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DEALING WITH DISSATISFACTION MEASURE IN QFD MODEL TO DERIVE TARGET OF ENGINEERING CHARACTERISTICS

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Quality Function Deployment (QFD) is a design tool for developing product to maximize customer satisfaction. Implementation of QFD demands deeply understanding about customer requirements. Kano model is broadly used to give insight about customer requirements categories. In the Kano model there are three major categories that have to be considered regarding its influence on customer's satisfaction or dissatisfaction. Attractive requirements and must be requirements have more than proportional influence on customer's satisfaction or dissatisfaction. One dimensional requirements are requirements that affect customer satisfaction proportionally. In dealing with factors that lead to satisfaction or dissatisfaction, Kano model is considered parallel to Motivation-Hygiene (M-H) theory. According to Kano model and M-H theory, fulfilling factors that lead to satisfaction is not automatically eliminating dissatisfaction. In Kano model, factors that merely lead to satisfaction (attractive requirements) differ from those that only lead to dissatisfaction (must be requirements). A number of studies on QFD have tried to incorporate Kano model into QFD process. Some of those which proposed mathematical model used nonlinear function to represent requirements that have disproportional influence on satisfaction. However, those studies focused mainly in maximizing customer satisfaction without paying much attention in dissatisfaction measurement. This research is conducted to deal with maximizing customer satisfaction and minimizing dissatisfaction as well. A mathematical model is developed to set target of engineering characteristics. Verification of model developed is done by a simple hypothetical case. Although it shows that it is well verified, validation is still needed. It may be done in the future by implementing the model for solving real cases.

Keywords: QFD, Kano, M-H theory, dissatisfaction, specification.

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1. INTRODUCTION

In the product design field, there is a method namely Quality Function Deployment (QFD), that is broadly used to derive a set of specification target. QFD was developed by Y. Akao and then implemented at Mitsubishi Heavy Industries' Kobe shipyard in 1972. It is a tool to translate voice of costumer into product engineering characteristic values, and later deployed into parts characteristics, manufacturing operations and day-to-day operations and controls, by the means of using matrices. The first matrix, which is known as House of Quality (HoQ), relates the customer needs to engineering characteristics. Using cross-functional team to achieve its goal of maximizing customer satisfaction, implementation of QFD is considered able to decrease cost and reducing cycle time for developing new or improved products (Cohen, 1995).

As inputs that later will be translated by QFD process, it is necessary to explore customer needs deeply. A deep understanding of customer needs will help the design team to create product which provides high level of customer satisfaction. Kano model (Sauerwin et al., 1996) developed by N. Kano in 1984, is useful for classifying customer needs according to its ability to drive customer satisfaction.

According to its influence on satisfaction, Kano model distinguishes customer needs into three major categories:
Must-be (M): a category for the needs that considered taken for granted by customer. Fulfillment of these needs will not lead to customer satisfaction increase, but not fulfilling these needs will lead to great customer dissatisfaction.
One-dimensional (O): a category for the needs that will increase customer satisfaction proportionally to its fulfillment.
Attractive (A): a category for the needs that will give a significant increase (more than proportional) in customer satisfaction by a little improvement, but not lead to customer dissatisfaction if not met.

In coherence with classification of customer needs in the Kano model, factors that lead to customer dissatisfaction (M category) are differ from factors that lead to customer dissatisfaction (O and A category). Therefore, fulfilling factors that increase customer satisfaction is not automatically eliminating dissatisfaction factors. It is parallel with Herzberg's Motivation-Hygiene (M-H) theory about job satisfaction that states what makes workers satisfied with their job is not the opposite of what makes them dissatisfied (Hedberg et al., 2002).

Beside deal with customer needs, the other challenge in QFD is concerning decision making procedures. As regard of complexity of the process, the design team often relies on sub-optimal procedures. More formal approach in the form of mathematical model has developed by Wasserman (1993). Later, Wasserman's model was used as basic model in Park and Kim (1998), Askin and Dawson (2000) etc.

