Sustainability Modeling Approach on Remanufacturing Conventional Lathe into CNC Machine Tool

Ziyad Tariq Abdullah[1*], Ekhlas Ahmad Abdulrazaq[1] and Sara Saad Ghazi[1]

[1]Mechanical Techniques Department, Institute of Technology-Baghdad,
Middle Technical University, Baghdad, Iraq.

Authors' contributions

This work was carried out in collaboration among all authors. Author ZTA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author EAA managed the analyses of the study. Author SSG managed the literature searches. All authors read and approved the final manuscript.

Article Information

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ABSTRACT

Aims: Sustainability 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 mixed with literature based analysis to weight the criteria and the alternatives of assessment. Global weights are found to rank the alternatives. Suitable literature can be projected comparatively to construct sustainability model. Sustainability assessment models 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 2019 and 2020.
Methodology: 1- Literature survey to find out the most used sustainability assessment criteria.
2-Economic, environmental and social criteria specifying.
3-Normilizing weights of criteria.

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*Corresponding author: E-mail: ziyadtariqabdullah@gmail.com, ziyad7tariq@yahoo.com;

4- Matching local weights of assessment criteria with fuzzy triangular numbers to find out the whole weights.

5-Senairo based analysis application to find out alternatives of remanufacturing.

6-Weighting alternatives, criteria and sub-criteria.

7- Find global weights and rank the alternatives.

Decision making for selection of remanufactured alternatives and remanufacturing alternatives can include :(1) Spindle , gearbox and dovetail guide ways reuse scenario. (2) Spindle remanufacturing scenario. (3) Gearbox remanufacturing scenario. (4) Dovetail guide ways remanufacturing scenario.(5) Spindle and gearbox remanufacturing scenario. (6) Spindle and dovetail guide ways remanufacturing scenario. (7) Spindle, gearbox and dovetail guide ways remanufacturing scenario. Alternatives in field of machine tools remanufacturing are reviewed. Experience in field of machine tool remanufacturing is exploited to remodeling the existence models to optimize a remanufactured lathe into CNC machine case study.

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. The most promising technological key is the use of mate/insert/screw to assembly ball guide ways to disable dovetail guide ways and highlight structural specifications of CNC lathe. Thus precision, accuracy, repeatability and reliability will be enhanced considerably. Comparative literature based analysis and experience based analysis with uncertainty reduction can substitute the leak of relevant data acquisition for remanufacturing-upgrading modeling. Which enables simplify certain difficulties and the calculations of some criteria and adopts simplified methods so that theoretic and practical gap can be directed towards certain actual conditions to reach the optimum solution.

1. INTRODUCTION

Several remanufacturing-upgrading alternatives should be studied since lathe is of various structural characteristics which lead to different uncertainties in the service process. Cost performance and customer concern satisfaction represent a complicated function of remanufacturing cost, remanufacturing time, accuracy, reliability, processing efficiency, processing range and ergonomics which can be the evaluation criteria. Quantitative methods analyzing that incorporate these criteria need to be studied to suggest relatively simple quantitative method to determine the evaluation weights and decide the rank of alternative. Uncertainty will lead to suggest different preferences for each criterion so different weights can be related to same criterion. Entropy based analytical hierarchy process can determine the weights of evaluation criteria to be theorized to be used as decision making method of lathe remanufacturing-upgrading and form a relatively optimal solution to help improve the comprehensive benefits of lathe remanufacturing-upgrading. Many considerations let the decision making to select suitable alternative to be complex problem where unreasonable decisions can result in significant losses to the degree of that final choice of the alternative is not necessarily optimal which required to be corrected based on experience in the implementation of remanufacturing-upgrading of lathe and literature adjusted information. Excessive uncertainty of remanufacturing-upgrading process of lathe alters process of definitive optimal alternative solution of lathe remanufacturing-upgrading. As example, For simplifying purposes, criterion evaluation process may not quantify the uncertainty of the remanufacturing-upgrading. Quantification method can suffer from irrelevant data so that the calculation of some criteria needs to be simplified which causes a gap between quantified and exact solutions. The acquisition of relevant data for decision making has certain difficulties and

the calculation of some criteria adopts a simplified method, thus there is a certain gap with the actual conditions. Studies of lathe remanufacturing-upgrading can include uncertainty of both of the lathe to be remanufactured and the remanufacturing process to be used for remanufacturing-upgrading. More criteria can be integrated within the decision making process to be comprehensive benefits assessment based multiple stakeholders system to determine the optimal alternative solution which can satisfy [1]:-

