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Sustainability Modeling of Conventional Milling Machine Remanufactured CNC Machine Tool Upgraded

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Aims: Accelerated developments of CNC machines will let huge amount of milling machines to be out of date. To cope with such problem conventional milling machines can be upgrading by using what is called emerged technology which is of attributes of:

- The same performance of new machines can be obtained in like-new form remanufactured CNC milling machine.
- Economic feasibility can be certain.
- Various purposes can be satisfied include education, training and industry.
- Efficiency and accuracy requirements can be within limits of customer expectations.
- Sustainability assessment approach that contains feasibilities of technology, economic and environment modeling for conventional milling into CNC machine tool remanufacturing.

Study Design: Literature is surveyed for specifying criteria of feasibilities of technology, economic and environment modeling. Mathematical sub-models are confirmed based on comparative literature based analysis to be used to find the values of indexes of assessment feasibilities within insights of experience based analysis. Feasibilities which are selected to conduct sustainability assessment of remanufacturing processes include sub-feasibility of:-

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1- **Easy of disassembly sub-feasibility:** As low as the time of disassembly, the higher the index of criterion and the easier disassembly.
2- **Sub-feasibility of cleaning:** As easy as the cleaning process, the lower the index value of criterion.
3- **Sub-feasibility of inspection and sorting:** As low as the time of inspection and sorting, the higher the index of criterion and the easier inspection and sorting.
4- **Sub-feasibility of upgradability:** As high as the accuracy of remanufactured milling into CNC machine tool, the higher the index value of criterion.
5- **Easy of reassembly sub-feasibility:** As low as the time of reassembly, the higher the index value of criterion and the easier reassembly.
6- **Sub-feasibility of tack-back cost:** It is net price of conventional milling machine to be remanufactured into CNC machine tool.
7- **Sub-feasibility of remanufacturing process cost of:** It is expense of purchasing replacing parts, material resource consumption and electrical energy consumption.
8- **Sub-feasibility of overhead cost:** Operating expense to keep continues machine tool remanufacturing business.
9- **Material saving sub-feasibility:** It is the mass of reused components.
10- **Energy saving sub-feasibility:** It is the ratio of consumed energy to embodied energy as a result of preventing manufacturing processes by remanufacturing.
11- **Pollution reduction sub-feasibility:** It is embodied emissions reduction as a result of preventing manufacturing processes by remanufacturing.

Place and Duration of Study: Middle Technical University, Institute of Technology-Baghdad, Mechanical Techniques Department, between February 2020 and July 2020.

Methodology: Study methodology includes the following outlines:-

- Literature survey.
- Comparative literature based assessment application.
- Experience based analysis application.
- Isolation of indices
- Weighting of indexes
- Sustainability Index calculation

Results: Comparative literature based analysis and experience based analysis are used to find the indexes of sub-feasibilities where assessment feasibilities can be calculated through multiplication of index weight by weight of importance. Three evaluation results are calculated to assess the performance of sustainability where index value of (70%) can refer to that conventional milling machine is of high innovative contribution potentials to deliver sustainable solution of CNC machine tool remanufacturing.

Conclusion: Technology, Economic and environment are of good evaluation indexes and conventional milling into CNC machine tool remanufacturing is directed toward sustainability.

Keywords: Remanufacturing sustainability modeling; conventional milling remanufacturing; remanufacturing based sustainability; CNC machine tool remanufacturing; CNC conversion sustainability.

1. INTRODUCTION

To provide factual background, clearly define problem and propose solution requirement, surveys are required to adjust literature to analyse the industrial development status of machine tool remanufacturing and refer to that the machine tool remanufacturing industry is active due to interaction among:-

- Original Equipment Manufacturers of machine tool: Such remanufacturing approach can provide interaction of technology, talented persons and logistics to form the main in brand directive of machine tool remanufacturing industry.
- Manufacturers of Numerical Control system can conduct remanufacturing of conventional machines into CNC machine tools
- Individual remanufacturers can be emerged as a consequence of interaction between the first two mentioned directives.

Development characteristics of milling remanufacturing industry can be analyzed through various models of machine tool remanufacturing including:

- Technical viability is satisfied where the comparison of satisfied precision between remanufactured and new machines can prove that high restoration of precision values can be satisfied which means high percentage of quality can be met according to standard parameters.

- Economic viability is satisfied where cost of remanufactured milling machine can be 40%-60% of the new one. Economic viability can also be measured based on differences of production processes, production time or production cycle which are production capacity measures that represent economic criteria.

- Environmental viability is satisfied where remanufacturing can improve the milling machine efficiency by 10%-20% during operating. While reusing value-added parts can save more than 80% of mass and power which are required for manufacturing new milling. As example, carbon coefficient of embodied emission of reused cast iron component is 1.91kgCO_2/kg, while the carbon coefficient of embodied energy is of reused cast iron component 0.785kgCO_2/kWh.

High flexibility, which means technical viability, and environmental viability are consistent where further reduction of power and carbon emissions through using of CNC machines technology to eliminate worn dovetail guide ways which can lead to save high added-value components of milling machine. Social viability can be satisfied based on technical, economic and environmental viabilities where human employment, development and experience accumulation can be delivered through education, training and remanufacturing industry [1].

According to Abdullah et al. [2] and Abdullah et al. [3], remanufacturing is sustainable development with technical economic and environmental viabilities with high potentials to be applied in large scale to develop triple-bottom lines sustainability to help emerge and dominate sustainable manufacturing to be a long-term developing approach through closing the supply chain of production. By application of conventional milling remanufacturing into CNC machine tool, as low as possible cost and resources and facilities sharing can be obtained.

Remanufacturing is a business opportunity and in many cases, it can be implemented to promote environmental sustainability. A multi-criteria assessment modeling is required to help conventional milling into CNC machine remanufacturing to be conducted economically and effectively. Such modeling approach can be used for selecting remanufacturing technology portfolios which are fertile to be optimized concern benefits associated with each portfolio. Multi-criteria modeling can include time, quality, cost and service as economic criteria and process emission and resource consumption which weight. Such multi-criteria can include:-

- Quality is very required to continue the remanufacturing business through retained mechanical structure to its quality standard which lets accuracy, reliability, processing efficiency to be improved so that processing range increases and ergonomics satisfy operator.
- Time is divided into cycle time and remanufacturing time.
- Resource consumption can be divided into energy consumption and amount of raw material consumption.
- Cost is the cost of equipment and tooling.
- Frequency of maintenance and frequency of training form criterion of service.
- Process emission is the amount of solid waste and amount of liquid waste.

Faults that can be observed to occur in sliding parts such as dovetail guide ways and saddles under conditions of heat, coolant, lubricants and chips can include:

- Wear can be rectified by application of thermal spraying or arc welding as additive operation to be followed by milling and grinding as machining operation.

- Nicks and dents can be rectified by application of thermal spraying or arc welding as additive operation to be followed by milling and grinding as machining operation.

- Corrosion can be rectified by application of thermal spraying or arc welding as additive operation to be followed by milling and grinding as machining operation.

Synergistic effects consider the overall benefits of remanufacturing technology portfolio where highest synergistic benefits remanufacturing portfolio alternative is the most attractive solution when it is compared with the portfolio alternative which is of the highest singular benefits. This can highlight the significant of synergistic benefits since high synergistic benefits can be delivered with the lowest cost of remanufacturing process [4].

Flow chart of remanufacturing environmental performance evaluation methodology can be of configuration as shown in Fig. 1. High level of customer satisfaction can be observed by reviewing Fig. 2 which means that environment conscious remanufactured products are of high acceptance. High (profit/cost) ratio is a nature of environment conscious remanufactured products where all the remanufactured products satisfy a profit ratio as shown in Fig. 3.

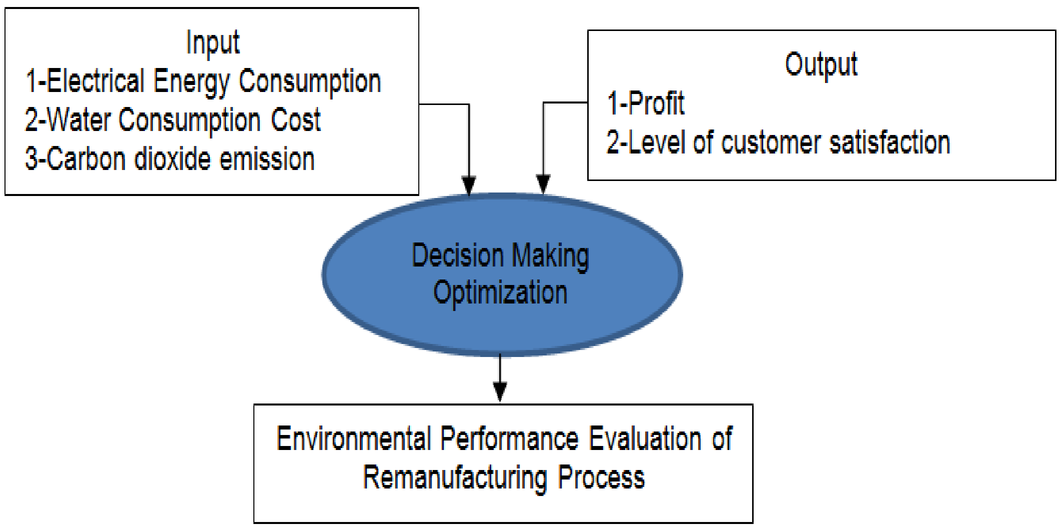

Fig. 1. Environmental performance of remanufacturing evaluation methodology flow chart [5]

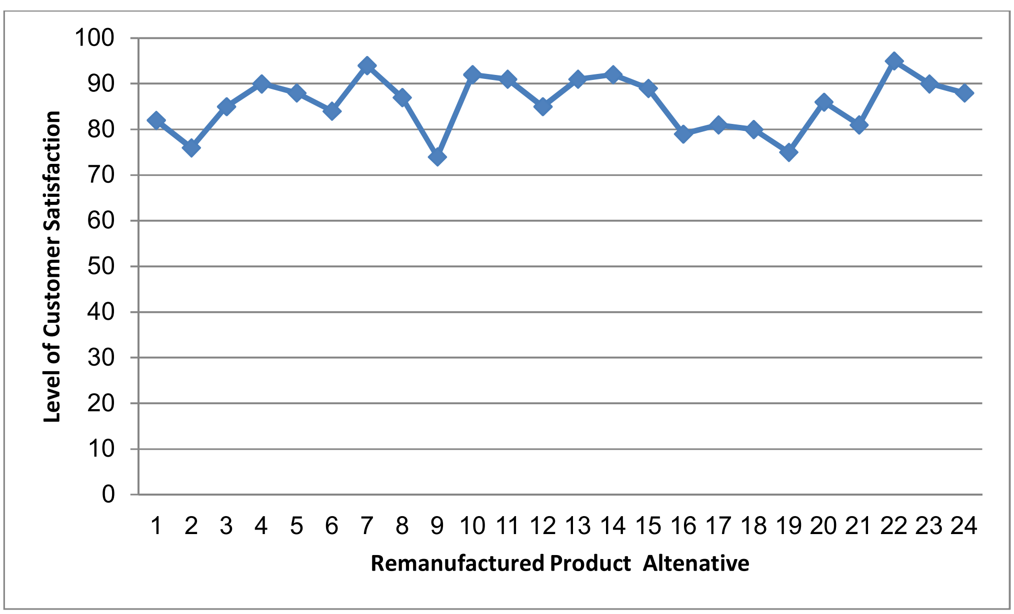

Fig. 2. Remanufactured product alternative based level of customer satisfaction assessment [5]