To take advantage of Kano model, some researches (development of conceptual and mathematical models) have been done to involve Kano model in QFD process. Shen et al. (2000) proposed a process model to integrate Kano model into QFD for innovative product development. Tan and Shen (2000) incorporated Kano model into planning matrix of QFD to develop a transformation function to adjust the improvement ratio of each customer attribute. In the field of intangible product or service development, Tan and Pawitra (2001) proposed a framework that integrated Servqual, Kano model and QFD to help organizations to evaluate customer satisfaction, guide improvement efforts and expedite the development of innovative services. Rahaju (2006) used Kano model to accommodate nonlinearity relationship between fulfillment of customer need and satisfaction perceived by customer. However, particularly for mathematical models, the purpose of those researches is merely improving or maximizing customer satisfaction, and did not deal with dissatisfaction perceived by customer yet.

Considering increasing customer satisfaction is not the same meaning with decreasing customer dissatisfaction, this paper composes to deal with both, customer satisfaction and dissatisfaction, as setting target of engineering characteristics. To provide more formal procedure in QFD the decision making process, this paper proposes a mathematical model.

2. THEORETICAL BACKGROUND

The next sections present theories related to the development of the model.

2.1 House of Quality

The first matrix of QFD is known as the House of Quality (HoQ). It is the central construct of QFD, almost everyone using QFD starts with HoQ (Cohen, 1995). The arrangement of HoQ is showed by Figure 1.

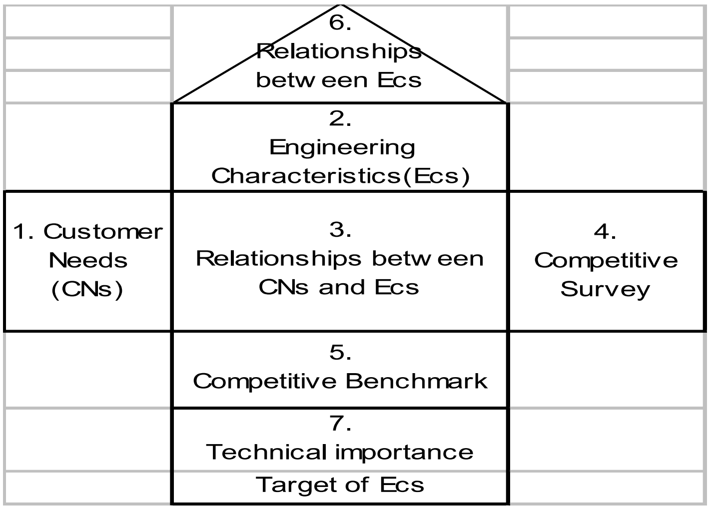

Figure 1. The House of Quality

The HoQ concerns with translating customer need to the technical importance and or the target of engineering characteristics. Such translation is carried by following steps (Wang, 1999):

1. Obtaining the customer needs and those relative importance weight.
2. Developing engineering characteristics responsive to the customer needs.
3. Relating engineering characteristics to customer needs.
4. Completing the customer competitive survey.
5. Performing the competitive technical benchmarking.
6. Determining the relationships among engineering characteristics.
7. Calculating the technical importance ratings of engineering characteristics and evaluating their technical difficulties and estimated cost to establish the target of engineering characteristics.

2.2 Kano Model

Kano model divides customer needs into three major categories (Sauerwein, et al., 1996):

1. Must-be category: The needs which considered taken for granted by the customers. It will generate extremely dissatisfaction if not fulfilled, but fulfilling these needs will not increase customer satisfaction.
2. One-dimensional category: The needs which usually explicitly demanded by the customer. The higher the level of fulfillment, the higher the customer's satisfaction and vice versa.
3. Attractive category: The needs which have the greatest impact on customer satisfaction. Fulfilling these needs will lead to more than proportional satisfaction, but there is no feeling of dissatisfaction if they are not fulfilled.

The graphical representation of Kano's model of customer satisfaction is presented by Figure 2.