1- Reduce the cost of lathe remanufacturing-upgrading.
2- Improve the performance of lathe through change it into CNC machine.
3- Achieve high value-added remanufacturing-upgrading.
4- Improve the success rate of lathe remanufacturing-upgrading.
5- Reduce the difficulty of lathe remanufacturing-upgrading

Lathe remanufacturing-upgrading is obviously of fully utilizing of the used resources with advantages of low cost, energy saving and environmental friendliness and promising strategy of developing closed loop economy to recycle the used resources of lathe and upgrade the functionality and re-manufacturability of the conventional machine tool. Lathe remanufacturing-upgrading is a new remanufacturing mode for high demands of productivity and energy efficiency. Original equipment manufacturers of machine tool can conduct lathe remanufacturing-upgrading as a new development strategy for gathering advantages of develop original brand based remanufacturing as a strategy of human development and employment where technology, equipment, logistics and talented persons are interact to accumulate[2].

Cost, quality, time and service are performance assessment criteria of hybrid eco-social effects to highlight the integrated environmental effect of remanufacturing system as environmental conscious technology. Remanufacturing technology alternatives can be environmentally evaluated through adoption of different criteria of resource consumption and process emission. Generally different criteria can be utilized to represent the area of performance and specific measures should be defined to quantify each criterion to study the performance. A set of limited candidates technologies under constraints of financial capital and human resources which represent remanufacturing-upgrading alternatives can be called remanufacturing technology portfolio.

As example, if the remanufacturing technologies include:

- Buy a new CNC grinding machine
- Upgrading turning capabilities of an existing conventional lathe which include remanufacturing-upgrading with servo motors, ball screws and CNC machines features
- Purchase thermal spraying equipment.
- Procure arc welding equipment.

Then these technologies can be ordered according to faults statute to generate remanufacturing technology portfolio that can include:

1- Buy new CNC grinding machine- Remanufacturing-upgrading lathe- Purchase thermal spraying equipment.
2- Buy a new CNC grinding machine- Remanufacturing-upgrading lathe- Procure arc welding equipment.
3- Buy a new CNC grinding machine- Purchase thermal spraying equipment - Procure arc welding equipment.
4- Remanufacturing-upgrading lathe- Purchase thermal spraying equipment- Procure arc welding equipment.

Financial capital and human resources of alternative number two, which includes remanufactured-upgraded lathe to be used for remanufacturing, is the best with good singular benefit, highest synergistic benefit and lowest portfolio cost.

Considering synergistic effects of technologies are helpful because [3]:-

1- Technology portfolio cannot consider the overall enterprise benefit.

2- Technology portfolio that produces significant synergistic benefits can be more attractive than a technology with high singular benefit.

Remanufacturing-upgrading performance of a lathe can be assessed by using criteria of reliability and cost where a remanufactured-upgraded lathe can cost only (40%-60%) of a new lathe and better machining accuracy and

production efficiency can be offered. Lathe bed includes dovetail guide ways, saddle and spindle which are repairable components and can encounter faults of crack, wear and corrosion. Remanufacturing technology portfolio alternative operations to recovery the faults can include:

1- Cold welding and grinding respectively to restore dovetail guide ways which suffers from cracks.
2- Cold welding, milling and grinding respectively to restore spindle which suffers from cracks.
3- Grinding, laser cladding and fine grinding respectively to restore saddle which suffers from cracks.

Consideration of failure rate of remanufacturing portfolio, capability of remanufacturing portfolio and decay of machines and tool which are affected by the quality of returned products can be used to model reliability. Remanufacturing process planning is an optimization process of decision making to select the optimum sequence of remanufacturing technologies within a certain group of portfolios. Improve efficiency of remanufacturing portfolio and the reliability of remanufactured-upgraded lathe and reduce process cost can be fulfilled by integrating the quality of returned conventional lathe within evaluation model of remanufacturing process [4].

To optimize the remanufacturing process of a lathe, keeping costs low can maximize the resulting service life and efficiency. Damaged and worn lathes are with varying level of damage and remaining life of each component so that components need to be evaluated in terms of damage level and remaining life before determining the optimal value recovery options. The failure mode of wear can be measured through comparison of the images of component to be remanufactured with new one. Quantified damage level can remaining life of components for the identical lathe can also be obtained using similar analysis. Quantified damage condition based remaining life of used components can be developed to evaluate the lathe comprehensively and identify the value recovery options of used components. The remaining life deviation from the life of the product as a whole can be measured according to recovered individual components. Cost criterion can be modeled for selecting the remanufacturing portfolio alternative and modeling can be done based on the remaining life value recovery options for used components. Extend the remaining useful life of

a conventional lathe can be through recovering of valuable components and using components as an application of remanufacturing to reduce production cost. Value recovery options for each component can include new, reuse and reconditioned scenarios to be forecasted by each valuable component of a conventional lathe. So that value recovery process is combinatorial optimization problem. To obtain the optimal remanufacturing portfolio alternative of valuable components and improve the economic benefits from remanufacturing, an evaluation criterion is required to be quantified within insights of damage level and remaining life of used components to identify value recovery options for each used component [5].

