 DOI: 10.4305/METU.JFA.2018.2.8

PRODUCT DESIGN CONCEPT EVALUATION BY USING ANALYTICAL HIERARCHY AND ANALYTICAL NETWORK PROCESSES

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Received: 28.11.2015; **Final Text:** 24.05.2018

Keywords: Analytical hierarchy process; analytic network process; design concept selection; product design; hand cart design.

INTRODUCTION

Ulrich and Eppinger (2008) define the design process in six steps: 1. Investigating user needs, 2. Concept design, 3. Initial development, 4. Concept evaluation and detailed design of the selected concept, 5. Design checks by drawings, models and mock-ups, 6. Information exchange with engineers and customers. Concept design at Step 2 is an important part of the design process in which design solutions are found and product functions are structured prior to the detail design processes which would require great investment and create heavy workload.

For concept design selection, designers evaluate a number of design concept ideas according to criteria such as their creative thoughts, user needs and known specs of successful products and then decide on which one of the available ideas should be selected for further improvement (Xiao et al., 2007). When the design concept is selected, the main structure and form of the product that is the main target to achieve will be strictly known (Kim and Lee, 2010). Therefore this task directly affects the success of both the design process and the final product (Salonen and Perttula, 2005; Ayağ, 2005). Correctly deciding on which design concept to continue working on is important as an incorrect selection may cause problems that might be difficult to resolve later (Hsu and Woon, 1998; Zhang et al., 2006). A good selection at this phase means good sale, customer satisfaction and high profits as well as shorter development time and cost. Mistakes made during design concept selection might increase the cost and the duration of the design process due to repetitive corrections. Eventually this may lead to the targeted product design not being completed within the available time-budget and may even cause a total project failure. Therefore, a proper concept selection, performed at the early stages of the product design process is important for product success (Fung et al., 2007).

Concept design selection involves complex multi-criteria decision making tasks that can be simplified by using suitable tools (Xu et al., 2007).

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Different evaluation trends and tools are available for this purpose such as Simulation, TOPSIS, GIS, Goal Programming, DEA, Delphi, balanced scorecard, factor analysis, fuzzy logic model, genetic algorithm, SWOT analysis, AHP and ANP (Sipahi and Timor, 2010).

Contemporary decision making processes in industrial design are user-centered, ethnographic, collective and participatory (Nova 2014). Participatory or cooperative design consists of a distinct set of design and research practices, in which designers and users actively work together for improving the quality of life (Halskov and Hansen, 2015). This article investigates the Analytical Hierarchy Process (AHP) and the Analytical Network Process (ANP) methods and then proposes a model to use them in the product design process to evaluate industrial design concepts. The reasons behind the selection of AHP and ANP as the research methods were their participatory structure and ability to process subjective data gathered from user interviews, enabling the users to be placed at the center of the design process. The reasons for applying these methods in the industrial design process are for increasing the accuracy of decision making, simplifying the overall work by using a methodic approach and making the process more user-centered.

This section briefly covered the product design and design concept selection processes. In the following sections, the uses of the AHP and ANP methods in the literature are reviewed. Then the methods are described and their adaptation to the industrial design process as design concept selection methods are explained. Finally, their application is demonstrated with a study in which seven selected design concepts are evaluated by using both methods and the one having the highest performance score is selected for further design development.

LITERATURE REVIEW

A search of the academic literature brings up a substantial amount of studies from different fields that utilize AHP and ANP in various specific ways and for different purposes. Sipahi and Timor (2010) performed a study to produce a general overview of AHP and ANP applications by investigating over 600 research papers. Their study gives good overall information about the literature pointing out that the methods are increasingly being used in various scientific fields ranging from manufacturing, environmental management, agriculture, energy management, transportation, construction, healthcare to education, logistics, e-business, information technologies, research and development, telecommunications, finance, military, government, marketing, tourism, archeology, auditing and mining.

In our own research of the literature concentrated on the use of AHP and ANP mainly on design related issues, we saw that the methods are used in several main ways; a group of studies singlehandedly use either AHP or ANP such as the following. Battistoni et al. (2013) used AHP to investigate the user response to the products being developed. Hambali et al. (2008) worked on using AHP in concept design selection tasks of the design process. In their study, they used AHP to evaluate disability chair design concepts to select one of them for production. Hambali et al. (2009) used AHP to determine the production method for a product concept. They demonstrated the use of their method in an application in which they evaluated production methods for a composite car bumper. Sarfaraz and Jenab (2012) proposed a model based on fuzzy AHP to be used in concept design evaluation. They demonstrated the use of this model in an applied study in which several hospital bed design concepts are evaluated. Boonkanit and Aphikajornsin (2009) studied the use of ANP on the evaluation of ecological product design concepts.

Some studies incorporate AHP and ANP together cooperatively and comparatively such as the following. Cheng and Li (2004) used AHP and ANP to propose a method for evaluation-selection of industrial production firms and compared the two methods in terms of their applications. Sharma et al. (2015) proposed a method which was based on AHP and ANP to select the most suitable material for the production of a product component. Eshtehardian et al. (2012) proposed a method based on ANP and AHP to evaluate material providers. Begičević et al. (2007) made a research in which they used the AHP and ANP methods comparatively on strategic planning. Graham (2012) proposed a hybrid AHP-ANP methodology for the evaluation and selection of sustainable transportation networks. Azizi and Maleki (2014) comparatively used the AHP and ANP methods for evaluation of the provider firms in automotive industry. Beltrán et al. (2014) proposed a multi criteria decision making approach based on AHP-ANP for investigating the profitability of investments.

Other studies use AHP and ANP together with additional methods such as the following. Bedessi and Lisi (2011) proposed a hybrid method in which the AHP, ANP and ANN (Artificial Neural Networks) methods were used together for multi criteria decision making problems and they investigated the advantages and disadvantages of their model, pointing out the technical differences of the three processes. Marini et al. (2016) worked on ecological product design and investigated the use of AHP and ANP together with Quality Function Deployment (QFD) in concept design and material selection for making better decisions to improve product success. Gupta et al. (2015) proposed a method based on TOPSIS and fuzzy AHP which can be used in concept design evaluation. They demonstrated their method in an application in which various suitcase design concepts were evaluated according to criteria like cost, quality, human and environmental factors. Renzi et al. (2017) researched the use of AHP and ANP together with other multi-criteria decision methods for design evaluation in the automotive industry, trying to transfer knowledge on decision making methods to the industrial context. Toksari and Toksari (2011) used fuzzy AHP to evaluate strategies for evaluating target markets of white goods. Nagahanumaiah et al. (2007) developed a method in which Fuzzy AHP and Quality Function Deployment (QFD) are used together in visual C++ programming language for evaluation and selection of rapid production tools. They also compared traditional manufacturing methods with today's rapid production methods according to cost. Hsiao (2002) used AHP together with QFD, Failure Mode Effects Analysis (FMEA) and Design for Assembly (DFA) to introduce a process to help designing competitive toys suitable for infants. Kwong and Bai (2003) used AHP and triangular fuzzy numbers to improve hair drier designs by calculating weighted importance values of user needs. Felice and Petrillo (2010) used AHP and QFD together in a study to gather data about the needs of ceramic product users. Delice and Güngör (2009) performed a user-centered research to analyze the usability problems of website designs by means of AHP and Heuristic Evaluation (HE). Wey and Chiu (2013) did a user-centered research to assess today's pedestrian needs for transit oriented environment design by using the House of Quality matrix (HOQ) technique combined with ANP.