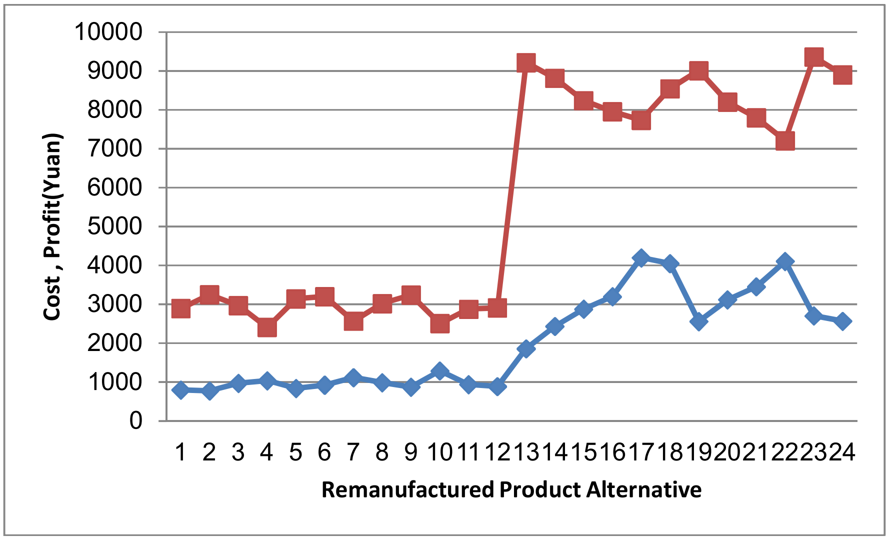

Fig. 3. Remanufactured product alternatives based cost-profit assessment, Blue: cost, Red: Profit [5]

Remanufacturing sustainability assessment can include criteria of [5]:-

Economic measure criteria include:

1- Remanufacturing cost can be divided into cost of purchasing of end-of-life conventional milling machine, transportation cost, inventory cost, reconditioning cost and cost of purchasing new materials and components to be replaced.
2- Remanufacturing Income can be divided into remanufacturing profit, parts reuse income, waste disposal income, government incentive income, total asset utilization and net asset yield.
3- Environmental protection fund investment can be classified into environmental management investment, pollution control investment and environmental rehabilitation investment.
4- Production input can be divided intomanagement service cost, logistics cost, cost of supplemental material, depreciation for plant assets and waste management cost.

Environment measure criteria include:

1- Environmental benefit can be divided into energy saving rate, comprehensive utilization rate of industrial wastewater, comprehensive utilization rate of industrial exhaust fumes, comprehensive utilization rate of industrial solid waste, the utilization rate of environmentally friendly materials and rate of remanufacturing for end-of-life products.
2- Exhaust fumes emissions can be divided into carbon dioxide emission, sulfur dioxide emission and compounds of nitrogen and oxygen emission.
3- Sewage discharge can be divided into wastewater discharge and ammonia nitrogen emission.
4- Waste discharge can be divided into solid waste, non-recyclable waste resource and energy.

Resource and energy measure criteria include:

1- Original energy consumption can be divided into coal consumption, crude oil consumption, natural gas consumption and water consumption.
2- Electrical energy consumptioncan be divided into resource utilization rate of material reuse, rate of material recovery and other material resource consumption.

Society measure criteria include:

1- Service level can be divided into level of customer satisfaction in remanufacturing products, level of customer dissemination for remanufacturing information, level of remanufacturing quality management, market response time, recovery convenience and remanufacturing capacity

2- Social responsibility can be divided into corporate green image, degree of cleaner production, meet emission standards, comply with the laws and regulations and market share of remanufactured products.

Environmental performance evaluation criteria can include, weights of importance of criteria are show in Fig. 4:

Material Resource Consumption, Electrical Energy Consumption, The Utilization Rate of Environmentally friendly Materials and Cost of Purchasing Replace Parts criteria weight are the highest. Mate/Insert/Bolt based emerged CNC technology based assembly can certain reduction of cost of purchasing replace parts, material resource consumption and electrical energy consumption. The utilization rate of environmentally friendly Materials can be enhanced relatively since all new part will not be manufacturing locally and assembly process will be energy-free. Remanufacturing ecological performance evaluation is of great significance for realizing the economic and environmental benefits. Different techniques can be used to model the remanufacturing ecological performance which includes:

- Data driven Modeling.
- Qualitative Evaluation.
- Data Envelopment Analysis.

Evaluation techniques can suffer from, with keep in mind big data technology can be utilized to increase the objectivity and universality of the results and enhance the accuracy of the analysis:

- Some criteria have uncertain effect on the results.
- Generalizability of the findings is constrained.

Clustering techniques can be used to select indicators and avoid subjective results generated by random indicators selecting. Ecological performance and remanufactured public acceptability based remanufacturing technology optimization is an effective measures. Energy-saving rate, remanufacturing process cost and rate of remanufacturing are key drivers that impact the remanufacturing ecological performance.

Economic and environmental feasibilities can be analyzed in terms of resource saving and greenhouse gas reduction. Economic value can be certain by remanufacturing of major parts of equipment and machinery to generate added-value. Environment value can be measured as resource saving and greenhouse gas reduction which can be of high percentage, Fig. 5. Even remanufactured quantity is low and the price of remanufactured unit is high, but high economic feasibility can obtained. Economic and environmental effects of revitalization based remanufacturing can expand remanufacturing market [6].

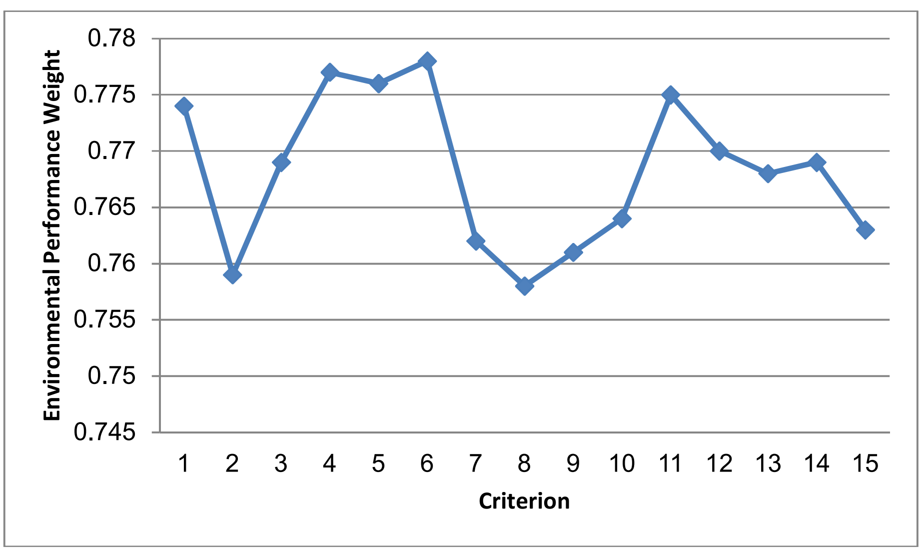

Fig. 4. Weights of environmental remanufacturing performance assessment criteria [5]

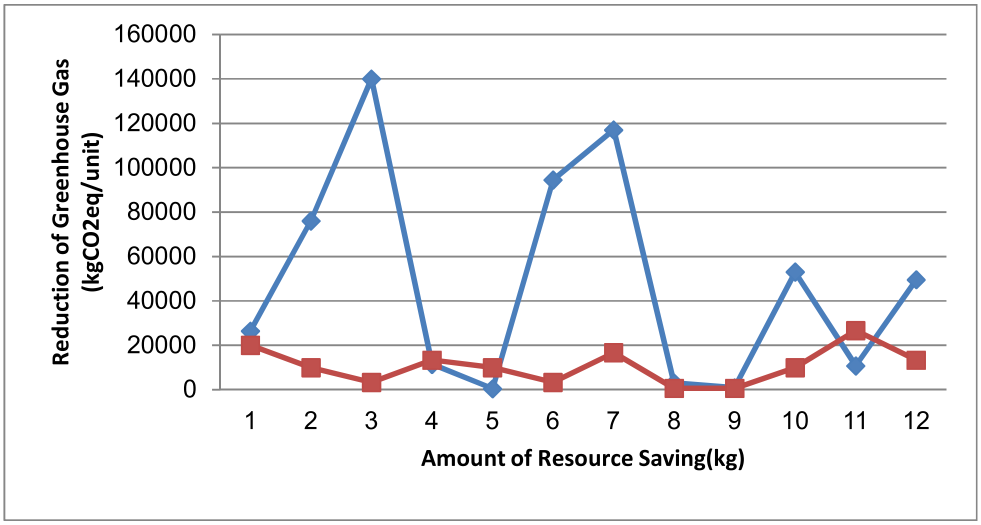

Fig. 5. Variation of reduction of greenhouse gas with amount of resource saving [6]

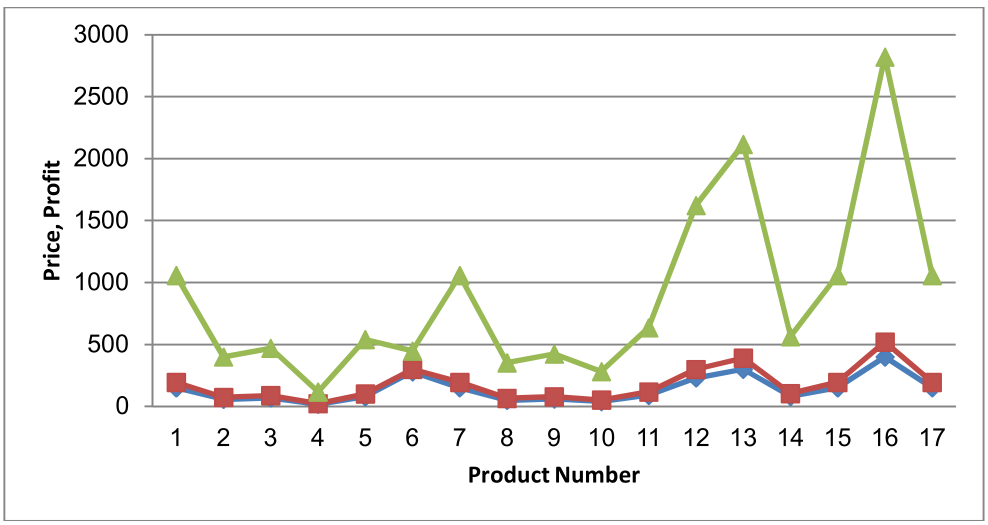

Fig. 6. Variation of remanufactured product price, reused product price and remanufactured product profit for different product, Blue: reused product price, Red: remanufactured product price, Green: remanufactured product profit [6]

Contents based analysis and comparative literature based analysis of economic feasibility which is the difference in price between used and remanufactured equipment. Variation in price of reused and remanufactured equipment and machinery and the profit can be gathering by remanufacturing can be shown in Fig. 6.

Sustainability can be assessed by weighting the following activities of remanufacturing which include inspection and sorting, cleaning, disassembly, diagnostic testing, repair and upgrade, reassembly, functional test and final restoration and inspection. The variation of activity satisfaction which is based on product design, returned availability, fault statute, required time and level of technical expertise required to achieve the remanufacturing activity. Sustainability index weight can vary between (0.662) and (0.448) based on [7]:

- Size,
- Period of trading in the market ,
- Percentage of billable returns ,
- Warranty conditions,
- Labor restrictive.

Tactical decisions regarding remanufacturing activity can be based on industry experts based expectation, as example, remanufacturing activity can take between 80% and 120% of the time (t) that it can be taken to manufacture new product according to remanufacturing activity time index as following:

Remanufacturing activity is favorable, if: $t_{reman.}$<80 % $t_{man.}$,
Remanufacturing activity is unfavorable, if: t_{reman}. >120 % $t_{man.}$

Remanufacturing sustainable performance can be assessed by using criteria of environmental feasibility, economic feasibility and technological feasibility which are of different weights as show in Fig. 7.