Lathe remanufacturing requirements can include [6]:

1- Easy to disassemble.
2- Disassembly stability.
3- Damage resistance.
4- Clear wear conditions.
5- Upgradable.
6- Reliability, stability and safety.
7- Clear working life.
8- Easily identifiable.

Lathe remanufacturing can be assessed by using criterion of remanufacturing performance design which is mainly reflected in two aspects:

1- Disassembly criterion.
2- Reassembly criterion.

Non-destructive disassembly of product is an important to be guaranteed so that remanufacturing process can success. Disassemblability can be analyzed to solve all problems during design stage by checking:

1- If the components of lathe can be reduced.
2- If disassembly costs can be reduced.
3- If disassembly time can be shorter.

Technical, economic and environmental measures criteria can be used to construct a comprehensive sustainability evaluation model of remanufacturing system. Evaluation process of remanufacturing sustainability of lathe spindle which is a rotating shaft that encounters alternating loads of bending and torsion which can lead to cause torsional fatigue and bending fatigue fractures. According to faults statutes analysis, at high-speed operation spindle can suffer from severe vibration may cause excessive deformation, cracks or fatigue fracture.

Remanufacturing includes process of cleaning and testing, surface repair and mechanical processing which required remanufacturing portfolio alternatives that satisfy engineering technical characteristic parameters based accuracy and reduce cost, energy consumption and carbon emissions [7].

Machine tool which in service for over twenty five years can encounter so high failure rate which is caused by long service time and bad working condition, instead of be recycled by smelting , it can be remanufactured into CNC machine tool successfully as a cost saving conscious solution instead of new purchasing. Such high added-value machine tool requires remanufacturability to be evaluated before remanufacturing to be conducted where assessment measures and criteria can include:-

- Technology feasibility is a remanufacturability measure to be controlled by criteria of disassembly, cleaning, inspection and sorting, reconditioning, upgrading and reassembly.

- Economic feasibility is a remanufacturability measure to be controlled by criterion of cost which can be divided into costs of returning used machine tool, costs of remanufacturing process and overhead costs.

- Environmental benefits is a remanufacturability measure to be controlled by criteria of material saving, energy saving and pollution reduction.

Upgrading potentials can include:-

1- Backwards in controlling technology can be replaced with an emerged CNC control.
2- High energy consumption can be reduced by introduction of emerged CNC technology.

Machining accuracy of the machine tool can be as high as new one due to structural characteristics enhancing due to ball screws, servo motors and closed loop system introduction [8].

Various failure types and failure degrees 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 a decision making assessment. Economic indicator, quality, resource consumption and environmental emission can be used as sustainability or remanufacturability assessment criteria which can lead to more efficient and cleaner remanufacturing. Remanufacturability can be defined as the suitability of the component to be remanufactured. Due to the different faults conditions, component can be restored according to multiple process remanufacturing portfolios so they have different remanufacturability even they have the same structure but of different faults conditions [9].

Faults features and damage degrees can be characterized and quantified by using fault tree analysis and fuzzy comprehensive evaluation to be used for optimization of remanufacturing portfolio planning. Reasoning rules and operation paths can be applied to generate remanufacturing portfolio alternatives. Optimization model that considers quantification of fault features and multi-objective optimization are more feasible and effective than other models. Faults features can be quantified and integrated within unified platform to enable process of portfolio planning optimization. Remanufacturing portfolio optimization to release the maximum residual value of used components that satisfy the lowest of cost, energy consumption and time requires different restoring portfolios to be studied and practiced due to the different damage degrees and fault locations. Based on quantified fault features, environmental factors and remanufacturing knowledge have impacts on the optimization process of remanufacturing portfolio planning so that they should be taken into consideration for optimizing remanufacturing process planning [10].

The characteristics of remanufacturing knowledge resources can be used to develop evaluation index attributes of remanufacturing service which provide a relatively better referential based evidences evaluation. The mutual isolation between indexes and the weighted differences of primary indexes to reveal the causal relationship between indexes can make the result more accurate and objective. Objectivity, problems of evaluation methods reduce the influence of subjective factors and realize the objective and comprehensive evaluation and selection. As example, technological viability of remanufacturing of lathe dovetail guide ways and saddles by cold welding

process needs the basic knowledge of material, size of the dovetail guide ways, pretreatment parameter information, the basic information of grinding tools, the knowledge of welding repair principle and the knowledge of post-welding processing to be involved within selection, evaluation and modeling of quality of such remanufacturing service. Experts based indexes establishing can be exploited to weight criteria of remanufacturability measures which can include [11]:

- Time measure includes criteria of response time, execution time and reverses logistics transport time.