Raharjo et al. (2008) used QFD based on ANP as a customer driven tool to deal with subjectivity issues in early product design phase.

It is seen that the methods are used for different tasks including evaluation, selection and decision making; they are used in conjunction with other methods and tools; they are used at various stages of the design process and not only at the final stage for selection among alternatives; they are used for critical decision making not only regarding designs but also regarding design-related activities and process-related issues. The popularity of the methods to be used in so many different purposes and fields can be seen as a sign of their value and versatility. While some of the studies we encountered in our own search of the literature occasionally use the words product design, they usually referred to the engineering aspects of product development. Therefore the studies seem to focus on solving mostly the technical issues of design, seen by engineers' eyes. In view of these facts, this article presents an effective, versatile and customizable framework for industrial designers to use AHP and ANP for various needs of their industrial design projects.

ANALYTICAL HIERARCHY PROCESS

Analytic Hierarchy Process (AHP) was first proposed by Myers and Alpert (1968) and further developed for application in Wharton School of Business (Saaty, 1980), establishing a place for itself as a tool of decision making and priority identification (Vaidya and Kumar, 2006; Cheng et al., 2005; Lai et al., 1999; Min, 1994). AHP is basically a measurement theory based on priority values obtained from pairwise comparisons between criteria and alternatives (Yılmaz, 1999). It can be used for solving decision making problems in systems having complex relations with its subsystems. It works by analyzing and modeling these systems heuristically as simplified hierarchical structures (Özden, 2008). By using a simplified structure, AHP prevents costly, distractive and delay imposing problems frequently encountered in large decision making processes such as lack of focus, lack of involvement and planning mistakes (Koçak, 2003).

In AHP, the relation between the decision processes is unidirectional and the overall process is comprised of three steps (Wind and Saaty, 1980). For the solution of the problem, first a hierarchical structure is formed (An et al., 2007). Then a pairwise comparison matrix which determines the priorities in terms of the relative importance values of the criteria is calculated (Cao et al., 2008; Başak, 2002). Saaty's Eigenvector method is used to calculate the relative importance values (Garcia-Cascales and Lamata, 2009). Then the consistency of the values in the matrix is checked by calculating the consistency ratio (Chou and Hsu, 2008). If the consistency ratio is between acceptable limits, the process continues with assessing the priorities of the alternatives to see which of the alternative has the highest priority, therefore is the most successful (Yılmaz, 2010).

The process steps in detail are as follows:

Setting Up the Model (Structuring the Hierarchy)

Structuring a problem as a hierarchical schema means separation of the problem into different layers. This procedure is called the modeling (Peng and Dai, 2009; Chandran et al., 2005). Modeling gives the decision makers the opportunity to effectively see and compare the criteria, sub criteria and alternatives (Lee and Hwang, 2010). The purpose of the overall evaluation

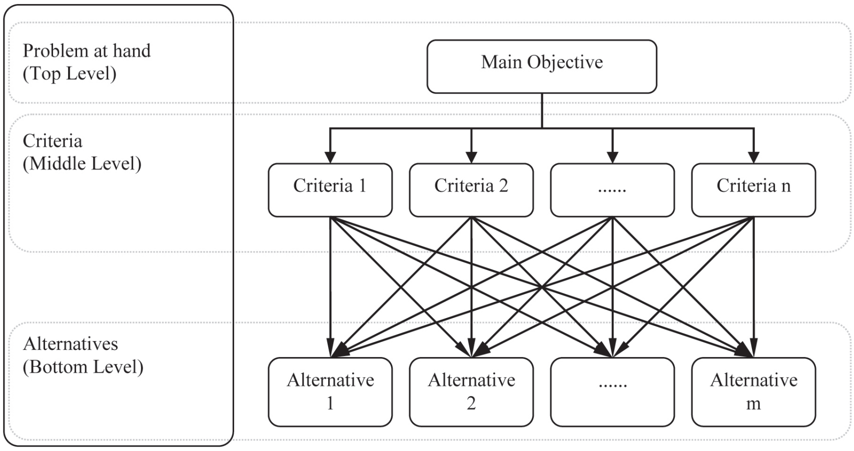

Figure 1. AHP's hierarchical structure

procedure is written at the top of the hierarchy (Pineda-Henson et al., 2008). Below this level, the criteria to be used in the evaluation are listed and at the next level alternatives to be evaluated are listed (Braunschweig and Becker, 2004). The resulting hierarchical structure can be seen in **Figure 1** (Wang, Liu and Elhag, 2008).

Forming the Pairwise Comparison Matrices and Designating the Weighted Values

In the second step of AHP, the pairwise comparison matrices are formed and the relative importance value of each criteria is investigated (Chandran et al., 2005). These values are found by doing pairwise comparisons by the persons taking part in the study (Sharma et al.,2008). Knowledge and experience of the participants are important for the efficiency of the comparisons (Chandran et al., 2005). The pairwise comparison matrix for the criteria is shown in **Table 1**.

Table 1. The pairwise comparison matrix for the criteria

	Criteria 1	Criteria 2	Criteria ...	Criteria j
Criteria 1	$\frac{w_1}{w_1}$	$\frac{w_1}{w_2}$	...	$\frac{w_1}{w_j}$
Criteria 2	$\frac{w_2}{w_1}$	$\frac{w_2}{w_2}$	...	$\frac{w_2}{w_j}$
Criteria ...	...	...	...	...
Criteria i	$\frac{w_i}{w_1}$	$\frac{w_i}{w_2}$	...	$\frac{w_i}{w_j}$
w: weighted value / relative importance value				

Table 2. Relative importance 1-9 scale used in AHP and their definitions

Relative Importance Value	Meaning	Explanation
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over the other
5	Essential or strong value	Experience strongly favors one requirement over the other
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over the other is on the highest possible order of affirmation
2,4,6,8	Intermediate values	These values should only be used when a compromise is needed.

Table 3. The formulas used

Formula 1	$w_i = \frac{1}{n}\sum_{j=1}^{n} \frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}$
Formula 2	$CR = \frac{CI}{RI}$
Formula 3	$CI = \frac{\lambda_{\max} - \mathrm{n}}{n-1}$
Formula 4	$\lambda_{\max} = \frac{1}{\mathrm{n}}\sum_{i=1}^{n} \frac{(Aw)_i}{w_i}$

The next step is to calculate the importance of the criteria relative to each other. The decision maker uses Saaty's 1-9 scale shown in **Table 2** to give importance values to criteria pairs by comparing all of them two at a time (Saaty 1986).

Then the overall relative importance sequence of all the criteria is calculated. The preferred method for this calculation is Saaty's Eigenvector method (Hurley, 2001).

Calculation of the Relative Importance of the Criteria-Sub Criteria and the Consistency Ratio

The Eigenvector is calculated by using Formula 1 given in **Table 3** (Ramadhan et al. 1999). The next step is to calculate the consistency ratio (CR) of the comparison matrix (Hafeez et al. 2007). The purpose of this is to determine whether the participant gave consistent information while comparing the criteria. If the CR exceeds 0.10, this means the matrix data is inconsistent and the comparisons should be reviewed or repeated (Donegan et al., 1992; Stain and Mizzi, 2007). Therefore the consistency of the matrix is inversely proportional to the CR value and the most consistent matrix is achieved with a CR of zero (Jian-Zhong et al., 2008). Saaty and Özdemir (2003) prefer to use Formula 2 to calculate the consistency of the comparison matrix (Zhou and Shi, 2009; Saaty and Özdemir, 2003). Consistency Index (CI) in Formula 2 can be calculated with Formula 3 (Zhou and Shi, 2009). The λ_{max} in Formula 3, which is the maximum Eigen value, is calculated with Formula 4 (Peng and Dai, 2009).