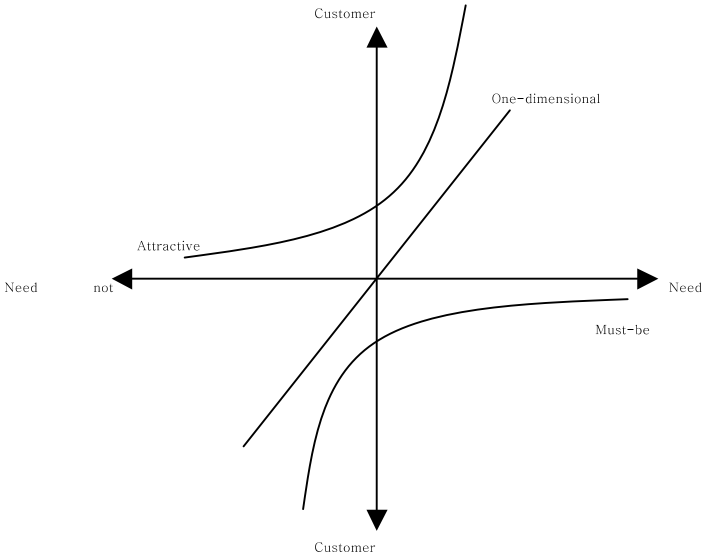

Figure 2. Kano's Model of Customer Satisfaction

3. PROPOSED MODEL

The model proposed was developed based on Askin and Dawson's model (see Askin and Dawson, 2000). As a reference model, Askin and Dawson, 2000 has explained functional relationship between each customer need (CN_j) with engineering characteristic(EC_i)s related. A mathematical model was arranged and purposed to determine target of engineering characteristics (x_i). Construction of functional relationship between fulfillment level of CN_j (V_j) with level of satisfaction (S_j) or dissatisfaction (DS_j) perceived by customer was influenced by Tan and Shen, 2000.

The objective (SF) is to maximize the sum of total adjusted importance weight of all CNs, that is the sum of importance weight which involve customer satisfaction, denoted by $TOTWS$, or dissatisfaction, denoted by $TOTWDS$ (Equation 1). Here $TOTWS$ will not take negative value and $TOTWDS$ is never in positive value.

Regarding the differences in scaling and domain of the ECs, it is necessary to normalize the decision variables (Equation 2). The normalized decision variable is denoted by x_i^{cc}. U_i and L_i are the upper and lower value of the feasible range of EC_i (Equation 5).

Level of CN_j fulfillment given by certain design (V_j) is represented by Equation 3, where β_0 and β_i are regression parameters and V_j lies on the range 1 to 5 (Equation 4). Equation 3 can be defined by least squares method (see Box, et al., 1976). In such method, sample data V_j can be obtain as a result of customer judgments for different designs concerning design performance in fulfilling CN_j.

Improvement made for each EC_i in the new design, denoted by Z_i is presented by Equation 6.

Equation 7 and 8 present resource constraints, which show the amount of budget and time provided, denoted by B and T, that limit the improvement of the design. R & D cost incurred per unit improvement of EC_i is given by c_{D_i}, production cost incurred per unit improvement of EC_i is given by c_{P_i}, whereas t_i states development time per unit improvement of EC_i.

Equation 9 to 38 concern with involving Kano model and relative importance weight of each CN (λ_j) in the model. To involve Kano model, here is defined the customer satisfaction and dissatisfaction function for each CN (i.e.

S_j and DS_j) that represent the level of satisfaction or dissatisfaction perceived by customer if CN_j is fulfilled at the level of V_j. The general form of S_j and DS_j equations is defined for each Kano category (Equation 9, 11, 16, 17, 18, 19, 21). In such equations, the equation constant α_j and γ_j can be obtained using linear or nonlinear regressions (see Box, et al., 1976). Analogous to V_j, S_j and DS_j are the result of customer assessment for different level of V_j. The value of S_j maximum, that is commonly achieved by the best performance level of V_j, (except for certain CNs in attractive category), is denoted by $\max S_j$ (Equation 10, 14, 20). The value of DS_j maximum, that is usually reached by the worst performance level of V_j, (except for certain CNs in must-be category), is denoted by $\max DS_j$ (Equation 12, 15, 22).