- Cost measure includes criteria of rental prices for integrated platforms, cost of knowledge services, cost of processing and testing and default fine.

- Flexibility measure includes criteria of service resources and service module.

- Security measure includes criteria of network operation, knowledge transfer and Information storage.

- Reliability measure includes criteria of scheme, craft and Knowledge.

- Scalability includes criteria of includes technology and scale.

2. CRITERIA SELECTION, WEIGHTS NORMILIZING, FUZZICATION AND GLOBAL WEIGHTING, RANKING METHODOLOGY

2.1 Step1: Criteria Selection

By application of literature survey, comparative literature based analysis can be highlighted which is based on reviews of a sample of published papers [1-24] which contain data, information, knowledge and criteria in the following fields:-

1- Sustainability assessment.

2- Remanufacturaility assessment.

3- Remanufacturing portfolio planning assessment.

4- Sustainability based supply chain and suppliers selection.

5- Sustainably decision making.

Comprehensive remanufacturing-upgrading sustainability assessment criteria can be divided into:-

Economic sub-sustainability assessment which includes four criteria and twelve sub-criteria as following:-

1- Cost Criterion-Material Cost Sub-Criterion.

2- Cost Criterion - Freight Cost Sub-Criterion.

3- Cost Criterion-After Sale Services Cost Sub-Criterion.

4- Quality Criterion-Rejection Rate of the Product Sub-Criterion.

5- Quality Criterion-Capability of Handling Abnormal Sub-Criterion.

6- Quality Criterion-Process of Internal quality Audit of Material Sub-Criterion.

7- Delivery and services Criterion-Lead Time Flexibility Sub-Criterion.

8- Delivery and services Criterion-After Sales Services Sub-Criterion.

9- Delivery and services Criterion-Time to Solve the Complaint Sub-Criterion.

10- Delivery and services Criterion-On Time Delivery Sub-Criterion.

11- Flexibility Criterion-Flexibility in Giving Discount Sub-Criterion.

12- Flexibility Criterion-Flexibility in Delivery Time Sub-Criterion.

Environmental sub-sustainability assessment which includes three criteria and fourteen sub-criteria as following:-

1- Environmental Management System Criterion-Environmental Performance Evaluation Sub-Criterion.

2- Environmental Management System Criterion-Eco-labeling Application Sub-Criterion.

3- Environmental Management System Criterion-Friendly Raw Material Sub-Criterion.

4- Green Products Criterion-Reuse Sub-Criterion.

5- Green Products Criterion-Green Packaging Sub-Criterion.

6- Green Products Criterion-Air Emission Sub-Criterion.

7- Green Products Criterion-Waste Water Sub-Criterion.

8- Green Products Criterion-Hazardous Waste Sub-Criterion.

9- Green Warehousing Criterion-Inventory of Non-Hazardous Substances Sub-Criterion.

10- Green Warehousing Criterion-Warehouse Management Sub-Criterion.

11- Eco-design Criterion-Remanufacturing of Product When Design Sub-Criterion.

12- Eco-design Criterion-Reduction of the Use of Hazardous Materials Sub-Criterion.

13- Eco-design Criterion-Ability to Alter Process and Product for Reducing the Impact on Natural Resources Sub-Criterion.

14- Eco-design Criterion-Material used in the Supplied Components that Reduce the Impact on Natural Resources Sub-Criterion.

Social sub-sustainability assessment which includes one criterion and five sub-criteria as following:-

1- Social Performance Criterion-Work Place Design Sub-Criterion.

2- Social Performance Criterion-Ergonomics and Safety Sub-Criterion.

3- Social Performance Criterion-Training and Development of Employee Sub-Criterion.

4- Social Performance Criterion-Innovation Management Sub-Criterion.

5- Social Performance Criterion-Corporate Image Sub-Criterion.

2.2 Step2: Local Weights Normalizing

High variation in values of weights which requires to divide criteria into different groups according to their references then values of weights are divided on the weight of highest importance of each group of criteria. Thus the variation of weights of criteria can be isolated and new importance of each criterion is assigned through comparative literature based analysis and remanufacturing experience based application. Thus economic measure with criteria of cost, quality, delivery and flexibility and twelve sub-criteria are emerged. Environmental measure with criteria of environmental management system, green products and eco-design and fourteen sub-criteria are emerged. Social measure with criteria of social performance and five sub-criteria are emerged. The step of local weights normalizing and comparative literature based new local weights assignment can be concluded to include:-

1- Normalizing local weights of specified criteria of comprehensive sustainability assessment of conventional lathe into CNC machine remanufacturing-upgrading.