By adding the values obtained by multiplying the relative priorities with the columns of the comparison matrix, the weighted total vector is formed. The arithmetic average of the value obtained by dividing elements of the weighted total vector into the corresponding relative priority value gives λ_{max} value (Güngör and İşler, 2005). The values of RI according to matrix size are given in **Table 4** (Karagiannidis et al., 2010; Wang et al., 2008).

For the final solution to the problem, a hybrid vector of priorities that will be used to rank the alternatives is generated by calculating the weighted average of the vectors for the priorities of all the variables. The final priority values of the alternatives obtained by using these averages are called decision points and they are used to form the hybrid vector on which the decision makers can see and easily compare the performances

Table 4. Change of random index values according to matrix size

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

of the alternatives, and therefore can select the option with the highest performance score (Zahedi, 1986; Kuruüzüm and Atsan, 2001).

ANALYTIC NETWORK PROCESS

Analytic Network Process (ANP) is a method which has been developed and proposed by Saaty for supporting multi criteria decision making processes and its importance and use have improved considerably in the recent years (Dağdeviren and Yüksel, 2007; Saaty and Shih, 2009). ANP method holistically considers the relations between units and unit groups, interdependencies within those groups and the feedbacks between criteria (Dağdeviren and Yüksel, 2007; Saaty and Shih, 2009). This enables the method to solve decision making problems more efficiently and realistically. As shown in **Figure 2**, ANP method has a web like structure, which precisely models the problems, internal relations between their main and side components and the directions of the relations. Therefore ANP can consider the direct or indirect interaction and feedback between parts of the problem, which are not methodically investigated in AHP.

While AHP treats the decision making problem as a unidirectional hierarchical structure to systematically calculate the priorities of the criteria, ANP can model and analyze more complex structures. In AHP, criteria of the same level are assumed to be independent of each other and the effects between them are ignored. But in real life problems, criteria that affect a decision usually also affect other criteria. As shown in **Figure 2**, ANP appraises these interior relations (Dağdeviren et al., 2006) by modeling the decision problem like a web in which exterior dependencies and feedbacks between criteria groups, as well as interior dependencies within the groups are considered. This enables more complex problems to be modeled that would be hard to model with a hierarchical structure and provides the evaluations or decisions to be more precise and effective (Karsak et al., 2002).

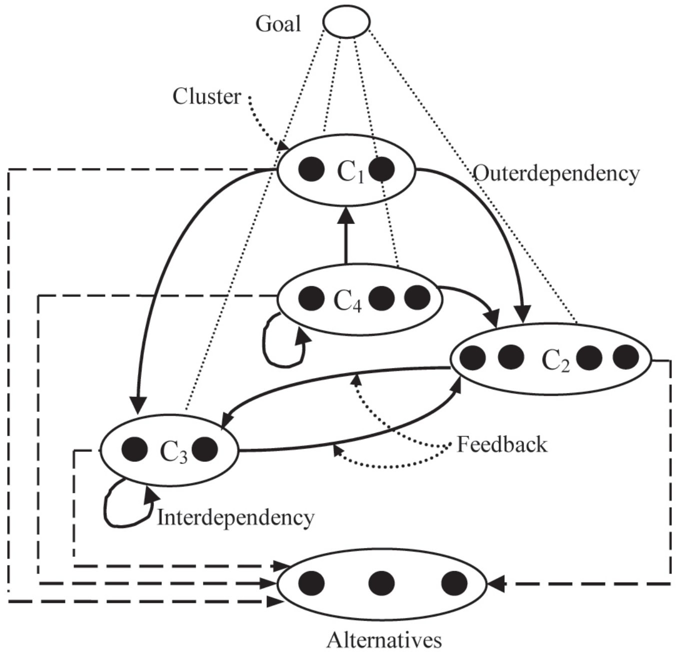

Figure 2. Model structure of ANP

Priority vectors are calculated in both methods by using dual comparison matrices but while the AHP procedure works in a sequential way, ANP follows a more complex route. In ANP, the relations between the criteria clusters (external dependency) or mutual effects between criteria belonging to the same cluster (internal dependency) are calculated as vectors and added to a comparison matrix as a column. As a criteria cluster does not necessarily affect another criteria cluster or a single criteria all the time, values belonging to these kinds of neutral criteria in the vector are taken as zero (Büyükyazıcı and Sucu, 2003).

The process steps in detail are as follows (Bayazıt, 2006).

Determining the Main Purpose and Forming the Model

The criteria and alternatives are designated and listed. They are classified into separate clusters according to their interior relations. Then the ANP web structure is formed by investigating and considering interactions and dependencies between clusters.

Forming of the Dual Comparison Matrices and Calculating the Eigen Vector

Pairwise comparison data obtained from interviews with participants are entered into matrices by using the same 1-9 scale also used in the AHP method.

If the consistency ratio calculated from the pairwise comparison data is below 0.1, the evaluations performed by the participants are accepted to be sufficiently consistent and therefore correct. The value in the matrix belonging to a criterion which is found to have no relation with any other criterion is taken as zero. This enables the Eigen vector to be calculated without problem at all times. An un-weighted super matrix is formed by placing the Eigen vectors into the columns of the formed matrix.

$$A = (a_{ij})_{nxn} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & . & . & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

Calculation of the Weighted Super Matrix

A new matrix is formed by multiplying the values in the un-weighted super matrix with the weights of the cluster they belong to and this new matrix is called the weighted super matrix. If the sum of the columns of the weighted super matrix is not equal to 1, a normalization operation needs to be done to equalize this sum to 1. To equalize the priorities at one point, the matrix is raised to powers to capture all transitivity of an order that is equal to that power. The new matrix formed is called the limit super matrix.

Organizing the Alternatives and Reaching the Results

The final priorities of the criteria and the alternatives are calculated by normalizing each cluster. Then the alternatives are organized in a vector from high to low according to their priority values.

USING AHP AND ANP FOR THE EVALUATION OF HAND CART DESIGN CONCEPTS

In this section, a case study is presented to demonstrate the applicability and validity of AHP and ANP methods.

The Application

A number of hand cart design concepts are evaluated by using the two methods and one of them is selected for further design development and production. For this, the criteria which may affect buyers' hand cart selection preferences are listed and the priorities of these criteria among each other are assessed. Then these criteria are used for evaluating the hand cart design concepts by using the AHP and ANP methods and thus the final concept is selected. Results obtained from the two methods are compared and discussed.

The Method

After investigating the utilization of AHP and ANP in the literature, our adaptation of the two methods into industrial design is planned. It is seen that the AHP and ANP methods are known to work with both objective as well as subjective input data (Kuruüzüm and Atsan, 2001) and according to the literature, there is no strict number for the amount of samples required. Therefore 15 people attending the university's design research center were randomly selected to take part in the study, consisting of a professor and eight designers to represent design experts and six design students to represent users (referred to as participants from here on). One on one interviews were conducted with the participants to give scores for the priorities of the criteria and the alternatives. To create a common decision for the whole sample group, the geometric mean of the input data was calculated for both methods (Saaty, 2004; Saaty, 2008). Storage and processing of the data gathered from the interviews were done on separate PC software dedicated to each method and the findings were obtained separately.

