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QFD-ANP Approach for Improving Conceptual Product Design of a Mattress Manufacturing Company

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ABSTRACT

As the market competition is high, the impact of customer requirements on the conceptual design of any product cannot be underestimated. QFD is one of the efficient tool to convey customer requirements CRs to Technical requirements TRs. In case of mattress manufacturing companies, the QFD tool usage is very limited. However, there are increasing trends of ergonomic and clinical studies regarding the comfort aspect. Massive efforts have already been done on increasing the effectiveness of QFD tool by hybridising with suitable decision making algorithm. QFD-ANP approach is one of the hybrid algorithms considering both inner dependency and inter (outer) dependency of various attributes (CRS and TRs). In this paper, a study was aimed to improve the conceptual product design of a mattress manufacturing company. The QFD-ANP approach was employed to gather the information and to find the overall interdependent priorities of TRs considering both inner and outer dependencies. The study results showed that the QFD approach is a design tool of vital importance, which enables companies to convey the customer needs to relevant product technical requirements and the overall priorities of TRs were identified. The algorithm such as ANP make the multiple criteria (collective) decision making more systematic. The designer can keep in mind and improve the existing product by considering the overall priority results.

Keywords: *Quality, Manufacturing Company, QFD, ANP*

1. INTRODUCTION

Quality Function Deployment can be considered as an old quality management tool to convey the customer requirements to technical requirements. The tool became more systematic by incorporating different decision making algorithms. Different decision making algorithms have been implemented to enrich the QFD tool like fuzzy logic, AHP, TOPSIS, ANP etc. (Chieh Yuan et al. [1], Bhattacharya et al. [2], Lin et al. [3], Lam et al. [4]). For instance, Bevilacqua et al. [5] suggested a fuzzy based QFD method for supplier selection and applied it to a clutch couplings manufacturing company. Hanumaiah et al. [6] presented a QFD-AHP method for selection and parameter prioritization of rapid tooling processes. In order to handle the supplier selection problems of small and medium enterprises, Kumaraswamy et al. [7] adopted a combined QFD-TOPSIS methodology. Moreover, Lam et al. [8] applied the ANP-QFD approach for developing environmental sustainability in shipping operations.

For situations involving attributes having both inner and outer dependency, ANP have found to be more effective. The scope of QFD tool has widened beyond product design improvements to larger areas of manufacturing and supplementary fields. However, when considering conceptual product design of a mattress manufacturing company, QFD studies have got limited attention. But, mattress ergonomics have been studied widely.

The objective of this work is to identify the customer requirements or needs (CRs) and analogous technical requirements (TRs) of a mattress manufacturing company followed by identification of inner dependencies and inter dependencies of CRs and TRs and furthermore the estimation of overall priorities of TRs by using ANP-QFD hybrid algorithm considering customer requirements as the focus.

2. METHODOLOGY

The research methodology hybridises the quality tool (QFD) with the multi-criteria resolution algorithm (ANP). This study forms a 'house of quality' (HOQ) which links the CRs and TRs of a mattress manufacturing company's conceptual design for improved products. The HOQ is helpful in this study to exhibit the importance weightings of the TRs, which are determined by the importance ratings of CRs together with the relationships between CRs and TRs.

Drawing reference from Saaty [10], the maritime researcher Jasmine Siu Lee Lam [9] presented the QFD-ANP methodology in a systematic way. The traditional QFD method make use of absolute importance degrees, so it is difficult to differentiate the outer dependence of different attributes. In order to tackle this situation, Lam [9] proposed the usage of ANP tool which can deal with the hierarchical network of inter-relationships (outer dependence) among the different attributes. The method is to perform a series of pairwise comparisons of these attributes. A ratio scale of 1-9 is utilized to compare any two attributes. A score of 1 means equal importance among the two attributes whereas 9 represents the highest level of dominance of one attribute with respect to the other one. On the other hand, 1/9 indicates a much lower importance of a particular attribute versus the other. In order to ensure consistency in human judgement, the consistency ratio of a pairwise comparison matrices must be lower than 0.1.

Drawing reference from Lam [9], we develop the QFD–ANP approach as specified by the following steps:

Step 1: Identify the CRs and TRs.

