Conventional Lathe Remanufacturing into CNC Machine Tool: Uncertainty Modeling Approach

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ABSTRACT

Aims: Uncertainty modeling to study possibility of proposing several remanufacturing alternatives of conventional lathe into CNC machine tool.
Study design: Conventional machine tool into CNC machine remanufacturing-upgrading experience is used to project the suitable literature comparatively to construct uncertainty modeling. Faults modes of conventional lathe are studied to propose different remanufacturing solution based on faults viewpoints in field of lathe remanufacturing-upgrading are reviewed and modified to accommodate new changes that accompany the current case study.
Place and Duration of Study: Middle Technical University, Institute of Technology-Baghdad, Mechanical Techniques Department, between January 2020 and July 2020.
Methodology: Decision making for selection of remanufactured alternatives and remanufacturing portfolio alternative in field of machine tools remanufacturing is reviewed. Experience in field of machine tool remanufacturing is exploited to remodeling of existence models to optimize a remanufactured lathe into CNC machine as a case study. Methodology can be concluded into:-

1- Literature survey to find two paths of:
   a- Faults and their statutes study.
   b- Remanufacturing portfolio study.
2- Literature re-presentation and modeling.
3- Literature results graphical modeling.
4- Mathematical modeling of remanufacturability.
5- Restoration alternative modeling
6- Modeling of uncertainty.

Results: Emerging technology aided conventional-CNC lathe remanufacturing-upgrading alternative exhibits good behavior of criteria toward optimization. While advanced technology aided conventional-CNC lathe remanufacturing exhibits behavior to be of interesting developing potentials. Conventional-Conventional lathe remanufacturing is of lower potentials to be developed into optimum solution.
Conclusion: Remanufacturing-upgrading of conventional lathe into CNC machine in its mechanical part, it is merely traditional remanufacturing process of conventional lathe where gearbox can be eliminated due to use of motorized axis. Feed rod and lead screws, in both forward and transvers directions, can be replaced with motorized ball screws. Also tool post can be replaced with automatic tool changer while saddle can be reused. Comparative literature based analysis and experience based analysis with uncertainty reduction can substitute the leak of relevant data acquisition for decision-making in field of remanufacturing. Which enables simplify certain difficulties and the calculation of some criteria and adopts simplified method so that theoretic and practical gap can be directed towards certain actual condition to reach the optimum solution.

Keywords: Remanufacturing uncertainty modeling, Decision making for remanufacturing modeling, Conventional lathe remanufacturing, remanufacturing-upgrading, CNC machine tool remanufacturing

1. INTRODUCTION

Selection of remanufacturing technologies should be based on the principle of uncertainties reduction which requires generalizing expert thinking based decision making. Economic value, technical adequacy and environmental effects criteria can be used to assess remanufacturability based sustainability. The performance of assessing using guiding criteria should be elaborated to accommodate and enhance knowledge contribution in field of selection of technology. Remanufacturing technology portfolio selection can suffer from managerial significant due to human being ambiguity in decision making which requires uncertainty to be moderated in evaluating , ranking and selecting appropriate technology. Purchasing cost, disposal cost, operating cost and flexibility impact technology performance largely which require experience based experts complementation. Diversity of criteria can help management to conduct thorough analysis and make informed decisions that accommodate ambiguity of experts in decision making [1]. Environmental benefits and costs of remanufacturing can be quantified in term of carbon emissions based on an overall quality coefficient that reflects the quality distribution of faults in lathe bed to set up a correlation between the carbon equivalent emissions and remanufacturing difficulty factor. An overall complex quality coefficient can be measured under the condition of multiple remanufactured machine tools to describe the uncertainty in the quality of lathe to be remanufactured. End-of-life technology routings can include whole machine remanufacturing, direct reuse of components, remanufacturing of components for cannibalization or scraping of components for materials. Matrix of step transition probability to denote the process step transition probability and a matrix of the difficulty factor for each step and for each complete process flow overall quality coefficient can be constructed to reflect the quality distribution and perform a quantitative analysis of net environmental benefits and costs. Uncertainty of faults conditions quantifying can lead to determine overall quality coefficient and the end-of-life strategy routing factor. Environmental benefits and uncertainty can be correlated and determined carbon emissions reduction in the real remanufacturing. The amount of reduction in carbon emissions increases with the increase in the overall complex quality coefficient .Optimal remanufacturing point can fulfill the environmental responsibility to dominate environmentally friendly industrial activities [2].Various failure types and failure degree can lead to that remanufacturability should be evaluated to determine the remanufacturing value. Sustainability or remanufacturability is usually evaluated based on multi-process routes, multi-parameters process or portfolio of alternatives as decision making assessment. Economic, indicator, quality, resource consumption and environmental emission can be used as Sustainability or remanufacturability assessment criteria can lead to more efficient and cleaner remanufacturing. Remanufacturability can be defined as the suitability of the component to remanufacture. Due to the different faults conditions, component can be restored according to multiple process remanufacturing portfolios so they have different remanufacturability even the have the same structure but of different faults conditions [3]. Remanufacturing feasibility can be calculated under each portfolio to check whether components can be remanufactured or not. Portfolio can be divided according to priority into the most economic viability portfolio, the most environmental viability portfolio, the most technical viability portfolio and the most social portfolio to formulate optimal the most sustainable remanufacturing portfolio. Different performance of remanufacturing portfolio alternatives and different fault conditions require flexible evaluation method to be provided such as scenarios based sustainability assessment. Sustainability-remanufacturability based assessment can lead to that remanufacturing efficiency can be increased by 22.4% and the remanufacturing. Practical extensions based analyzing situations involving is required since remanufacturing is complicated due to consideration of uncertainties and original product information obtaining based difficulty [4].

Reasoning algorithm can let define the cause and possible failures process mechanism that could be occurred after remanufacturing. Literature and industrial comparing and evaluating are required to identify the most serious causes of faults based on failure type that can occur after remanufacturing process .The cause of failure should be defined in order to improve the quality and reliability of remanufactured lathes. Remanufacturing portfolio and after remanufacturing failure relationship can be studied by analyzing a

variety of failures that could be occurred after remanufacturing. Failure modes and remanufacturing portfolio relationship identification can be obtained through noise based expert's opinions analysis which can reduce failure rate and process defect rate [5].
Remanufacturability assessment can be expertise opinion enabled decision making of the end of life machine tool. So that quantitative and qualitative attributes of end of life lathes can be incorporated. Technical, economic, resource utilization and the environmental indicators can be combined to form overall remanufacturability indicators. Remanufacturing process times are extremely variable and the fault statute based variability can cause process times to impact the whole remanufacturing system which require detailed remanufacturing process analysis to be carried out to find weights of assessing remanufacturability. Remanufacturability assessment can be resulted in the form of multi-products evaluations comparisons to develop indexes. Comprehensive comparative literature approach is required to incorporate aspects of remanufacturing such as reverse logistics, government legislation, take back polices and portfolio technology development within remanufacturability assessment modeling [6].
Selection and planning of the reconditioning processes can be enabled through sustainability assessment and remanufacturability assessment based on the fault conditions. Criticality of faults , synergistic effects and the nature of selected technology are crucial steps in the reconditioning process sequence planning to be engineering requirements based Reliability.Reconditioning based remanufacturing portfolio operations can process core components with varying conditions and different faults which need for reconditioning processes to be planned according to paths of certain sequence to each component in the core. Reconditioning process sequence for a core component depends on fault conditions to determine the optimal reconditioning process sequence [7].
Component remanufacturing is an important approach to achieve sustainable development of the closed loop industry. Industrial technologies are key factors to promote component based remanufacturing industry development. Design, market strategy, repair technology and talent quality can be used to assess re-manufacturability. Re-manufacturability needs to be propelled by related technology issues which are suitable for different industry globally with similar development stages and conditions. Advanced restoration techniques such as surface engineering can be used to restore the physical wear of components based on faults modes analysis and life assessment. Reconstruction or upgrading technology can be used to extend the service life of components that have reach technical or economical life [8].

2. COMPARATIVE LITERATURE BASD FAULT ANALYSIS

Machine tool has a great environmental benefits and good re-manufacturability to be restored into like-new conditions and the remanufacturing-upgrading CNC modifications include the following [9]:-

- Digital AC servo motors and drives to be attached with x-axis and z-axis.
- Advanced technology of SIMENS 840D is used as the Computer Numerical Control system.
- Closed-loop system developing.
- Automatic Tool Changer. spindle is digital AC servo motor
- Spindle is driven by digital AC servo motor with frequency inverter.

Even feasibility and validity of machine tool range between (0.778) for economic viability, (0.84) for technical viability and (0.928) for environmental viability, figure 1, show that environmental benefit is an important index for the evaluation of social sustainability but machine tool can suffer from some disadvantages include:

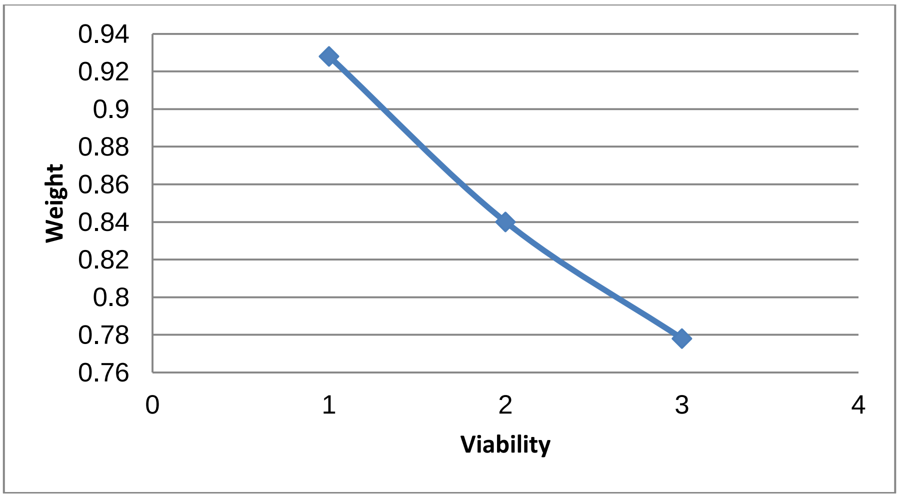

Fig.1. Range of weights of (1): Technical viability, (2): Environmental viability, (3): Economic viability [9].

- Some errors due to the uncertainties from stochastic product returns and the unknown condition of returned products.
- The evaluation process result, which can provide data and information for remanufacturing process, is generally acceptable in respect of the normal error scope.
- Uncertainties from stochastic product returns and the unknown conditions of returned products make the remanufacturing-upgrading of machine tools difficult modeling process.
- Many criteria can only be determined qualitatively, and the
- Calculation method of each evaluation index needs to be analyzed in-depth to improve the evaluation accuracy.
- Neglecting of social benefits due to the data availability and complexity.
- Incorporating the social benefits into re-manufacturability evaluation requires further efforts to be made.
- Computer aided re-manufacturability evaluation tool should be developed to help quick decision making.
- Empirical and practical case studies are also needed to be conducted to enhance re-manufacturability evaluation of machine tool.
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Technical criteria weights can be varied according to their viability weights to form the curve in figure 2. Upgrading is the most performance contributor criterion with satisfaction weight of (0.92) which cannot be obtained without emerged CNC machines technology application. Disassembly, cleaning, inspection and sorting, reconditioning and reassembly are of satisfied weight of (0.8), (0.74), (0.8), (0.84), and (0.8) respectively. Conventional lathe into CNC machine tool remanufacturing-upgrading can satisfy percentage of weights of environmental criteria as shown in figure 3. By applying comparative literature aided analysis, ball linear assembly based remanufacturing-upgrading of lathe into CNC machine can lead to increasing in technical performance to (5%) at least so technical criteria satisfaction weights can be of values as shown in figure 4 .Energy saving and pollution reduction weight (0.973) and (0.95) to be the highest while the material saving weight as low as (0.893). Ball linear assembly based remanufacturing-upgrading can lead to environmental conscious remanufacturing-upgrading so that energy saving, pollution reduction and material saving weights are (0.938),(0.973) and (0.998) respectively, figure5.

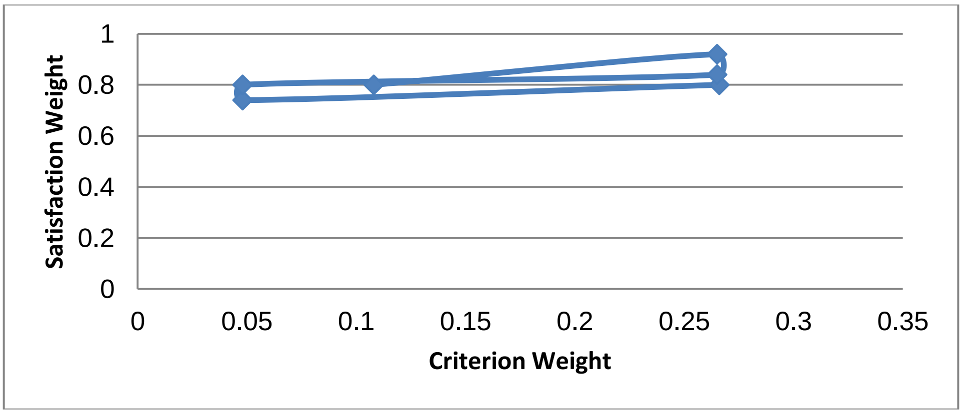


Fig.2.Technical criterion satisfaction weights as a function of technical criterion weights [9].

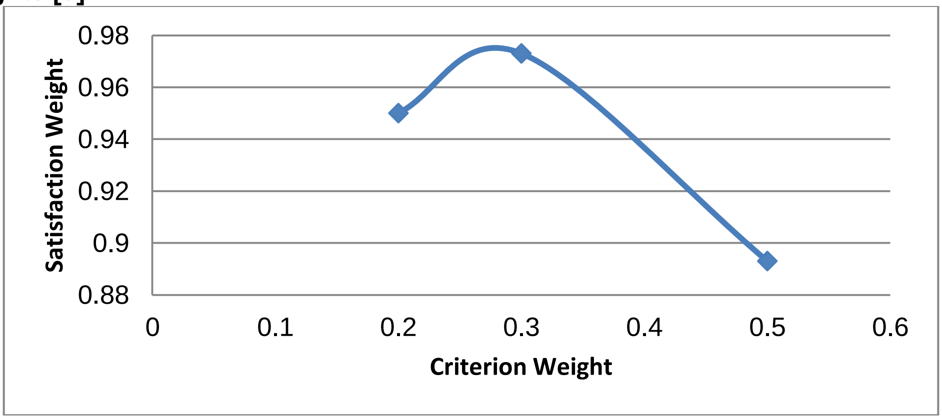


Fig. 3: Environmental criterion satisfaction weights as a function of environmental criterion weights [9].

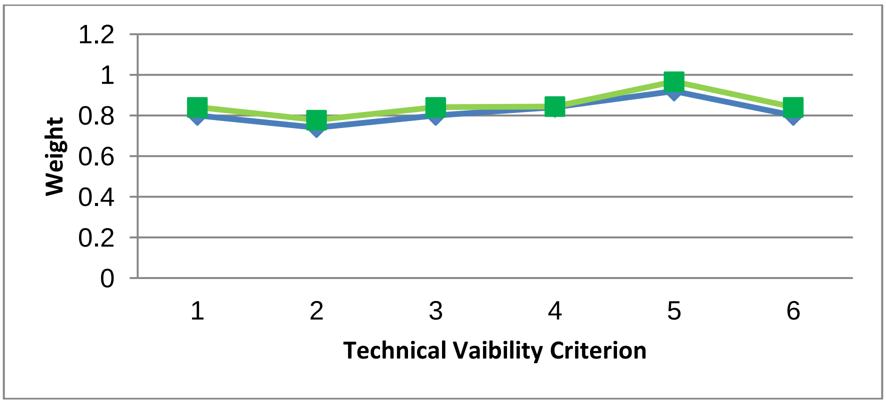


Fig4. Increasing of technical criteria viability weights due to application of linear ball guide ways assembly based remanufacturing, Green: linear ball guide ways assembly, Blue: Conventional assembly [9].

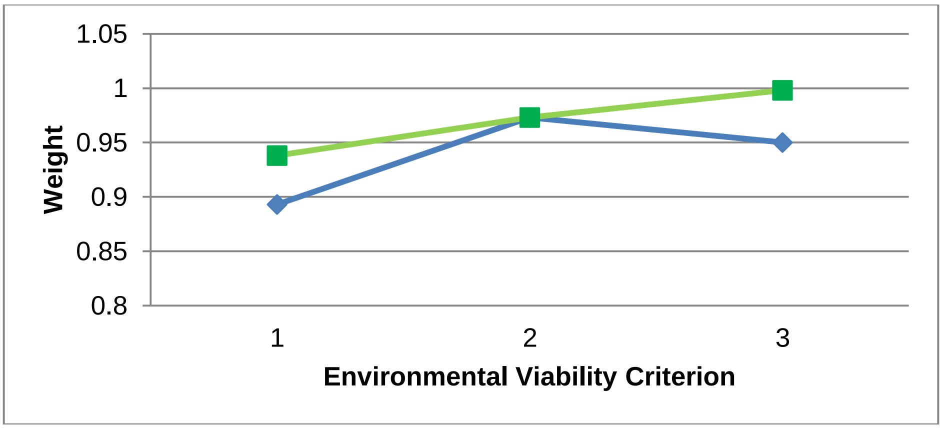


Fig.5. Increasing of environmental viability criteria weights due to application of linear ball guide ways assembly based remanufacturing.