The Common Tasks of the Two Methods

As ANP is derived from AHP, initial parts of the processes are similar. Both methods operate around a main objective and use a set of criteria and sub criteria to perform the evaluations. So the main objective was defined first as "selection of the best hand cart design concept". This implies selecting the design which will have the greatest chance of being successful in market, creating the highest profit. Then the criteria and sub criteria were selected and gathered from literature articles that used various methods for similar evaluations (Hambali et al., 2008; Hambali et al., 2009; Ayağ, 2005; Hsiao et al., 2002; Xiao et al., 2007). As shown in **Table 5**, the selected main criteria are: performance, safety, cost, human factors, and maintenance and the self-explanatory sub criteria are: ease of transfer, ease of operation, ease of storage, lightness, frame strength, stability, sharp edge elimination, material cost, manufacturing process cost, ease of holding, user friendly handles and locks, ease of repair, and ease of dismantling.

Then, as the design alternatives to be investigated, seven hand cart design concepts shown in **Figure 3** were selected from among a number of designs that were investigated in an earlier study (Bayrakçı, 2004).

The brief specifications of the seven selected design concepts are as follows.

Performance	Properties that can affect the general working and usability of the hand cart, such as ease of carrying, ease of operation, folding for storage, weight of the product, having a sturdy frame to carry heavier loads.
Safety	Properties that can protect the user from harm or the product itself from damage such as, being able to stand alone or move in a stable straight line without rolling or falling, not having any sharp edges that might harm the user or the goods being carried.
Cost	Purchase price of the product is affected from the cost of materials used in manufacture and the cost of manufacturing itself and this is always an important factor affecting any purchase.
Human Factors	Properties related to user-product physical interface, product dimensions compatible with anthropometric measures, ease of holding, pulling, opening-closing and folding-unfolding the product for daily use and storage.
Maintenance	The periodical servicing that the product may need, the interval of this necessary servicing, the possibility of the servicing to be performed by the user, whether the interior details of the product are easily seen and reachable to enable problem finding and the possibility of the product to be dismantled easily to reach the faulty point.

Table 5. List of criteria and their definitions

HC-1 is a soft bag design with a flexible lid, hard bottom and a rectangular frame, which can be pulled or pushed by a handle or carried by two shoulder straps as a backpack.

HC-2 is an open top folding bag supported by four solid fence sides and a diagonal frame.

HC-3 is a basket type bag with semi rigid sides and lid, supported by a strong frame.

HC-4 is a folding bag with minimal frame and small wheels, and has the smallest dimensions among the seven when folded.

HC-5 is a bag with expandable body, rigid top and bottom with telescopic side frames and a carrying handle.

HC-6 is a handcart made from a rectangular strong frame carried by two big wheels and it houses two detachable smaller bags.

Figure 3. The seven hand cart design concepts, one of which to be selected for further design development (front and rear perspective views)

HC-7 is a flexible folding bag with supporting rigid frames and multiple wheels for easy operation on steps.

For the interviews, a private room was prepared with a computer, a table and two seats that the participant and the interviewer used while the participant was asked to do the required comparisons. The interviews usually took between 45 and 60 minutes each. The pictures of the alternatives were shown two by two to the participants on a 23 inch LCD screen for the comparisons. First HC-1 and HC-2 were shown and compared, then HC-1 and HC-3, followed by HC-1 and HC-4. After completing the comparison of the HC-1 and HC-7 pair, the routine restarted for the HC-2 and HC-3 pair, continuing with HC-2 and HC-4 up to HC-2 and HC-7, and then for the pairs of HC-3 and HC-4, HC-3 and HC-5, and so on. The comparison process always followed this same order for every participant. Each comparison was orally given to the participant as a question like "Please state the importance values for performance and safety, which one do you think is more important for a hand cart?", "Which one of the two displayed design concepts is safer to use? Please comparatively score the displayed design concepts according to safety". This oral and visual approach enabled the surveys to be performed easily like an informal conversation. The number of necessary comparisons between n items can be calculated by the combination formula $n * (n - 1)/2$ (Godwin, 2000). As there were seven alternatives to be compared, $7 * (7 - 1)/2 = 21$ comparisons were necessary for each criterion. And as there were 13 sub criteria under the main criteria, 21 * 13 = 283 comparisons were performed for the alternatives. Additional $5 * (5 - 1)/2 = 10$ comparisons were performed among the main criteria and 14 comparisons among the sub criteria, increasing the total comparison number to 307. The participants were asked to do the scoring by using Saaty's 1-9 scale. Received scores were simultaneously entered into the Expert Choice (for AHP) and the ANP Solver (for ANP) programs by the interviewer for later calculations, saving additional time.

The Application of AHP

After the completion of the common tasks, the study proceeded with method specific tasks. To begin with, a hierarchical structure was formed as shown in **Figure 4**, in which the main objective of the study was written at the top, the criteria-sub criteria were listed at mid level and the alternatives to be evaluated were listed at the bottom. The criteria and sub criteria were used as the input for the Expert Choice PC program (Version 11). Empty pairwise comparison matrices produced by the program were filled with data gathered from the interviews in which the participants comparatively evaluated the criteria and the alternatives in pairs by using the 1-9 scale shown in **Table 2**.

When the interviews were complete, the AHP calculations were done by the PC program. As the number of participants was more than one, the program calculated geometric mean average of the values obtained from the interviews for use at the computations. The averages found for the criteria are listed in **Table 6**. The inconsistency ratio belonging to the criteria comparisons matrix was found to be 0.00, while a value below 0.1 implies a consistent result.

According to the findings presented in **Figure 5**, the participants found the most important criteria for the hand cart design concept to be human

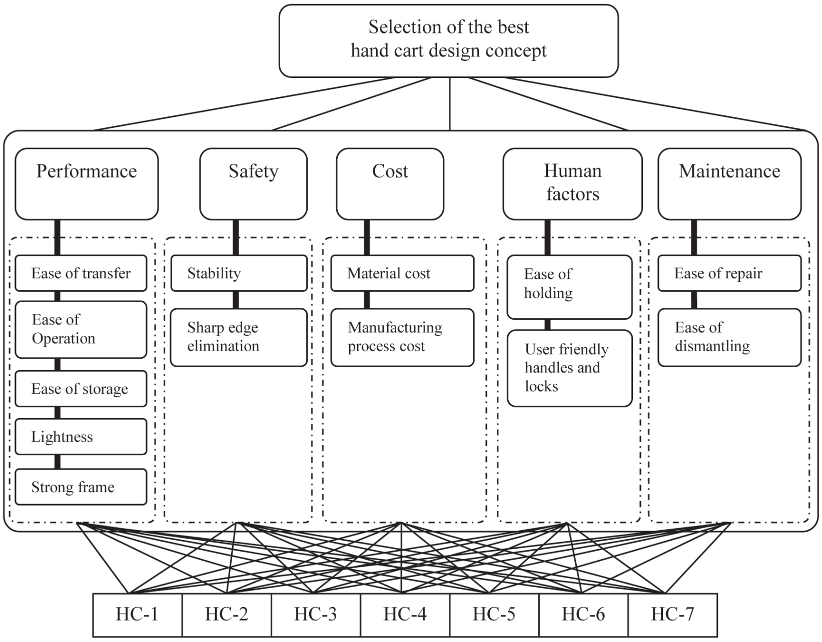

Figure 4. The hierarchical model of the process

	Performance	Safety	Cost	Human factors	Maintenance
Performance		1.16591	1.08447	1.14471	1.55185
Safety			1.03996	1.35566	1.52767
Cost				1.09682	1.22106
Human factors					2.13354
Maintenance					
Inconsistency Ratio:0,00					

Table 6. Pairwise comparison matrix for the main criteria

factors and this was followed by performance, cost, safety and finally maintenance.