Resource depletion potential, global warming potential, respiratory inorganics, acidification potential and water eutrophication potential can be criteria to assess environmental feasibility.Processing cost criterion can be used to assess economic feasibility. Bonding strength, substrate deformation, hardness and porosity criteria can be used to assess technological feasibility. Global weights and local weights of criteria which can be used for assessing sustainability to find sustainability index weight of remanufacturing alternatives as show in Figs. 8 and 9. Laser cladding, plasma arc surfacing, brushing electroplating and plasma spray are remanufacturing portfolio alternatives. Euclidian distance from each alternative to the ideal solution and the negative ideal solution can be determined to find relative closeness of each alternative to the ideal solution. As big as the difference between distances, as big as the relative closeness so that the highest rank can be obtain by an alternative. Euclidian distances and relative closeness of remanufacturing portfolio alternatives of laser cladding, plasma arc surfacing, brushing electroplating andplasma spray and the result show that brushing electroplating rank the first as an additive remanufacturing technology Fig. 10 [8].

Some findings can be proposed:

- Disassembly-assembly oriented remanufacturing system can enhance technical viability of remanufacturing conventional milling into CNC machine tool comparing with traditional remanufacturing system which includes disassembly, cleaning, inspection and sorting, reconditioning and reassembly.
- Selection system criteria of decision-making requires informative multiple stakeholders data collection to integrate more criteria through comprehensive selection of benefits alternative. Informative assessment criteria weighting can be based on literature surveying.

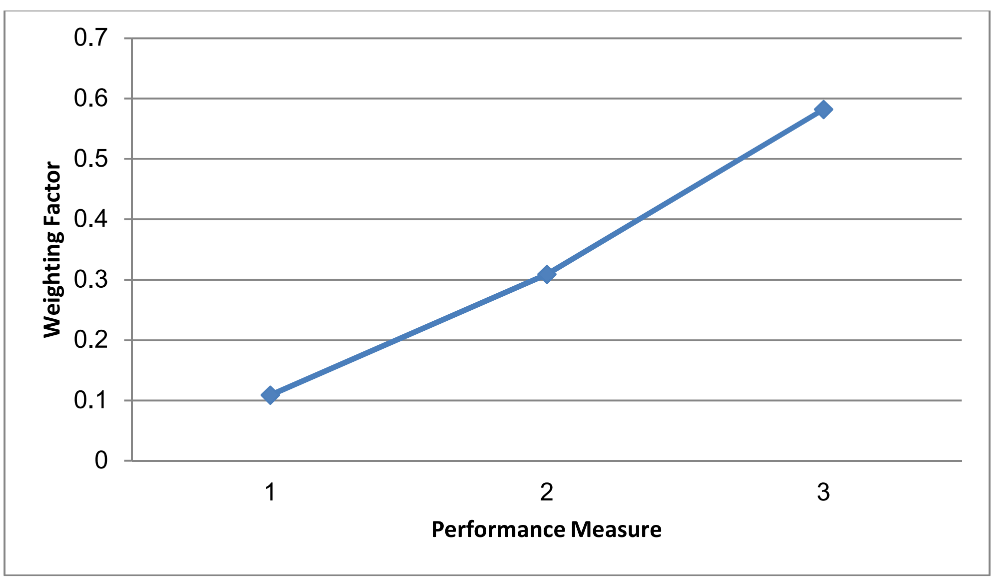

Fig. 7. Remanufacturing sustainability assessing measures, (1): Environmental feasibility, (2):Economic feasibility, (3): Technological feasibility [8]

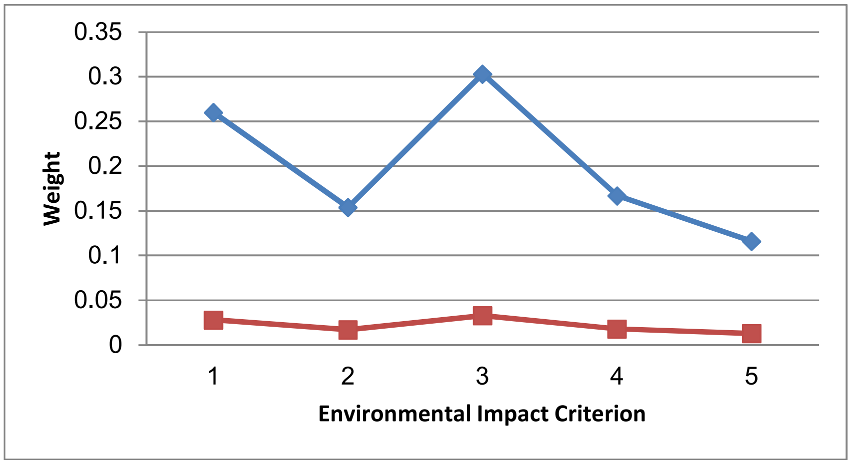

Fig. 8. Variation of global and local weights of environmental impact criteria, Blue: local weight, Red: global weight [8]

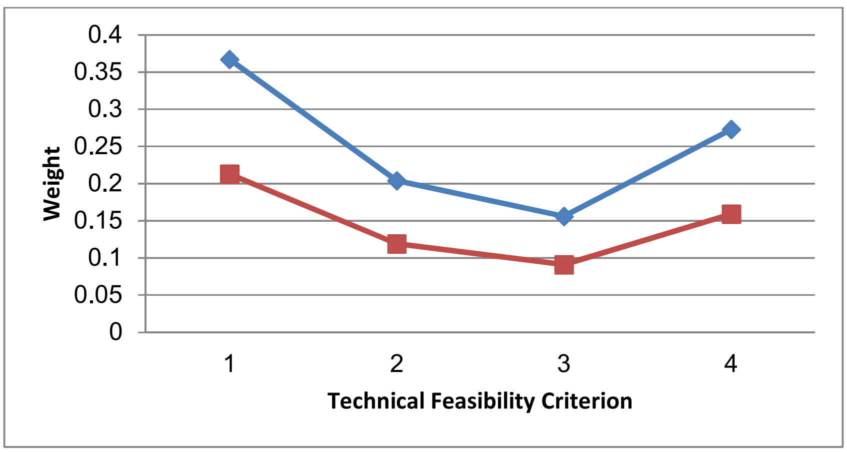

Fig. 9. Variation of global and local weights of technical viability criteria, Blue: local weight, Red: global weight [8]

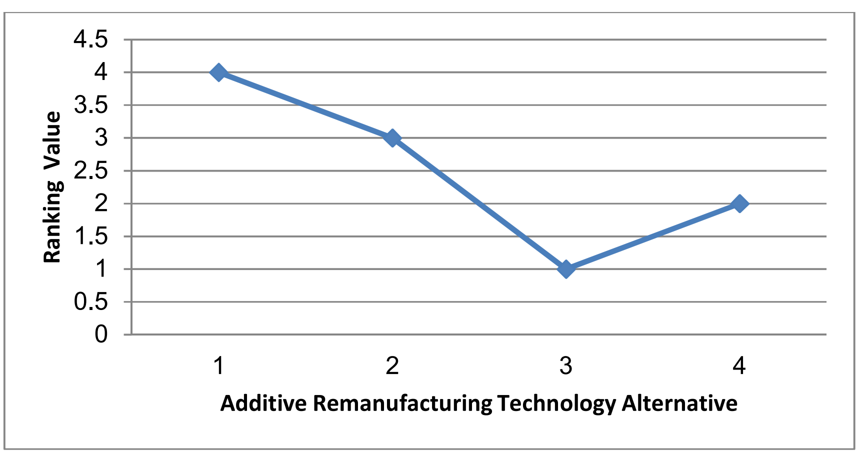

Fig. 10. Ranks of additive remanufacturing portfolio alternatives, (1): Laser Cladding,(2): Plasma Arc Surfacing,(3): Brushing electroplating,(4): Plasma spray [8]

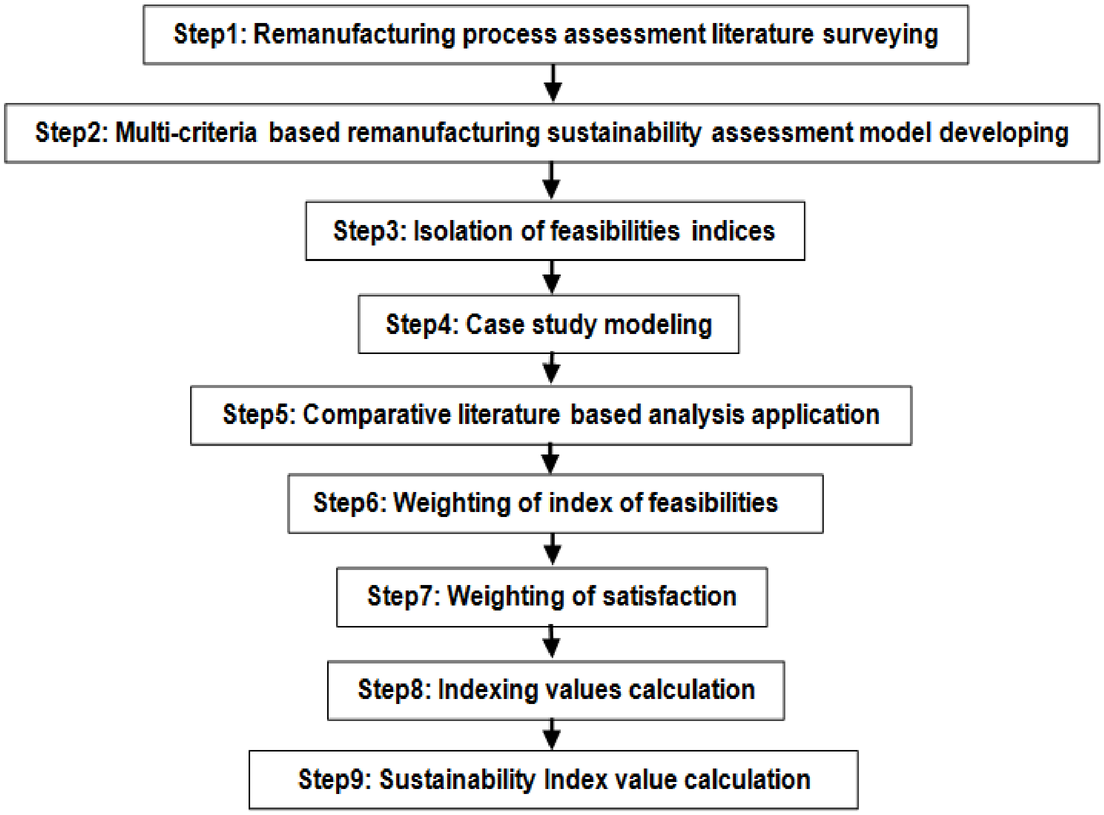

Fig. 11. Comparative literature based assessment application methodology

2. SUSTAINABLITY ASSESSMENT METHODOLOGY

Multi-criteria assessment methodology to find sustainability index of remanufacturing process to convert conventional milling machine into CNC machine tool can include the steps that show in Fig. 11. A literature sample of (26) [1-22] [27-30] articles is reviewed and surveyed to elicit the most suitable techniques and indices to conduct sustainability assessment.

3. RESULTS AND DISCUSSION

Structural analysis application can lead to divide conventional milling machine into following components, Fig. 12:

1- Electrical power supply.
2- Electrical motor.
3- Machine head.
4- Quill Sleeve.
5- Ram.
6- X-axis handles.
7- X-axis lead screw mounts.
8- Worktable.
9- Lead screw of x-axis.
10- Y-axis handle.
11- Y-axis lead screw mount.
12- Lead screw of y-axis.
13- Yoke.
14- Saddle.
15- Z-axis handle.
16- Z-axis lead screw mount.
17- Lead screw of z-axis.
18- Knee.
19- Z-axis lead screw nut holder.
20- Column.