Step 2: Calculate importance degrees (weightage) of CRs (W_1) by conducting pairwise comparisons of CRs considering that there is no dependence amid the CRs.

Step 3: Calculate importance degrees of TRs (W_2) by conducting pairwise comparisons of TRs with regard to each CR considering that there is no dependence amid the TRs.

Step 4: Calculate inner dependency matrix (W_3) of the CRs by conducting pairwise comparisons of the CRs with regard to each CR.

Step 5: Calculate inner dependency matrix (W_4) of the TRs by conducting pairwise comparisons of the TRs with regard to each TR.

Step 6: Calculate inter-dependent priorities (W_C) of the CRs by using equation $W_C = W_3 \times W_1$.

Step 7: Calculate inter-dependent priorities (W_A) of the TRs by using the equation $W_A = W_4 \times W_2$.

Step 8: Calculate overall priorities of the TRs (W^{ANP}) by using the equation $W^{ANP} = W_A \times W_C$.

Step 9: represent weightage values in final HOQ.

3. CASE STUDY OF A MATTRESS MFG. COMPANY

Different types of mattress are available in market. Its varieties depend on the types of raw materials, compositing practices and other several processing steps. A rubberized coir mattresses manufacturing company was considered for this study which is located at Kannur district of Kerala, having 8000 metric ton annual production capacity. Natural Coir is the primary main raw material of the in the industry which is sufficiently available in the country. Due to the increased number of competitors, innovations are essential for each company. So, it is indispensable to give proper consideration to the customer requirements and effective translation to respective technical requirements.

Groover [11] proposed 8 methods for capturing customer requirements for performing the QFD, they were interviews, comment cards, formal surveys, focus groups, study of complaints, customer returns, internet and field intelligence. In this study, we used field intelligence, i.e., second hand information was collected from employees who interact with customers. The primary list of corresponding technical requirements was prepared with the help of quality and manufacturing departments of the company. A few brainstorming sessions were used for the abstraction of the data.

3.1 Customer requirements and design requirements of the mattress manufacturing company

The ANP-QFD method started with the investigation of CRs and related TRs. We adopted a thorough procedure in two stages, namely literature research, and brainstorming sessions. Literature study was done on both CRs and TRs. The understandings of this study was helpful in conducting effective brainstorming sessions with company employees. Along with insights from literature study, important suggestion from the company employees were also accepted. After conducting 4 brainstorming sessions, we prepared the final list of important CRs and TRs.

Table 1 shows the five customer requirements for improved conceptual design of mattress products, namely (1)Affordable Price, (2)Comfort during use, (3)Fire Safety, (4)Mattress Aesthetics and (5)Reduction of Mattress Dust. The first CR is specifically related to the economic aspect of the design of the product. Price affordability is very crucial in retaining the market share of any brand and in case of mattress, the price determination is more influenced by the coir quality, foam usage and cloth material. The second CR involves need of comfort and it depends on quality of coir material, proper application of latex compound and further processing and foam layer Compositing. In case of new generation, the fourth CR is an indispensable attribute and it must be properly considered. Moreover, CR3 and CR5 are also considerable because modern customers are highly concerned about safety and physical health.

Table 1
Customer requirements for improved conceptual design

Notations	Customer requirements
CR1	Affordable Price
CR2	Comfort During Use
CR3	Fire Safety
CR4	Mattress Aesthetics
CR5	Reduction of Mattress Dust

Higashi et al. [12] evaluated the comfort of mattress by using magnetoencephalogram and pressure distribution were measured. The authors emphasized that it was essential to develop the pressure release properties and comfort of mattresses (CR2) suitable for elderly people and bed-ridden patients. Nazaré [13] reviewed the fire blocking technologies for soft furnishings, explained the importance of fire resistant soft furnishings including mattresses and conducted a detailed survey of fire barrier fabrics and fire resistant foam materials (CR3). Forsten [14] invented a fire resistant fabric composite and the authors also explained the different aspects of mattress aesthetics like aesthetics of the cushioning material, initial tactile aesthetics, retention of aesthetics (CR4) etc. In Norwegian Institute of Public Health, Bertelsen et al. [15] conducted a clinical study on mattress dust and they found that it was a source of severe food allergens. Even if the current customers are not very much concerned about CR5, it has also to be addressed.