After the main criteria, pairwise comparisons were performed for the sub criteria. The inconsistency ratio for the comparisons was calculated as less than 0.1. As can be seen in **Figure 6**, the most important sub criterion of the criterion of performance was found to be ease of operation, which was followed by ease of transfer, frame strength, ease of storage and lightness. The most important sub criterion of the criterion of safety came up as stability, while the most important sub criterion of cost was material cost, the most important sub criterion for human factors was ease of holding, and the most important sub criterion for maintenance was ease of dismantling.

Overall Inconsistency = ,01

Figure 7. Decision points of the alternatives

Figure 5. Score order of the criteria with respect to the objective

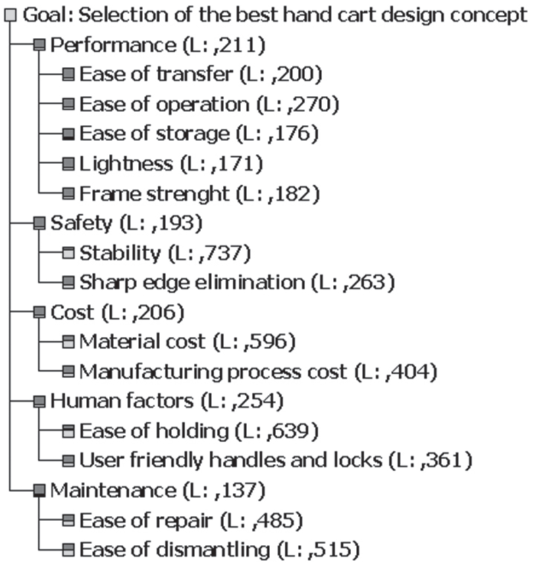

Figure 6. Hierarchical schema of importance values for the criteria and sub criteria

The resulting decision points (weighted importance values) for the seven hand cart alternatives are listed in **Figure 7**. It is seen that HC-4 has the highest overall performance score (16.1%) and HC-1 has the second highest (16%), while HC-6 has the lowest (11.9%). Therefore after considering all criteria and sub criteria, HC-4 was found to be the most promising design concept alternative for further design development. This was the hand cart design concept with folding bag on minimal frame and small wheels.

The Application of ANP

The same set of criteria and sub criteria were also used for ANP. As the main difference of the ANP method is to consider the internal and external dependencies between criteria and sub criteria, these dependencies were also determined by consulting the participant professor in a separate interview session. In other sessions, he also participated in the study for comparing the HC alternatives as a design expert. Obtained dependency data is saved on dependency determination matrices provided by the ANP solver program shown in **Table 7** and **Table 8**. Whenever there is any dependency between left column and first line elements, "true" is displayed at the corresponding cell and "false" otherwise. If the column and the line element is the same and the cell says true, this means that there is interdependency between its sub criteria. The dependency schematic generated by the PC program by using the dependency matrices is shown in **Figure 8**; in this figure the straight arrows show the relations in between criteria groups and the round arrows show interdependencies.

Table 7. Dependency determination matrix for the main criteria

Clusters	Performance	Safety	Cost	Human factors	Maintenance	Alternatives
Performance	True	True	True	True	True	True
Safety	True	False	True	True	True	True
Cost	True	True	False	True	True	True
Human factors	True	True	True	True	True	True
Maintenance	True	True	True	True	True	True
Alternatives	True	True	True	True	True	False

Nodes	Ease of transfer	Ease of operation	Ease of storage	Lightness	Frame strength	Stability	Sharp edge elimination	Material cost	Manufacturing process cost	User friendly handles and locks	Ease of holding	Ease of repair	Ease of dismantling	HC-1	HC-2	HC-3	HC-4	HC-5	HC-6	HC-7
Ease of transfer	F	T	F	T	F	T	T	F	F	T	T	F	T	T	T	T	T	T	T	T
Ease of operation	T	F	F	T	T	T	T	F	F	T	T	T	F	T	T	T	T	T	T	T
Ease of storage	F	F	F	T	F	T	T	F	F	F	T	F	T	T	T	T	T	T	T	T
Lightness	T	T	T	F	F	F	F	T	T	T	F	T	T	T	T	T	T	T	T	T
Frame strength	F	T	F	F	F	F	F	T	T	F	F	T	F	T	T	T	T	T	T	T
Stability	T	T	T	F	F	F	F	F	F	T	T	F	T	T	T	T	T	T	T	T
Sharp edge elimination	T	T	T	F	F	F	F	F	T	T	T	T	T	T	T	T	T	T	T	T
Material cost	F	F	F	T	T	F	F	F	F	T	F	T	F	T	T	T	T	T	T	T
Manufacturing process cost	F	F	F	T	T	F	T	F	F	T	F	F	F	T	T	T	T	T	T	T
User friendly handles and locks	T	T	T	F	F	T	T	T	T	F	T	F	T	T	T	T	T	T	T	T
Ease of holding	T	T	T	F	F	T	T	F	F	T	F	F	T	T	T	T	T	T	T	T
Ease of repair	F	T	F	T	T	F	T	T	F	F	F	F	T	T	T	T	T	T	T	T
Ease of dismantling	T	F	T	T	F	T	T	F	F	T	T	T	F	T	T	T	T	T	T	T
HC-1	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F
HC-2	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F
HC-3	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F
HC-4	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F
HC-5	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F
HC-6	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F
HC-7	T	T	T	T	T	T	T	T	T	T	T	T	T	F	F	F	F	F	F	F

Table 8. Dependency determination matrix for the sub criteria

After determining the dependencies, the 15 participants were asked to carry out pairwise comparisons using the 1-9 scale which was also used for the AHP method. Then the geometric average of this data was calculated and entered to the ANP solver program (ANP Solver, 2016) to obtain the final results. As the inconsistency rates for all of the matrices were calculated as lower than 0.1 by the program, the evaluations were accepted as valid. **Table 9** shows the un-weighted super matrix, with the calculated Eigenvectors.

The weighted matrix was next formed by multiplying the values in this matrix to the weight of the related set. If the sum of the values at each column of the weighted super matrix does not add up to 1, normalization should be performed. **Table 10** shows the weighted super matrix. As the