For CN_j included in the must-be category, according to its nature as a taken for granted need, it has no effect on satisfaction and only affects on dissatisfaction perceived by customer (Equation 9 and 11). As opposed to the must-be category, the attractive category only affects the level of customer satisfaction (Equation 19 and 21). One-dimensional is the only category which may have influence on customer satisfaction or dissatisfaction, depends on the level of V_j. As the category for spoken needs, one-dimensional consists of the CNs which also are aimed to be fulfilled by similar products. Here customer will benchmark the developed design to the competitor's design for its performance in fulfilling such CN. If the developed design is considered able to fulfill CN better than competitor's, customer will be satisfied. On the other hand, dissatisfaction will be perceived if customer considers that competitor's design performs better (Equation 13, 16, 17, 18).

The different value of Kano parameter k is chosen for the different category (Equation 11, 13, 19). The value of k will affect on the shape of graphical representation of S_j and DS_j. According to the steepness of the graphical representation, it is probable for certain CN, most probable for CN contained in must-be or attractive category, that such CN will reach maximum dissatisfaction or satisfaction level, denoted by $\max DS_j$ and $\max S_j$, even if V_j is not taken its bound yet ($\min V_j$ or $\max V_j$). Considering such behavior, it is necessary to keep S_j and DS_j level in the allowable range, those are 0 to 100 for S_j and -100 to 0 for DS_j (Equation 24 and 26). Therefore, after those reach its lower bound for DS_j or upper bound for S_j, those function will be pressed not to increase its customer dissatisfaction (for DS_j) or satisfaction (for S_j) level (Equation 23 and 25). The analogous situation also applied to $\max S_j$ and $\max DS_j$ (Equation 27 to 30). Otherwise, it is also probable for a certain CN_j, mostly for the need that considered common found in the similar products, to never achieve its maximum bound of S_j.

Most of the time, the span of satisfaction and dissatisfaction, denoted by $TOTMAXS$ and $TOTMAXDS$ (Equation 31 and 32), that can be reached by certain design are unequal. Hence a unit incremental in total dissatisfaction contained in a design has different value with a unit incremental in total satisfaction. To quantify both units in the same degree, it is necessary to create a normalized value, denoted by $normDS_j$ and $normS_j$, that is presented by Equation 33 and 34.

The model constructed not only to give bigger priority for CNs which have more effect in maximizing customer satisfaction or minimizing customer dissatisfaction, but also considering relative importance weight of CNs (λ_j) in setting priority as showed by Equation 35 to 38. The model works to increase customer satisfaction, which is considered low, in CNs with higher λ_j. Also, it is will decrease customer dissatisfaction, which is considered high, in CNs with higher λ_j. The objective function will reach its maximum value by increasing customer satisfaction aspect in WS_j and or decreasing dissatisfaction aspect in WDS_j.

Below is the complete mathematical model proposed:

Objective:

Maximize $SF = TOTWS + TOTWDS$ ... (1)

Subject to:

$$x_i^{cc} = \frac{\{x_i - ((U_i + L_i)/2)\}}{(U_i - L_i)/2} \qquad \forall i, \qquad \ldots \qquad (2)$$

$$V_j = \beta_0 + \sum_i \beta_{ij} x_i^{cc} \qquad \forall j, \qquad \ldots \qquad (3)$$

$$\min V_j \le V_j \le \max V_j \quad \forall j \qquad \ldots \qquad (4)$$

where $\min V_j = 1, \max V_j = 5,$

$$L_i \le x_i \le U_i \quad \forall i, \qquad \cdots \tag{5}$$

$$Z_i = \left| x_i - x_0 \right| \quad \forall i, \qquad \cdots \tag{6}$$

$$\sum_i \left(c_{D_i} Z_i + c_{p_i} Z_i \right) \le B, \qquad \cdots \tag{7}$$

$\sum_i t_i Z_i \le T$ (if improvement activities are performed in series) or $\max_i t_i Z_i \le T$ (if improvement activities are performed in parallel), … (8)