Table 2 lists the technical requirements for improved conceptual design of mattress products. Cloth material selection (TR1) is of high importance in point of view of fire resistance and aesthetics. As Nazaré [13] claimed, it is important for designers to consider the fire safety of soft furnishings like mattress. In this sense, proper selection of cloth material (TR1) and foam material (TR4) are very important.TR4 is also essential in ensuring proper comfort by implementing foam compositing with coir layers, which will promote more cushioning effect. Modification of Manufacturing Control System (TR2) was proposed to be executed by proper maintenance latex treatment section, rectification of problems with current PLC controls and implementation of SCADA control systems (if possible).TR2 is a method for ensuring product quality and thus the comfort level. Screening of Coir Suppliers (TR3) can be implemented by strict quality checks, Grading or raw material suppliers etc. TR 3 is also a a method for ensuring product quality and thus the comfort level. But, the trade-off between TR3 and TR2 will definitely depend on cost incurred and other considered attributes.

Table 2
Technical requirements for improved conceptual design

Notations	Technical requirements
TR1	Cloth Material Selection
TR2	Modification of Manufacturing Control System
TR3	Screening of Coir Suppliers
TR4	Usage of Foam

3.2 Results of current study using QFD–ANP approach

Referring to Section 2, the study proceeds to step 2 in which importance degrees (weightage) of CRs (eigenvector W1) are calculated by conducting pairwise comparisons of CRs considering that there is no dependence amid the CRs. Two important considerations in this comparisons were: (1) ensurance of customer needs; and (2) supposing the independence of CRs. The ANP algorithm recommends pairwise comparisons to be done for each CR. This is shown in Table 3 we have indicated scores for the different CRs. Using CR1 Affordable price as the reference for comparison in the first row of Table 3, a reading of 3 under CR2 and CR5 use indicates their moderate importance relative to CR1. On the same row (first), the score of 5 given to CR3 and CR4 reflects their strong importance relative to CR1. Consistency ratios for all the pair-wise comparisons in the case are below 0.1. Computation of eigenvector W1 is performed by completing the pairwise comparison matrix. As seen in Table 3, CR1 has the highest eigenvector score of 0.464, followed by CR2 at 0.248. The results reveals that in the measure of relative importance, the highly important CRs are CR1 and CR2 while CR3 and CR5 are ranked with relatively lower importance. The importance degrees (weightage) of CRs (W1) are represented in the rightmost column of the HOQ in Fig. 2.

Table 3

Pairwise comparisons to find importance degrees (weightage) of CRs (eigenvector W1)

	CR1	CR2	CR3	CR4	CR5	E-Vector
CR1	1	3	5	5	3	0.46466
CR2	1/3	1	4	3	3	0.24865
CR3	1/5	1/4	1	3	1	0.06508
CR4	1/5	1/3	1/3	1	3	0.14106
CR5	1/3	1/3	1	1/3	1	0.08055

Thereafter, step 3 requires the calculation of importance degrees of TRs (eigenvector W2) supposing that there is no dependence among the TRs. Results of pairwise comparisons of TRs with respect to CR1 – Affordable price are shown in Table 4. Considering the second row as an example, TR2 Modification of Manufacturing Control System was found to be less important than TR1 Cloth Material Selection and therefore a score of 1/3 was assigned. In the same row, the score of 1/3 with reference to TR3 and TR4 indicates that TR2 is moderately less important than TR3 and TR4. Replicating the method for the remaining TRs, the other pairwise comparison results (matrices) are depicted in the Appendix. Table 5 shows the accumulated list of importance degrees of TRs (eigenvector W2) with regard to each CR. The transpose of eigenvector matrix W2 is depicted in the central portion of the HOQ in Fig. 2.

Table 4

Pairwise comparisons of TRs with respect to CR1 Affordable price.