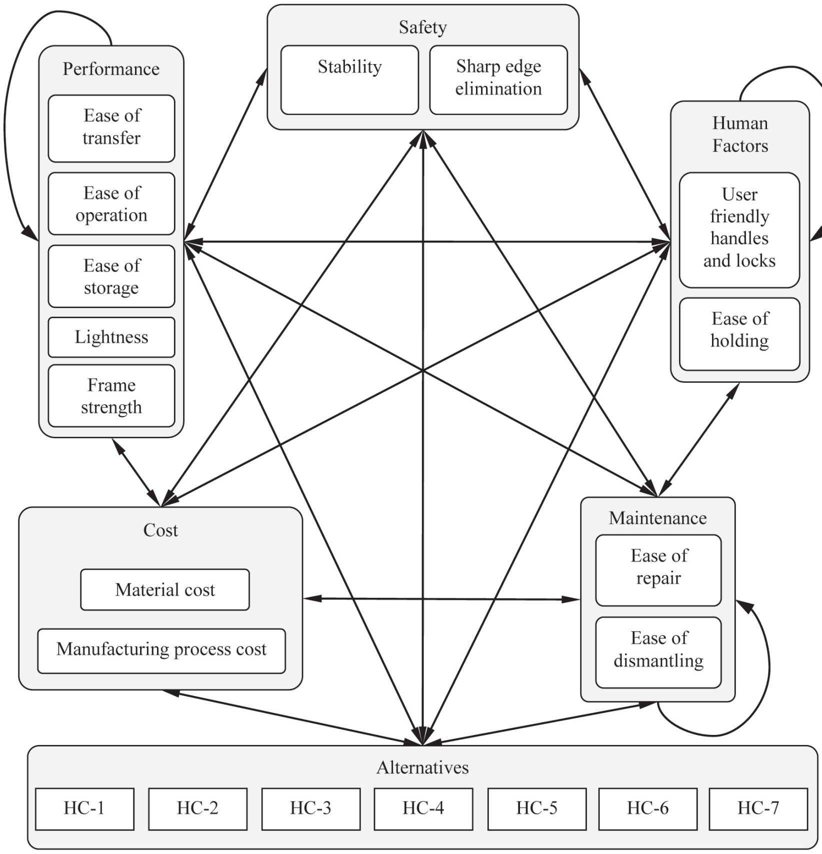

Figure 8. ANP dependency schematic

sum of the column values all added up to 1, it was not necessary to perform normalization.

To equalize the importance weights at a point, the $(2n+1)^{th}$ power of the super matrix is calculated. The "n" value is a randomly selected large number. The resulting matrix shown in **Table 11** is called the limit super matrix and it lists the weights of the importance values belonging to criteria, sub criteria and design concept alternatives that were compared in the process. The design concept with the highest importance value is the strongest candidate to be selected for further development, and the criteria with the highest importance value is the one having the most effect in the decision making process.

Among the hand cart design concept alternatives listed in **Table 12**, HC-1 (0,194) has the highest overall performance score, HC-4 (0,145) has average and HC-7 (0,105) has the lowest performance score. The most important criterion is safety (0,41), followed by performance (0,306). The most important sub criterion for performance is ease of transfer (0,271), the most important sub criterion for safety is stability (0,734), the most important sub criterion for cost is material cost (0,603), the most important sub criterion for human factors is user friendly handles and locks (0,637), and the most important sub criterion for maintenance is ease of repair (0,581). Overall performance scores of all of the alternatives for both methods are listed in **Table 13**.

	Ease of transfer	Ease of operation	Ease of storage	Lightness	Frame strengh	Stability	Sharp edge elimination	Material cost	Manufacturing process cost	User friendly handles and locks	Ease of holding	Ease of repair	Ease of dismantling	HC-1	HC-2	HC-3	HC-4	HC-5	HC-6	HC-7
Ease of transfer	0,23	0,231	0,23	0,234	0,23	0,337	0,392	0	0	0,393	0,393	0	0,354	0,271	0,268	0,293	0,307	0,286	0,271	0,285
Ease of operation	0,236	0,234	0,234	0,23	0,234	0,285	0,323	0	0	0,323	0,323	0,424	0	0,222	0,217	0,211	0,226	0,215	0,232	0,22
Ease of storage	0,186	0,185	0,186	0,187	0,186	0,193	0,285	0	0	0,284	0,284	0	0,327	0,2	0,2	0,188	0,176	0,184	0,187	0,185
Lightness	0,18	0,194	0,181	0,181	0,181	0	0	0,518	0,548	0	0	0,292	0,319	0,171	0,177	0,17	0,159	0,17	0,168	0,17
Frame strength	0,169	0,155	0,169	0,169	0,169	0,185	0	0,482	0,452	0	0	0,284	0	0,136	0,138	0,138	0,13	0,145	0,142	0,14
Stability	0,733	0,733	0,733	0	0	0,744	0	0	0	0,737	0,733	0	0,744	0,657	0,608	0,632	0,588	0,642	0,637	0,559
Sharp edge elimination	0,267	0,267	0,267	0	0	0,256	0	0	0	0,263	0,267	0	0,256	0,343	0,392	0,368	0,412	0,358	0,363	0,441
Material cost	0	0	0	0,596	0,596	0	0	0	0	0,596	0	0	0	0,619	0,638	0,612	0,595	0,631	0,611	0,613
Manufacturing process cost	0	0	0	0,404	0,404	0	0	0	0	0,404	0	0	0	0,381	0,362	0,388	0,405	0,369	0,389	0,387
User friendly handles and locks	0,64	0,64	0	0	0	0,64	0,64	0	0	0	0	0	0,637	0,629	0,624	0,643	0,615	0,628	0,615	0,608
Ease of holding	0,36	0,36	0	0	0	0,36	0,36	0	0	0	0	0	0,363	0,371	0,376	0,357	0,385	0,372	0,385	0,392
Ease of repair	0	0	0	0,515	0	0	0,515	0	0	0	0	0	0	0,619	0,65	0,598	0,618	0,608	0,608	0,597
Ease of dismantling	0	0	0	0,485	0	0	0,485	0	0	0	0	0	0	0,381	0,35	0,402	0,382	0,392	0,392	0,403
HC-1	0,185	0,181	0,216	0,194	0,198	0,22	0,215	0,178	0,194	0,174	0,228	0,179	0,176	0	0	0	0	0	0	0
HC-2	0,179	0,166	0,177	0,182	0,176	0,203	0,168	0,179	0,167	0,166	0,137	0,174	0,166	0	0	0	0	0	0	0
HC-3	0,131	0,149	0,188	0,161	0,17	0,159	0,151	0,145	0,167	0,153	0,142	0,151	0,15	0	0	0	0	0	0	0
HC-4	0,135	0,142	0,124	0,153	0,147	0,123	0,139	0,155	0,129	0,15	0,137	0,153	0,148	0	0	0	0	0	0	0
HC-5	0,125	0,129	0,098	0,117	0,11	0,102	0,107	0,123	0,121	0,127	0,118	0,108	0,13	0	0	0	0	0	0	0
HC-6	0,129	0,121	0,103	0,102	0,105	0,095	0,11	0,112	0,11	0,122	0,122	0,116	0,124	0	0	0	0	0	0	0
HC-7	0,116	0,112	0,094	0,091	0,095	0,097	0,11	0,108	0,112	0,107	0,114	0,118	0,106	0	0	0	0	0	0	0