Calculation of sustainability assessment index (S_i) include application of expert experience analysis, comparative literature analysis and mathematical modeling to find values of index of feasibilities that compose the architecture of sustainability index value calculation as following:

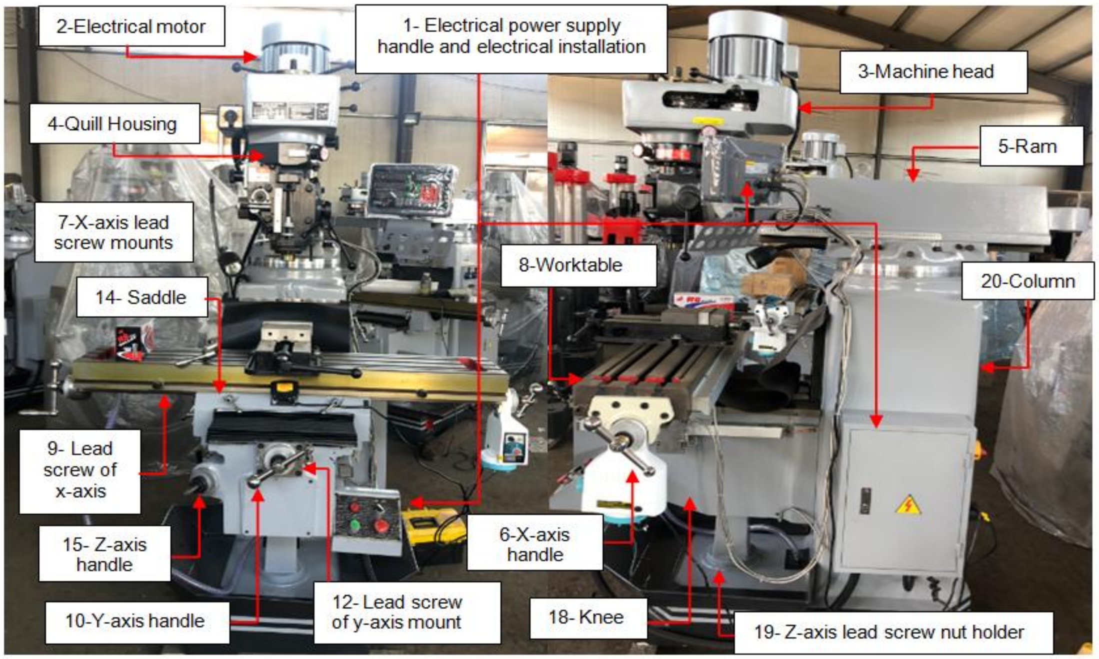

Fig. 12. Conventional vertical turret milling machine structure analysis

3.1 Technology Feasibility(T)

Technology feasibility evaluation requires calculating six sub-feasibilities of:

3.1.1 Ease of disassembly sub-feasibility

Ease of disassembly is a qualitative index expert opinion based evaluation in terms of number of fastening structures, complexity of fastening structures and number of disassembled components to simplify and quantify the index of ease of disassembly to find out the disassembly time. Ease of disassembly index value (t_d) can be obtained according to assessment condition which states that as low as the time of disassembly, the higher the index value and the higher the easy of disassembly. At first intermediate variable (δ) should be calculated by using the following equation [20,21]:

$$\delta = \frac{\sum_{i=1}^{N} c_i \times t_i}{T_d} \quad (i = 1, 2, \cdots, N)$$

Where,

t_i : disassembly time of i_{th} fastening device,
c_i: quantity of i_{th} fastening device,
N: quantity of variety of fastening devices,
T_d: reference or standard disassembly time,
δ: intermediate variable,
t_d: index value of ease of disassembly.

Expert's experience based disassembly time analysis can be specified to be (2100) second per rout to finish four main disassembly routes by one worker per route [20,21].

Ease of disassembly sub-feasibility can be accounted for the following sub-systems:

Intermediate variable (δ_1) of Electrical power supply ($c_{i11}xt_{i11}$), Electrical motor ($c_{i12}xt_{i12}$), Machine head ($c_{i13}xt_{i13}$), Quill Sleeve ($c_{i14}xt_{i14}$) and Ram ($c_{i15}xt_{i15}$),
Intermediate variable (δ_2) of X-axis handles ($c_{i21}xt_{i21}$),X-axis lead screw mounts ($c_{i22}xt_{i22}$), Worktable ($c_{i23}xt_{i23}$) and Lead screw of x-axis ($c_{i24}xt_{i24}$),
Intermediate variable (δ_3) of Y-axis handle ($c_{i31}xt_{i31}$), Y-axis lead screw mount ($c_{i32}xt_{i32}$), Lead screw of y-axis ($c_{i33}xt_{i33}$), Yoke andSaddle ($c_{i34}xt_{i34}$),
Intermediate variable (δ_4) of Lead screw of z-axis ($c_{i41}xt_{i41}$), Knee ($c_{i42}xt_{i42}$) and Z-axis lead screw nut holder ($c_{i43}xt_{i43}$).

δ_1=((4x5.7)+(2x5.7)+(4x7.6)+(4x7.6)+(4x7.6)+(4x7.6)+(4x7.6))/2100=186.2/2100=0.089
δ_2=((2x7.6)+(8x7.6)+(1x600)+(1x600))/2100=1276/2100=0.610

δ_3=((1x7.6)+(4x7.6)+(1x300)+(4x7.6)+(1x150))=518.4/2100=0.247
δ_4=((3x7.6)+(1x600)+(2x7.6))=638/2100=0.303

Calculated intermediate variable (δ) should be matched with an expert's experience based thresholds of ease of disassembly (t_d). Thresholds can be approximately determined according to predefined identities to be as following:

$$t_d = \begin{cases} 1.00 & \delta \le 1.0 \\ 0.85 & 1.0 < \delta \le 1.2 \\ 0.60 & 1.2 < \delta \le 1.4 \\ 0 & 1.4 < \delta \end{cases}$$

So that ease of disassembly sub-feasibility (t_d) is:

t_{d1}=1, t_{d2}=1, t_{d3}=1, t_{d4}=1
t_d=(t_{d1}+ t_{d2}+ t_{d3}+ t_{d4})/4
=(1+1+1+1)/4
=1

Fig. 13 is comparative literature based calculation verification curve which shows high consistency of ease of disassembly which are results registered in this study comparing with [20,21].

3.1.2 Sub-feasibility of cleaning

After disassembly, cleaning is required to be applied. Industry practice based assumption can lead to that feasibility of cleaning is an expert's experience based evaluation process which results in four grades of {A,B,C,D} that have values of {0.95, 0.81,0.65,0.45} respectively to show the simplicity of cleaning process. The value of feasibility of cleaning index value (t_c) can be obtained according to assessment condition which states that rigid component with uniform and smooth surface area and lower internal cavities is of high feasibility of cleaning and vice versa so evaluation can be as following:

Sub-feasibility of cleaning can be accounted for the following sub-systems:

Feasibility of cleaning (t_{c1}) of Electrical power supply, Electrical motor, Machine head, Quill Sleeve and Ram,

Feasibility of cleaning(t_{c2}) of X-axis handles,X-axis lead screw mounts and Worktable,
Feasibility of cleaning(t_{c3}) of Y-axis handle,Y-axis lead screw mount,Yoke and Saddle,
Feasibility of cleaning(t_{c4}) of Lead screw of z-axis,Knee,Z-axis lead screw nut holder and Column.

So that Sub-feasibility of cleaning (t_c) is:

t_{c1}=[((1x0.65)+(1x0.95)+(1x0.95)+(1x0.95)+(1x0.95))/5]
=[4.45/5]
= 0.890
t_{c2}=[((2x0.95)+(2x0.95)+(1x0.95))/5]
= [4.75/5]
=0.950
t_{c3} =[((1x0.95)+(1x0.95)+(1x0.95)+(1x0.95))/4]
=[3.8/4]
=0.950
t_{c4} =[((1x0.95)+(1x0.95)+(1x0.95)+(1x0.81)/4]
=[3.66/4]
=0.920
t_c =(t_{c1}+ t_{c2}+ t_{c3}+ t_{c4})/4
=(0.890+0.950+0.950+0.920)/4
=0.928

Fig. 14 is comparative literature based calculation verification curve which shows high consistency of feasibility of cleaning results which are registered in this study comparing with [20,21].

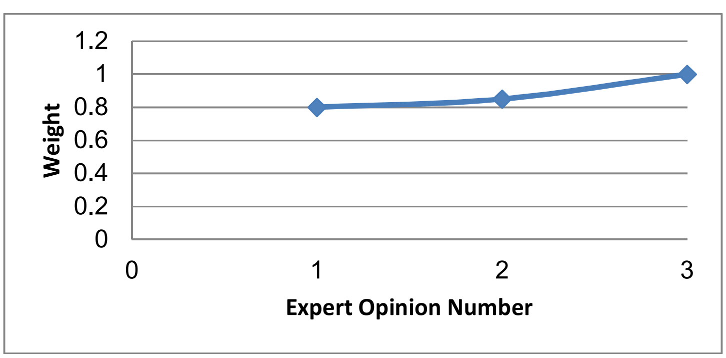

Fig. 13. Expert's experience based sub-feasibility index variation, ease of disassembly,(1):[20] , (2): [21], (3):current study

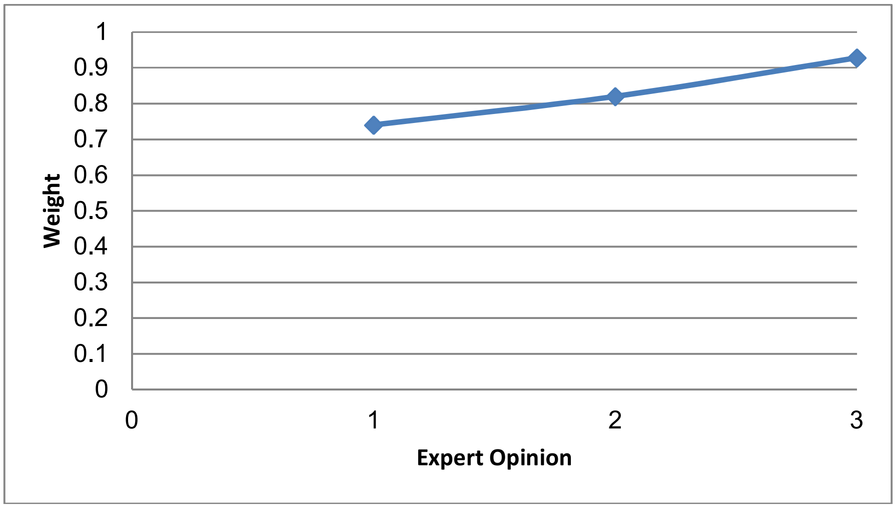

Fig. 14. Expert's experience based sub-feasibility index variation, feasibility of cleaning, (1):[20], (2): [21], (3): current study

3.1.3 Sub-feasibility of inspection and sorting

Feasibility of inspection and sorting can guarantee high quality of remanufactured conventional milling machine into CNC machine tool. All disassembled components should be examined for damage so that inspection and sorting is indirect time intensive value-added generator process where the remanufacturing time may be delayed due to inspection for the cracks or damages of the machine hulk. Based on the inspection results, conditions based analysis can be classified into three categories of:

1- Reusing without reconditioning.
2- Reconditioning.
3- Replacing.

Feasibility of inspection and sorting is expert's experience based evaluation process which results in four grades of {A, B, C, D} that value {0.95, 0.81,0.65, 0.4} respectively to show the simplicity of inspection and sorting process due to hybrid of diversity of components and damages in the form of extent inspection time. Observations in this step can be used to determine the feasibility of reconditioning process of components.

Sub-feasibility of inspection and sorting (t_{is}) can be accounted for the following sub-systems:

Feasibility of inspection and sorting (t_{is1}) of Electrical power supply, Electrical motor, Machine head, Quill Sleeve and Ram.

