KANO MODEL APPROACH FOR DESIGN IMPROVEMENT ASSOCIATED WITH ERGONOMICS ISSUES IN CNC MACHINE DESIGN

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ABSTRACT: Application of Computer Numerical Control (CNC) technology in manufacturing industry has been recognized as one of the effective solutions to high productivity, efficiency, and precision. In advancement of CNC machine tool technology development; however, the ergonomic issues related to human-machine design are still less-addressed by scholars. This study was carried out to analyze a CNC machining center based on the operators' requirements. The functional and dysfunctional questionnaire form developed based on Kano method was applied to determine the operators' requirements related to technical specifications of the CNC machining center. Another questionnaire form equipped with a diagram of human body parts and ergonomics features was used to acquire information on the CNC machining center design. This study found that there is a significant correlation between the ergonomics problems in the feet towards facilities required for the CNC machining center – an adjustable standing platform. This study concluded that application of Kano model can contribute to operators' satisfaction in terms of ergonomic design of CNC machining center.

KEYWORDS: *CNC Machine, Ergonomics Issues, Kano Model*

1.0 INTRODUCTION

Highly automatic machines, i.e Computer Numerical Control (CNC) machine center, are complex systems, however, they do not lead to the elimination of accidents in production plants [1]. To address this concern is not an easy task as there is no common applicable solutions to all types of machines. [2]. In reports related to issue on defeating the interlocks on CNC machine (which is as commonplace across the UK engineering industry), it is found that the problems of most machine design in operators' requirements are not only due to visibility, usability, and accessibility issues. They include people's subjective feeling to the preference and needs in the design of CNC machine tools [3].

Based on the above reason, the company management has to consider both physical and psychological of CNC machine operators, as these factors can affect the productivity performance [4]. The focus is on how the company creates conditions for users to take part in the designing of product in actively [3] as well as through implementing the cooperation between the different scientific fields, people, techniques, backgrounds, views, and so on (i.e., risk perception, knowledge of risks, machine design, and procurement) [2]. In addition, the companies should think that there is a bottom-line tradeoff between safety and efficiency where they embrace ergonomics [5]. This is as shown on the effects of training on CNC machine, in which the results show that the CNC operator can perceive more correctly a hazardous condition based on psychophysical [6]. Also, this is an essential basis to reduce the risk of failures in operation as well as physical complaints such as back pain due to awkward body posture during work [7] where the people-oriented principle must be held in the design of hardware human-man interface [3].

To address this issue, this study was performed to investigate the machine's operators satisfaction related to CNC machine design. Additionally this study analyzed the CNC machine characteristics related to prevalent ergonomics problems as well as the improvement required.

2.0 KANO APPROACH TOWARDS CUSTOMER SATISFACTION AND IMPROVEMENT

Kano brings a fresh quantitative Voice of the Customer (VOC) data to the final feature set decision process towards the product attributes that are perceived to be important to customers. There are six Kano categories (Table 1) based on Kano's evaluation table as the combination of customer responses to functional and dysfunctional questions [8].

Table 1: Kano's attributes evaluation

		DYSFUNCTIONAL				
FUNCTIONAL		**1. Like**	**2. Must-be**	**3.Neutral**	**4.Live with**	**5. Dislike**
	1. Like	Q	A	A	A	O
	2. Must-be	R	I	I	I	M
	3. Neutral	R	I	I	I	M
	4. Live with	R	I	I	I	M
	5. Dislike	R	R	R	R	Q

A = Attractive ; M = Must- be; R = Reverse; O = One- dimensional ;
I = Indifferent; Q = Questionable