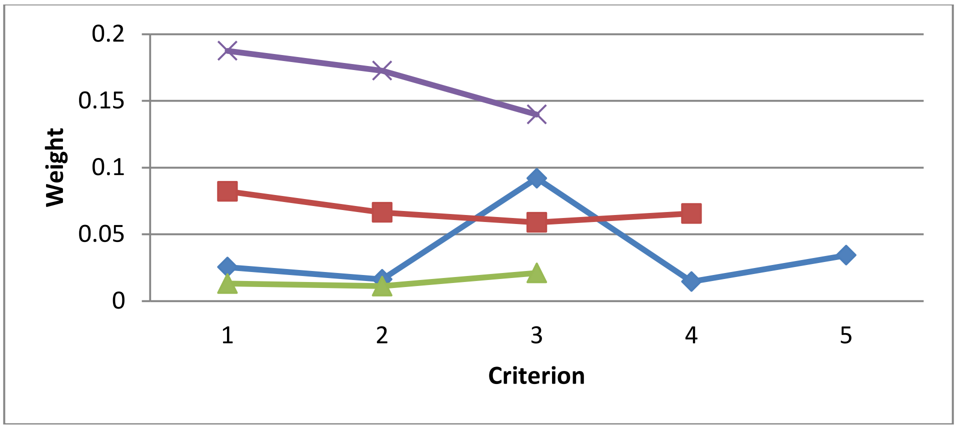


Fig. 6. Remanufacturing assessment criteria, Blue: geometrical criteria, Red: precision criteria, Green: economic criteria, Purple: failure criteria [10].

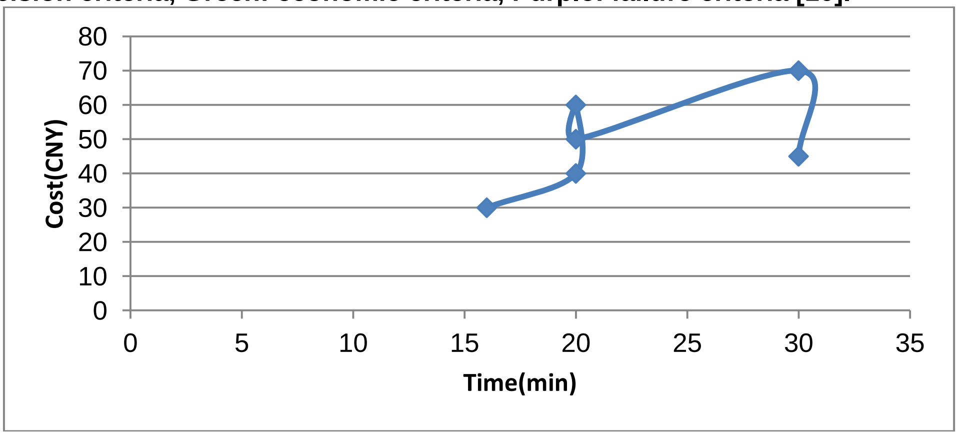


Fig.7.Variation of remanufacturing cost with time [10].

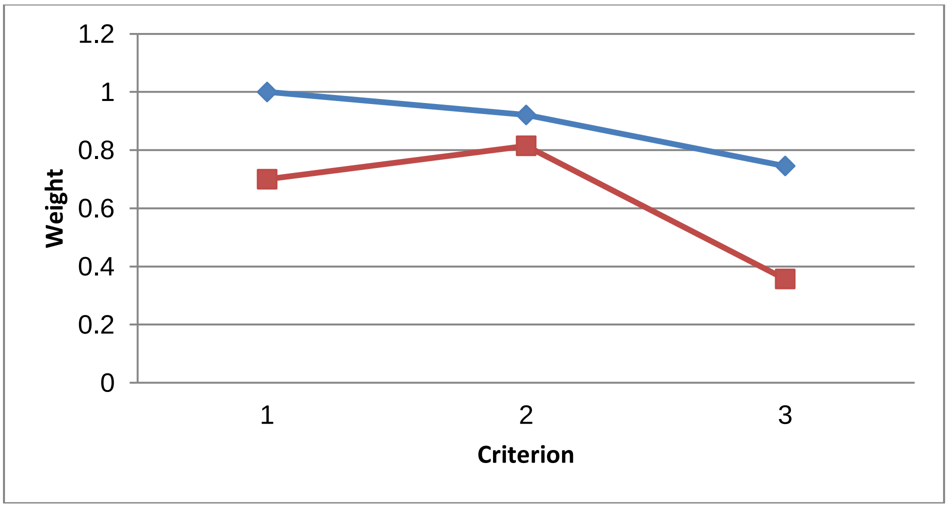


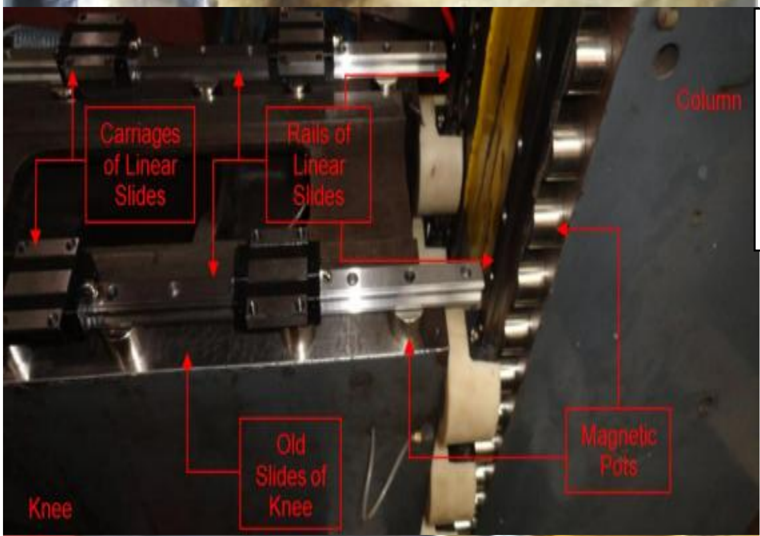
Fig.8. Comparative literature aided analysis, variation of failure criteria weights for remanufacturing assessment,(1):failure mode or damage,(2):failure degree,(3):failure location[10].

According to figure 6, remanufacturing assessment criteria can include technical viability criteria include of geometrical, precision and failure criteria. Geometrical criteria can be sub-divided into geometry, size, material, weight, and diameter. Precision criteria can be sub-divided into roughness, hardness, parallelism and precision. Economic criteria include brand, manufacturer and price. Remanufacturing cost can vary with the time that is required for remanufacturing according to figure 7. Failure criteria can be sub-divided into failure mode, failure degree and failure location figure 8[10].

Figure 11 is the application of replacing of frictional linear guide ways which are dovetail guide ways by linear ball guides ways for structural characteristics improving for conventional milling into CNC machine remanufacturing [11].The replacing is applied for the both parts of dovetail guide way where the rail of linear ball guide way is attached to the male dovetail guide way. While carriage of linear ball guide way is used to replace the female dovetail guide (saddle). Figuratively, the reconditioning process is the replacing of dovetail guide way by linear ball guide way, figure 7. Thus, jib strip of dovetail guide ways can be removed so friction can be highly reduce and mechanical hysteresis can be reduced through linear ball guide ways which leads to improve mechanical characteristic of remanufactured lathe to be reflected as an improvement in Accuracy, reliability, and processing efficiency of remanufactured lathe into CNC machine.

By application of remanufacturing to upgrade conventional machine lathe into CNC machine for educational and industrial training application, cost will be at its lower level and chance for resources sharing and facilities between education, training industry and remanufacturing industry can be obtained. Environmental viability is also consistent where high flexibility are supported with 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 parts of lathe . Social viability will be satisfied based on economic and environmental viabilities where human employment, development and experience accumulation can be delivered through education, training and remanufacturing industry. Mate/Insert/Bolt based emerged CNC technology assembly can certain reduction of cost of purchasing replacing parts, material resource consumption and electrical energy consumption [11].

Conventional lathe dovetail guide way and saddle [12]



The replacing is applied for the both parts of dovetail guide way where the rail of linear ball guide way is attached to the male dovetail guide way. While carriage of linear ball guide way is used to replace the female dovetail guide (saddle).This remanufacturing-upgrading portfolio is applied to conventional milling into CNC machine tool [11].

Dovetail guide way is remanufactured through cold welding and grinding. Saddle is remanufactured using grinding, laser cladding and fine grinding to recover wear. This remanufacturing-upgrading portfolio is applied to conventional milling into CNC machine tool [12].

Fig.7. Insert/mate/screw ball linear guide based assembly and dovetail guide way based remanufactured **[11][12].**

Remanufacturing-upgrading of conventional lathe into CNC machine tool can be applied according to proposed methodology in figure 8 and remanufacturing-upgrading assessment methodology can be shown in figure 9:-

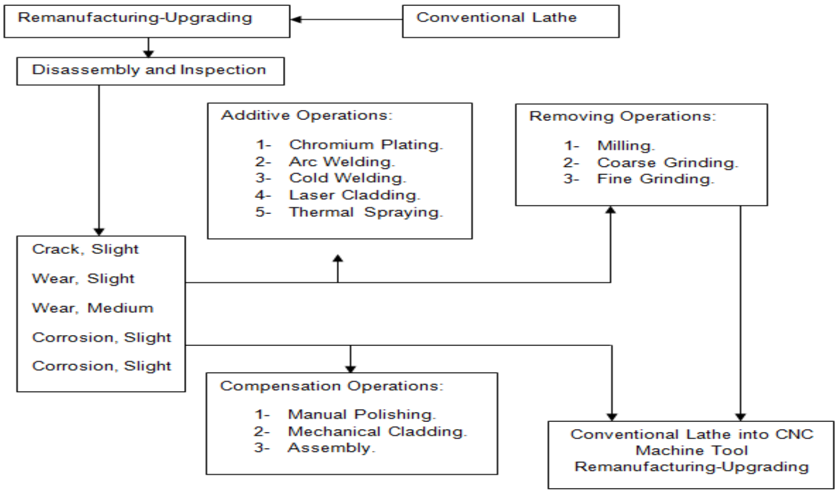


Fig.8. Remanufacturing-upgrading methodology to convert conventional lathe into CNC machine tool.

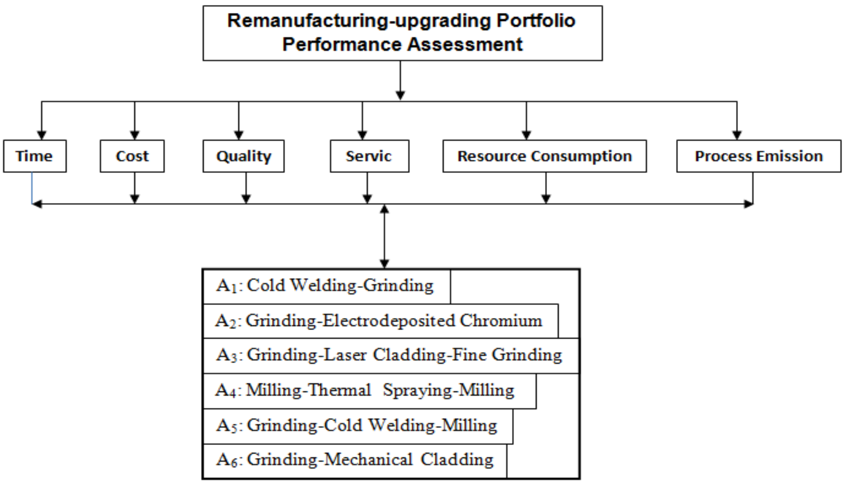


Fig.9. Remanufacturing-upgrading portfolio performance assessment methodology.

Remanufacturing can restore standard quality with reduction up to 60% in energy, 70% in materials, 50% in cost and 80% in air pollution which are important parts of circular economy. Reliability of remanufactured products is a major since conventional lathes are of cores with varying condition. Cost includes machine cost and tool cost. Reliability and cost criteria are critical since they play role in realizing a successful remanufacturing process planning since they directly affects the success rate of remanufacturing. Reliability can be represented by failure rate of remanufacturing operations which is influenced by the quality of remanufactured lathe. Genetic Algorithm can be used to solve remanufacturing problems of improving reliability and reducing cost which are multi-objective optimization [12].

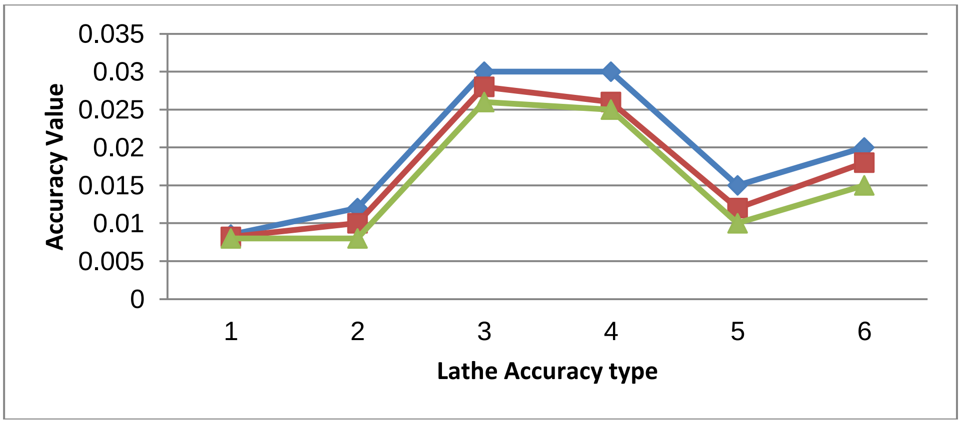


Fig. 10. Accuracy type based accuracy weight variation, Blue: new conventional lathe, Red: remanufactured-upgraded lathe traditionally without reliability, Green: Reliability based lathe remanufacturing-upgrading (1): Roundness, (2): Flatness,(3): pitch error,(4): Surface parallelism,(5): Repeatability of positioning from feed (X-axis),(6): Repeatability of positioning from feed(Y-axis)[12].

Technical viability is satisfied where the comparison of the precision of traditionally remanufactured machine, reliability based remanufactured lathe and the new one with standard parameters can be shown in figure 10. High restoration of precision values can be satisfied which mean high percentage of quality standard can be met to the extent of that accuracy of remanufactured-upgraded lathe is better than that of new conventional lathe. The reliability and cost optimization of remanufacturing process planning for a lathe bed can be based on Genetic Algorithm. Lathe bed is typical electromechanical product which is of great potential for remanufacturing. A remanufactured lathe may cost only 40%-60% of that of a new lathe whist offering better machining accuracy and production efficient. Real circumstances remanufacturing of conventional lathe include dovetail guide ways, saddle and spindle. Remanufacturing failure is a multi-criteria decision making for remanufacturing portfolio, which is also called technological path, due to high sensitivity of failure to location, degree and type. Thus, inspection is the first step toward remanufacturability assessment. Experience based assessment of the quality of conventional lathe to be remanufactured can classify failures as following [12]:-

1- Dovetail guide ways:-
   a- Failure mode is Crack which is called inside defect.
   b- Location is on surface.
   c- Intensity is 0.05mm.
   d- Degree is Slight.
2- Saddle :-
   a- Failure mode is wear which is called surface roughness.
   b- Location is on surface.
   c- Intensity is 1.2mm.
   d- Degree is Medium.
3- Spindle :-
   a- Failure mode is corrosion which is non-working surface damage.
   b- Location is outside the surface.
   c- Intensity is 0.2mm.
   d- Degree is Medium.

Crack, wear and corrosion can be rectified by using the following remanufacturing portfolio or remanufacturing technological path:-

1- Crack which requires remanufacturing to be rectified to portfolio that includes Cold welding and grinding.
2- Wear which requires remanufacturing to be rectified to portfolio that includes grinding and electrodeposited chromium or grinding, laser cladding and fine grinding.

3- Corrosion which requires remanufacturing to be rectified to portfolio that includes milling, thermal spray and milling or grinding, cold welding and milling.

Experts based evaluation can be used to asses desired quality of remanufactured lathe bed that can be weighted according to quality of lathe bed by entropy weight method, figures 11, 12 and 13.

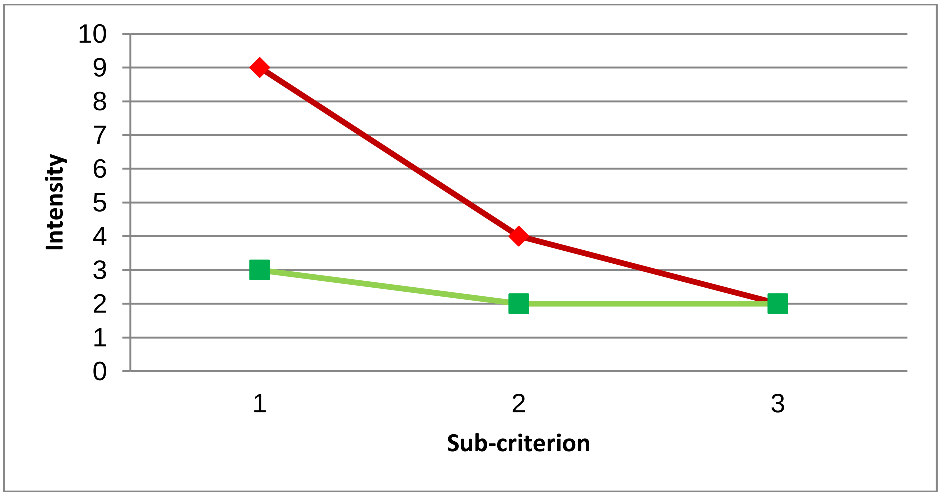


Fig.11. Experts based evaluation of inside defect of dovetail guide ways, Red: conventional lathe, Green: remanufactured-upgraded, (1): Damage, (2): Degree, (3): Position [12].