Table 9. Un-weighted super matrix

	Ease of transfer	Ease of operation	Ease of storage	Lightness	Frame strengh	Stability	Sharp edge elimination	Material cost	Manufacturing process cost	User friendly handles and locks	Ease of holding	Ease of repair	Ease of dismantling	HC-1	HC-2	HC-3	HC-4	HC-5	HC-6	HC-7
Ease of transfer	0,064	0,064	0,086	0,072	0,088	0,007	0,374	0	0	0,113	0,15	0	0,097	0,06	0,059	0,065	0,068	0,063	0,06	0,063
Ease of operation	0,065	0,065	0,087	0,071	0,09	0,006	0,307	0	0	0,093	0,123	0,245	0	0,049	0,048	0,047	0,05	0,048	0,051	0,049
Ease of storage	0,052	0,051	0,069	0,057	0,071	0,004	0,271	0	0	0,082	0,108	0	0,089	0,044	0,044	0,042	0,039	0,041	0,041	0,041
Lightness	0,05	0,054	0,067	0,055	0,069	0	0	0,297	0,314	0	0	0,169	0,087	0,038	0,039	0,038	0,035	0,038	0,037	0,038
Frame strength	0,047	0,043	0,063	0,052	0,065	0,004	0	0,276	0,259	0	0	0,165	0	0,03	0,031	0,031	0,029	0,032	0,032	0,031
Stability	0,196	0,196	0,263	0	0	0,728	0	0	0	0,198	0,261	0	0,215	0,141	0,13	0,136	0,126	0,138	0,137	0,12
Sharp edge elimination	0,071	0,071	0,096	0	0	0,25	0	0	0	0,071	0,095	0	0,074	0,074	0,084	0,079	0,088	0,077	0,078	0,095
Material cost	0	0	0	0,163	0,203	0	0	0	0	0,146	0	0	0	0,128	0,132	0,126	0,123	0,13	0,126	0,127
Manufacturing process cost	0	0	0	0,11	0,138	0	0	0	0	0,099	0	0	0	0,079	0,075	0,08	0,083	0,076	0,08	0,08
User friendly handles and locks	0,163	0,163	0	0	0	0	0,011	0	0	0	0	0	0,152	0,124	0,123	0,127	0,121	0,124	0,121	0,12
Ease of holding	0,092	0,092	0	0	0	0	0,006	0	0	0	0	0	0,087	0,073	0,074	0,07	0,076	0,073	0,076	0,077
Ease of repair	0	0	0	0,102	0	0	0,007	0	0	0	0	0	0	0,099	0,104	0,096	0,099	0,097	0,097	0,096
Ease of dismantling	0	0	0	0,096	0	0	0,007	0	0	0	0	0	0	0,061	0,056	0,064	0,061	0,063	0,063	0,065
HC-1	0,037	0,036	0,058	0,043	0,055	0	0,003	0,076	0,083	0,035	0,06	0,075	0,035	0	0	0	0	0	0	0
HC-2	0,036	0,033	0,047	0,04	0,049	0	0,003	0,076	0,071	0,033	0,036	0,073	0,033	0	0	0	0	0	0	0
HC-3	0,026	0,03	0,051	0,036	0,047	0	0,002	0,062	0,071	0,03	0,037	0,064	0,03	0	0	0	0	0	0	0
HC-4	0,027	0,028	0,033	0,034	0,041	0	0,002	0,066	0,055	0,03	0,036	0,065	0,029	0	0	0	0	0	0	0
HC-5	0,025	0,026	0,026	0,026	0,03	0	0,002	0,053	0,052	0,025	0,031	0,046	0,026	0	0	0	0	0	0	0
HC-6	0,026	0,024	0,028	0,023	0,029	0	0,002	0,048	0,047	0,024	0,032	0,049	0,025	0	0	0	0	0	0	0
HC-7	0,023	0,022	0,025	0,02	0,026	0	0,002	0,046	0,048	0,021	0,03	0,05	0,021	0	0	0	0	0	0	0
SUM	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table 10. Weighted super matrix

	Ease of transfer	Ease of operation	Ease of storage	Lightness	Frame strength	Stability	Sharp edge elimination	Material cost	Manufacturing process cost	User friendly handles and locks	Ease of holding	Ease of repair	Ease of dismantling	HC-1	HC-2	HC-3	HC-4	HC-5	HC-6	HC-7
Ease of transfer	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083	0,083
Ease of operation	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075
Ease of storage	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061	0,061
Lightness	0,045	0,045	0,045	0,046	0,046	0,045	0,045	0,046	0,046	0,045	0,045	0,046	0,045	0,045	0,045	0,045	0,045	0,045	0,045	0,045
Frame strength	0,041	0,041	0,041	0,041	0,041	0,04	0,041	0,041	0,041	0,041	0,041	0,041	0,041	0,041	0,041	0,041	0,041	0,041	0,041	0,041
Stability	0,3	0,3	0,3	0,299	0,299	0,301	0,3	0,299	0,299	0,3	0,3	0,299	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
Sharp edge elimination	0,109	0,109	0,109	0,108	0,108	0,109	0,109	0,108	0,108	0,109	0,109	0,108	0,109	0,109	0,109	0,109	0,109	0,109	0,109	0,109
Material cost	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038	0,038
Manufacturing process cost	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025	0,025
User friendly handles and locks	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044
Ease of holding	0,025	0,025	0,025	0,026	0,026	0,025	0,026	0,026	0,026	0,026	0,025	0,026	0,025	0,026	0,026	0,026	0,026	0,026	0,026	0,026
Ease of repair	0,018	0,018	0,018	0,018	0,018	0,017	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018	0,018
Ease of dismantling	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013
HC-1	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024	0,024
HC-2	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021
HC-3	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019	0,019
HC-4	0,017	0,017	0,017	0,018	0,018	0,017	0,017	0,018	0,018	0,017	0,017	0,018	0,017	0,018	0,018	0,018	0,018	0,018	0,018	0,018
HC-5	0,015	0,015	0,015	0,015	0,015	0,014	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015	0,015
HC-6	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014
HC-7	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013	0,013

Table 11. Limit super matrix

Clusters	Nodes	(1) Ratio scale priority in the network	(2) Ratio scale priority of clusters	(3)=(1)/(2) Ratio scale priority of nodes in their cluster
Performance	Ease of transfer	0,083	0,306	0,271
	Ease of operation	0,075		0,245
	Ease of storage	0,061		0,199
	Lightness	0,046		0,150
	Frame strength	0,041		0,134
Safety	Stability	0,301	0,41	0,734
	Sharp edge elimination	0,109		0,266
Cost	Material cost	0,038	0,063	0,603
	Manufacturing process cost	0,025		0,397
Human factors	User friendly handles and locks	0,044	0,069	0,637
	Ease of holding	0,025		0,362
Maintenance	Ease of repair	0,018	0,031	0,581
	Ease of dismantling	0,013		0,42
Alternatives	HC-1	0,024	0,124	0,194
	HC-2	0,021		0,169
	HC-3	0,019		0,153
	HC-4	0,018		0,145
	HC-5	0,015		0,121
	HC-6	0,014		0,113
	HC-7	0,013		0,105

Table 12. The relative importance of nodes and clusters

As seen in **Table 13**, the overall performance levels of HCs-1, 2 and 3 are in a descending order in both methods. HC-4 took the first and HC-1 took the second high performance score in the AHP results. The scores they received are close to each other, placing HC-1 also close to the top of the list. In the ANP results, HC-1 took the first place and HC-4 took the fourth place with considerable quantitative score difference. The performance levels of HCs-5 and 6 also follow each other with small difference in performance scores, which also validate the results of both methods. On the other hand, while the place of HC-7 in the list changes according to the two methods, the design concepts HC-5, HC-6, HC-7 have very close performance scores.