To depict the customer standpoint towards satisfaction based on Kano attributes, the customer satisfaction index (CSI) based on the rate of CS (satisfied customers) if the attribute is present and DS (dissatisfied customers) if the attribute is absent or insufficient [9]. The quality attribute is classified as 'A' (Attractive) if CS > 0.5 and DS < 0.5; 'M' (Must-be) if DS ≥ 0.5 and CS ≥ 0.5; 'O' (One-Dimensional) if CS > 0.5 and DS > 0.5; and Indifferent (I) or Neutral if CS < 0.5 and DS < 0.5. The CS and DS coefficient are shown as follows:

- Satisfaction index based on CS = $\frac{(A+O)}{(A+M+O+I)}$
- Dissatisfaction index based on DS = - $\frac{(M+O)}{(A+M+O+I)}$

The improvement ratio is m = max (|CS|,|DS|) in which the Kano category is found through CS-DS plot [10]. By manipulating into four quadrants, they are parallel to Importance-Performance Analysis (IPA) for customer satisfaction [11]. The quadrant 1 (Q1) represents 'Low Priority' (Low Importance – Low Satisfaction), the quadrant 2 (Q2) represents 'Possible Overkill' (High Importance – Low Satisfaction), the quadrant 3 (Q3) represents 'Keep Up the Good Work' (High Importance-High Satisfaction), and the quadrant 4 (Q4) represents 'Concentrate Here' (Low Importance-High Satisfaction). Yang [12] articulated Q1 as 'Care-free', Q2 as 'Surplus', Q3 as 'Excellent', and Q4 as 'To be improved'. The difference between CS-DS approach to both approach is, however, the center point of the quadrant that is based on the mean values between 'Importance' and 'Performance' or 'Satisfaction' values. In addition, through the approach of using the graph, there are some contradictions since the Kano approach is not based on data quantification, especially if they are interpreted into the quadrant to represents Kano attributes based on data collected.

3.0 METHODOLOGY

This study performed a survey among 30 CNC machine operators. They had working experience more than five years in CNC machining operation. This study applied a questionnaire that contains of ergonomics problems in the body parts (Figure 1), ergonomics features requirements and failure experiences of using CNC, the usability criteria, critical components of CNC, and control components of CNC (Table 2). This study also applied Kano approach to analyze the 'what' improvement required based on quality attributes related to ergonomics issues and technical requirements of CNC machine (Table 2).

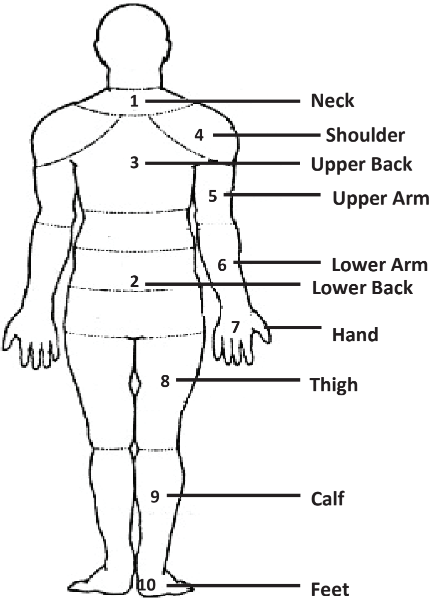

Figure 1: Area of pain due to ergonomics issues

Table 2: Type of failures and critical CNC machine facilities

ERGONOMICS FEATURES REQUIREMENT		CRITICAL PART OF CNC COMPONENT		CONTROL COMPONENTS	
1	Adjustable Working height	1	Base	1	Buttons
2	Adjustable control panel	2	Saddle / Table	2	Switches
3	Wheel chair for disable person	3	Cutting Tools	3	Indicators
4	Adjustable right lever	4	Accessories	4	Sensors
5	Adjustable tool holder – horizontal movement			5	Actuators
6	Adjustable machine table			6	Computer Controllers

FREQUENT FAILURE EXPERIENCED		USABILITY CRITERIA	
1	Overload Fracture	1	Are the controls of the machine are difficult to be reached and controlled?
2	Wear & Tear	2	Are the control of the machine are placed where they are difficult to be seen?
3	Corrosion (Rusting)	3	Does the task require a fine visual judgment?
4	Thermal Failure	4	Are the warning lights of machine located far away from the center field of vision?
5	Chipping		
6	Looseness		