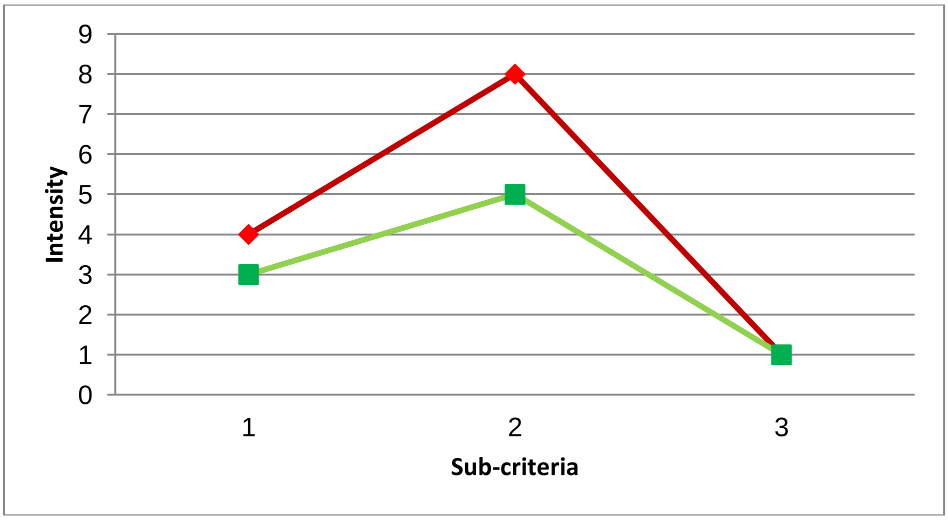


Fig.12. Experts based evaluation of non-working surface damage of saddle, Red: conventional lathe, Green: remanufactured-upgraded, (1): Damage, (2): Degree, (3): Position [12].

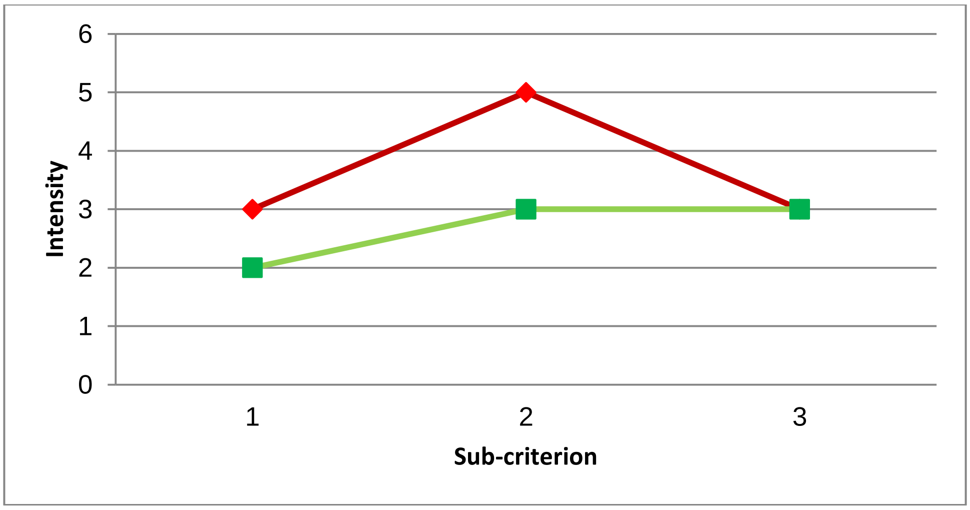


Fig.13. Experts based evaluation of non-working surface damage of spindle, Red: conventional lathe, Green: remanufactured-upgraded, (1): Damage, (2): Degree, (3): Position [12].

Three alternatives re-manufacturing portfolio are assessed by using economic criteria of time and power include [13]:

- Cold Welding – Bead Welding– Electric Arc Spraying–Soldering-Slotting-Cold Welding- Electrical Arc Spraying-Bead Welding-Soldering-Mending-Turning-Rough Grinding -Fine Grinding-Local Repair.
- Electric Arc Spraying-Cold Welding- Bead Welding-Soldering-Slotting-Mending-Local Repair-Turning-Rough Grinding-Fine Grinding.
- Mending-Local Repair -Turning-Rough Grinding-Fine Grinding.

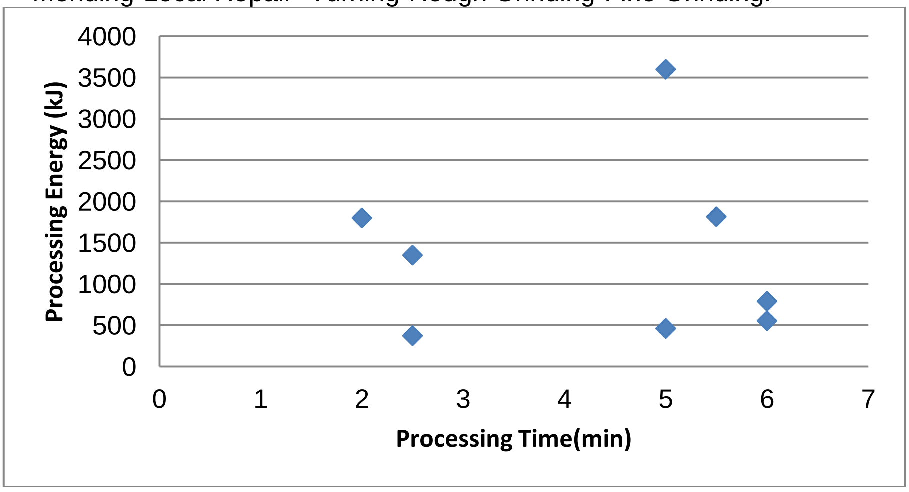


Fig.14. Energy-time variation based remanufacturing portfolio alternative based assessment

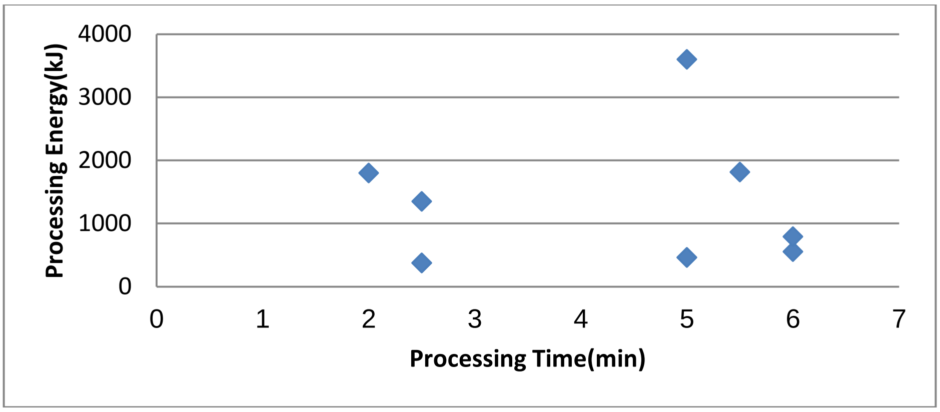


Fig.15. Energy-time variation based remanufacturing portfolio alternative based assessment

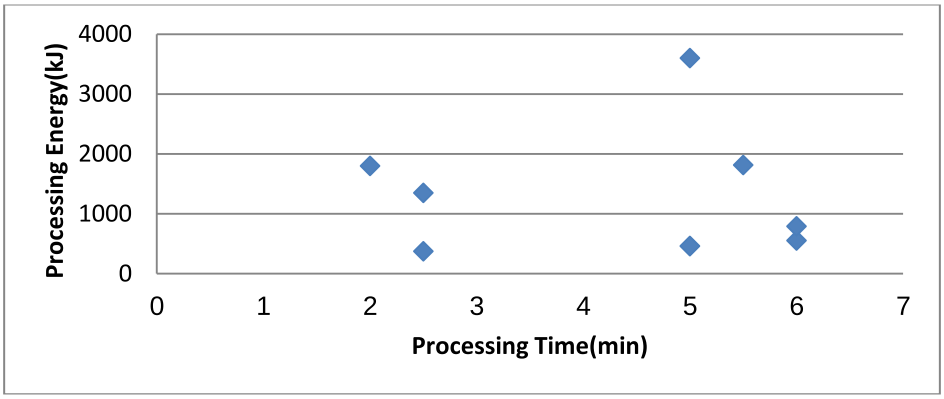


Fig.16. Energy-time variation based remanufacturing portfolio alternative based assessment

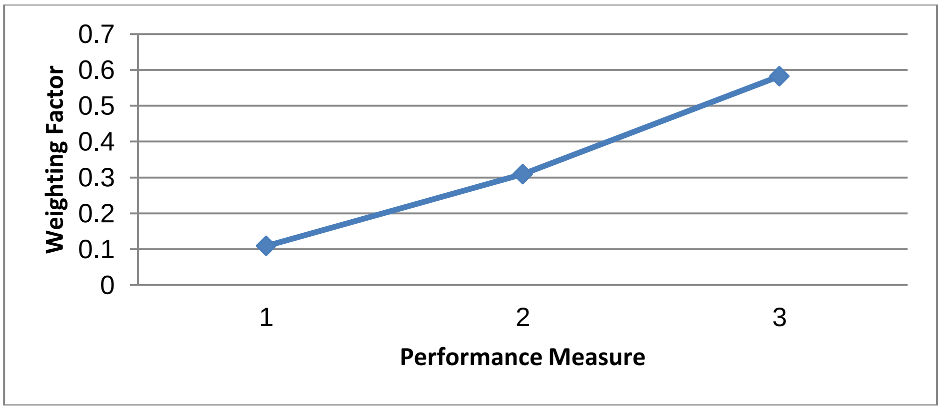


Fig.17. Lathe remanufacrurability measures, (1): Fault criticality, (2): remanufacturing portfolio synergistic effects, (3) the final restoration degree [14].

Conceptual methodology can be used to aid in the selection and planning of the remanufacturing portfolio based on the conditions of the faults. Selection and planning can be engineering requirements based selection of the remanufacturing portfolio. Fault ranking and precedence relationships are crucial steps in the remanufacturing portfolio sequence planning. Fault criticality, remanufacturing portfolio synergistic effects and the final restoration degree can be used to specify reliability to the remanufactured lathe, figure17 [14].

Remanufacturing, which can certain cost saving capabilities and benefits based emission reduction, includes activities of core components to be disassembled, cleaned, inspected, reconditioned, reassembled and tested to ensure reliability. Different defects let the core components to be of varying conditions which result in reconditioning process paths to vary so that specific path to each component will be required. Mate/Insert/Bolt based emerged CNC technology assembly can certain reduction of cost of purchasing replace parts, material resource consumption and electrical energy consumption through generalizing reconditioning processes of dovetail guide ways and saddle of lathe. The reconditioning process will decide the remanufacturing portfolio sequence which needs to be optimized depends on faults conditions. The types of reconditioning processes can be classified into five main categories include remove surface and shape defects, material addition or surface replacement , restore material properties, assembly and fastening manipulation and surface finish. Mate/Insert/Bolt based emerged CNC technology assembly can certain the five reconditioning processes to be integrated in one generalized solution. Defects, such as cracks, scratches, nicks and burrs, burnt or corroded regions and inclusions are removed by machining processes such as turning, milling and drilling to be followed by grinding and polishing to obtain the required surface finish and tolerances. More lathe cores can be classified to be of good condition and does not need to be further treated so that mate/insert/bolt based assembly can certain final surface quality to be performed and be technically feasible. Even surface defects such as cracks are deep, the material around the defect is no need to be gouged out and refilled since mate/insert/bolt based assembly can provide suitable surface-to-surface contact to produce salience to enable bolt assembly. Gouging out and refilling can impair the strength and safety requirements of the part and heat treatment is also required so that stress raisers can be removed. Shape defects such as bends, warps and dimples should be removed to get straight surface to enable mate/insert/bolt based assembly to be technically feasible and basic design of conventional lathe can be considered as eco-design. Remanufacturing portfolio to recover dovetail guide ways and saddle of lathe that suffer from wear can include grinding, laser cladding and fine grinding. Corrode dovetail guide ways and saddle can be recovered by using portfolio milling, thermal spraying and milling while burnt can be recovered by using welding and finishing. The key features of the conceptual framework are:

1. Use of product design engineering requirements to determine the reconditioning processes.
2. Regionalization of defects per engineering surface.
3. Rank criticality assessment of the defects.

Reconditioning processes can be of the following sequence:

1. Identify defects and their locations.
2. Assess and rank defect criticality.
3. Identify reconditioning operations for each defect.
4. Identify precedence relationships.
5. Devise reconditioning process sequence.
6. Risk and reliability assessment.
7. Preliminary selection.

Both of environmental and technical feasibilities assessments can show performance enhancing when insert/bolt assembly based remanufacturing is compared with traditional remanufacturing, figure18 and 19.

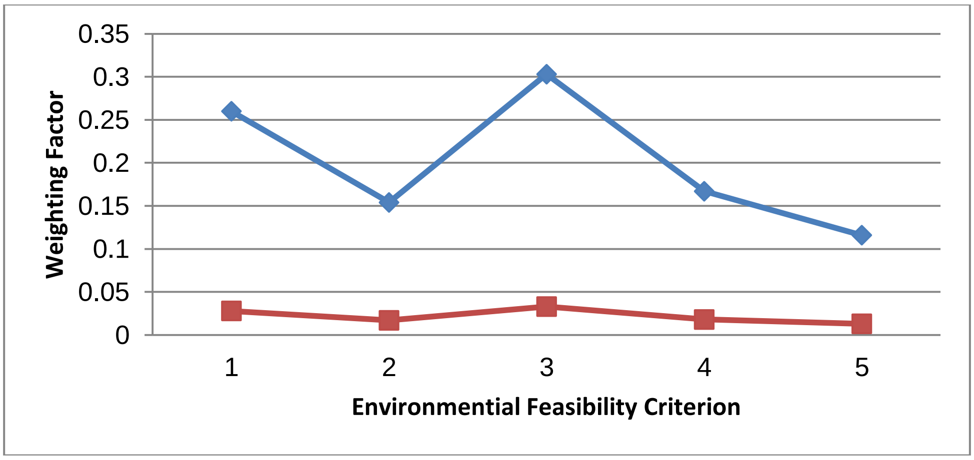


Fig.18/. Environmental feasibility assessment, Red: traditional remanufacturing, Blue: mate/insert/bolt assembly based remanufacturing

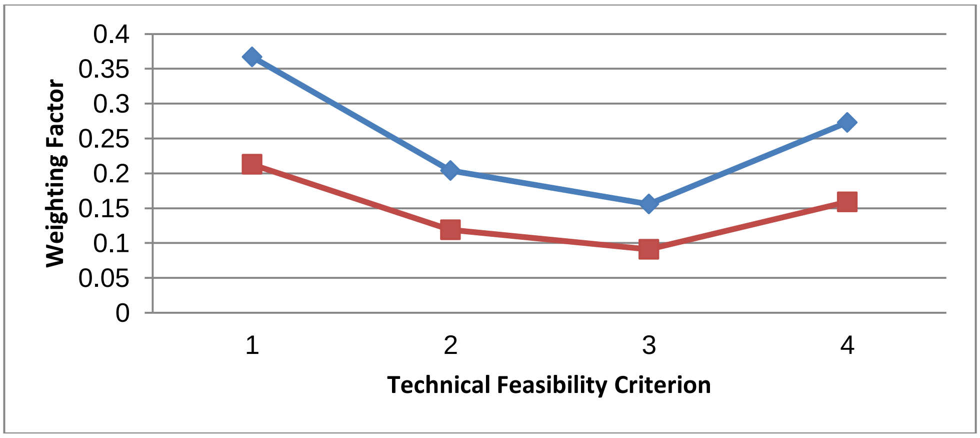


Fig.19. Technical feasibility assessment, Red: traditional remanufacturing, Blue: mate/insert/bolt assembly based remanufacturing

By applying comparative literature between [11] and [15], disassembly-assembly oriented remanufacturing system can be emerged, figure 20 . Based on [5], disassembly-assembly oriented remanufacturing system can enhance technical viability of remanufacturing-upgrading of CNC lathe comparing with remanufacturing system show by [8], figure 15.

Mate/Insert/Bolt based emerged CNC technology assembly can certain reduction of cost of purchasing replacing parts, material resource consumption and electrical energy consumption. Fastening-unfastening system can include:

(1) Mate/Insert
(2) Mate/Insert/Bolt
(3) Bolt/Bolt-Nut/Screw
(4) Gear, Belt-Mesh.
(5) Key/Interference Fit/Bearing
(6) Rivet/Welding.

Fastening-Unfastening based difficulty analysis is show in figure 17.Mate/Insert system is usually used to assembly machine tool bulk component such saddle to bed and cross slide to saddle in case of lathe machine and knee to column , saddle to keen and table to saddle in case of milling machine. To develop assembly based remanufacturing Mate/Insert system is developed into mate/insert/bolt to fulfill assembly of ball linear guides and carriages to machine tools body, figure 18 and 19[11][16].