	TR1	TR2	TR3	TR4	E-Vector
TR1	1	3	1	3	0.36789
TR2	1/3	1	1/3	1/3	0.09557
TR3	1	3	1	3	0.36789
TR4	1/3	3	1/3	1	0.16864

Table 5

Importance Degrees of TRs with respect to each CR (W2)

	CR1	CR2	CR3	CR4	CR5
TR1	0.36789	0.12003	0.75000	1	0
TR2	0.09557	0.20528	0	0	0
TR3	0.36789	0.33814	0	0	0
TR4	0.16864	0.33655	0.25000	0	1

Step 4 is to establish the inner dependency matrix of the CRs with regard to each CR (eigenvector W3). As with previous steps, the method uses pairwise comparison to find the effect that each CR has on one another. Wherever any CR had no effect on other CRs, the comparison matrices excluded them. Fascimilating the method for the remaining CRs, the other pairwise comparison results (matrices) are depicted in the Appendix. Table 6 shows the accumulated list of eigenvectors of inner dependency matrices of the CRs with regard to each CR (W2). The eigenvector matrix W3 is depicted in the left portion of the HOQ in Fig. 2.

Table 6

Inner dependency matrix of CRs (W3)

	CR1	CR2	CR3	CR4	CR5
CR1	0.46532	0.27671	0.58416	0.25000	0.28083
CR2	0.24097	0.41883	0.28083	0	0.13501
CR3	0.06885	0.07441	0.13501	0	0
CR4	0.14516	0.15602	0	0.75000	0
CR5	0.07970	0.07404	0	0	0.58416

Step 5 is to calculate the inner dependency matrix of TRs with regard to each TR (eigenvector W4). Out of the considered TRs, none of them have comparable relative impact. So, only self-comparison TRs are done by assigning value 1 correspondingly. Table 7 gives the inner dependency matrix of the TRs in relation to each TR (eigenvector W4) and the value of 0 is allocated when the TRs are not related. The eigenvector matrix W4 is depicted as the roof in the final HOQ (Fig. 2).

Table 7

Inner dependency matrix of TRs (W4)

	TR1	TR2	TR3	TR4
TR1	1	0	0	0
TR2	0	1	0	0
TR3	0	0	1	0
TR4	0	0	0	1

In step 6, with regard to the values of matrices W3 and W1 calculated in above steps, the interdependent priorities of the CRs were computed using the following formula: $W_C = W_3 \times W_1$. For instance, Wc of CR1 = ((0.46532×0.46466) + (0.27671×0.24865) + (0.58416×0.06508) + (0.25×0.14106) + (0.28083 x 0.08055)) = 0.380. We get the following results.

$$W_C = \begin{bmatrix} 0.46532 & 0.27671 & 0.58416 & 0.25000 & 0.28083 \\ 0.24097 & 0.41883 & 0.28083 & 0 & 0.13501 \\ 0.06885 & 0.07441 & 0.13501 & 0 & 0 \\ 0.14516 & 0.15602 & 0 & 0.75000 & 0 \\ 0.07970 & 0.07404 & 0 & 0 & 0.58416 \end{bmatrix} \begin{bmatrix} 0.46466 \\ 0.24865 \\ 0.06508 \\ 0.14106 \\ 0.08055 \end{bmatrix}$$

$$W_C = \begin{bmatrix} 0.380 \\ 0.245 \\ 0.059 \\ 0.212 \\ 0.102 \end{bmatrix}$$

In step 7, with regard to the values of matrices W_4 and W_2 calculated in above steps, the interdependent priorities of the TRs were computed using the following formula: $W_A = W_4 \times W_2$.

We obtained the following results.

$$W_A = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.36789 & 0.12003 & 0.75000 & 1 & 0 \\ 0.09557 & 0.20528 & 0 & 0 & 0 \\ 0.36789 & 0.33814 & 0 & 0 & 0 \\ 0.16864 & 0.33655 & 0.25000 & 0 & 1 \end{bmatrix}$$

$$W_A = \begin{bmatrix} 0.36789 & 0.12003 & 0.75000 & 1 & 0 \\ 0.09557 & 0.20528 & 0 & 0 & 0 \\ 0.36789 & 0.33814 & 0 & 0 & 0 \\ 0.16864 & 0.33655 & 0.25000 & 0 & 1 \end{bmatrix}$$

Moreover, step 8 is to determine the overall priorities of the TRs as W^{ANP}, which indicate the inter-relationships within the final HOQ, it is calculated by the following equation