Feasibility of inspection and sorting (t_{is2}) of X-axis handles,X-axis lead screw mounts,Worktable andLead screw of x-axis.
Feasibility of inspection and sorting (t_{is3}) of Y-axis handle,Y-axis lead screw mount,Lead screw of y-axis,Yoke andSaddle.
Feasibility of inspection and sorting (t_{is4}) of Lead screw of z-axis, Knee andZ-axis lead screw nut holder.

So that Sub-feasibility of inspection and sorting (t_{is}) is:

t_{is1}=[((1x0.45)+(1x0.65)+(1x0.65)+(1x0.65)+(1x0.95))/5]
=[3.35/5]
=0.67
t_{is2} =[((2x0.95)+(2x0.95)+(1x0.95)+(1x0.95))/6]
= [5.7/6]
=0.95
t_{is3} =[((1x0.95)+(1x0.95)+(1x0.95)+(1x0.82)+(1x0.65))/5]
=[4.32/5]
=0.864
t_{is4} =[((1x0.95)+(1x0.65)+(1x0.95))/3]
=[2.55/3]
=0.85
t_{is}=(t_{si1}+ t_{si2}+ t_{si3}+ t_{si4})/4
=(0.670+0.950+0.864+0.850)/4
=0.834

Fig. 15 is comparative literature based calculation verification curve which shows high consistency of feasibility of inspection and sorting results which are registered in this study comparing with [20,21].

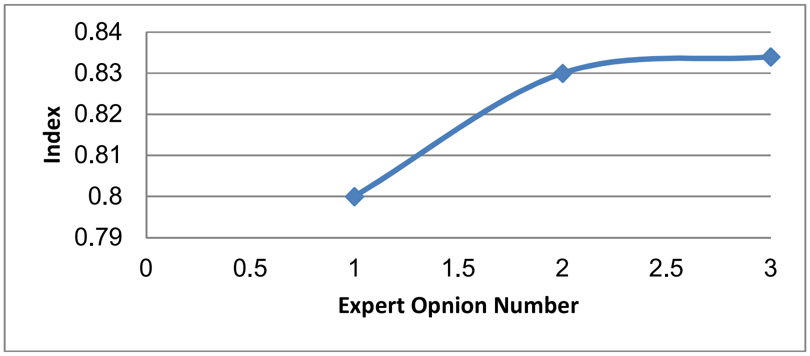

Fig. 15. Expert's experience based sub-feasibility index variation, inspection and sorting,(1): [20] , (2): [21],(3):current study

3.1.4 Sub-feasibility of reconditioning

Feasibility of component reconditioning is the selection of the most suitable remanufacturing steps to ensure a like-new condition on both of the component level and machine level. Returned machines quality can be vary considerably due to different usage patterns to graduate between extensively to limited degrading statutes. Probability based reconditioning analysis can result that the component may be reused, reconditioned or fail to be remanufactured, the worse the quality of milling machine, the high the possibly of failure to reconditioned to occur so that component should be replaced or reused with another component. The index of component reconditioning sub-feasibility can be calculated according to rule that states that reused is of grade (A) which of weight of (0.90), replaced with reused component is of grade (B) which of weight of (0.88), replaced with new component is of grade (C) which of weight of (0.77) and reconditioning is of grade (D) which of weight of (0.55).

Sub-feasibility of reconditioning can be accounted for the following sub-systems:

Feasibility of reconditioning (t_{r1}): Electrical power supply, Electrical motor, Machine head, Quill Sleeve and Ram.
Feasibility of reconditioning (t_{r2}): X-axis handles, X-axis lead screw mounts,Work table and Lead screw of x-axis.
Feasibility of reconditioning (t_{r3}) of Y-axis handle, Y-axis lead screw mount, Lead screw of y-axis, Yoke andSaddle.
Feasibility of reconditioning (t_{r4}) ofLead screw of z-axis, Knee and Z-axis lead screw nut holder.

So that sub-feasibility of reconditioning (t_r) is:

t_{r1}=[((1x0.77)+(1x0.88+1x0.77)+(1x0.65)+(1x0.90)+(1x0.90))/5]
=[4.87/5]
=0.812
t_{r2} =[((2x0.90)+(2x0.77)+(1x0.90)+(1x0.77))/6]
= [5.01/6]
=0.835
t_{r3}=[((1x0.90)+(1x0.77)+(1x0.77)+(1x0.90)+(1x0.90))/5]
=[4.24/5]
=0.848
t_{r4}=[((1x0.77)+(1x0.90)+(1x0.90))/3]
=[2.57/3]
=0.857
t_r=(t_{r1}+ t_{r2}+ t_{r3}+ t_{r4})/4
=(0.812+0.835+0.848+0.857)/4
=0.838

Fig. 16 is comparative literature based calculation verification curve which shows high consistency of feasibility of reconditioning results which are registered in this study comparing with [20,21].

3.1.5 Sub-feasibility of upgrading

Components upgrading is applied according to rule that states that as high as the innovative potentials of component to be upgraded, the high the contribution of component to conventional milling machine upgrading into CNC machine tool. Evaluation process can be conducted according to five grades include grade (A) which is of weight of (1), grade (B) which is of weight of (0.8) , grade (C) which is of weight of (0.6) ,grade D which is of weight of (0.4) and grade (F) which is of weight of (0.2). As high as the contribution of a certain component to milling machine upgrading, as high as the grade to be assigned to the component.

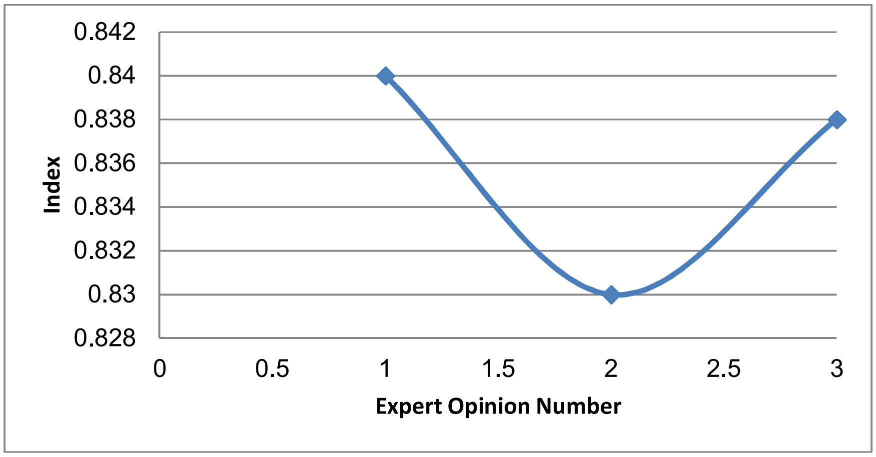

Fig. 16. Expert's experience based sub-feasibility index variation, feasibility of reconditioning,(1): [20], (2): [21],(3):current study

Sub-feasibility of upgrading can be accounted for the following sub-systems:

Feasibility of upgrading (t_{u1}) of Electrical power supply, Electrical motor, Machine head, Quill Sleeve and Ram.

Feasibility of upgrading (t_{u2}) of X-axis handles, X-axis lead screw mounts, Worktable and Lead screw of x-axis.

Feasibility of upgrading (t_{u3}) of Y-axis handle, Y-axis lead screw mount,Lead screw of y-axis, Yoke and Saddle.

Feasibility of upgrading (t_{u4}) of Lead screw of z-axis, Knee and Z-axis lead screw nut holder.

So that Sub-feasibility of upgrading (t_u) is:

t_{u1}=[((1x1)+(1x0.8)+(1x0.6)+(1x0.6)+(1x0.6))/5]
=[3.6/5]
=0.72
t_{u2}=[((1x0.6)+(1x0.8)+(1x0.6)+(1x1))/4]
= [3.4/4]
=0.85
t_{u3}=[((1x0.6)+(1x0.8)+(1x1)+(1x1)+(1x0.6))/5]
=[4/5]
=0.8
t_{u4}=[((1x1)+(1x0.6)+(1x1))/3]
=[2.6/3]
=0.867
t_u =(t_{r1}+ t_{r2}+ t_{r3}+ t_{r4})/4
=(0.72+0.85+0.80+0.867)/4
=0.81

Fig. 17 is comparative literature based calculation verification curve which shows high consistency of feasibility of upgrading results which are registered in this study comparing with [20,21].

3.1.6 Ease of reassembly sub-feasibility

Ease of reassembly is a function of the time that will be spent to reassembly component on machine hulk to be like new configuration. As low as the reassembly time, as high as the easy to reassembly so that index of easy to reassembly sub-feasibility can be evaluated. Component easy to reassembly can be classified into four grades of [A,B,C,D] respectively to be one of the four various weights of [0.90, 0.85, 0.65,0.45]. As high as the simplicity of a certain component reassembly, as high as the grade to be assigned to the component.

Time of ease of reassembly is related to fastening structure, reassembly accuracy, quantity of reassembly relation, quantity of standard parts and reassembly path so that it is of high uncertainty and so difficult to be quantified so that ease of reassembly evaluation process is a qualitatively expert judgment based assessment [20].

Ease of reassembly (t_{ra}) can be accounted for the following sub-systems:

Ease of reassembly (t_{ra1}): Rails of Ball Linear guide ways to column reassembly, Carriages of Ball Linear guide ways to knee reassembly, Rails of Ball Linear guide ways to knee reassembly, Carriages of Ball Linear guide ways to Saddle reassembly, Rails of Ball Linear guide ways to worktable reassembly, Carriages of Ball Linear guide ways to Saddle reassembly.

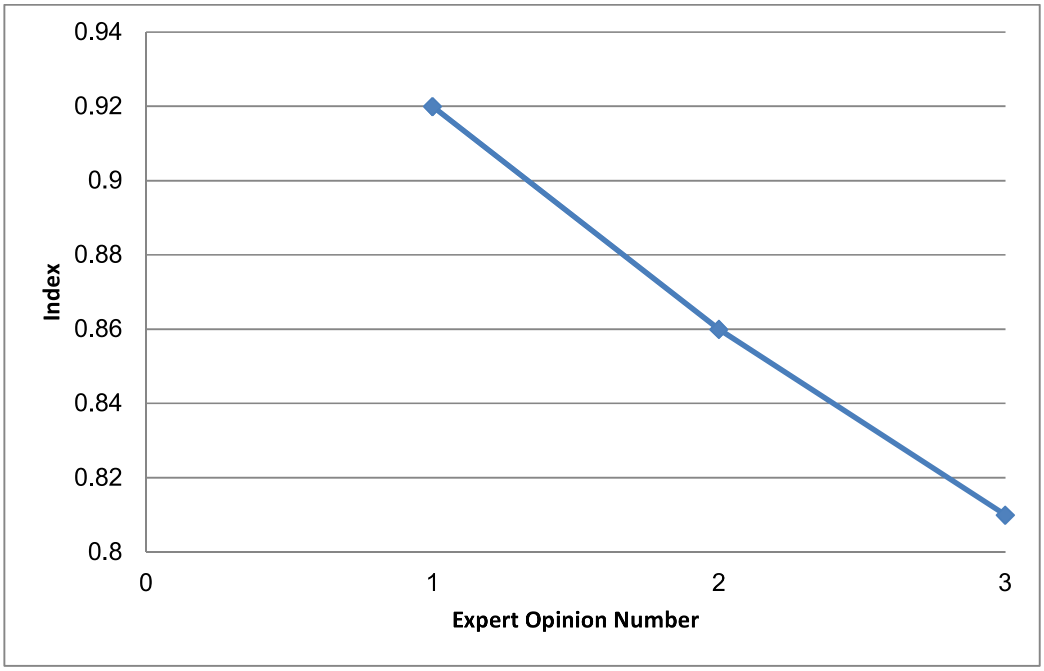

Fig. 17. Expert's experience based sub-feasibility index variation, feasibility of upgrading,(1):[20] , (2):[21],(3):current study

Ease of reassembly (t_{ra2}): Electrical power supply, Electrical motor, Machine head, Quill Sleeve, Ram.

Ease of reassembly (t_{ra3}): X-axis handles, X-axis ball screw and servo motor mounts, Worktable.