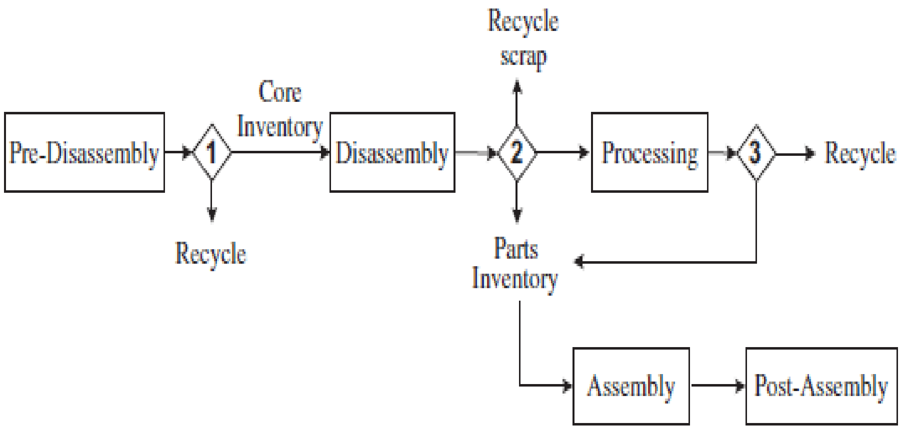


Fig.20. Traditional remanufacturing system [15].

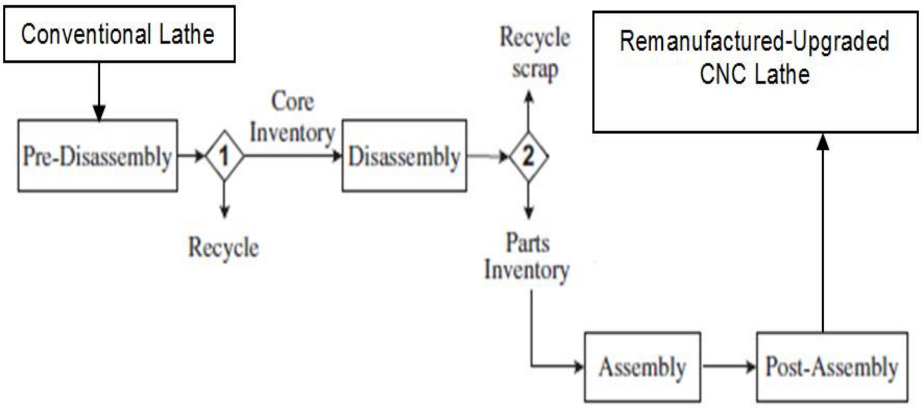


Fig.21. Assembly-disassembly oriented remanufacturing system, developed based on [11][15].

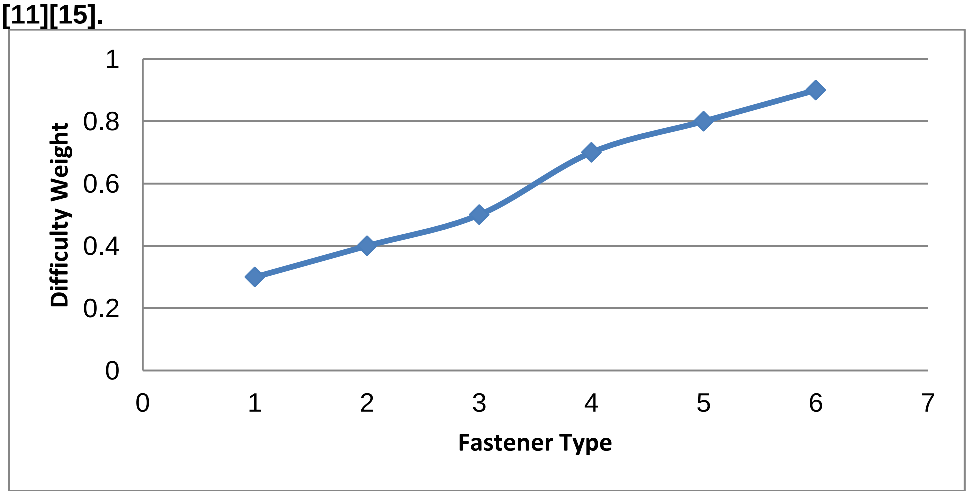


Fig. 22. Fastening-Unfastening based difficulty analysis , (1): Mate/Insert , (2):Mate/Insert/Bolt,(3):Bolt/Bolt-Nut/Screw,(4):Gear, Belt-Mesh ,(5):Key/Interference Fit/Bearing,(6):Rivet/Welding, modified based on [16] .

Mate/Insert/Bolt fastening to fulfill assembly of ball linear rails to machine knee	Mate/Insert fastening to fulfill assembly of ball carriage, protection cover and magnetic pot to enable saddle assembly

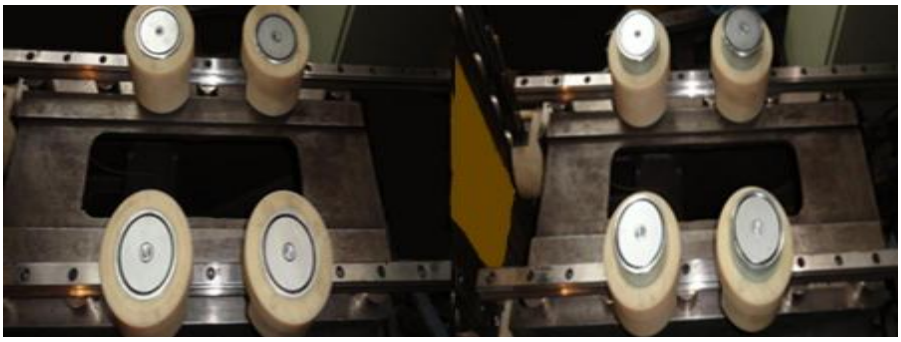


Fig.23. Mate/Insert/Bolt and Mate/Insert fastenings to fulfill assembly-disassembly oriented remanufacturing system, developed based on [11].

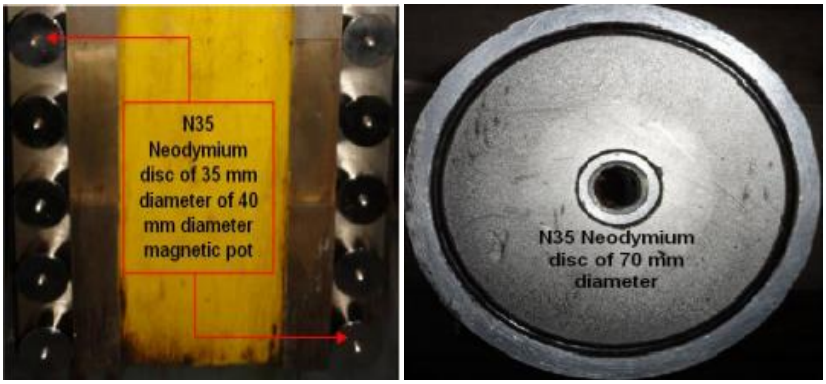


Fig.24. Mate/Insert/Bolt which magnetic rare earth pots to fulfill assembly-disassembly oriented remanufacturing system [11].

Remanufacturing viability assessment can includes fifteen criterion such as re-manufacturability design, market strategy , disassembly technology, cleaning technology, inspection technology, repair technology, reprocess technology, reassembly technology , testing technology, talent quality, standard performance, quality certification, information management, recovery network, and sale mode . Global weights as a function of local weights can show in the figure 25. The rank of assessment criteria as function of global weights of importance are shown in figure 26. Crack , wear , and corrosion can cause hybrid faults such as adhesion wear, contact fatigue breakage, root crack , outer cone wear , free surface damage , flat wear and oxidation corrosion[17] .

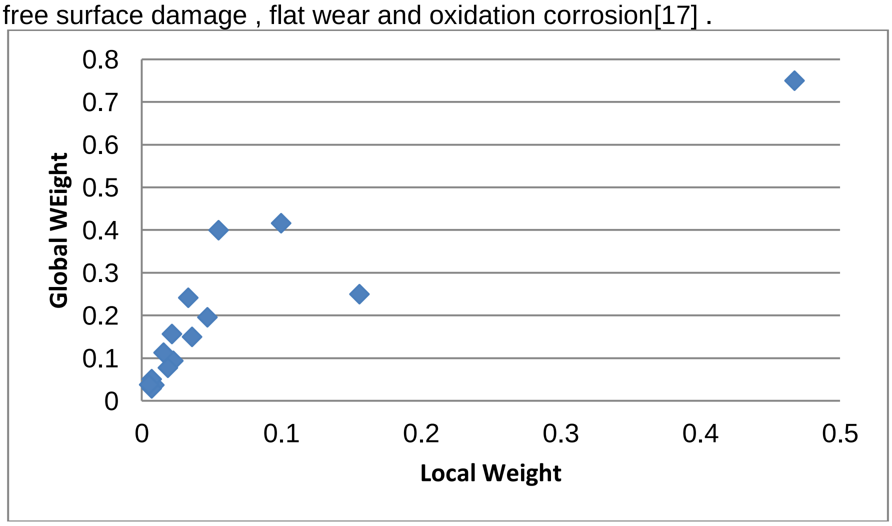


Figure 25 :Remanufacturing viability assessments criteria , global weight of importance as a function of local weight[17].

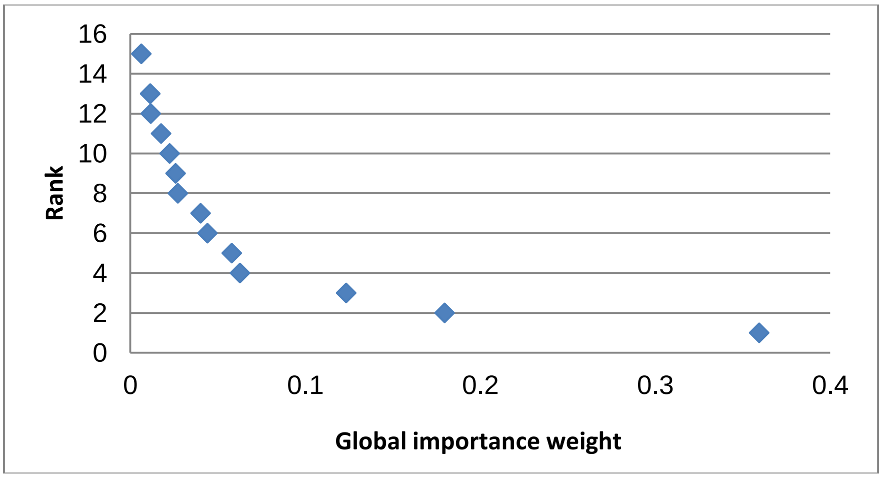


Figure 26: Remanufacturing viability assessments criteria, global weight of importance as a function of local weight [17].

Re-manufacturability can be assessed by weighting the activities of remanufacturing which include inspection and sorting, cleaning, disassembly, diagnostic testing, repair and upgrade, reassembly, functional test and final restoration and inspection. An example of two remanufactured products (A) and (B) are used to illustrate 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 figure 27 [6].

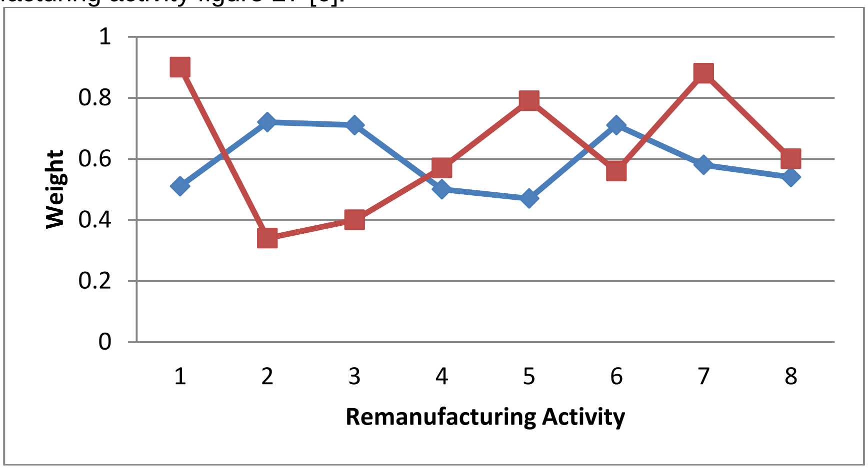


Figure 27 : Remanufacturing activities satisfaction weight variation, Blue: Product A, Red: Product B[6].

By applying ascending ordering, Time is of the lowest weight of importance of criterion and it is divided into cycle time and remanufacturing time. Resource consumption can be divided into energy efficiency and amount of raw material consumption. Resource consumption is of greater weight than Time and thus it is importer than it. Cost is more importance than Time and Resource consumption which is the cost of Equipment and Tooling. Frequency of maintenance and frequency of training form criterion of Service which is more importance than Cost. Process emission is the amount of solid waste and amount of liquid waste and it is of the second highest weight of importance after Quality which is of the highest weight of importance and it is divided into Capability and Reliability. Remanufacturing portfolio based technology planning can be presented by considering economic and environmental criteria of sustainability as multi-criteria decision-making based on both of the singular and synergistic benefits of different technology alternatives. Weights for various criteria and measures can demonstrate the effectiveness of remanufacturing system and its technology portfolio. Four technology alternatives can be integrated to form different portfolios, these technology alternatives include:-

(1) Buy a new CNC grinding machine
(2) Remanufacture a lathe and upgrade it with a power feed, digital readout of position and CNC features.
(3) Purchase thermal spraying equipment
(4) Procure arc welding equipment
So that different portfolios of remanufacturing system can include:-
First: Buy a new CNC grinding machine, Remanufacture a lathe and upgrade it, and Purchase thermal spraying equipment.
Second: Buy a new CNC grinding machine, Remanufacture a lathe and upgrade it, and Purchase thermal spraying equipment.
Third: Remanufacture a lathe and upgrade it, and Purchase thermal spraying equipment, and Purchase thermal spraying equipment.
Fourth: Buy a new CNC grinding machine, and Purchase thermal spraying equipment, and Purchase thermal spraying equipment.

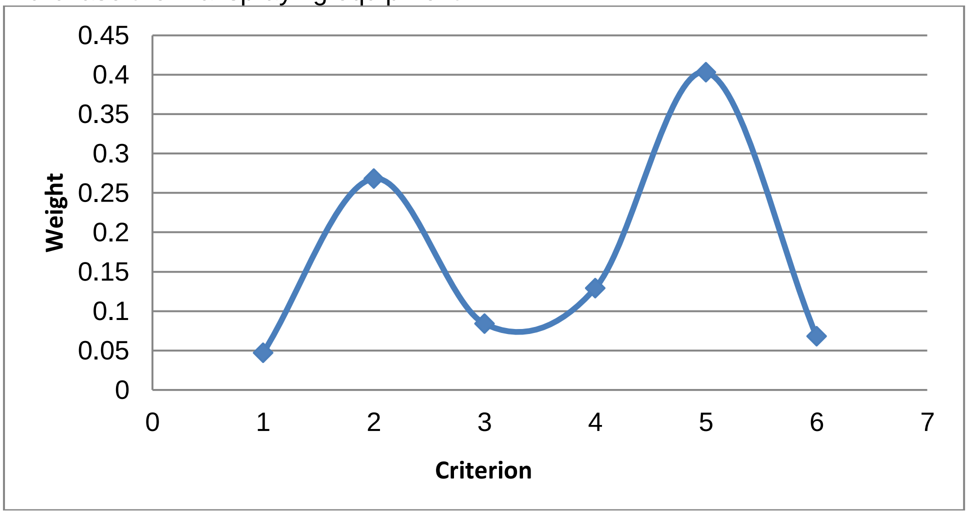


Fig.28. Remanufacturing sustainability assessment criteria, (1): Time, (2): Quality, (3): Cost, (4): Service, (5): Process Emission, (6): Resource Consumption [15].

Synergistic effects consider the overall benefits of remanufacturing technology portfolio would be created that does not enterprise. Second portfolio is of the highest synergistic benefits so it is the most attractive solution comparing with the third portfolio which is of the highest singular benefits which highlights the significant of synergistic benefits. High synergistic benefits can be delivered with lowest cost of second portfolio. Figure (5) show how synergistic benefits, singular benefits and cost vary with remanufacturing system portfolio [15].

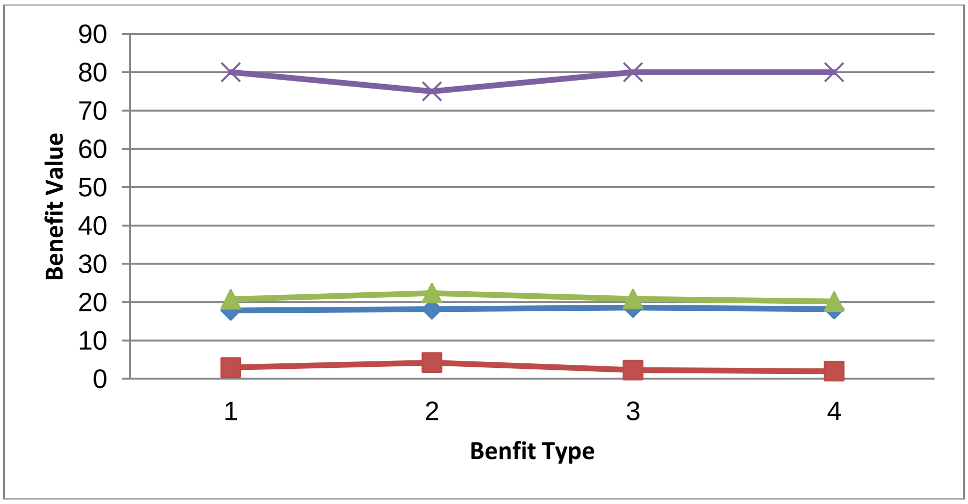


Fig.29.Remanufacturing portfolio based benefit analysis [15].