$W^{ANP} = W_A \times W_C$.

$$W^{ANP} = \begin{bmatrix} 0.36789 & 0.12003 & 0.75000 & 1 & 0 \\ 0.09557 & 0.20528 & 0 & 0 & 0 \\ 0.36789 & 0.33814 & 0 & 0 & 0 \\ 0.16864 & 0.33655 & 0.25000 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.380 \\ 0.245 \\ 0.059 \\ 0.212 \\ 0.102 \end{bmatrix}$$

$$W^{ANP} = \begin{bmatrix} 0.425 \\ 0.087 \\ 0.223 \\ 0.263 \end{bmatrix} = \begin{bmatrix} TR1 \\ TR2 \\ TR3 \\ TR4 \end{bmatrix} = \begin{bmatrix} \text{Cloth Material Selection} \\ \text{Modification of Manufacturing Control System} \\ \text{Screening of Coir Suppliers} \\ \text{Usage of Foam} \end{bmatrix}$$

The last step of the current approach is the depiction of the final HOQ. The results were verified by the case company, they regarded it as practical and informative. The overall priorities (W^{ANP}) of the TRs are placed in the last row of the final HOQ in Fig. 2.

Deduced from the results of the case, the most important TR for improved conceptual design of mattress products is TR1 Cloth Material Selection, which has a relative importance value of 0.425. The second and third most important TRs are found to be TR4 Usage of Foam (value of 0.263) and TR3 Screening of Coir Suppliers (value of 0.223). TR2 Modification of Manufacturing Control System (value of 0.087) is ranked as the least important technical requirement. The following bar graph (Figure 1) depicts the overall priorities of different TRs.

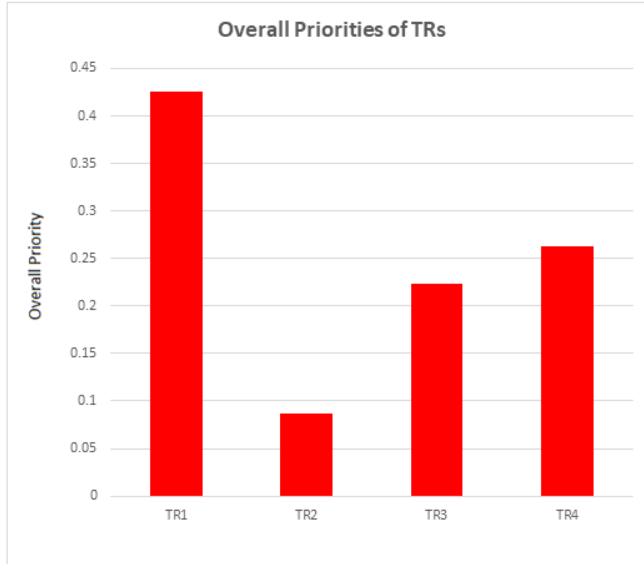

Fig 1. Overall priorities of TRs

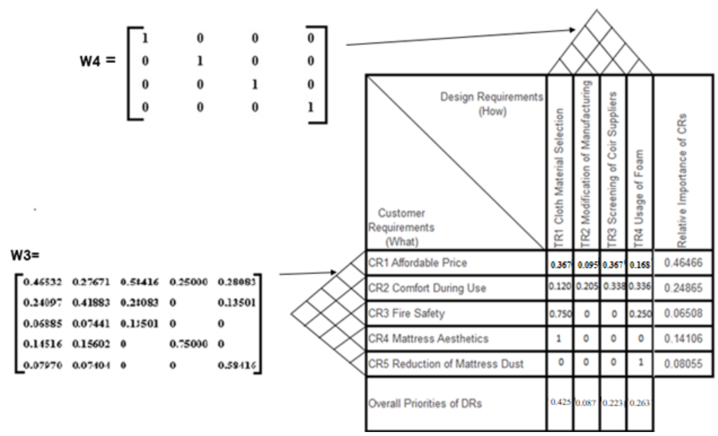

Fig. 2. Final House of quality of the study.