Ease of reassembly (t_{ra4}): Y-axis handle,Y-axis ball screw and servo motor mount,Yoke, Saddle.

Ease of reassembly (t_{ra5}): Ball screw and motor of Z-axis mechanism to quill reassembly, Fig. 18, Pulley belt and motor of Z-axis mechanism to quill feed shaft reassembly, Fig. 19, Ball screw and motor of Z-axis mechanism to knee-Z-axis handle reassembly, Fig. 20, Ball screw and motor mechanism to Z-axis lead screw nut holder reassembly, Fig. 21.

Ease of reassembly (t_{ra6}): Keen to column reassembly, saddle to knee reassembly, worktable to saddle reassembly

So that ease of reassembly sub-feasibility of up (t_{ra}) is:

t_{ra1}=[((1x0.90)+(1x0.85)+(1x0.90)+(1x0.85)+(1x0.90)+ (1x0.85))/6]
=[5.25/6]
=0.875

t_{ra2}=[((1x0.65)+(1x0.90)+(1x0.9)+(1x0.9))+ (1x0.9))/5]
= [4.25/5]
=0.850

t_{ra3}=[((1x0.9)+(1x0.85)+(1x0.9))/3]
=[2.65/3]
=0.833

t_{ra4}=[((1x0.9)+(1x0.85)+(1x0.90)+(1x0.9+1x0.85)) /5]
=[4.4/5]
=0.880

t_{ra5}=[((1x0.9)+(1x0.85)+(1x0.65))/3]
=[2.4/3]
=0.800

t_{ra6}=[((1x0.9+1x0.85)+(1x0.9+1x0.85)+ (1x0.9+1x0.85))/6]
=[5.25/6]
=0.875

t_{ra} =(t_{ra1}+ t_{ra2}+ t_{ra3}+ t_{ra4})/4
=(0.875+0.850+0.833+0.880+0.800+0.875)/6
=0.852

Fig. 22 is comparative literature based calculation verification curve which shows high consistency of ease of reassembly results which are registered in this study comparing with [20,21].

Fig. 18. Ball screw and motor of Z-axis mechanism to quill reassembly [23]

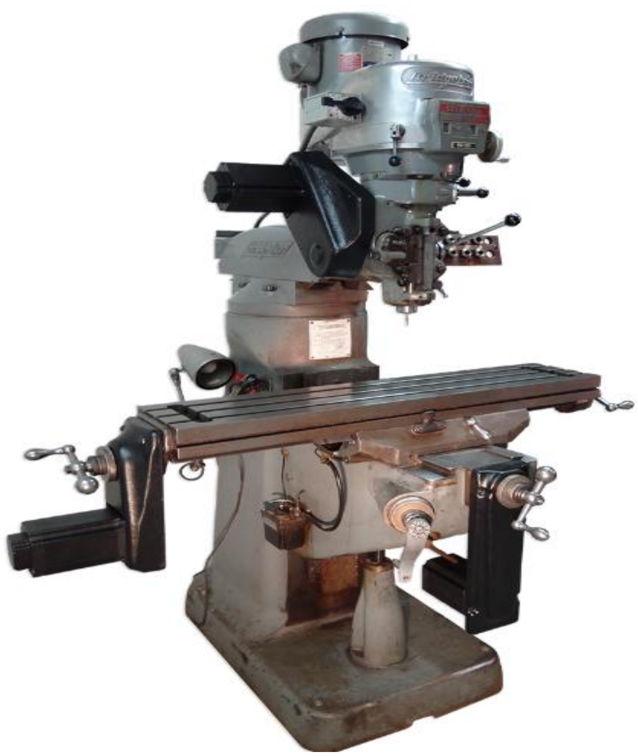

Fig. 19. Pulley, belt and motor of Z-axis mechanism to quill feed handle reassembly [24]

Fig. 20. Ball screw and motor of Z-axis mechanism to knee-Z-axis handle reassembly [25]

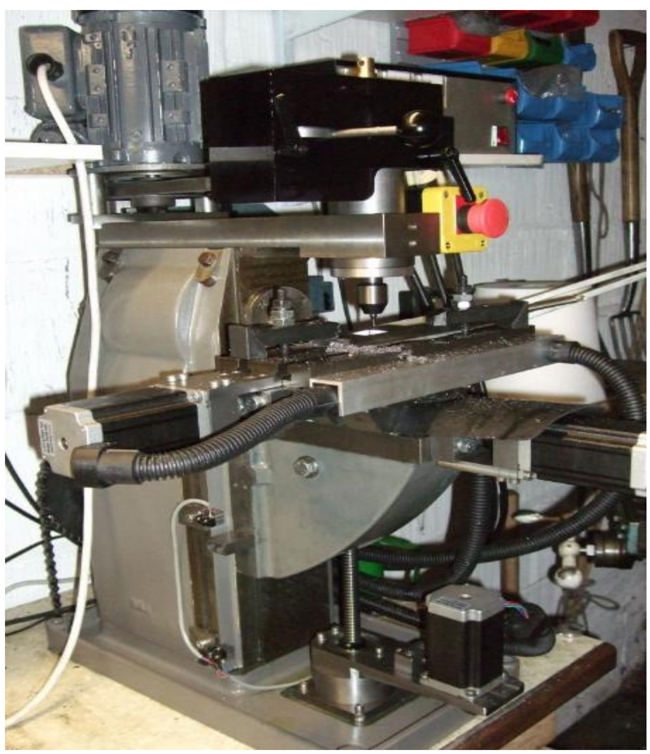

Fig. 21. Ball screw and motor mechanism to Z-axis lead screw nut holder reassembly [26]

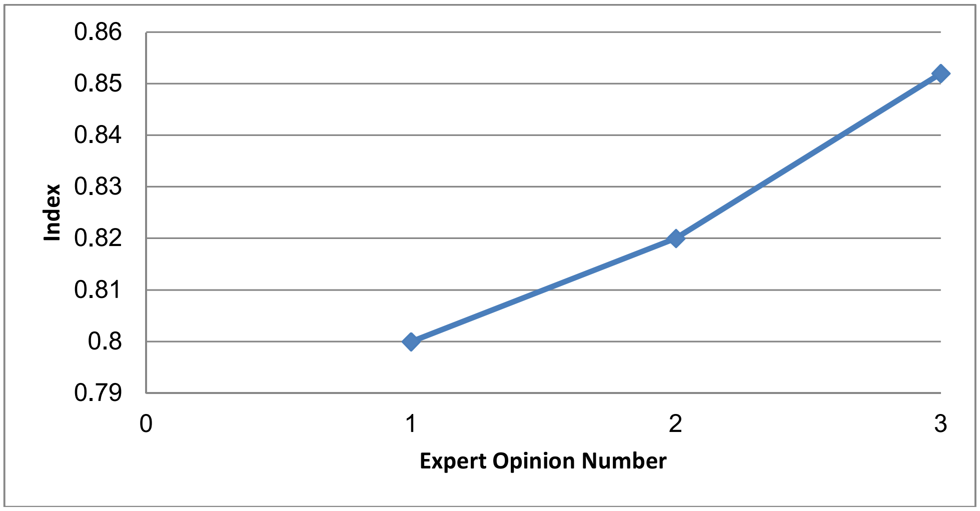

Fig. 22. Expert's experience based sub-feasibility index variation, easy of reassembly,(1):[20], (2): [21], (3):current study

Table 1. Evaluation matrix of the sub-feasibilities of technology feasibility

Sub-feasibility	Value	Index Value	Weight of Importance
Ease of disassembly	t_d	1	0.900
Feasibility of cleaning	t_c	0.928	0.758
Feasibility of inspection and sorting	t_{si}	0.834	0.817
Feasibility of reconditioning	t_r	0.838	0.758
Feasibility of upgrading	t_u	0.810	0.900
Feasibility of reassembly	t_{ra}	0.852	0.900
Technical feasibility	T		0.736

**Weights of importance are calculated by using experience based analysis and literature based analysis*

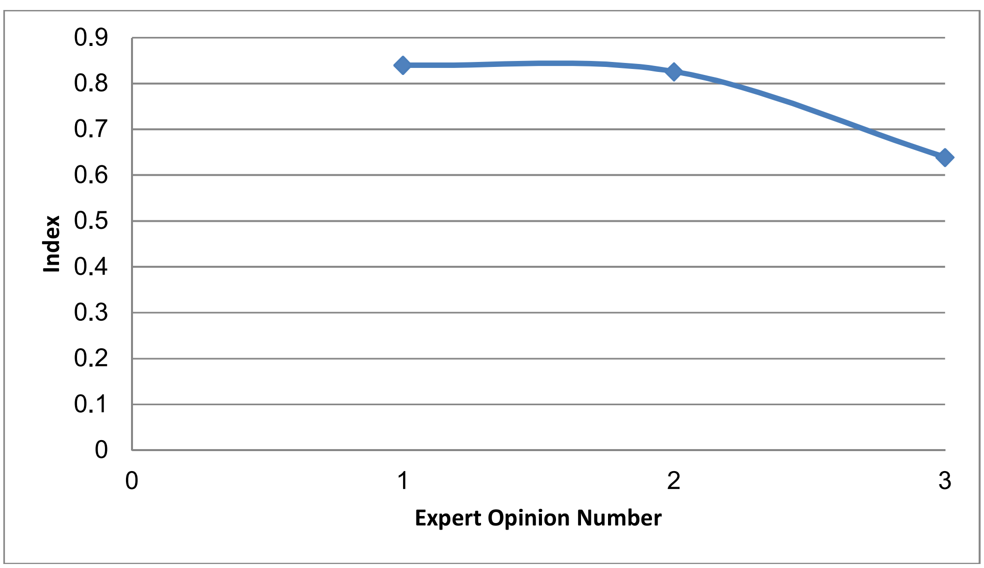

Fig. 23. Expert's experience based feasibility index variation, technical feasibility,(1):[20], (2):[21], (3):current study

Table 1 is the evaluation results of the sub-feasibilities of technical feasibility So that technical feasibility (T) is:

Technical feasibility (T) = $(t_d x w_d + t_c x w_c + t_{si} x w_{si} + t_r x w_r + t_u x w_u + t_{ra} x w_{ra})/6$ = (1x0.900+0.928x0.758+0.834x0.817+0.838x0.758+0.810x0.900+0.852x0.900)/6 = 0.736

Fig. 23 is comparative literature based calculation verification curve which shows high consistency of technical feasibility results which are registered in this study comparing with [20,21].

3.2 Economic Feasibility(C)

Economic feasibility can be measured through specifying the costs of remanufacturing conventional milling into machine tool (C_R) which includes:

3.2.1 Mean used conventional milling machine price (C_1)

Accelerated developments of CNC machines will let huge amount of milling machines to be out of date which requires to cope with to take them back for remanufacturing and upgrading and price of conventional milling machine to be taken back is the mean used conventional milling machine price.

3.2.2 Remanufacturing processes cost (C_2)

Cost of remanufacturing processes refers to all the expenses that can cover labor costs of processes of disassembly, cleaning, inspection and sorting, components reconditioning, machine upgrading and reassembly and costs of new purchased materials, components and sub-assemblies which include bearings, fastening devices, dials and scales, ball linear guide ways, ball screws, lubrication pump, coolant pump, mechanical kit and CNC control system kit.

3.2.3 Overhead cost (C_3)

Required expenses to let the business of machine tool remanufacturing to continue is called overhead cost which can include accounting fees, advertising, depreciation, insurance, interest, legal fees, rent, repairs, supplies, taxes, telephone bills, travel and utilities costs, but the most predominated costs include taxes, management fees, advertising and sales fees.

Remanufactured conventional milling machine into CNC machine tool price (C_R) should be less than price of new CNC milling machine to be attractive for the both of consumers and the remanufacturers based on simple axioms of:

- Profit should be made.
- Remanufactured and new milling machine have the same configuration.
- The same performance should be kept.