$\forall j$:

If j is a must be:

$$S_j = 0, \qquad \cdots \tag{9}$$

$$\max S_j = 0, \qquad \cdots \tag{10}$$

$$DS_j = \alpha_j \left(V_j \right)^k \text{ where } k \langle 0 \text{ and } \alpha_j \langle 0, \qquad \cdots \tag{11}$$

$$\max DS_j = \alpha_j \left(\max V_j \right)^k, \qquad \cdots \tag{12}$$

If j is an one-dimensional:

$$F = \alpha_j \left(V_j \right)^k + \gamma_j \qquad \text{where } k = 1 \text{ and } \alpha_j \rangle 1, \qquad \cdots \tag{13}$$

$$\max S_j = \alpha_j \left(\max V_j \right)^k + \gamma_j, \qquad \cdots \tag{14}$$

$$\max DS_j = \alpha_j \left(\min V_j \right)^k + \gamma_j, \qquad \cdots \tag{15}$$

$$\text{If } F \langle 0: \qquad S_j = 0 \text{ and } DS_j = F, \qquad \cdots \tag{16}$$

$$\text{If } F = 0: \qquad S_j = 0 \text{ and } DS_j = 0, \qquad \cdots \tag{17}$$

$$\text{If } F \rangle 0: S_j = F \text{ and } DS_j = 0, \qquad \cdots \tag{18}$$

If j is an attractive:

$$S_j = \alpha_j \left(V_j \right)^k \text{ where } k \rangle 1 \text{ and } \alpha_j \rangle 0, \qquad \cdots \tag{19}$$

$$\max S_j = \alpha_j \left(\max V_j \right)^k, \qquad \cdots \tag{20}$$

$$DS_j = 0, \qquad \cdots \qquad (21)$$

$$\max DS_j = 0, \qquad \cdots \qquad (22)$$

$$\forall j: \quad \text{If } S_j \rangle 100 \text{ then } S_j = 100, \qquad \cdots \qquad (23)$$

$$0 \le S_j \le 100 \quad \forall j, \qquad \cdots \qquad (24)$$

$$\forall j: \quad \text{If } DS_j \langle -100 \text{ then } DS_j = -100, \qquad \cdots \qquad (25)$$

$$-100 \le DS_j \le 0 \qquad \forall j, \qquad \cdots \qquad (26)$$

$$\forall j: \quad \text{If } \max S_j \rangle 100 \text{ then } \max S_j = 100, \qquad \cdots \qquad (27)$$

$$0 \le \max S_j \le 100 \qquad \forall j, \qquad \cdots \qquad (28)$$

$$\forall j :\text{If } \max DS_j \langle -100 \text{ then } \max DS_j = -100, \qquad \cdots \qquad (29)$$

$$-100 \ge \max DS_j \ge 0 \quad \forall j, \qquad \cdots \qquad (30)$$

$$TOTMAXS = \sum_j \max S_j, \qquad \cdots \qquad (31)$$

$$TOTMAXDS = \sum_j \max DS_j, \qquad \cdots \qquad (32)$$

$$normS_j = S_j / TOTMAXS \qquad \forall j, \qquad \cdots \qquad (33)$$

$$normDS_j = DS_j / TOTMAXDS \qquad \forall j, \qquad \cdots \qquad (34)$$

$$WS_j = \lambda_j normS_j \qquad \forall j \qquad \text{where } 0 \langle \lambda_j \langle 1, \qquad \cdots \qquad (35)$$

$$WDS_j = \lambda_j normDS_j \quad \forall j, \qquad \cdots \qquad (36)$$

$$TOTWS = \sum_j WS_j, \qquad \cdots \qquad (37)$$

$$TOTWDS = \sum_j WDS_j \qquad \cdots \qquad (38)$$

4. ILLUSTRATIVE EXAMPLE

The mathematical model proposed will be applied to a hypothetical example to observe how the model works. The example is composed partially adapted from Askin and Dawson, 2000, Rahaju, 2006.

