (Chattanooga, TN). This device measures the motion in the lumbar and lower thoracic sections of the spine.

Data Collection

Both objective and subjective measures were collected at different times during the experiment. Objective measures were collected during the trials at each of three stair positions (initial step, mid-stair, and landing) using the University of Michigan's 3D Static Strength Prediction Program^{TM} (3D SSPP) and a Lumbar Motion Monitor (LMM). Postural data were extracted from the videotapes using the camera with the most orthogonal view for the given subtask. Body segment orientations were expressed in terms of the coordinate system specified within the University of Michigan's 3D Static Strength Prediction Program^{TM} (3D SSPP). The three-dimensional trunk postures, namely the degree of forward bending, side bending, and twisting, were obtained from the LMM. Biomechanical analyses were conducted on these objective measures to quantify the risk of low back disorder (LBD) (Marras, et.al., 1993) and L5/S1 disc shear and compression.

Ratings of perceived exertion (RPE) (Borg, 1970) for each chair/position combination were collected at the conclusion of each trial. Additionally, an 11-point subjective comfort scale (Shackel et.al., 1969) was administered following three trials of each chair/position combination. (Note : a score of one corresponds to "I feel completely relaxed", and a score of 11 corresponds to "I feel unbearable pain").

Analysis

To rank the chair designs via mean cross-efficiencies, the DEA methodology of Baker and Talluri (1997) was employed. Three separate ranking schemes are presented based on three scenarios. The scenarios differ by the position that the leader is facing. The three scenarios include: (i) leader facing backward, (ii) leader facing forward (two models did not have the capability for this carry - Models 2 & 4), and (iii) leader facing according to the manufacturer's recommendation. (Note: for four models it is recommended that the leader should face backward (Models 1, 2, 3, & 4). The recommendation for the other two models is that the leader should face forward (Models 5 & 6).) The mean values listed in Tables 1, 2, and 3 correspond to these three scenarios, respectively. Each mean is based upon an aggregation of the data collected for both the follower and leader for each chair design. The five subjective and objective measures listed in Tables 1, 2, and 3 are the outputs used in the DEA model. The input for each chair is the carrying task itself, and since it is the same for each chair, it is set at unity. Finally, since we wish to maximize desirable output attributes, the reciprocal of all five-output measures are used in the DEA calculations. The simple efficiencies and the mean cross-efficiencies calculated for each scenario are found in Tables 4, 5, and 6, along with the corresponding ranks of the stairchairs (a rank of 1 being the most desirable).

Table 1: Mean Values for Follower/ Leader Backward Combination.

Chair Model	Subjective Carry (11 point scale)	RPE (Borg) (6-20 point scale)	LBD (%)	L5/S1 Compression (Newton)	L5/S1 Shear (Newton)
1	4.188	10.906	30.069	2058.4	489.9
2	4.531	12.458	32.118	2293.3	491.5
3	3.938	10.292	20.278	2800.0	484.8
4	3.969	11.208	33.250	2318.9	493.4
5	3.000	10.094	31.910	2134.3	487.3
6	2.313	6.542	13.611	951.7	252.5

Table 2: Mean Values for Follower/Leader Forward Combination.

Chair Model	Subjective Carry (11 point scale)	RPE (Borg) (6-20 point scale)	LBD (%)	L5/S1 Compression (Newton)	L5/S1 Shear (Newton)
1	4.063	10.813	24.361	1731.4	484.2
3	4.438	11.292	19.240	2527.0	482.5
5	2.750	9.823	25.611	1607.5	480.3
6	2.250	6.729	12.528	885.5	250.4

Table 3: Mean Values By Manufacturer Recommended Positions.

Chair Model	Subjective Carry (11 point scale)	RPE (Borg) (6-20 point scale)	LBD (%)	L5/S1 Compression (Newton)	L5/S1 Shear (Newton)
1	4.188	10.906	30.069	2058.4	489.9
2	4.531	12.458	32.118	2293.3	491.5
3	3.938	10.292	20.278	2800.0	484.8
4	3.969	11.208	33.250	2318.9	493.4
5	2.750	9.823	25.611	1607.5	480.3
6	2.250	6.729	12.528	885.5	250.4

Table 4: Simple and Mean Cross-efficiency Scores for Follower/Leader Backward Combination.

Chair Model	Simple Efficiency (self-appraisal)	Mean Cross-efficiency (peer-appraisal)	Rank
1	0.600	0.544	4
2	0.525	0.487	6
3	0.671	0.584	3
4	0.583	0.536	5
5	0.771	0.598	2
6	1.000	1.000	1

Table 5: Simple and Cross-efficiency Scores for Follower/Leader Forward Combination.

Chair Model	Simple Efficiency (self-appraisal)	Mean Cross-efficiency (peer-appraisal)	Rank
1	0.622	0.578	4
3	0.596	0.588	3
5	0.818	0.669	2
6	1.000	1.000	1

Table 6: Simple and Cross-efficiency Scores for Manufacturer Recommended Positions.

Chair Model	Leader Position	Simple Efficiency (self-appraisal)	Mean Cross-efficiency (peer-appraisal)	Rank
1	Backward	0.617	0.572	4
2	Backward	0.540	0.507	6
3	Backward	0.654	0.584	3
4	Backward	0.600	0.558	5
5	Forward	0.818	0.685	2
6	Forward	1.000	1.000	1

CONCLUSIONS

Regardless of the scenario, the design of Model 6 outperforms the other five designs. Mean cross-efficiency scores show that this type of design is a good overall performer, and Tables 1-3 further substantiate the effectiveness of this design based on individual attributes. From Tables 1-6, it is also evident that the leader forward position has an advantage over the leader backward position, for all chairs that are capable of using this position. Finally, while rankings have been assigned to each chair design based on cross-efficiency scores, it is difficult to clearly distinguish between the performances of Models 1 – 5.

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