The relationship function between (C_R) and (p_n) can be established to be:

$C_R = p_R p_n$ if $p_r = 0.5 p_n$

Where,

p_R: Remanufactured machine price to new machine price ratio,
p_r: Remanufactured milling machine into CNC machine price,
p_n: New milling machine price.

Price ratio (p_R) is used to find economic feasibility index (C) which is function of (p_R) that various within the range (0-1) to obey linear regressive analysis and expert experience based thresholds determination according to certain conditions as following [1,20,21]:

Either

$C = 1$ if $p_R \leq 1$, the remanufactured machine tool is profitable
Or
$C = -0.8 p_R + 1.8$ if $p_R > 1$, it may be difficult for the remanufactured machine tool to be sold at a profit

Mean price of new CNC milling machine (p_n) =20000usd
Mean used conventional milling machine price (C_1) =2500usd
Mean cost of remanufacturing process (C_2) =5000usd
Mean Overhead cost (C_3) =2500usd

The remanufacturing economic feasibility of conventional milling machine into CNC machine tool can be calculated to be either:

$C_R = C_1 + C_2 + C_3 = 2500 + 5000 + 2500 = 10000$usd, then $= C_R/p_n = 10000/20000 = 0.5$, since $p_R < 1$ then $C = 1$

Or

Another approach to ensure that the remanufacturing of milling machine is profitable by economic feasibility calculation as following [21]:
$f=(C_1+C_2+C_3)/p=(2500+5000+2500)/20000=10000/20000=0.5$

According to value of (f), economic feasibility index (C) can be evaluated as following:

$$C = \begin{cases} 1 & f < 0.4 \\ 1.8 - 2f & 0.4 \le f \le 0.7 \\ 0 & 0.7 < f \end{cases}$$

Since calculated (f) is of (0.5), then C=1.8-2x0.5=0.8

So that Economic feasibility is (C) = (1+0.8)/2=0.9

The economic feasibility of remanufacturing evaluation results show that the used conventional milling machine has good economic feasibility and remarkable economic benefits and especially high profit can be obtained. This can be endorsed by [1,20,21] where through milling machine remanufacturing, life can be extended as components recovery based milling machine remanufacturing to preserve the added-value that is developed during initial phases of design and manufacturing as a cost saving to be ($C_R = 0.4p_n$-$0.6p_n$) to satisfy customer demand of an economic solution of production.

Fig. 24 is comparative literature based calculation verification curve which shows high consistency of economic feasibility(C) and price ratio(p_R)results which are registered in this study comparing with [20,21].

3.3 Environmental Feasibility (E)

Energy saving, material saving and pollution reduction are usually used to term the environmental benefits that can be gathering through satisfaction of environmental feasibility of remanufacturing of conventional milling machine into CNC machine tool. Environmental feasibility calculation requires the determination of sub-feasibilities of:

3.3.1 Material saving sub-feasibility

Material saving can be calculated by the summation of the masses of the reused components to remanufacture the conventional milling machine. Material saving can be calculated by using the following equation [20,21]:

$$M_r = \sum_{g=1}^{L} M_g^r (g = 1, 2, \cdots, L)$$

Where,

L : Quantity of reused components,
M^r_g: Mass of g_{th} components reused,
M_r: Total material saving of remanufacturing milling machine.

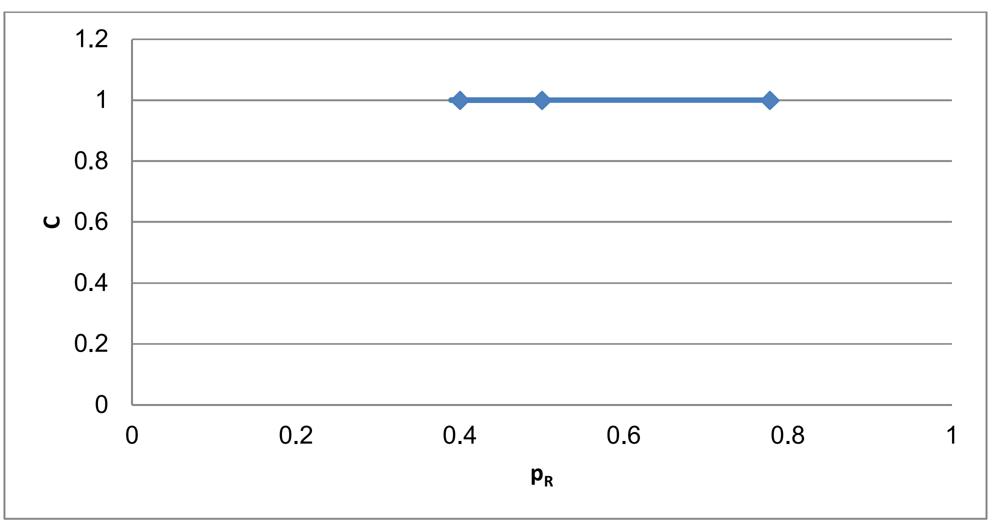

Fig. 24. Expert's experience based price ratio (p_R) and economic feasibility index (C)variation,(first):[20] , (second):[21],(third):current study

Material reusing ratio of conventional milling machine remanufacturing into CNC machine tool is [20,21]:

$$\Psi_m = \frac{M_r}{M_t}$$

Where,

Ψ_m: Material reusing ratio,
M_r: Weight of the reused component,
M_t: Total weight of the remanufactured conventional milling machine.

Total weight of the remanufactured conventional milling into CNC machine tool is (M_t=1500kg), weight of the reused component (M_r=1200kg) so that Material reusing ratio (Ψ_m) is:

Ψ_m=(1200/1500) x 100%=80%

Expert experience and linear regressive analyses based thresholds determination of material saving sub-feasibility can obey the following identities [20,21]:

$$\mu_m = \begin{cases} 1 & \text{if } \psi_m \geq 80\% \\ 1.25\psi_m & \text{if } \psi_m < 80\% \end{cases}$$

Since Ψ_m=80%, So that material saving sub-feasibility is (μ_m= 1).

Fig. 25 is comparative literature based calculation verification curve which shows high consistency of material saving resultswhich are registered in this study comparing with [1,20,21].

3.3.2 Energy saving sub-feasibility

Components reused based energy saving so that processes of raw material extraction, material processing and manufacturing are not required. Energy saving quantify is uncertainty problem due to lack of data which is required literature based analysis and experience based weight specifying. Energy saving ratio (ψ_e) of milling machine remanufacturing can be calculated by following equation [20,21]:

$$\psi_e = \frac{\sum_{g=1}^{L} M_g^r E_g - E_r}{E_m}$$

Where,

ψ_e : Energy saving ratio,
E_g : Respective energy embodied in the material of g_{th} reused component,
E_r : Energy consumption during the remanufacturing process,
E_m : Sum of the energy embodied in all the materials within the remanufactured milling machine.

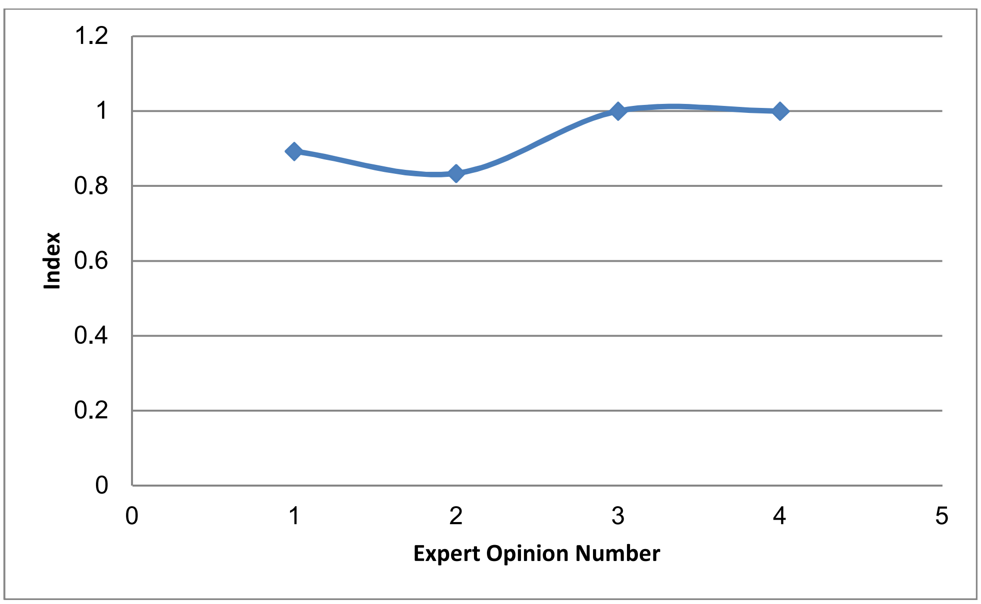

Fig. 25. Expert's experience based sub-feasibility index variation, material saving sub-feasibility, (1): [20], (2): [21],(3) :[1],(4): current study

Expert experience and linear regressive analysis based thresholds determination of energy saving sub-feasibility index (μ_s) can obey the following identities [20,21]:

Either

μ_s=1 ,if $\Psi_m \geq 75\%$

Or

μ_s=4 ψ_e/3 ,if $\Psi_m < 75\%$

Since ψ_m= 80%, so that energy saving sub-feasibility is (μ_s = 1).

Where,

μ_s : Energy saving sub-feasibility index,
ψ_e : Energy saving ratio,
Ψ_m : Material reusing ratio.

Fig. 26 is comparative literature based calculation verification curve which shows high consistency of energy saving results which are registered in this study comparing with [1,20,21].

3.3.3 Pollution reduction sub-feasibility

Pollution reduction is the calculation process of pollution emissions embodied in conventional milling machine hulk which is produced due to activities of raw material extraction, casting, forging, welding, heat treatment, machining, and surface treatment which are manufacturing processes of new milling machine while disassembly, cleaning, inspection and sorting, reconditioning, upgrading and reassembly are remanufacturing processes. Pollution reduction can be based on components based reused emission reduction so thatindex of pollution reduction should be assessed qualitatively by the method of expert's experience based judgment. The evaluation of pollution reduction sub-feasibility (μ_p) can be based on component contribution in pollution reduction so that four assessment grades are used which can be divided into {A, B, C, D} respectively and each grade can be of one value of {0.95, 0.80, 0.65, 0.40}, as high as the contribution of a certain component to pollution reduction, as high as the grade to be assigned to the component.

Pollution reduction sub-feasibility can be accounted for reassembly sub-systems as following:

Pollution reduction sub-feasibility (μ_{p1}) of Rails of Ball Linear guide ways to column reassembly, Carriages of Ball Linear guide ways to knee reassembly, Rails of Ball Linear guide ways to knee reassembly, Carriages of Ball Linear guide ways to Saddle reassembly, Rails of Ball Linear guide ways to worktable reassembly and Carriages of Ball Linear guide ways to Saddle reassembly.

Pollution reduction sub-feasibility (μ_{p2}) of Electrical power supply, Electrical motor, Machine head, Quill Sleeve and Ram.

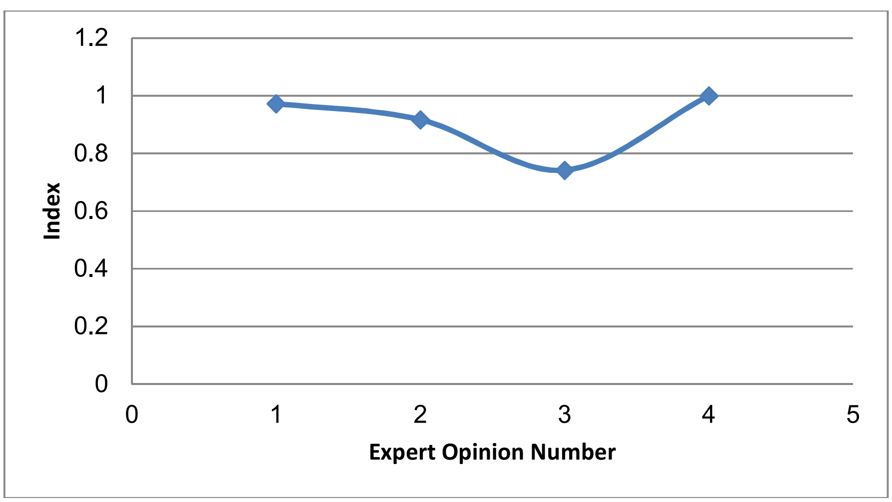

Fig. 26. Expert's experience based sub-feasibility index variation, energy saving fsub-feasibility, (1): [20], (2): [21],(3): [1],(4): current study

Pollution reduction sub-feasibility (μ_{p3}) of X-axis handles, X-axis ball screw and servo motor mounts and Worktable.