3. RESULTS AND DISCUSSION

Scenario based analysis, remanufacturing experience based analysis and comparative literature based analysis are used as tools for modeling, analysis and discussion.Three scenarios are used to assess the remanufacturability of machine tool include:

A_1: Conventional technology aided conventional lathe remanufacturing

A_2: Emerged technology aided conventional lathe into CNC lathe remanufacturing

A_3: Advanced technology aided conventional lathe -CNC lathe remanufacturing

Mate/insert/bolt fastening system will be used to assembly mechanical structure of CNC machine to conventional machine tool. Criteria to assess the most appropriate alternative of end-of-life strategy which can lead to remanufacture-upgrade conventional lathe into CNC machine tool include:

C_1:Reuse

C_2:Repair

C_3:Recycle

C_4:Remanufacturing

C_5:Remanufacturing-Upgrading

Assessment philosophy is based on contribution of end-of-life strategy to get like new CNC lathe, figure 31. Such assessment philosophy states that the most appropriate end-of-life strategy which leads to change conventional lathe into like new CNC machine tool will be of the highest weight so assessment matric can be shown in table 1 and represented in figure 30. Relation interference is also taken means remanufacturing can be conducted as an intermediate step to be followed by upgrading so this will link strategies of remanufacturing and remanufacturing-upgrading. Reuse is also interfered with remanufacturing or remanufacturing-upgrading while repair or recycling will not lead to change conventional lathe into like new CNC machine tool.

Table 1: End-of-life strategy alternatives assessment matrix.

Alternative/Criterion	C_1(0.385)	C_2(0.146)	C_3(0.098)	C_4(0.559)	C_5(0.635)	Priority Weight	Rank
A_1	0.345	0.163	0.047	0.262	0.262	0.474	3
A_2	0.540	0.163	0.047	0.533	0.571	0.896	1
A_3	0.297	0.163	0.047	0.533	0.559	0.796	2

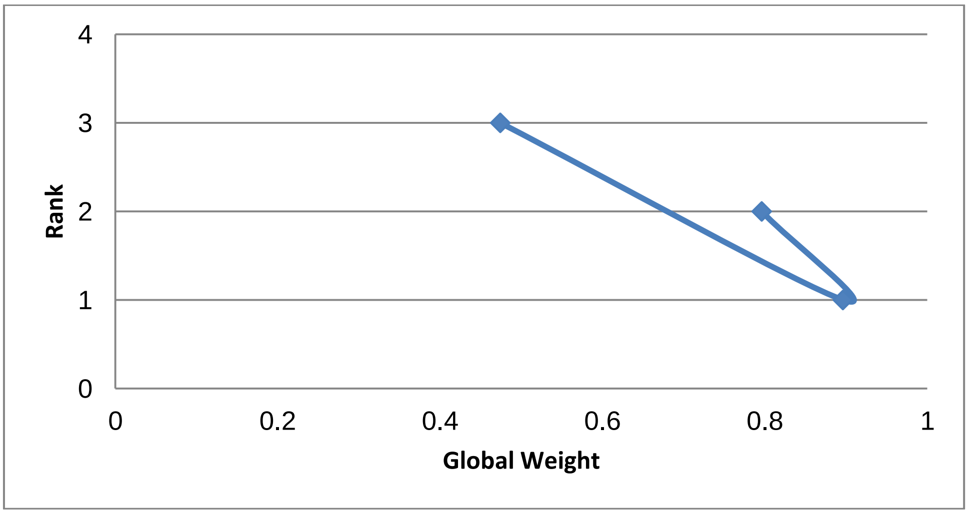


Figure 30: Rank-Global weight, variation of failure criteria.

Reuse can represent the foundation of remanufacturing-upgrading process as an effective economic and environmental alternative source of replacing components.

Repair cannot lead to change conventional lathe into like new CNC machine tool since there is no standard repairing by original equipment manufacturer or repairing third party to integrate their parts in lathe remanufacturing-upgrading but can be a source of knowledge and experience. Recycling is of zero contribution but it is weighted to maintain consistency of assessment matrix. Remanufacturing can be done by original equipment manufacturer or third party remanufacturer and remanufactured lathe can be used for remanufacturing-upgrading purpose so remanufacturing is good contributor to change conventional lathe into like new CNC machine tool.

Emerged technology aided conventional lathe into CNC lathe remanufacturing is more suitable to be conducted because it can harvest the same environmental and social benefits comparing with advanced technology aided conventional lathe -CNC lathe remanufacturing which is of lower economic benefit and required higher investment to start. Conventional technology aided conventional lathe remanufacturing can lead indirectly to change conventional lathe into like new CNC machine tool and can be a source of knowledge and experience so it is an alternative with postponed benefit to be gathered.

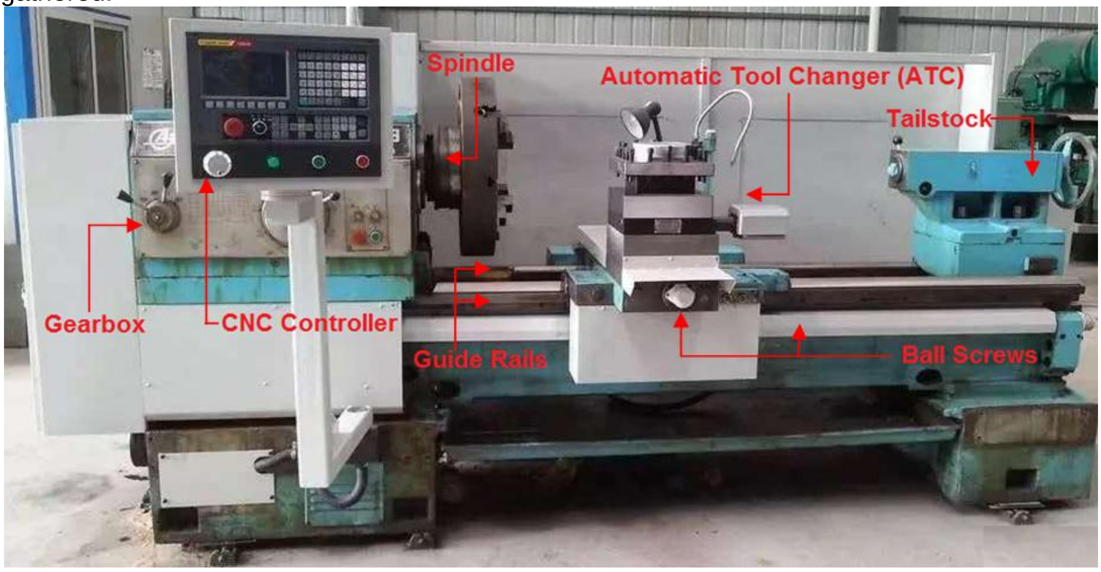


Fig. 31. Conventional lathe into CNC machine remanufacturing-upgrading

Table 2: End-of-life strategy alternatives uncertainty optimization fuzzy values.

Alternative/Criterion	A_1(0.748)	A_2(0.535)	A_3(0.853)	Priority Weight	Rank
A_1:Reuse	0.540	0.385	0.571	1.097	3
A_2:Repair	0.297	0.385	0.540	0.889	4
A_3:Recycle	0.163	0.163	0.098	0.293	5
A_4:Remanufacturing	0.778	0.385	0.635	1.330	2
A_5:Remanufacturing-Upgrading	0.920	0.385	0.635	1.436	1

Table2 can show various lathe recovery assessment process, five alternatives of A_1: Reuse,A_2: Repair,A_3: Recycle ,A_4: Remanufacturing and A_5: Remanufacturing-Upgrading. Assessment process includes criteria of C_1: Functional Status, C_2: Type of Supply Chain and C_3: Value Reclaim. Value Reclaim is of the highest weight, followed by Functional Status and Type of Supply Chain according to their weights respectively. According to Functional Status criterion, relative judgment is used to weight alternatives where Reuse can restore the basic functional statue of lathe which leads into CNC functional transformation as the first indirect choice, while repair needs to extend the efforts of restoration to the second indirect choice. Remanufacturing can certain indirect CNC functional transformation with advantage of like-new feature to be the first best indirect choice. Remanufacturing-Upgrading is the only best choice can lead into like-new CNC transformation directly to be the best choice that can provide functional status of conventional lathe into CNC machine transformation but recycling can lead to nothing. From Value Reclaim criteria view point, value-added based functional status recovery is the best for Remanufacturing-Upgrading and Remanufacturing. Reuse based Deteriorating is the best comparing with repair and recycle with priority of repair on recycling. Polices , such as manufacturer responsibility to tack-back and recovery and social developments through employment and human development cannot be certain without closed-loop recovery activities so that recycling is the worst open-loop recovery strategy. Figure 32 shows that the increasing of global weight will lead to decrease the rank.

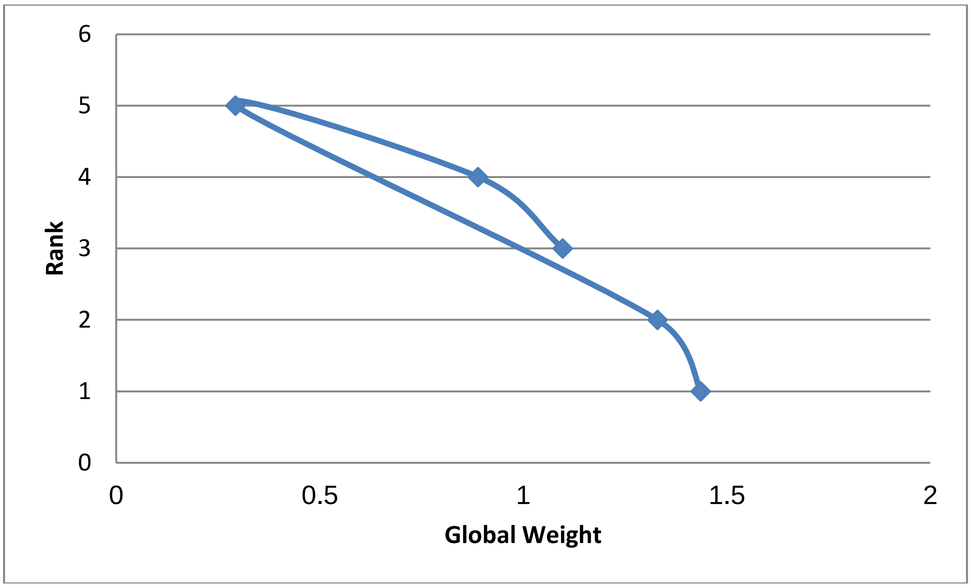


Fig.32. Rank-Global weight, variation of end-of-life strategy restoration capability.

3.1 REMANUFACTURABILITY ASSESSMENT MATHEMATICAL MODELING

3.1.1 Remanufacturing Cost Criterion:

Decision-making based similar performance of lathe remanufacturing into CNC machine can consider cost based difference between remanufacturing cost or price of remanufactured lathe and price of new machine. Decision making aided selection ratio of like new to new cost criterion can be determined based on formula developed by [7]:-

$$C_1 = 1 \text{ , if } C_r > C_n \qquad \text{and} \qquad C_1 = C_r/C_n \text{ if } C_r \leq C_n$$

C_1=Remanufactured lathe into CNC machine cost /New CNC machine cost.
C_r= Remanufactured lathe into CNC machine cost.
C_n= New CNC machine cost.

Decision making regulating ratio (C_r/C_n) increases the selection comparing with experience based criterion which states:-

- C_1 is less than 40%, the customer has a higher tendency to buy remanufacturing machine tool into CNC instead of purchasing a new CNC machine tool.
- C_1 is greater than 60%, the customer has a higher tendency to buy a new CNC machine tool.

While the decision making aided selection can be applied using cost ratio which is used in this study resembles greener selection tool comparing with experience based selection with taken in consideration that both are based on performance constancy. Remanufacturing of conventional lathe into CNC machine tool is of consistent economic viability where the cost criterion of remanufacturing is about less than $C_1=(C_r/C_n)=(1/2)=0.5$ since ($C_r<C_n$) where four conventional machine remanufacturing cost is less than the cost of manufacturing two new ones[7].

3.1.2 Remanufacturing Time Criterion:

Remanufacturing time is a source of uncertainty which needs to be formulated within customers' tolerance. Decision making aided selection can be applied using time ratio of remanufacturing time to delivery time so that criterion C_2 can be quantitatively calculated based on formula developed by [7], which states :-

$$C_2 = 1 \text{ , if } T_r < T_E \qquad \text{and} \qquad C_2 = T_E/T_r \text{ if } T_r \geq T_E$$

C_2=Remanufactured machine tool into CNC machine time / Delivery time.
T_r= Remanufactured machine tool into CNC machine time.
T_E= Delivery time.
Practice experience based assessment refers to:-

- As less as remanufacturing time comparing with delivery deadline of customer, there will be a greater expectation for buying remanufactured machine tool into CNC machine.
- As less as delivery deadline of customer comparing with remanufacturing time, there will be a greater expectation for buying new CNC machine tool.

Production capacity of conventional machine remanufacturing is about the double of that for new machine manufacturing. So the time criterion of remanufacturing C_2= 1 since Tr<TE where in manufacturing period of one new conventional machine two remanufactured machines can be produced[7].

3.1.3 Accuracy Criterion:

Remanufacturing can develop the accuracy of lathe to like-new CNC machine operating conditions and standard performance comparing with new CNC machine tools. Remanufactured machine tool into CNC machine performance is accuracy sensitivity assessment to be formulated in terms of geometric accuracy, working accuracy, positioning accuracy and repeat positioning accuracy. Accuracy analysis to satisfy an assessment criterion contains sorting of accuracy into types according to their weights of affection and factor of judgment of for which extent each sort of accuracy is satisfied per single remanufacturing attempt. Experts can be consulted for accuracy weight assessment and accuracy satisfaction judgment .The accuracy value corresponding to the factory standard of remanufactured machine tool into CNC machine is determined by[7],which states :-

$$C_3 = A_1 + A_2 + A_3 + A_4$$
$$A_1 = \omega_1 L_1$$
$$A_2 = \omega_2 L_2$$
$$A_3 = \omega_3 L_3$$
$$A_4 = \omega_4 L_4$$

Where:-
A_1 = geometric accuracy weight.
A_2 = working accuracy weight.
A_3 = positioning accuracy weight.
A_4 = repeat positioning weight.
ω_1= geometric accuracy weight.
ω_2= working accuracy weight.
ω_3= positioning accuracy weight.
ω_4= repeat positioning weight.
L_1= geometric accuracy judgment weight.
L_2= working accuracy judgment weight.
L_3=positioning accuracy judgment weight.
L_4= repeat positioning judgment weight.

3.1.4 Reliability Criterion:

Remanufacturing can develop the accuracy of lathe to like-new CNC machine operating conditions and standard performance comparing with new CNC machine tools. Remanufactured machine tool into CNC machine performance is accuracy sensitivity assessment to be formulated in terms of geometric accuracy, working accuracy, positioning accuracy and repeat positioning accuracy. Reliability reflects the time and durability of machine tool accuracy and is a key factor of remanufactured machine tools for customer acceptance. Reliability can be characterized by various criteria. The downtime and failure of machine tools will cause great losses to the customers. Redesign phase, it is application of eco-design as a foregone conclusion, is to rethinking to propose methods and tools to embed CNC machines technology through the structure of machine tool by remanufacturing. The mathematical modeling of Reliability states [7]:-

$$\mathbf{C_4 = 1\ , if\ MTBF_r \geq MTBF_n \quad and \quad C_4 = MTBF_r/MTBF_n\ if\ MTBF_r < MTBF_n}$$

MTBF= Mean Time Between Failures.
$MTBF_r$= Mean Time Between Failures of remanufactured machine tool into CNC machine.
$MTBF_n$= Mean Time Between Failures of new CNC machine.

<u>3.1.4 Processing Efficiency Criterion:</u>
Machine tools processing efficiency can be mainly the processing time of parts that. Remanufacturing can improve the processing efficiency of machine tools and the time for machining the same products would decrease. Processing efficiency can be evaluated by the processing time as shown [7]:

$$\mathbf{C_5 = t_r/t_n\ , if\ t_r \leq t_n \quad and \quad C_5 = 1\ if\ t_r > t_n}$$

tr and t_n represent the time required to produce the same work piece respectively for remanufactured machine tools and the used ones. In general, the processing efficiency of remanufactured machine tools can be improved by increased cutting feed rates, increased spindle speeds, converting manual machines to full CNC, consequently the processing time decrease [7].

<u>3.1.5 Flexibility Criterion:</u>
Flexibility can be quantified by expert judgment and classified on group of family knowledge processing range. Remanufactured machine tool into CNC machine can conduct more processes and produce more types of work-piece if it is of five axes configuration. The processing range is expanded and available processes are increased appropriately while the structure is a very complex if it is of four axes configuration while the structure is complex. The processing range is of good expanded while the structure is a little complex.

<u>3.1.6 Ergonomics Criterion:</u>
Easy-to-clean, easy-to-use, safety, maintainability, comfort and coordination of human-machine interaction are elements of ergonomics evaluation process. Ergonomics evaluation is an expert judgment based assessment of remanufactured machine tool into CNC machine. Lathe can mainly responsible for the processing of longitudinally mass distributed parts which conventionally is driven by automatic feeding and has a bed of two rail structures as well as a manual operated tool holder. The machine tool can be used for decades which, this can lead to[7]:-

- Serious worn of mechanical parts.
- Distortion of geometric precision.
- Malfunction of electrical control system and cables.
- The machining accuracy cannot be met.
- Surface roughness of cylindrical turning will be *Ra* 6.3~3.2
- Surface roughness of internal cylindrical turning will be *Ra* 6.3~3.2,
- Taper of cylindrical turning will be 0.05～0.1/100.