As the last step of the research, a validation survey was conducted with the participating professor as a design expert to assess the results obtained from both methods. Similar to the validation procedure performed by Harputlugil et al. (2014), the questions were scored using a 1-10 scale shown in **Table 14**. During the survey, it was argued that HC-1, with its sophisticated design including a lockable cover, strong sides enabling it to more safely house its contents, ability to be carried like a backpack, being pulled on wheels or carried by handle, and ability to stand by itself when stationary, is a design with higher capability in fulfilling the requirements

	ANP		AHP	
1	HC-1	0,194	HC-4	0,161
2	HC-2	0,169	HC-1	0,16
3	HC-3	0,153	HC-2	0,147
4	HC-4	0,145	HC-3	0,14
5	HC-5	0,121	HC-7	0,139
6	HC-6	0,113	HC-5	0,134
7	HC-7	0,105	HC-6	0,119

Table 13. Comparison of the results obtained from ANP and AHP

	Questions (Translated from Turkish)	Scores
1	Please score the AHP evaluation method for how well its results reflect your personal opinions.	7
2	Please score the ANP evaluation method for how well its results reflect your personal opinions.	9
3	Please score the reliability of the AHP evaluation results.	7
4	Please score the reliability of the ANP evaluation results.	9
5	Please score the AHP evaluation method for its applicability to industrial design.	9
6	Please score the ANP evaluation method for its applicability to industrial design.	8
7	Please score your level of recommendation for using the AHP method in evaluation tasks at the industrial design process.	8
8	Please score your level of recommendation for using the ANP method in evaluation tasks at the industrial design process.	9

Table 14. Survey questions and received scores

of the evaluation criteria compared to HC-4. Therefore it was reasoned that the ANP method with its additional capabilities in calculating internal interactions between criteria and alternatives have determined the scores of HC-1 and HC-4 more accurately. According to the validation survey results, ANP received a higher score in reflecting personal opinions and was found to be more reliable. Whereas AHP received a higher score for applicability to industrial design, it was ANP that received a higher score for recommendation to be used in the industrial design process. Finally both methods with their balancing advantages and disadvantages showed similar overall performances in this validation, receiving close scores.

CONCLUSION

In summary, this article has presented a methodology to facilitate informed design decisions under uncertainty, building on the multi attribute decision-making techniques of AHP and ANP. The use of the AHP and ANP processes as multiple criteria evaluation and decision making tools are investigated for concept evaluation and selection during the industrial design process. Both methods are demonstrated on separate industrial design applications in which the same set of hand cart design concepts are evaluated and the most suitable one is selected for further design development.

The methodology is divided into three segments, each consisting of multiple steps. The first segment involves setting up the problem by defining objectives, priorities, design attributes, and design concept alternatives. The second segment involves data collection from participators. And the last segment is the execution of PC programs to do the necessary calculations for generating the performance scores of the design alternatives.

The contributions of this article fall into three categories. Firstly, AHP and ANP were introduced and comparatively outlined. Secondly, several ways of visualizing and analyzing these methods' results were introduced that will be useful for clearly understanding and interpreting the findings. Thirdly, the proposed decision support process was demonstrated on a practical industrial design application.

By comparing the two sets of results of the evaluation processes and considering participator opinions gathered in a later validation survey, it is concluded that although its application was more complex and time consuming than AHP, ANP gave more accurate results for evaluating design concepts. This is due to ANP's capability of calculating interior relations between the criteria and alternatives. It is found that both AHP and ANP with their own advantages are useful for providing a framework for facilitating design decisions under uncertainty. It is concluded that these two methods are only meant to inform, not make a decision, which is the ultimate responsibility of the decision maker himself. Thus, AHP and ANP are most useful in scenarios where large numbers of alternatives need to be reduced to a manageable few, or where it yields a statistically significant 'best' design subject to little dispute. In instances where two or more designs receive close scores, further checks such as the validation survey we used for final testing the results might be necessary. Therefore our study might be considered as an initial guide to generate better and more developed adaptations of the methods to industrial design. In closing, based on the insights of this paper, it is hoped that the methods and ideas presented here are further developed and find broader use with industrial designers in the future.

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SYMBOLS AND ABBREVIATIONS

λ : Base Value Coefficient
AHP: Analytical Hierarchy Process
AHY: *Analitik Hiyerarşi Süreci*
ANP: Analytical Network Process
AHN: *Analitik Ağ Süreci*
CI: Consistency Index
CR: Consistency Ratio
DEA: Data Envelopment Analysis
DFA: Design For Assembly
FMEA: Failure Mode Effects Analysis
GIS: Geographic Information System
HC-n: Hand Cart No n
PC: Personal Computer
PD: Participatory Design
QFD: Quality Function Deployment
RI: Standard Correction Index Value
SWOT: Strengths, Weaknesses, Opportunities and Threats
TOPSIS: Technique for Order Preference by Similarity to Ideal Solution

Alındı: 28.11.2015**; Son Metin:** 24.05.2018

Anahtar Sözcükler: Analitik hiyerarşi süreci; analitik ağ süreci; tasarım fikri seçimi; ürün tasarımı; pazar çantası tasarımı.

ANALİTİK HİYERARŞİ VE ANALİTİK AĞ SÜREÇLERİ KULLANILARAK KAVRAMSAL ÜRÜN TASARIMLARININ DEĞERLENDİRİLMESİ

Bu çalışmanın amacı iki özelleşmiş değerlendirme ve seçim yöntemini endüstri tasarımına uyarlayıp karşılaştırmalı olarak sunmak, böylece endüstri tasarımı sürecinin parçası olan tasarım kavramı değerlendirme işleminin başarı ve verimliliğini artırmaktır. Kullanılacak yöntemler, Analitik Hiyerarşi Süreci (AHP) ve Analitik Ağ Süreci (AHN) olarak adlandırılmaktadır. Yöntemlerin uygulanmasında öncelikle amaç belirlenmekte, sonra değerlendirme ölçütleri ve kavramsal tasarım alternatifleri listelenmektedir. Sonrasında alternatif ve ölçütlerin birbirlerine göre önem dereceleri ve ilişkileri araştırılmaktadır. Sonra bu önem dereceleri ve yöntemlerce sağlanan araçlar kullanılarak tasarım alternatifleri ölçütler açısından değerlendirilmektedir. İki yaklaşımın sınanması için, yedi adet pazar çantası tasarım fikrinin her iki yöntem kullanılarak değerlendirildiği bir uygulama sunulmuştur. İlk olarak her iki süreçte ortak olan işlemler açıklanmış, sonra yönteme özel detaylara geçilmiştir. Ortak bölümde, değerlendirmede kullanılacak ölçütler belirlenmiş ve bunların ürün başarımına yapması beklenen etki, uzmanlarla gerçekleştirilen görüşmelerde yapılan ikili karşılaştırmalarla bulunmuştur. Sonrasında eldeki yedi pazar çantası tasarım alternatifi, ölçütler ve ilişkiler açısından her iki yöntem kullanılarak değerlendirilmiş ve göreceli başarım değerleri ortaya çıkartılmıştır. Elde edilen sonuçlar, büyükten küçüğe sıralanmış ve en yüksek göreceli önem değerine sahip tasarım, en başarılı ürün kavram tasarımı olarak belirlenmiştir. İki yöntemden alınan sonuçlar karşılaştırmalı olarak yorumlanmıştır.

PRODUCT DESIGN CONCEPT EVALUATION BY USING ANALYTICAL HIERARCHY AND ANALYTICAL NETWORK PROCESSES

The aim of this study is to improve the success and efficiency of the design concept evaluation and selection activity in industrial design by adapting two specialized evaluation-selection methods to the design process and comparatively demonstrating their use. The methods are called the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP). In their application, first the main design objective is decided upon and the evaluation criteria are determined accordingly, followed by the listing of the design concept alternatives. Then the criteria’s importance values as well as relations between them are investigated and evaluation of the alternatives is done according to the criteria by using the tools provided by the methods. The application presented in the article evaluates seven hand cart designs by using the two methods. First the tasks that are common in both methods, then the tasks specific to each method are explained. The general criteria to be used in the evaluation are identified and the effects of these criteria on the evaluation process are determined through interviews with designers and users participating in the study. Then the relative performance rankings of the available seven hand cart alternatives are calculated by using both methods. Numerical results are listed in a descending order to show the success levels of the design concepts, pointing to the one that received the highest overall performance. The findings obtained from two methods are comparatively interpreted.

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