Pollution reduction sub-feasibility (μ_{p4}) of Y-axis handle, Y-axis ball screw and servo motor mount, Yoke andSaddle.

Pollution reduction sub-feasibility (μ_{p5}) of Ball screw and motor of Z-axis mechanism to quill reassembly, Fig. 18, Pulley belt and motor of Z-axis mechanism to quill feed shaft reassembly, 19, Ball screw and motor of Z-axis mechanism to knee-Z-axis handle reassembly, Fig. 20 and Ball screw and motor mechanism to Z-axis lead screw nut holder reassembly, Fig. 21.

So that pollution reduction sub-feasibility (μ_p) is:

μ_{p1}=[((1x0.65)+(1x0.65)+(1x0.65)+(1x0.65)+(1x0.65)+ (1x0.65)+(1x0.95)+(1x0.95)+(1x0.95))/6]
=[6.75/9]
=0.750

μ_{p2}=[((1x0.65)+(1x0.95)+(1x0.95)+(1x0.95))+(1x0.95))/5]
= [4.45/5]
=0.890

μ_{p3}=[((1x0.95)+(1x0.65)+(1x0.95))/3]
=[2.55/3]
=0.850

μ_{p4}=[((1x0.95)+(1x0.65)+(1x0.65)+(1x0.95+1x0.65))/5]
=[3.85/5]
=0.770

μ_{p5}=[((1x0.65)+(1x0.65)+(1x0.65))/3]
=[1.95/3]
=0.650

μ_p =(μ_{p1}+ μ_{p2}+ μ_{p3}+ μ_{p4}+ μ_{p5})/5
=(0.750+0.890+0.850+0.770+0.650)/5
=0.800

Fig. 27 is comparative literature based calculation verification curve which shows high consistency of pollution reduction sub-feasibility results which are registered in this study comparing with [20,21].

Weight of importance of material saving is the highest since it is direct directive procedure to be applied through remanufacturing processes so it is full of innovative potentials of mitigation. Energy saving is of the lower weight of importance value since it includes two directives, the first is the indirect which is the predominated and strongly related to effectiveness of material saving procedure which is respective energy embodied in the material of reused component and the second is indirect energy consumption during the remanufacturing process so that energy saving is of limited mitigation potentials. Pollution reduction is of the lowest weight of importance since it is of an indirect consequence of material saving and energy saving and it does not include any innovative mitigation potential to be applied.

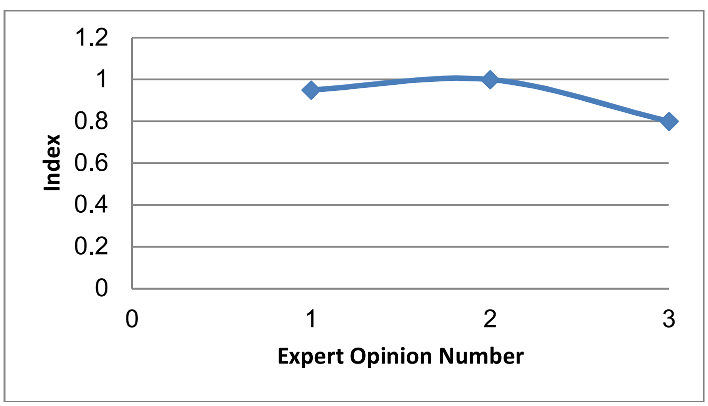

Fig. 27. Expert's experience based sub-feasibility index variation, pollution reduction sub-feasibility, (1): [20], (2) :[21],(3) : current study

Table 2. Sub- feasibilities matrix of environmental feasibility (E) evaluation

Sub-feasibility	Value	Index Value	Weight of Importance
Material saving	μ_m	1	0.900
Energy saving	μ_s	1	0.858
Pollution reduction	μ_p	0.800	0.817

**Weights of importance are calculated by using experience based analysis and literature based analysis*

Table 2 is sub-feasibilitiesmatrix of the environmental feasibility (E)evaluation which is calculated as following:

Environmental feasibility (E) = (μ_s x w_s+ μ_m x w_m+μ_p x w_p)/3
= (1x0.900+1x0.858+0.800x0.817)/3
= 0.804

Fig. 28 is comparative literature based calculation verification curve which shows high consistency of environmental feasibility resultswhich are registered in this study comparing with [1,20,21].

3.4 Sustainability Assessment Index (S_i)

Weight of importance of technology feasibility should be the highest since it is the first step to decide if the remanufacturing process can be conducted or not. All theoretical and practical innovations of eco-design, mitigation, environment conscious remanufacturing and upgrading to fulfill sustainability can be practiced through remanufacturing processes to let them technically feasible. Remanufacturing process to be continued, it should be economically feasible so the economic feasibility evaluation index is of second high weight of importance. Environmental feasibility can be obtained if the remanufacturing process is technically and economically feasible so environmental feasibility evaluation index is of the lowest weight of importance.

Table 3 is a sustainability assessment index calculation (S_i) matrix which is expert experience based analysis. Sustainability assessment index (S_i) can be calculated as following:-

S_i =(Tx W_T + C x W_C + E x W_E)/3
=(0.736x0.900+0.900x0.858+0.804x0.817)/3
=0.7 x 100%
= 70%

Fig. 29 illustrates a relation of indexes of the three feasibilities of conventional milling machine into CNC machine remanufacturing sustainability assessment with weights of importance of feasibilities and their effectiveness factorson the remanufacturing process. Such relation can be varying according to the following equation:

$$F_i=-75.256W^2 +128.39W + 53.862$$

Where,

F_i=Feasibility variation index,
W=Weight of importance of feasibility.

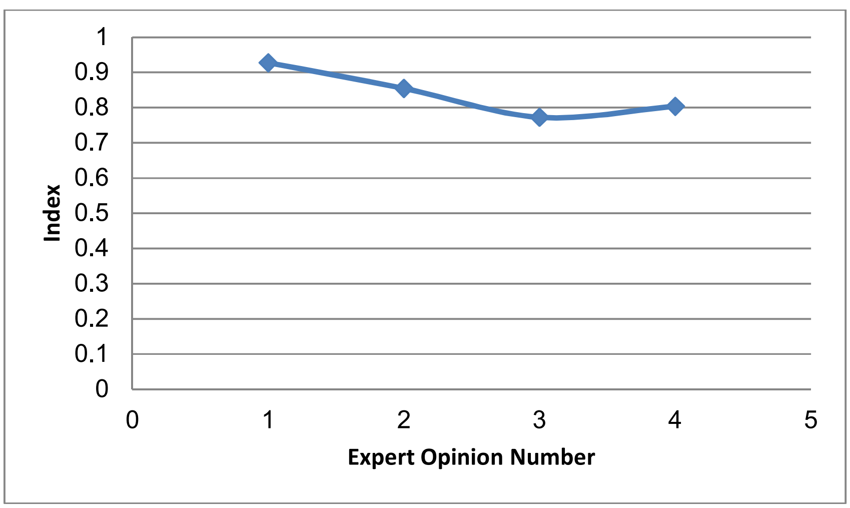

Fig. 28. Expert's experience based sub-feasibility index variation, environmental feasibility, (1): [20], (2) :[21],(3) :[1],(4): current study

Table 3. Feasibilities indexes matrix of sustainability assessment index evaluation

Criteria	Notions	Index	Weight of Importance
Technology feasibility	T	0.736	0.900
Economic feasibility	C	0.900	0.858
Environmental feasibility	E	0.804	0.817

**Weights of importance are calculated by using experience based analysis and literature based analysis*

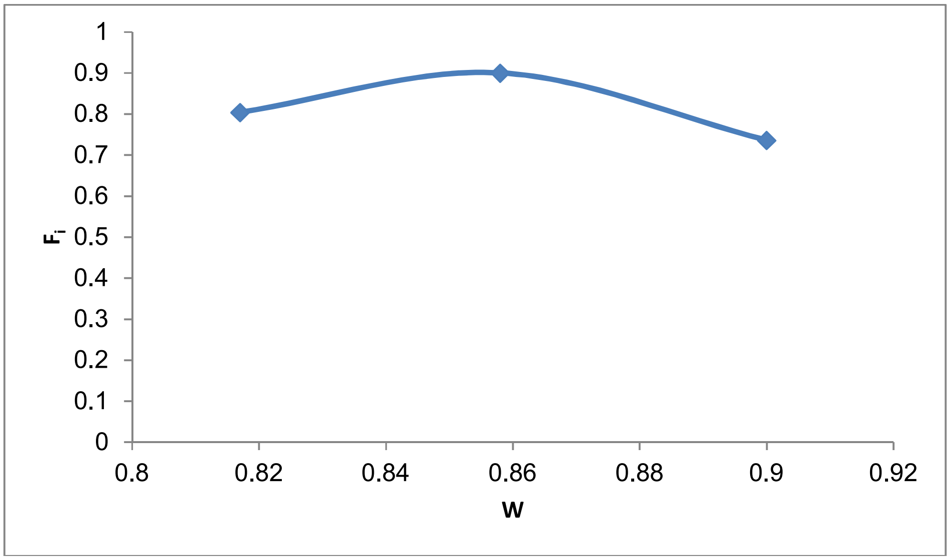

Fig. 29. Sustainability assessmentfeasibilities indexes as a function of weight of importance variation

Convex behavior of feasibilities variation indicates that economic and environmental feasibilities will form the bases of optimum solution so economic feasibility is located at the top of the curve which gives an indication that expert experience based analysis exceeds the negative effects of subjectivity, impreciseness and vagueness which distort the behavior of variation of feasibilities and sustainability.

4. CONCLUSION

Literature survey based analysis can be applied to construct a data base of weights to be used for multi-criteria assessment methods to select the most suitable sustainable alternative. Remanufacturing is an industrial process with uncertainty attributed inputs so that it requires uncertainty aided analysis techniques to be modeled. Multi-criteria assessment method is the most suitable technique to cope with problem of uncertainty of remanufacturing sustainability modeling. Feasibilities indexes evaluation in the form of multi-criteria assessment method can include technology feasibility, which can be divided into sub-feasibilities of disassembly, cleaning, inspection and sorting, reconditioning, upgrading and reassembly, economic feasibility and environmental feasibility which can be divided into material saving sub-feasibility, energy saving sub-feasibility and pollution reduction sub-feasibility. Structure of conventional milling machine is divided into four sub-assemblies according to fasten-unfasten relationships among components in the same sub-assembly.

Technical feasibility is of the lowest index of (0.736) but it is of allowable value according to literature based analysis where the lower value should be (T ≥ 0.6). Economic feasibility is of the highest index of (0.900) to make big difference with allowance threshold that mentioned in literature of (C ≥ 0.7). Environmental feasibility is of very good index value of (0.804) and is also over the allowance threshold of (E ≥ 0.6).

Sustainability assessment index of (S_i =0.7) means there is an efficiency (η=70%) of conventional milling machine to be converted into CNC machine tool which represents a good sustainability performance remanufacturing aided upgrading. Even so, but technical feasibilityis still the limiting factor which needs to be developed further to increase the index value.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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