Some papers study several scenarios of performance of the machine tool restoration by applying remanufacturing under two governing points :-

- Considering the customer requirements.
- Decision-maker preferences.
- Condition of the machine.

3.2 ALTERNATIVES OF REMANUFACTURING-UPGRADING SOLUTIONS

<u>3.2.1 Remanufacturing Cost Criterion:</u>
Alternatives of remanufacturing solutions of lathe can include:-.
3.2.1.1 Conventional-Conventional lathe remanufacturing which is attributed with:-

- Lowest cost alternative restoration.
- Like-new conditions.
- No CNC system to be used.
- Damaged or worn parts replacing.
- Reconditioned to satisfy the lathe functionality requirements such as lubrication pumps, lead screws and electrical wiring.
- New, reused or reconditioned components can be used.
- Cleaning, inspection and reassembling.

3.2.1.2 Emerging technology aided Conventional-CNC lathe remanufacturing which is attributed with:-

- Upgrading, Re-design and Remanufacturing of main drive system, feed system, bed rail, tailstock, hydraulic lubrication system as well as other mechanical components.
- CNC system using to rebuild the conventional machine tool into a CNC machine tool.
- Axes servo motors and drives using.
- Spindle motor and drives using.
- Accuracy, reliability, processing efficiency, processing range and ergonomics improving.

3.2.1.3 Advanced technology aided conventional-CNC lathe remanufacturing which is attributed with:-

- Pneumatic, hydraulic and electrical systems will be adoption.
- Ball screws based updating.
- Servo motors and drives based updating.
- Spindle motor and drives based updating.
- Accuracy, reliability, processing efficiency, processing range, and ergonomics can be greatly improving.

3.3 COMPREHENSIVE DEPENDENT DEGREE BASED ASSESSMENT

The comprehensive dependent degree *Kj*(*k*) ,which is proposed by [7], is used to differentiate alternatives for optimum selection. Final comprehensive evaluation value of each comprehensive alternative solution *Rk* can be illustrated with comprehensive dependent degree *Kj*(*k*) and the results are as shown in figures32,33,34,35,36 and 37. Evaluation results can show alternative 2 is the optimum solution of decision making solution for conventional lathe into CNC machine remanufacturing. Five differentiation degrees can be applied to study the informative selection procedure of alternatives modeling includes:-

1- Figure 33, comprehensive dependent degree can be a function of comprehensive alternative solution, with dependent degree of (-0.2728), alternative 2 can simulate excellent mixture of different effects of assessment criteria as an excellent strength of the informative selection analysis model.

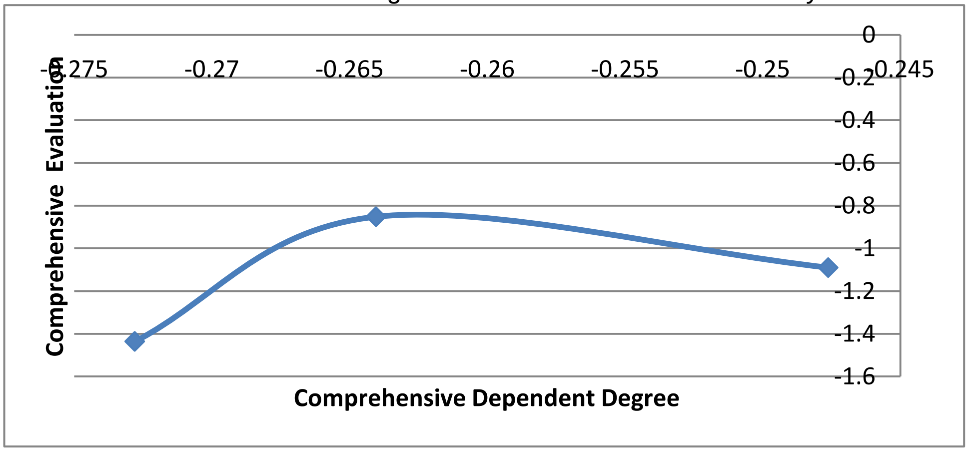


Fig.33. Alternative 2 simulates excellent mixture of different effects of assessment criteria.

2- Figure 34, comprehensive dependent degree can be a function of comprehensive alternative solution, with dependent degree of (-0.12792) , alternative 2 can simulate good mixture of different effects of assessment criteria as a good strength of the informative selection analysis model.

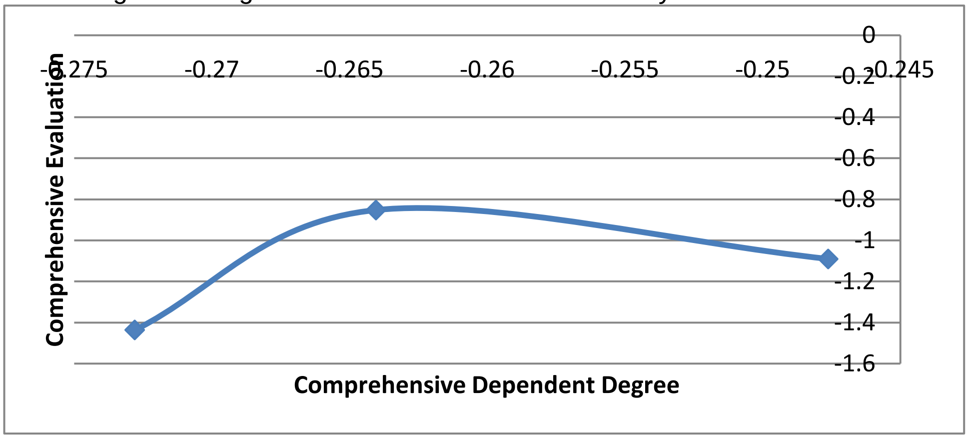


Fig.34. alternative 2 simulates good mixture of different effects of assessment criteria.

3- Figure 35, comprehensive dependent degree can be a function of comprehensive alternative solution, with dependent degree of (-0.20864), alternative 2 can simulate average mixture of different effects of assessment criteria as an average strength of the informative selection analysis model.

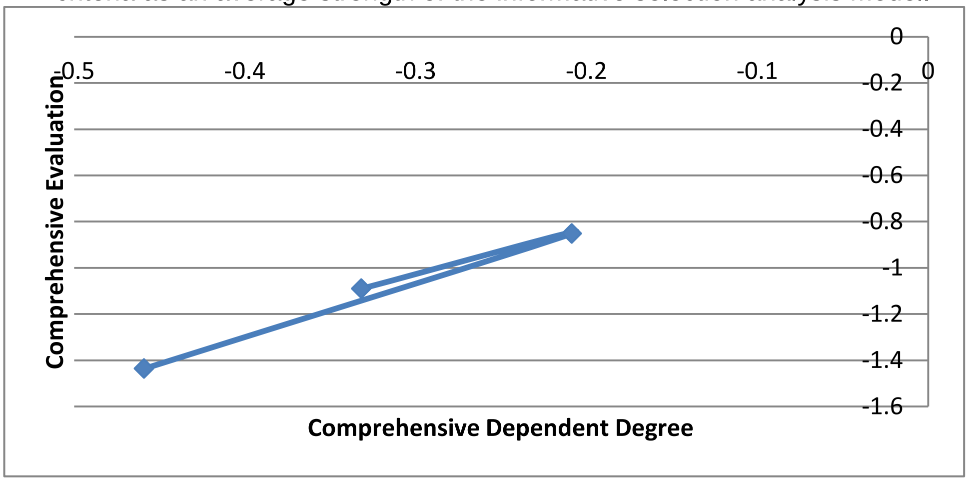


Fig.35.alternative 2 simulates average mixture of different effects of assessment criteria.

4- Figure 36, comprehensive dependent degree can be a function of comprehensive alternative solution, with dependent degree of (-0.28351), alternative 2 can simulate average mixture of different effects of assessment criteria as a fair strength of the informative selection analysis model.

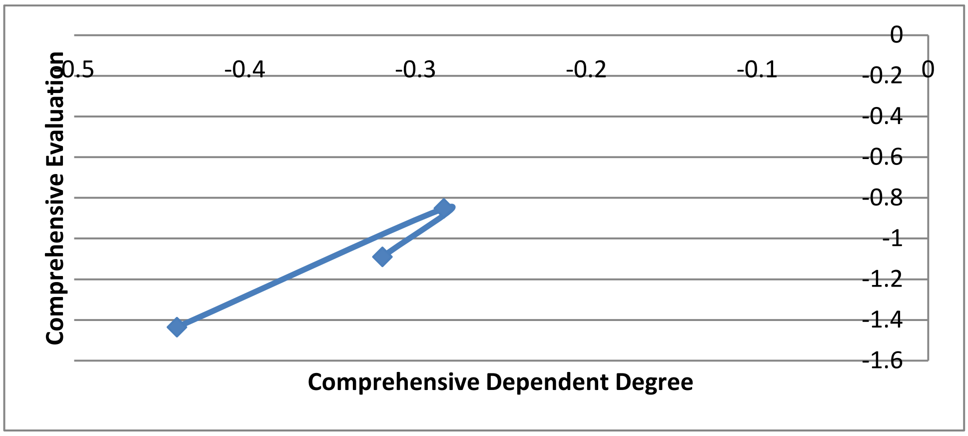


Fig.36. alternative 2 simulates fair mixture of different effects of assessment criteria.

5- Figure 37, comprehensive dependent degree can be a function of comprehensive alternative solution, with dependent degree of (-0.39147), alternative 2 can simulate poor mixture of different effects of assessment criteria as a poor strength of the informative selection analysis model.

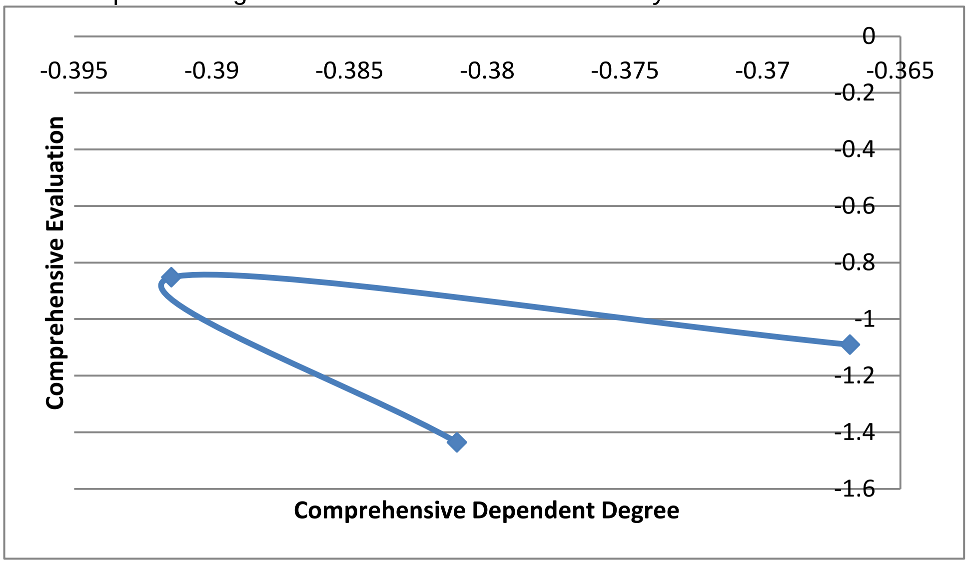


Fig.37.alternative 2 simulates poor mixture of different effects of assessment criteria.

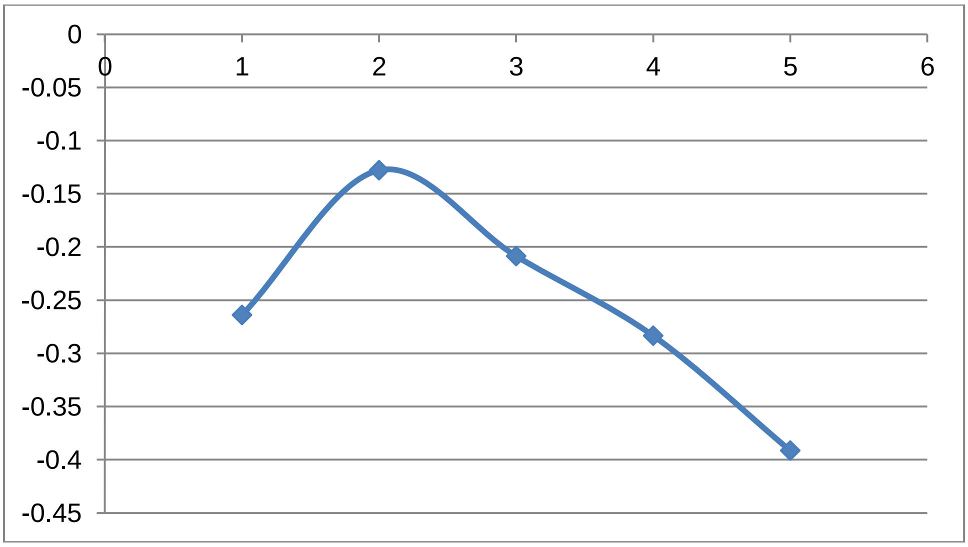


Fig.38.alternative 2 simulates poor mixture of different effects of assessment criteria.

Figure 38 shows the variety of alternative 2 due to various considerations of the customer requirements, expertise experience and condition of lathe.

3.4 CRITERIA ASSESSMENT

Each alternative is an integrated platform which is based on assumptions that take in account different stockholders preferences which are usually fluctuated to fulfill an alternative based criterion variation, figure 40.

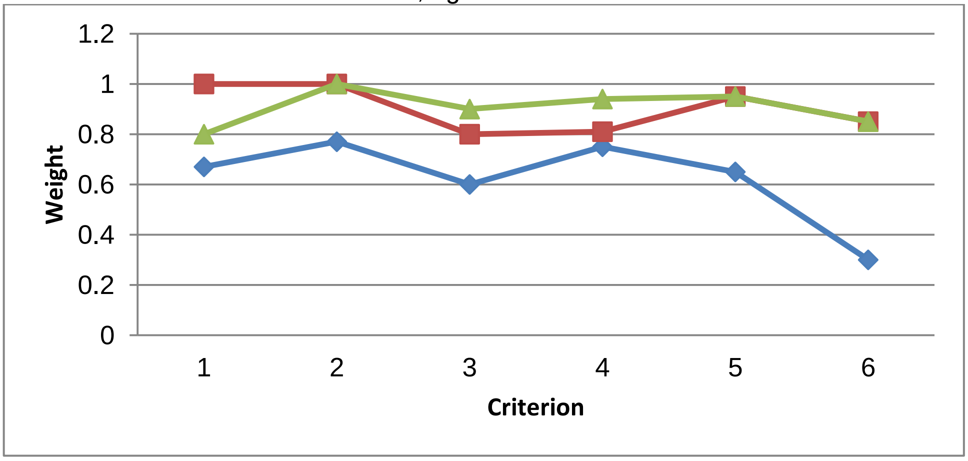


Fig.39.alternative based criterion weight variation, Blue: alternative 1, Red: alternative 2, Green: alternative 3.

Emerged technology aided conventional-CNC lathe remanufacturing is the best decision to be made which is the alternative of number two. It can balance most criteria to simulate optimal choice, in terms of the perspective of remanufacturing cost and remanufacturing time criteria, alternative 2 is the best to be not comparable. Accuracy of Alternative 2 and Alternative 3 are equal and higher than that of Alternative 1. Even reliability and processing efficiency of Alternative 3 are the higher, but Alternative 2 exhibits good mixture of effective criteria and this can be supported through the features of evaluation curves that show processing range and ergonomics criteria are of the same values for alternative 2 and alternative 3. Optimal comprehensive benefits of alternative 2 indicate that the decision-making of conventional remanufacturing emphasizes the overall perspective instead of one certain perspective. Figure 2 shows the lathe remanufacturing process. The results show that the accuracy, reliability, processing range, processing efficiency and ergonomics can certain high performance that is equivalent to performance of new machine tool, of the remanufactured conventional lathe into CNC machine with a cost which is only about (40%-50%) . Since more than 80% of lathe added-value can be reused, like new conditions lathe restoration is a low-cost alternative solution.

3.3 IMPACT FACTORS BASED DECISION-MAKING ANALYSIS

1- AHP-entropy weight method can be used to determine the weight of each criterion.
2- Different preferences of users or decision-makers will affect final criteria weights and may affect final decision result.
3- Determine the final evaluation value takes inconsideration evaluation value of five grades which will directly affect the final decision.
4- Any change in evaluation value of each grade will affect the choice to be made.

Comprehensive alternative weight can be of different values according to used converting techniques to change experience and preferences expression to be classified into an entropy weight, analytical hierarchy weight, or hybrid weight of analytical hierarchy- entropy, figure 35.