4. CONCLUSIONS

The following conclusions are obtained from the work,

- The QFD approach is a design tool of vital importance, which enables companies to translate customer needs to relevant product technical requirements.
- The algorithm such as ANP make the multiple criteria (collective) decision making more systematic.
- The decision approach aims to consider the interdependence (outer) between the CRs and TRs, and the inner dependence within the different attributes.
- In this case study, the overall priorities of TRs were identified. 'Cloth material selection' has the highest overall priority among all and 'Modification of Manufacturing Control System' has the lowest overall priority.
- The designer can keep in mind and improve the existing product by considering the overall priority results.

5. FUTURE RESEARCH SUGGESTIONS

- Newer and better multi-criteria (collective) decision making algorithms may be hybridized to QFD to make the tool more scientific and systematic.
- Multiple sensitivity analysis of hybrid algorithms will help to find out the best algorithm for enriching QFD tool.

- Development of add-on modules or additional options to handle hybrid algorithms along with pure ANP or AHP decision making software tools (e.g. Super Decisions) will help the industry people to use these powerful tools easily.

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List of Abbreviations

QFD	Quality Function Deployment
ANP	Analytical Network Process
AHP	Analytic Hierarchy Process
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
CR	Customer Requirements
TR	Technical Requirements
HOQ	House of Quality

Appendix

The fundamental scale of pairwise comparisons

Intensity of Importance	Definition Explanation	Explanations
1	Equal importance	Two activities equally contribute to the objective.
2	Weak	
3	Moderate importance	Experience and judgment favor one activity over the another slightly.
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over the another.
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over the another; its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Pairwise comparisons of TRs with respect to CR2 Comfort During Use.

	TR1	TR2	TR3	TR4	E-Vector
TR1	1	1/3	1	1/5	0.12003
TR2	3	1	1	1/3	0.20528
TR3	1	1	1	3	0.33814
TR4	5	3	1/3	1	0.33655

Pairwise comparisons of TRs with respect to CR3 Fire Safety. (Neglecting TR2, TR3 – no importance in current comparison)

	TR1	TR4	E-Vector
TR1	1	3	0.75000
TR4	1/3	1	0.25000

Pairwise comparisons of TRs with respect to CR4 Mattress Aesthetics. (Neglecting TR2, TR3, TR4 –no importance in current comparison)

	TR1	E-Vector
TR1	1	1

Pairwise comparisons of TRs with respect to CR 5 – Reduction of Mattress Dust. (Neglecting TR1, TR2, TR3 –no importance in current comparison)

	TR4	E-Vector
TR4	1	1

Pairwise comparisons of CRs with respect to CR1-Affordable Price.

	CR1	CR2	CR3	CR4	CR5	E-Vector
CR1	1	4	4	4	3	0.46532
CR2	1/4	1	4	3	3	0.24097
CR3	1/4	1/4	1	1/3	1	0.06885
CR4	1/4	1/3	3	1	3	0.14516
CR5	1/3	1/3	1	1	1	0.07970

Pairwise comparisons of CRs with respect to CR2-Comfort During Use.

	CR1	CR2	CR3	CR4	CR5	E-Vector
CR1	1	1/3	3	3	5	0.27671
CR2	3	1	4	3	3	0.41883
CR3	1/3	1/4	1	3	1	0.07441
CR4	1/3	1/3	3	1	3	0.15602
CR5	1/5	1/3	1	3	1	0.07404

Pairwise comparisons of CRs with respect to CR3-Fire Safety. (Neglecting CR4, CR5 –no importance in current comparison)

	CR1	CR2	CR3	E-Vector
CR1	1	3	3	0.58416
CR2	1/3	1	3	0.28083
CR3	1/3	1/3	1	0.13501

Pairwise comparisons of CRs with respect to CR4-Mattress Aesthetics. (Neglecting CR2, CR3, CR5 –no importance in current comparison)

	CR1	CR4	E-Vector
CR1	1	1/3	0.25000
CR4	3	1	0.75000

Pairwise comparisons of CRs with respect to CR5- Reduction of Mattress Dust. (Neglecting CR3, CR4 –no importance in current comparison)

	CR1	CR2	CR5	E-Vector
CR1	1	3	1/3	0.28083
CR2	1/3	1	1/3	0.13501
CR5	3	3	1	0.58416