2- Comparative literature based analysis and remanufacturing experience based application are used to weight the criteria locally again.

2.3 Step 3: Fuzzacation and Global Weighting

Two different fuzzy linguistic scales are used to express the importance of criteria and preference of alternatives. Local weights of criteria help to specify the fuzzication grade of each criterion where local weights are used to put the criteria in an order and prepare them for fuzzicarion process. Preference of alternatives based fuzzy linguistic matrices construction is applied. The triangular fuzzy numbers are used to construct the matrices of local weights of alternatives evaluation. It is a hybrid approach of comparative literature based analysis and remanufacturing experience based application and triangular fuzzy numbers based mathematical modeling to find out local weights of criteria, local weights of alternatives and global weights of alternatives.

2.4 Ranking

Global weight of each alternative is calculated to be used for ranking of seven alternatives which are proposed to simulate conventional lathe remanufacturing-upgrading into CNC machine tool which are suggested by using comparative literature based analysis , remanufacturing application based experience and scenario based analysis.
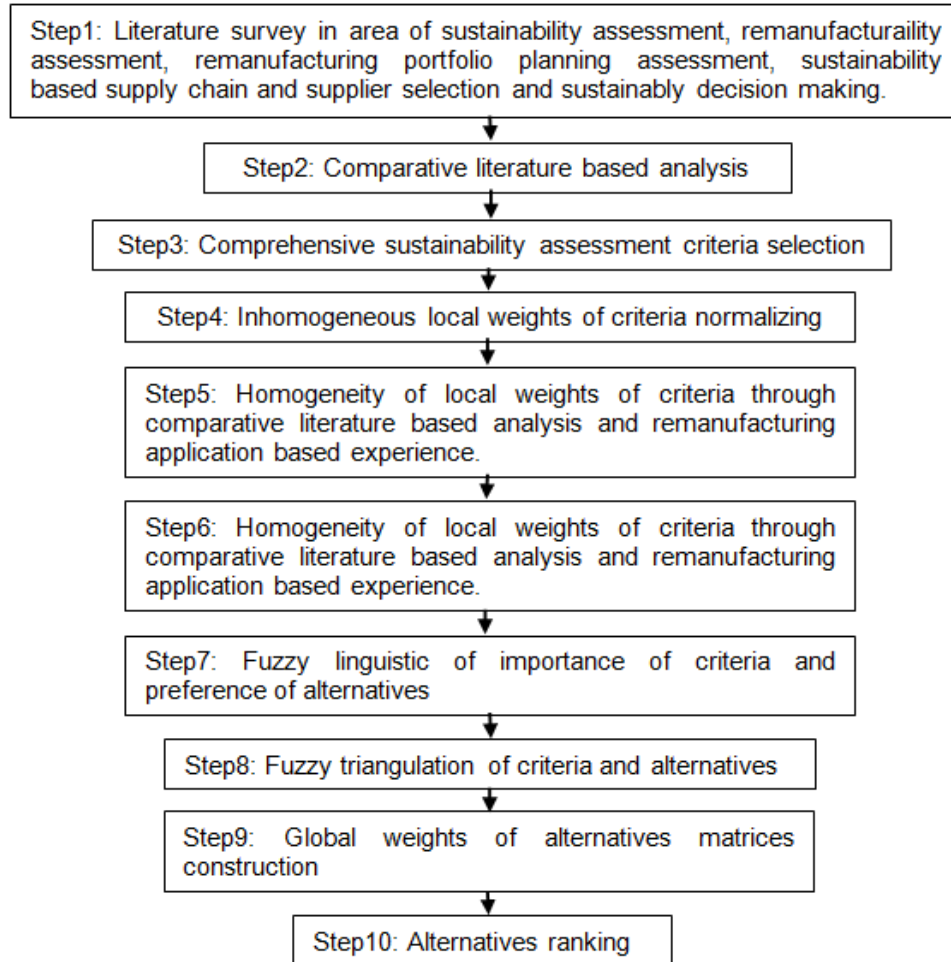
Step1: Literature survey in area of sustainability assessment, remanufacturaility assessment, remanufacturing portfolio planning assessment, sustainability based supply chain and supplier selection and sustainably decision making.

Step2: Comparative literature based analysis

Step3: Comprehensive sustainability assessment criteria selection

Step4: Inhomogeneous local weights of criteria normalizing

Step5: Homogeneity of local weights of criteria through comparative literature based analysis and remanufacturing application based experience.