4.0 RESULTS

Figure 3 shows the K2 (voice command control) and K13 (QC facility measurement and monitoring) which are 'Reverse' attributes that is located in Quadrant 1. The K20 (adjustable height) (Indifferent) that was located in Quadrant 1 was not in the right location. Therefore, the adjustment for center point would revise the center from (0.5; 0.5) to 0.54 and 0.43 (Figure 3). By this adjustment, only K13 in 'Reverse' attribute. The quality attribute of 'Reverse' and 'Questionable' is able to ignore the graph approach of CS versus DS [9]. Through Importance-Satisfaction graph approach – as an adaptation of Importance-Performance [10], Figure 2 shows the K3 (Probing system for tools setting and monitoring the dimensional accuracy) is 'Excellent'. The difference is on Quadrant 2 that represented 'Surplus' or 'Over Kill' criteria (K5 – tool wear detection system; K18 – control panel attached to machine frame; K21 – button to adjust the standing platform versus K4 – camera for remote monitoring; K5 - tool wear detection system; and K10 – probing inspection system). They were quality attributes of 'Indifferent', 'Indifferent', 'Indifferent' versus 'Indifferent', 'Attractive' and 'Attractive'. This means the K5 (tool wear detection system) was justified as quality attributes that gave satisfaction, even though the respondents felts this attribute was less important.