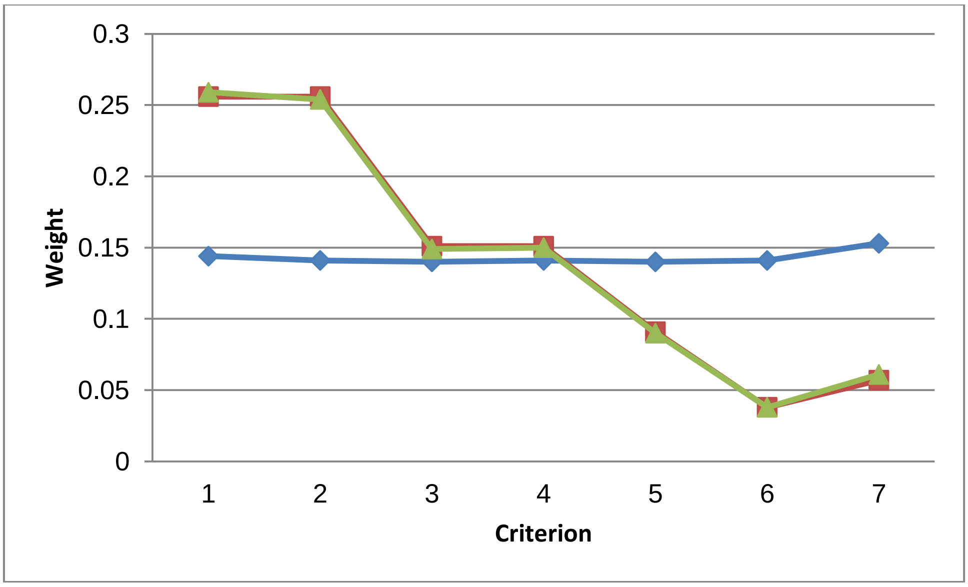


Fig.40.Converting techniques based criterion weight variation, Blue: entropy weight, Red: analytical hierarchy weight, Green: hybrid weight of analytical hierarchy- entropy.

3.4 UNCERTAINTY MODELING

By surveying literature and application of comparative literature based analysis [1]-[18],remanufacturing experience based analysis and scenario based analysis , main reasons of uncertainty of lathe remanufacturing can be of weight values as in weight-distribution curve as shown in figures35-40. Failure mode based uncertainty reason analysis and modeling, can be explained as following:-

<u>3.4.1 *Spindle Gearbox, figure 36*</u>

3.4.1.1 Conventional-Conventional lathe remanufacturing: Spindle Gearbox is Reused, Reconditioned, or New which needs several studying attempts to find solution so it is a reason of uncertainty which can be weighted as (0.662).

3.4.1.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Spindle gearbox is reused and modified or reconditioned and modified where gear ratio can be constant while spindle is driven by motor which is controlled by mean of AC current invertor with emerged technology which is available. So it is a reason of uncertainty which can be weighted as (0.398).

3.4.1.3 Advanced technology aided conventional-CNC lathe remanufacturing: Spindle gearbox is reused and modified or reconditioned and modified where gear ratio can be constant while spindle is driven by motor which is controlled by mean of AC current invertor with advanced technology which means that waiting time is required. So it is a reason of uncertainty which can be weighted as (0.592).

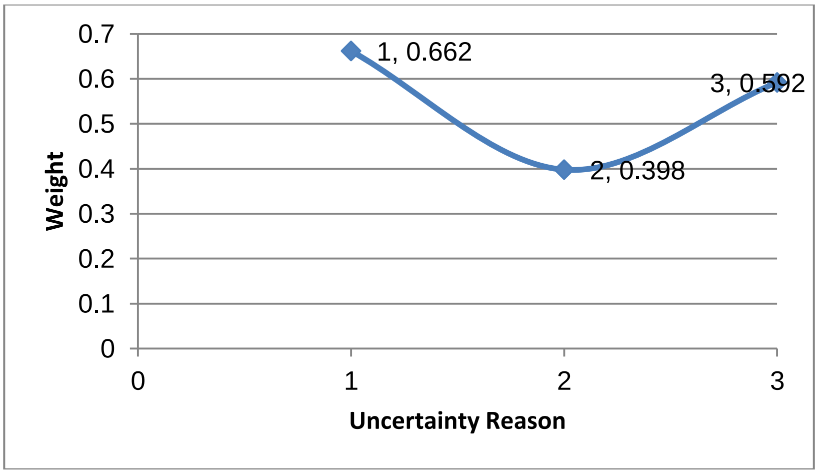


Fig.41.Weight-Uncertainty reason curve of Spindle Gearbox.

3.4.2 Feed Rod Gearbox, figure37:

3.4.2.1 Conventional-Conventional lathe remanufacturing: Feed rod gearbox is reused, reconditioned, or new which needs several studying attempts to find solution so it is a reason of uncertainty which can be weighted as (0.662).

3.4.2.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Feed rate is removed and motorized axis is used and controlled by mean of stepper motor, servo motor or absolute motor with emerged technology which is available. So it is a reason of uncertainty which can be weighted as (0.181).

3.4.2.3 Advanced technology aided conventional-CNC lathe remanufacturing: Feed rate is removed and motorized axis is used and controlled by mean of stepper motor, servo motor or absolute motor with advanced technology which needs time to be available. So it is a reason of uncertainty which can be weighted as (0.367).

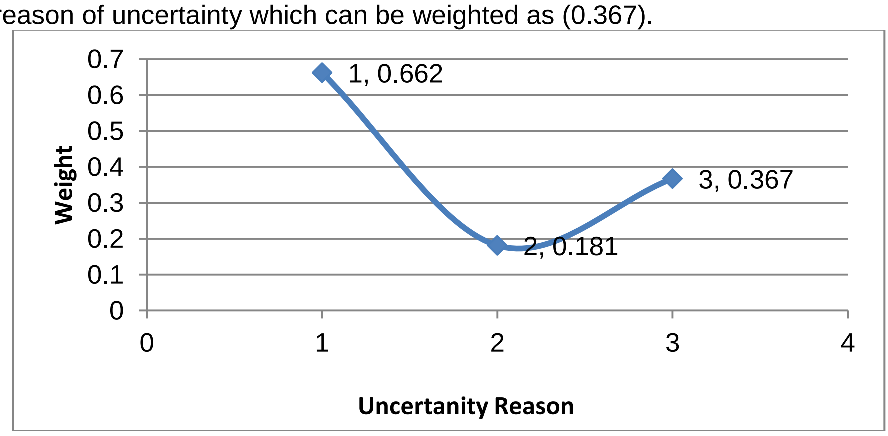


Fig.42. Weight-Uncertainty reason curve of Feed Rod Gearbox.

3.4.3 Spindle:

3.4.3.1 Conventional-Conventional lathe remanufacturing: Spindle is reused, reconditioned or new so it is a reason of uncertainty which can be weighted as (0.592).

3.4.3.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Spindle is reused, reconditioned or new so it is a reason of uncertainty which can be weighted as (0.592).

3.4.3.3 Advanced technology aided conventional-CNC lathe remanufacturing: Spindle is reused, reconditioned or new so it is a reason of uncertainty which can be weighted as (0.592).

3.4.4 Lead screw and feed rod, figure 38:

3.4.4.1 Conventional-Conventional lathe remanufacturing: Lead screw and feed rod are replaced with new ones so it is a reason of uncertainty which can be weighted as (0.120).

3.4.4.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Lead screw and feed rod are replaced by new ball screw so it is a reason of uncertainty which can be weighted as (0.181).

3.4.4.3 Advanced technology aided conventional-CNC lathe remanufacturing: Lead screw and feed rod are replaced by new ball screw so it is a reason of uncertainty which can be weighted as (0.190).

3.4.5 *Saddle, figure 39:*

3.4.5.1 Conventional-Conventional lathe remanufacturing: Saddle is reused means cannot be reconditioned which leads to refuse the lathe of worn and cracked saddle so it is a reason of uncertainty which can be weighted as (0.853).

3.4.5.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Saddle is reconditioned by new ball carriages of emerged technology so it is a reason of uncertainty which can be weighted as (0.392).

3.4.5.3 Advanced technology aided conventional-CNC lathe remanufacturing: Saddle is reconditioned by new ball carriages of advanced technology so it is a reason of uncertainty which can be weighted as (0.592).

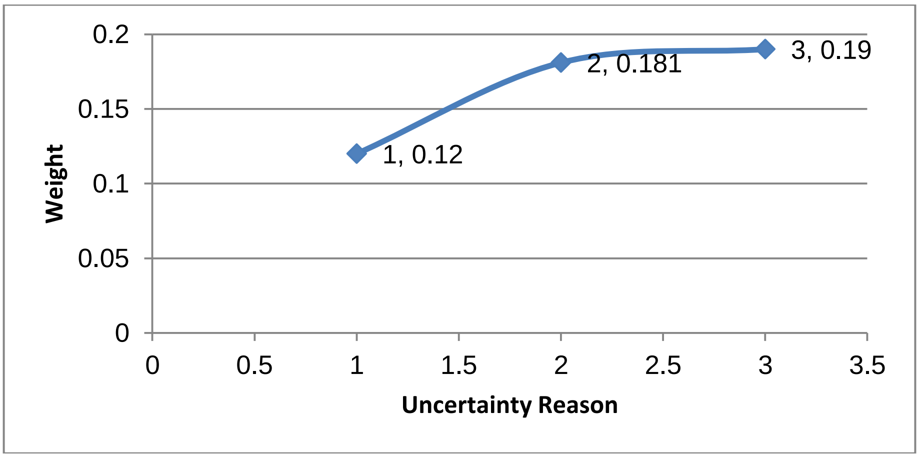


Fig.43. Weight-Uncertainty reason curve of Lead screw and feed rod.

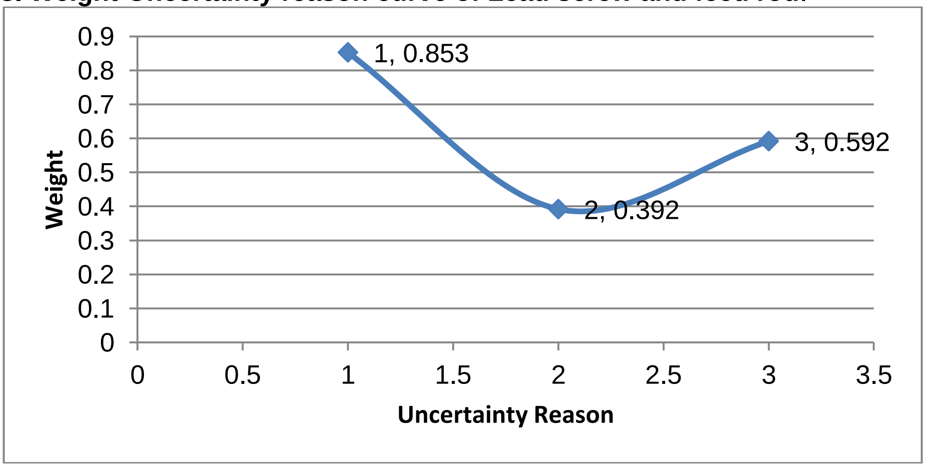


Fig.44.Weight-Uncertainty reason curve of Saddle.

3.2.6 *Tool Post, figure 45:*

3.2.6.1 Conventional-Conventional lathe remanufacturing: Tool post is replaced with new one so it is a reason of uncertainty which can be weighted as (0.120).

3.2.6.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Tool post is replaced with new automatic tool changer of emerged technology so it is a reason of uncertainty which can be weighted as (0.181).

3.2.6.3 Advanced technology aided conventional-CNC lathe remanufacturing: Tool post is replaced with new automatic tool changer of emerged technology so it is a reason of uncertainty which can be weighted as (0.190).

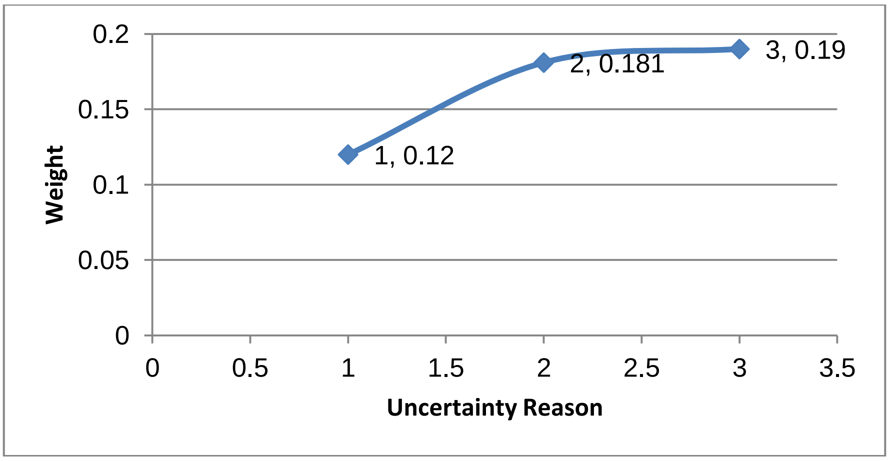


Fig.45.Weight-Uncertainty reason curve of Tool Post.

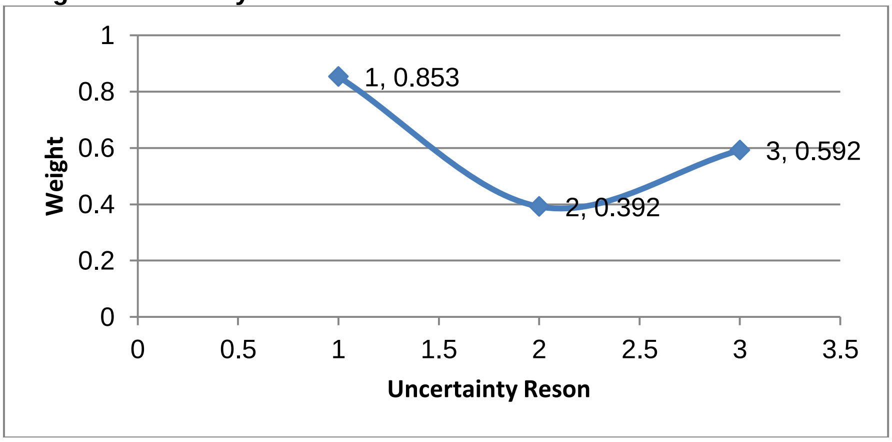


Fig.46. Weight-Uncertainty reason curve of guide rail.

<u>3.2.7 *Guide Rail, figure45:*</u>

3.2.7.1 Conventional-Conventional lathe remanufacturing: Guide rail is reused means cannot be reconditioned which leads to refuse the lathe of worn and cracked guide rail so it is a reason of uncertainty which can be weighted as (0.853).

3.2.7.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Guide rail is reconditioned by new ball guide ways of emerged technology so it is a reason of uncertainty which can be weighted as (0.392).

3.2.7.3 Advanced technology aided conventional-CNC lathe remanufacturing: Guide rail is reconditioned by new ball guide ways of emerged technology so it is a reason of uncertainty which can be weighted as (0.592).

<u>3.2.8 *Tailstock:*</u>

3.2.8.1 Conventional-Conventional lathe remanufacturing: Tailstock is reused so it is a reason of uncertainty which can be weighted as (0.067).

3.2.8.2 Emerged technology aided Conventional-CNC lathe remanufacturing: Tailstock is reused so it is a reason of uncertainty which can be weighted as (0.067).

3.2.8.3 Advanced technology aided conventional-CNC lathe remanufacturing: Tailstock is reused so it is a reason of uncertainty which can be weighted as (0.067).

Table 3 show fuzzy triangular number based assessment.

Table 3: Remanufacturing Alternatives Uncertainty Optimization Fuzzy Numbers.

Uncertainty Reason	**A_1(0.535)**	**A_2(0.853)**	**A_2(0.748)**

Spindle Gearbox	(0.662,0.354,0.508)	(0.398,0.339,0.369)	(0.592,0.443,0.518)
Feed Rod Gearbox	(0.662,0.354,0.508)	(0.181,0.154,0.168)	(0.367,0.275,0.321)
Spindle	(0.592,0.316,0.454)	(0.592,0.505,0.549)	(0.592,0.443,0.518)
Lead screw and feed rod	(0.120,0.064,0.092)	(0.181,0.154,0.168)	(0.190,0.142,0.166)
Saddle	(0.853,0.456,0.655)	(0.392,0.334,0.363)	(0.592,0.443,0.518)
Tool Post	(0.120,0.064,0.092)	(0.181,0.154,0.168)	(0.190,0.142,0.166)
Guide Rail	(0.853,0.456,0.655)	(0.392,0.334,0.363)	(0.592,0.443,0.518)
Tailstock	(0.067,0.036,0.052)	(0.067,0.057,0.062)	(0.067,0.050,0.059)

4. CONCLUSION

Lathe remanufacturing into CNC machine can simplify the analysis complexity due to uncertainty of the lathe remanufacturing process which can be overcome through compensative behavior of worm surface which leads to save added-value parts of lathe and highly reduce the potentials of uncertainty.
The uncertainty of the remanufacturing process analysis can improve the success rate of lathe remanufacturing and reduce the difficulty of into CNC machine upgrading.
Comparative literature can provide reasonable and scientific quantitative method for the weighting and ranking of criteria to be used for investigation based analysis to determine the optimal alternative solution that satisfies:-

- Reduce the cost of lathe remanufacturing.
- Improve the performance of remanufactured lathe.
- Achieve the highest value-added restoration by remanufacturing.

It is an actual remanufacturing process compared decision-making result orientation with self-correction based on relevant criteria to make lathe remanufacturing decision to provide scientific aided simplified selecting method.
Figure 47 is the application of replacing of frictional linear guide ways which are dovetail guide ways by linear ball guides ways for structural characteristics improving for conventional milling into CNC machine remanufacturing [11].
The replacing is applied for the both parts of dovetail guide way where the rail of linear ball guide way is attached to the male dovetail guide way. While carriage of linear ball guide way is used to replace the female dovetail guide. Figuratively, the reconditioning process is the replacing of dovetail guide way by linear ball guide way, figure 48. Thus, jib strip of dovetail guide ways can be removed so friction can be highly reduce and mechanical hysteresis can be reduced through linear ball guide ways which leads to improve mechanical characteristic of remanufactured lathe to be reflected as an improvement in Accuracy, reliability, and processing efficiency of remanufactured lathe into CNC machine.