Step6: Homogeneity of local weights of criteria through comparative literature based analysis and remanufacturing application based experience.

Step7: Fuzzy linguistic of importance of criteria and preference of alternatives

Step8: Fuzzy triangulation of criteria and alternatives

Step9: Global weights of alternatives matrices construction

Step10: Alternatives ranking

Fig. 1. Comprehensive sustainability assessment methodology of conventional lathe into CNC machine remanufacturing-upgrading

Fig. 1 shows comprehensive sustainability assessment methodology of conventional lathe into CNC machine remanufacturing-upgrading.

3. RESULTS AND DISCUSSION

Remanufacturing is an optimization assessment which is based on options of processes portfolio for added-value recovering where scenario based analysis is used to specify alternatives to be ranked out of group of scenarios [1-11]. A comprehensive sustainability assessment is conducted on the assumption that emerged CNC technology can be used to fulfill technologically viable remanufacturing-upgrading activities to convert conventional lathe into CNC one as shown in Fig. 2 and a comprehensive

sustainability assessment is developed through this study.

Conventional lathe remanufacturing-upgrading process portfolios, based on [1-24], include reusing or remanufacturing to recover the gearbox , spindle or guide rail and reusing of tailstock in all option while lead screw, feed rod and tailstock are replaced with new ones. Through trade-off among these option, seven scenarios of process portfolio are proposed.

In this study, scenarios based analysis states that gearbox, spindle and guide rail to be all-reused, all-remanufactured, two of them are remanufactured or one of them is remanufactured. Thus scenarios of
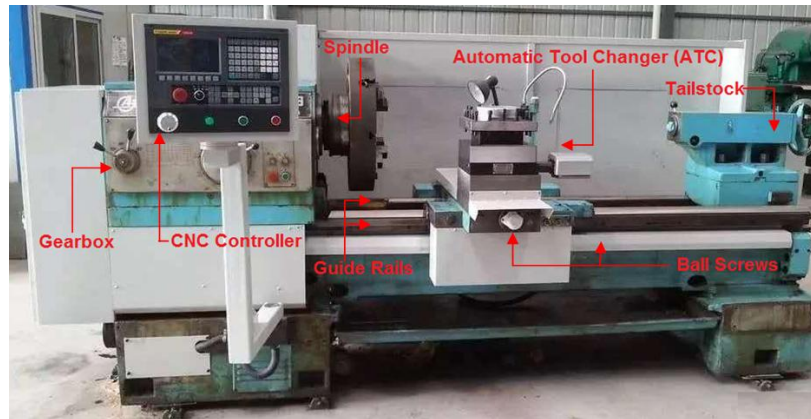
Fig. 2. Conventional lathe into CNC machine remanufacturing-upgrading

remanufacturing processes portfolio are developed where ball screws, servo motors, mounting accessories, automatic tool exchanger and CNC controller are new to be added for each processes portfolio scenario.

Remanufacturing to be of economic feasibility the following hypotheses should be adopted:

1- Dovetail guide ways which are heavy and big part of lathe bulk should be reused.
2- Remanufacturing can be done through replacing of worn component of lathe to be material substituting remanufacturing.
3- Remanufacturing can be done through adding emerged CNC technology to fulfill upgrading as a limited procedure to non-provided parts in local market.
4- Welding or cladding processes followed by machining and finishing processes to restore worn component cannot be taken in consideration since such activities cannot be done locally according to standard methods.
5- Emerged CNC technology is supposed to be integrated within each scenario to fitful upgrading. Due to reduction of power and natural resource exhaustion and reduction of waste and emissions with increasing complexity of the remanufacturing-upgrading system, and even increasing remanufacturing activities will be accompanied with exhaustion of power and natural resources and waste and emissions generation but they cannot compared with recovered embodied power and its related saving of material.

Upgrading-remanufacturing of conventional lathe into CNC lathe is analyzed based on several scenarios which are developed based on literature based analysis and experience based remanufacturing practicing. All previous work on machine tool remanufacturing, [1-24], are based on the idea of that economic and environment feasibilities revolve around the technological feasibility. Consequently sustainability based analysis of conventional lathe remanufacturing-upgrading into CNC lathe of triple bottom line of economic sub-sustainability, environmental sub-sustainability and social sub-sustainability are based on remanufacturing-upgrading process portfolio or technological feasibility or technological path.