Consider a HoQ which contains three customer needs (CN_1, CN_2 ,CN_3) and three engineering characteristics (EC_1, EC_2, EC_3). The technically achievable range of $EC_1$is $4 \le x_1 \le 8$, EC_2 is $2 \le x_2 \le 6$ and EC_3 is $2 \le x_2 \le 4$. The regression equations obtained by fitting the customer assessment data on performance of various design in fulfilling certain need (see Rahaju, 2006). Those equations are:
$V_1 = 3 + 2x_i^{cc}$, $V_2 = 3 + 0.875x_2^{cc} - 1.12x_3^{cc}$ and $V_3 = 3 + 1.5x_2^{cc} - 0.5x_3^{cc}$.

Given R&D cost per unit of improvement EC_i is $1 for EC_1, $0.3 for EC_2 and $0.2 for EC_3, production cost incurred per unit of improvement EC_i is $1 for EC_1, $0.1 for EC_2 and $0.2 for EC_3, while the total budget provided by the company is $5. Total time available for product development is 50 days, as the activities are assumed carried in series. Time needed to create a unit improvement EC_i is 12 days for EC_1, 9 days for EC_2 and 7 days for EC_3. Supposed parameter Kano for each category (k) is chosen as follows: 2 for CN_1 (attractive), 1 for CN_2 (one-dimensional) and -3 for CN_3 (must-be), whereas customer satisfaction and dissatisfaction function are defined as: $S_1 = 15(V_1)^2$, $F = 20V_2 - 40$ (for one-dimensional, the regression function is denoted by F), and $S_3 = -100(V_3)^{-3}$.
For each CN_j, the relative importance weight related is 0.167 for CN_1, 0.333 for CN_2 and 0.5 for CN_3.

The complete mathematical model that arranged based on the hypothetical case is enclosed in Appendix. The model is solved by Lingo 8.0. The solutions find the target of ECs (x_1, x_2, x_3) as 5.58, 3.89 and 2.0. Using the model, contribution of CN_1 and CN_2 ($normS_1$ and $normS_2$) will reach 62.50% and 25.90% of total satisfaction span, while dissatisfaction ($normDS_3$) is minimized to 2.09% of total dissatisfaction span. Total satisfaction span provided by the design ($TOTMAXS$) is 160 units and total dissatisfaction span contained in the design ($TOTMAXDS$) is 120 units. The result also showed the weight of CN_j that has considered its relative importance and satisfaction or dissatisfaction aspect (WS_1, WS_2 and WDS_3) as 0.10, 0.09 and -0.01. The values of WS_j mirrored the behavior of the model. It struggles to reduce dissatisfaction aspect in CN_3, the need with highest λ, thus WDS_3 could be minimized. Also, it works to increase satisfaction aspect in CN_1 that considered less important but generates high customer satisfaction, so WS_1 could be maximized. Those results have triggered objective function to achieve its optimal value on 0.18.

5. CONCLUSIONS

From the illustration presented, it shows that the target of engineering characteristics is obtained by the model that has considered customer satisfaction and dissatisfaction as well. The solutions attained reflect the expected behavior of the model.

6. FURTHER RESEARCH

The validity of the model proposed needs to be tested by implementing it to solve problem in a real case of product development. In the future, the model can be improved to involve relationship between ECs to create a more comprehensive model.

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BIOGRAPHICAL SKETCH

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7. APPENDIX

Objective:

Maximize $SF = TOTWS + TOTWDS$

Subject to:

$$x_1^{cc} = \frac{\{x_i - ((8+4)/2)\}}{(8-4)/2},$$

$$x_2^{cc} = \frac{\{x_i - ((6+2)/2)\}}{(6-2)/2},$$

$$x_3^{cc} = \frac{\{x_i - ((4+2)/2)\}}{(4-2)/2},$$

$$V_1 = 3 + 2x_1^{cc},$$

$$V_2 = 3 + 0.875x_2^{cc} - 1.12x_3^{cc},$$

$$V_3 = 3 + 1.5x_2^{cc} - 0.5x_3^{cc},$$

$$1 \le V_1 \le 5,$$

$$1 \le V_2 \le 5,$$

$$1 \le V_3 \le 5,$$

$$4 \le x_1 \le 8,$$

$$2 \le x_2 \le 6,$$

$$2 \le x_2 \le 4,$$

$$Z_1 = |x_1 - x_0|,$$

$$Z_2 = |x_2 - x_0|,$$

$$Z_3 = |x_3 - x_0|,$$

$$(Z_1 + 0.3Z_2 + 0.2Z_3) + (Z_1 + 0.1Z_2 + 0.2Z_3) \le 5,$$

$$12Z_1 + 9Z_2 + 7Z_3 \le 50,$$

$$S_1 = 15(V_1)^2,$$

$$\max S_1 = 15(5)^2,$$

$$DS_1 = 0,$$

$$\max DS_1 = 0,$$

$$F = 20(V_2) - 40,$$

$$\max S_2 = 20(5) - 40,$$

$$\max DS_2 = 20(1) - 40,$$

If $F \langle 0$: $S_2 = 0$ and $DS_2 = F$, If $F = 0$: $S_2 = 0$ and $DS_2 = 0$,

If $F \rangle 0$: $S_2 = F$ and $DS_2 = 0$,

$S_3 = 0$,

$\max S_3 = 0$,

$DS_3 = -100(V_3)^{-3}$,

$\max DS_3 = -100(5)^{-3}$,

If $S_1 \rangle 100$ then $S_1 = 100$,

If $S_2 \rangle 100$ then $S_2 = 100$,

If $S_3 \rangle 100$ then $S_3 = 100$,

$0 \leq S_1 \leq 100$,

$0 \leq S_2 \leq 100$,

$0 \leq S_3 \leq 100$,

If $DS_1 \langle -100$ then $DS_1 = -100$,

If $DS_2 \langle -100$ then $DS_2 = -100$,

If $DS_3 \langle -100$ then $DS_3 = -100$,

$-100 \leq DS_1 \leq 0$,

$-100 \leq DS_2 \leq 0$,

$-100 \leq DS_3 \leq 0$,

If $\max S_1 \rangle 100$ then $\max S_1 = 100$,

If $\max S_2 \rangle 100$ then $\max S_2 = 100$,

If $\max S_3 \rangle 100$ then $\max S_3 = 100$,

$0 \leq \max S_1 \leq 100$,

$0 \leq \max S_2 \leq 100$,

$0 \leq \max S_3 \leq 100$,

If $\max DS_1 \langle -100$ then $\max DS_1 = -100$,

If $\max DS_2 \langle -100$ then $\max DS_2 = -100$,

If $\max DS_3 \langle -100$ then $\max DS_3 = -100$,

$-100 \geq \max DS_1 \geq 0$,

$-100 \geq \max DS_2 \geq 0$,

$-100 \geq \max DS_2 \geq 0$,

$TOTMAXS = \max S_1 + \max S_2 + \max S_3$,

$TOTMAXDS = \max DS_1 + \max DS_2 + \max DS_3$,

$normS_1 = S_1 / TOTMAXS$,

$normS_2 = S_2 / TOTMAXS$,

$normS_3 = S_3 / TOTMAXS$,

$normDS_1 = DS_1 / TOTMAXDS$,

$normDS_2 = DS_2 / TOTMAXDS$,

$normDS_3 = DS_3 / TOTMAXDS$,

$$WS_1 = 0.167 normS_1,$$
$$WS_2 = 0.333 normS_1,$$
$$WS_3 = 0.5 normS_1,$$
$$WDS_1 = 0.167 normDS_1,$$
$$WDS_2 = 0.333 normDS_2,$$
$$WDS_3 = 0.5 normDS_3,$$
$$TOTWS = WS_1 + WS_2 + WS_3,$$
$$TOTWDS = WDS_1 + WDS_2 + WDS_3.$$

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