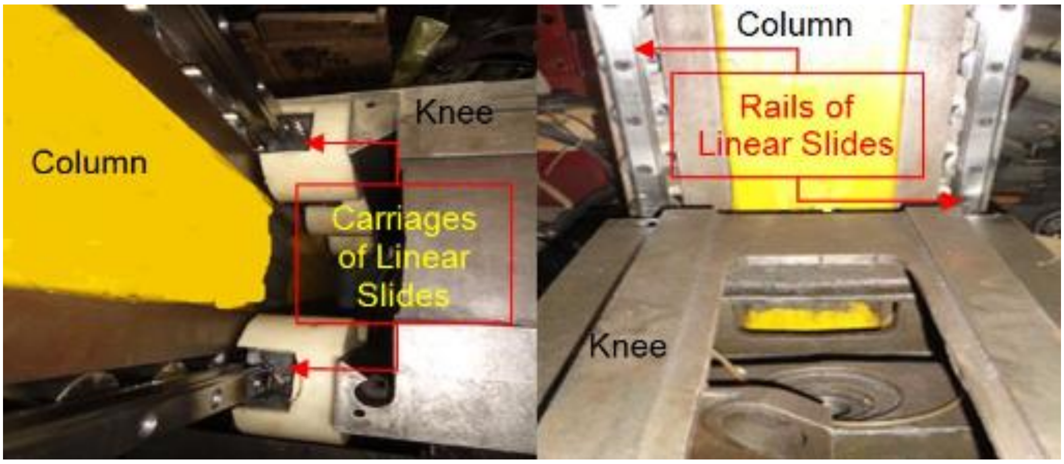


Fig.47.Feed rod based remanufacturing uncertainty optimization.

Assembly-disassembly based remanufacturing difficulty analysis, table 4,shows the applicability of Mate/Insert and Mate/Insert/Bolt fastening system to fulfill integrating CNC machine technology within structure of conventional lathe to change into CNC so that structural characters can maintain enough accuracy, precision and repeatability. Uncertainty optimization of spindle gearbox,figure44, feed rod,figure45, spindle,figure46, lead screw and feed rod,figure47, saddle ,figure48, tool post,figure49, Guide rail,figure50, and Tailstock,figure51.

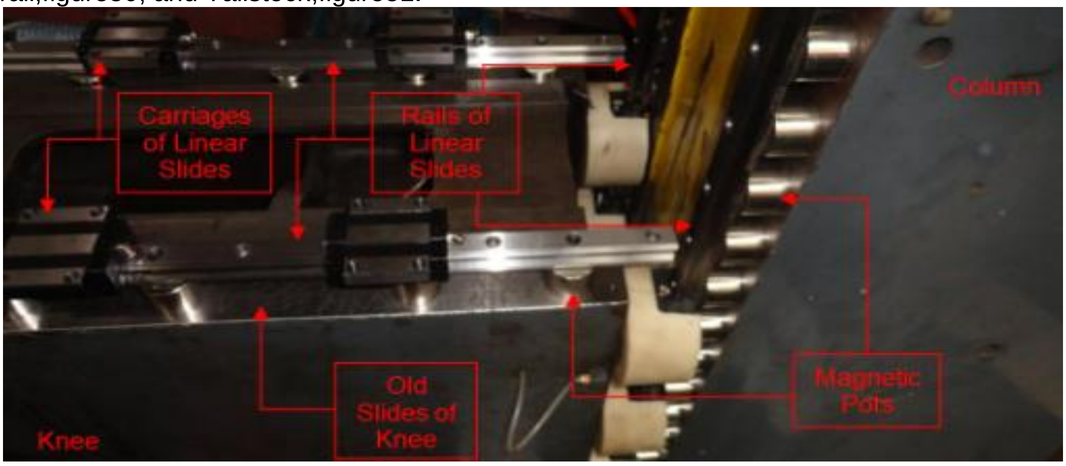


Fig.48.Feed rod based remanufacturing uncertainty optimization.

Table 4. Assembly-disassembly based remanufacturing difficulty analysis

Fastening-Unfastening Manner	**Assembly-Disassembly Difficulty Qualitative Measure**	**Difficulty Weight (0.778)**	**Substrate Deformation Weight (0.222)**	**Priority Weight**	**Rank**
Mate/Insert	Below Average	0.3	0.120	0.260	1
Mate/Insert/Bolt	Average	0.4	0.279	0.373	2
Bolt/Bolt-Nut/Screw	Above Average	0.5	0.345	0.466	3
Gear/Belt-Mesh	High	0.7	0.533	0.663	4
Key/Interference Fit/Bearing	Very High	0.8	0.635	0.763	5

Rivet/Welding	Extremely High	0.9	0.840	0.886	6

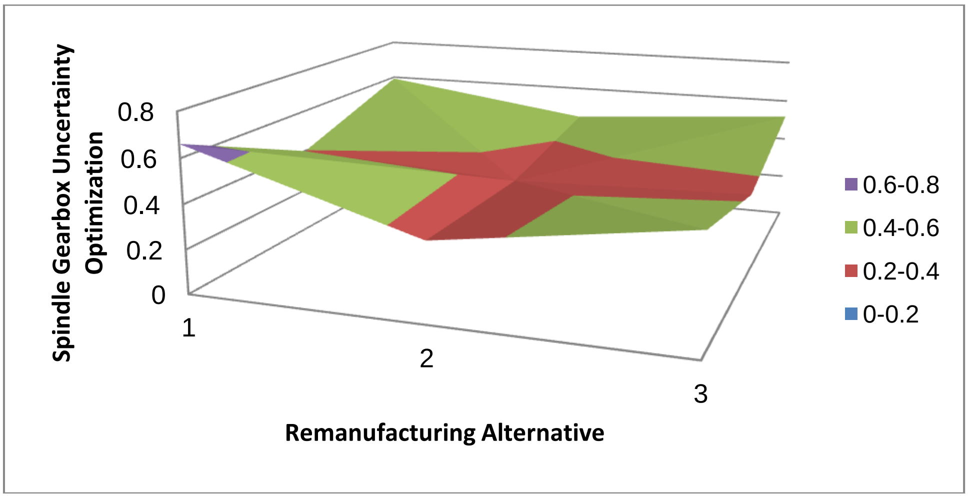


Fig.49.Spindle gearbox based remanufacturing uncertainty optimization.

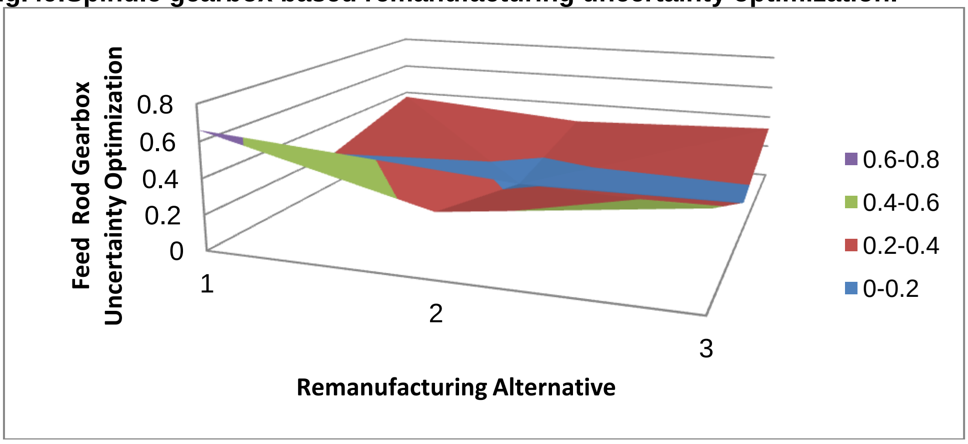


Fig.50.Feed rod based remanufacturing uncertainty optimization.

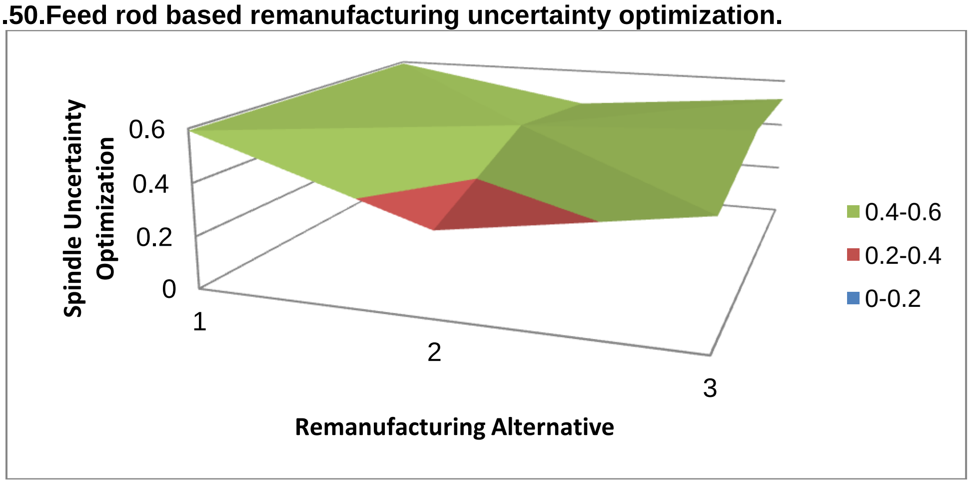


Fig.51.Spindle based remanufacturing uncertainty optimization.

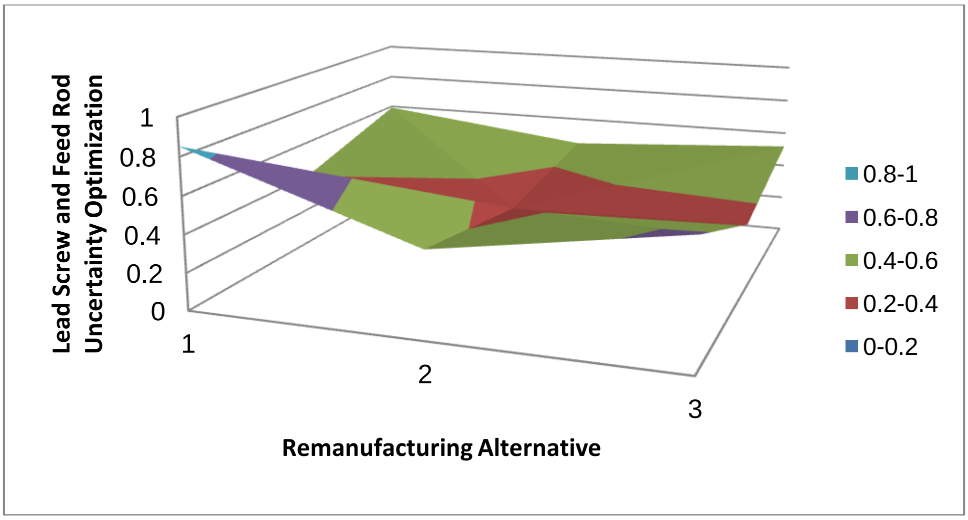


Fig.52.Lead screw and feed rod based remanufacturing uncertainty optimization.

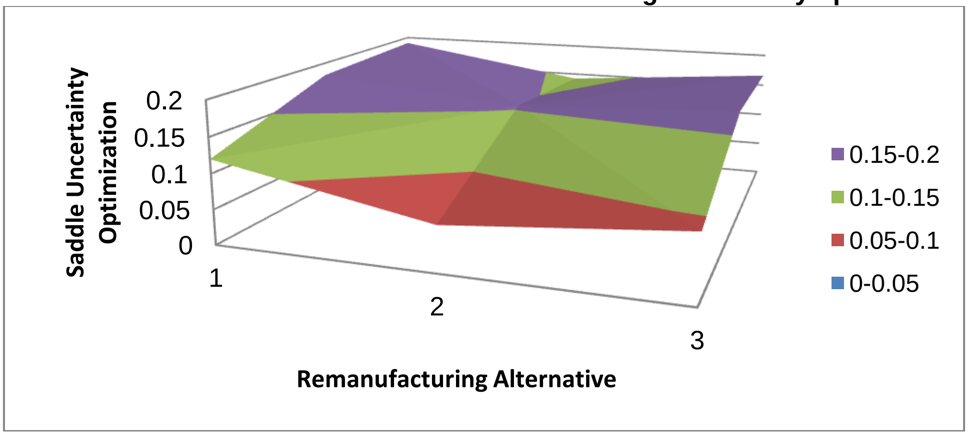


Fig.53.Saddle based remanufacturing uncertainty optimization.

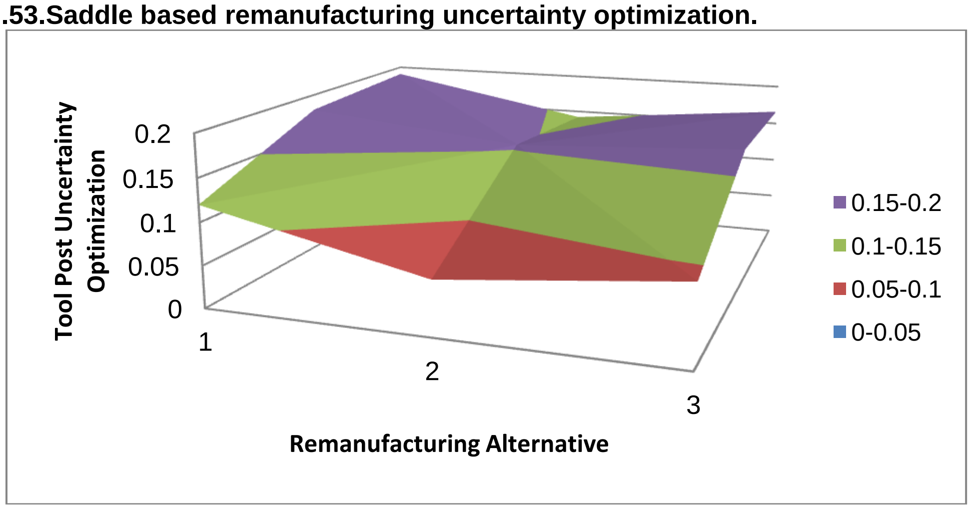


Fig.54.Tool post based remanufacturing uncertainty optimization.

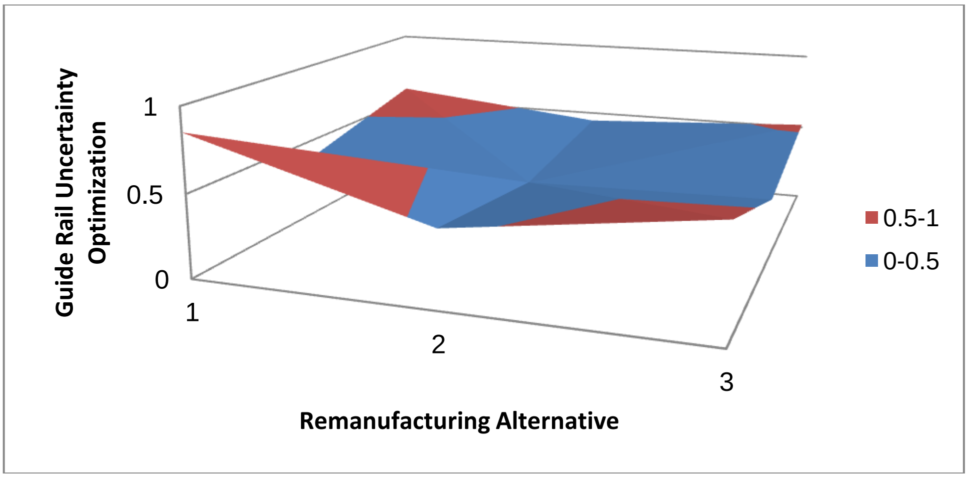


Fig.55.Guide rail based remanufacturing uncertainty optimization.

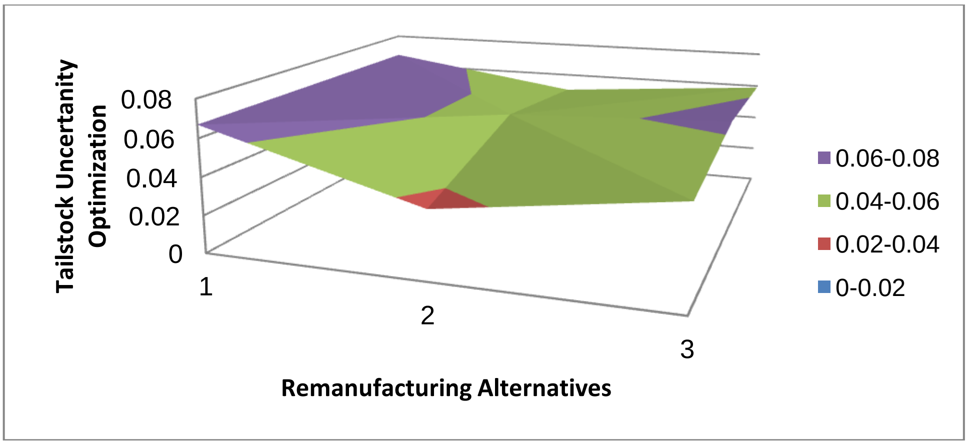


Fig.56.Tailstock based remanufacturing uncertainty optimization.

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APPENDIX