Multiple criteria decision making literature is used to analyze the different scenarios of remanufacturing-upgrading of conventional lathe into CNC lathe. In this study, each process within portfolio of remanufacturing-upgrading is called alternative and the objective is sustainability based analysis of these alternatives and sustainability measures weights include economic, environmental and social. Criteria are used to explain the Scenario Based Analysis implicitly where (31) criteria which are distributed into (12) economic sub-criteria, (14) environmental sub-criteria and (5) social sub-criteria are used for sustainability based assessment of remanufacturing-upgrading alternatives. Comparative literature based fuzzy judgment of process portfolios of remanufacturing-upgrading includes seven scenarios of:

o Spindle, gearbox and dovetail guide ways reuse scenario.
o Spindle remanufacturing scenario.
o Gearbox remanufacturing scenario.

- o Dovetail guide ways remanufacturing scenario.
- o Spindle and gearbox remanufacturing scenario.
- o Spindle and dovetail guide ways remanufacturing scenario.
- o Spindle, gearbox and dovetail guide ways remanufacturing scenario.

3.1 Economic Sub-sustainability Assessment

Comparative literature based weight analysis, scenario based analysis and experience based remanufacturing-upgrading analysis are analysis techniques to be applied to model the effects of sub-criteria of criteria of economic performance on decision making to select the most suitable remanufacturing-upgrading portfolio. It is comparative literature based matching of local weights with triangular fuzzy number to estimate the local weights corresponding to four sets of triangular fuzzy numbers for each one of different seven scenarios to find out the global weight of each scenario. These sub-criteria are of direct effect on remanufacturing-upgrading processes portfolio which require further analysis to select the best alternative as following:-

3.1.1 Cost criterion - material cost sub-criterion

Material cost assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine to include remanufactured components and buy new components instead of reuse them will drive sub-criterion of material cost toward very poor option due to increasing of recovery expenses , while decreasing these activities will drive the sub-criterion toward very good option. Literature based analysis, material cost sub-criterion scenario based analysis and experience of remanufacturing-upgrading of conventional lathe into CNC machine activities based analysis are applied to assess material cost. Fluctuated weights at high values to be followed by more stable non-steady state at low values start at scenario 1 to continue through the whole evaluation curve until reaches the lowest at scenario 7. Weights values variation of alternative scenarios are of range of (0.05 and 0.85), Fig. 3.

3.1.2 Cost criterion - freight cost sub-criterion

Freight cost philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of freight costs toward very poor option due to increasing of recovery expenses which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. Fluctuated weights at high values start with scenario 1 to be followed by more stable non-steady state at low values to continue through the whole evaluation curve that starts at scenario 1 until reaches the lowest weight value at scenario 7. Weights values variation of alternative scenarios are of range of (0.05 and 0.76), Fig. 4.
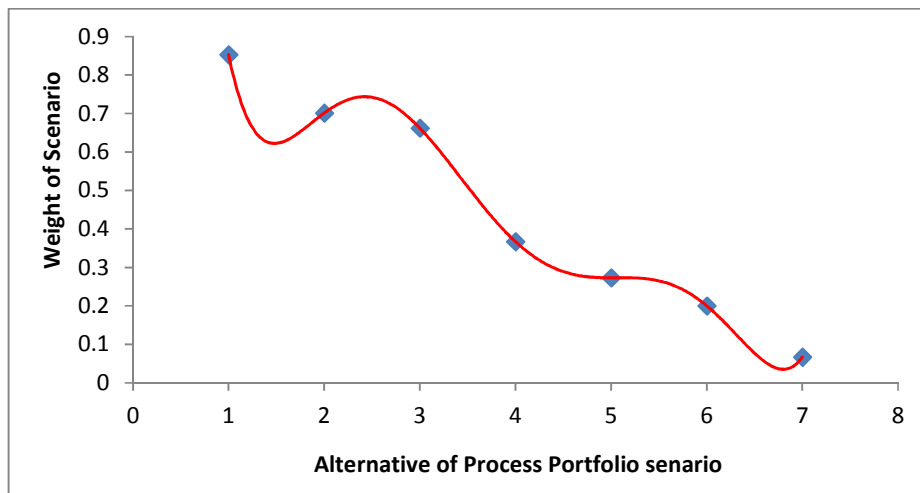

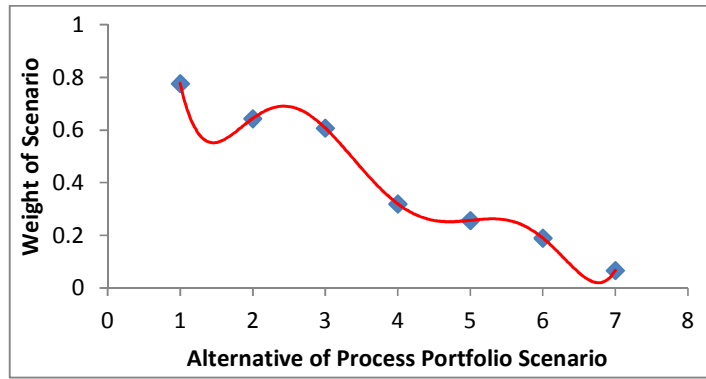**Fig. 3. Material cost sub-criterion, scenario based weight variation representation**