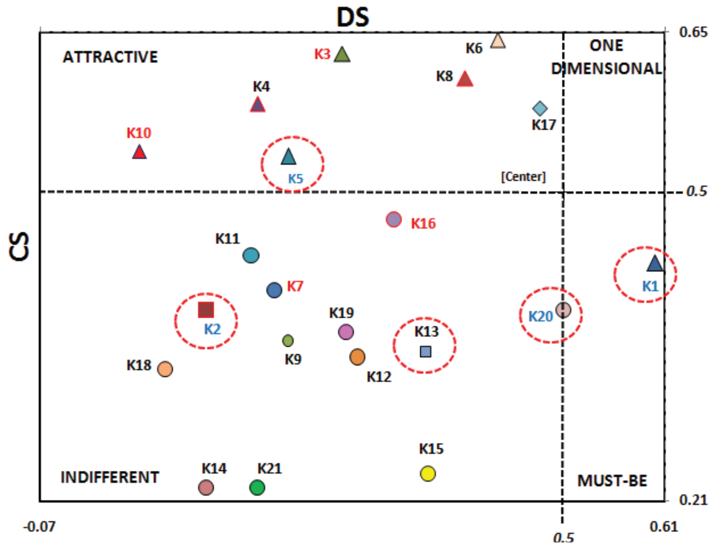

Figure 2: Customer satisfaction vs. customer dissatisfaction

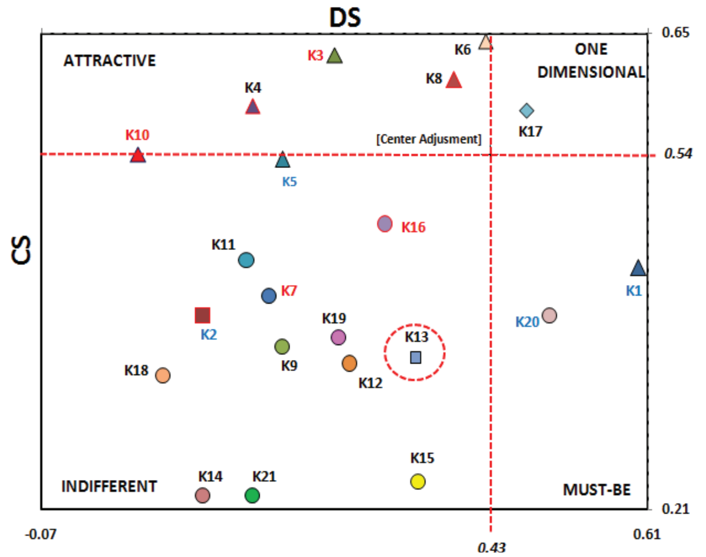

Figure 3: Adjustment customer satisfaction vs. customer dissatisfaction

This study found that most of the quality attributes (machine emergency stop button, machine monitoring facility, machine operation facility, machine control panel, and machine platform construction) had positive significant correlation compared to negative significant correlation. Specifically, the K1 (machine emergency stop button) had a significant correlation ($p<0.01$) with ergonomic problems in the arm. Meanwhile the K20 (adjustable height of standing platform) had a significant correlation ($p<0.01$) with ergonomic problems in the feet. Here, the K20 had a significant correlation with improvement required on the accessories component of CNC machine towards K1 and K20 quality attributes. As for the K8 (3D cutting software), that is 'Attractive' to the machine operators, it had an insignificant correlation with ergonomic problems.

Moreover, by inventing the CNC machine with the K17 (adjustable control panel vertically), the problems that can be addressed are 'Wear & Tear, Thermal, and Looseness'. Most of the failure experiences had a positive significant correlation with control components. The ergonomic requirement like 'Adjustable Tool Holder' and 'Adjustable Machine Table' mostly had a significant correlation with 'Lower Back' towards ergonomic problems, between low and high fatigue (low fatigue = light fatigue + moderate fatigue; high fatigue = very fatigue + extreme fatigue). This study found that the CNC machine operators suffered on the feet area; followed by calf, thigh, lower back, and upper back (Figure 4).

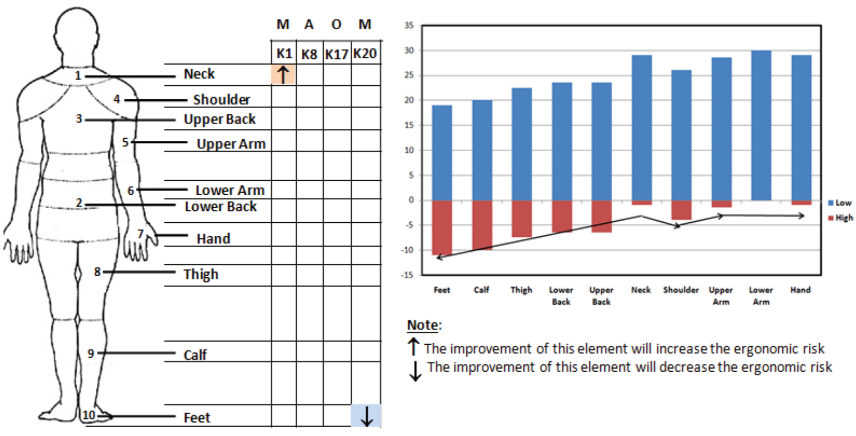

Figure 4: Kano of quality improvement required vs. ergonomics risk

The elements of CNC machine which need further improvement are K1 (red press button), K8 (3D cutting software), K17 (adjustable control panel), and K20 (adjustable height of standing platform). However, priority should be given to the adjustable height of standing platform in order to reduce the risk of ergonomics problems on feet.

5.0 CONCLUSION

There are significant correlations between quality attributes of CNC machine with ergonomics problems. This study concludes that the quality attribute that needs improvement is K20 (adjustable height of standing platform) as it has a significant correlation to reduce ergonomics problems in the feet. To determine the priority improvement required, this study proposes a utilization of graph CS vs. DS by the adjustment and the graph of 'Importance' vs. 'K*(CCS-DS)'. Both graphs show the consistencies for what elements of the required quality attributes need to be improved. However, further investigation is required towards the ergonomics problems interpreted in the graph based on importance and satisfaction.

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