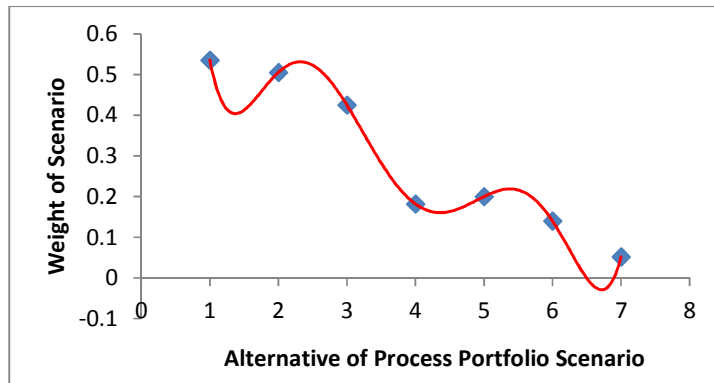**Fig. 4. Freight cost sub-criterion, scenario based weight variation representation**

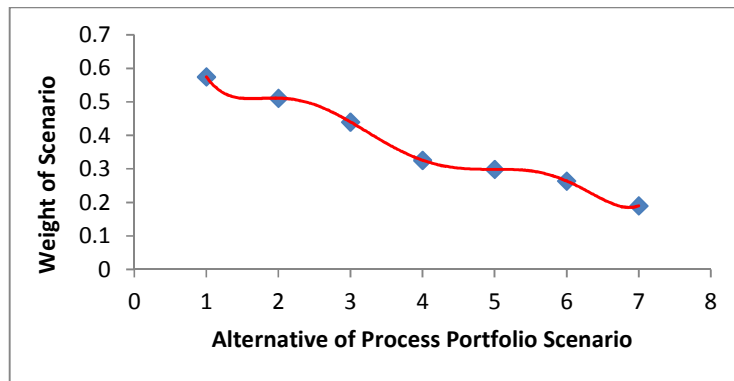**Fig. 5. After sale costs sub-criterion, scenario based weight variation representation**

Fig. 6. Rejection rate of the product sub-criterion, scenario based weight variation representation

3.1.3 Cost criterion – after sale services cost sub-criterion

After sale services cost philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of after sale services cost toward very poor option due to increasing of recovery expenses which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. Comprehensive sensitive scenario based analysis is used to model the effect of after sale services cost on decision making to select the suitable portfolio of remanufacturing-upgrading. Criterion is modeled where literature

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based analysis applied to conclude triangular fuzzy numbers to be met with weights to enable global weights calculation. Highly fluctuated and unstable non-steady state variation behavior of weights of alternative scenarios through the whole evaluation curve which starts at highest value of scenario 1 to continue until reaches the lowest value at scenario 7. Weights values variation is of range of (0.05 and 0.54), Fig. 5.

3.1.4 Quality criterion - rejection rate of the product sub-criterion

Rejection rate of the product philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of rejection rate of the product toward very poor option due to increasing of possibility of rejection to occur which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. More stable non-steady state with slight fluctuation attribute the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between high weight value of scenario 1 to continue until reaches the lowest weight value at scenario 7. Weights values variation is of range of (0.19 and 0.58), Fig. 6.

3.1.5 Quality criteria - capability of handling abnormal sub-criterion

Capability of handling abnormal assessment philosophy states that Increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of

capability of handling abnormal toward very poor option due to increasing rejection rate of product due to increasing complexity of the remanufactured-upgraded system that induce break down occurrence which limits flexibility of profit , while decreasing these activities will drive the sub-criterion toward very good option. High stable non-steady state attributes the variation of weights values of alternative scenarios through the whole evaluation curve which is limited between high weight of scenario 1 to continue until reaches the lowest weight value at scenario 7. Weights values variation is of range of (0.42 and 0.67), Fig. 7.

3.1.6 Quality criterion - process of internal quality audit of material sub-criterion

Process of internal quality audit of material assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive sub-criterion of process of internal quality audit of material toward very poor option due to increasing rejection rate of product due to increasing complexity of the remanufactured-upgraded system that induce break down occurrence which limits flexibility of profit , while decreasing these activities will drive the criterion of process of internal quality audit of material toward very good option. Stable non-steady state with slight fluctuation attribute the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between high weight value of scenario 1 to continue until reaches the lowest weight value at scenario 7. Weights values variation is of range of (0.4 and 0.65), Fig. 8.
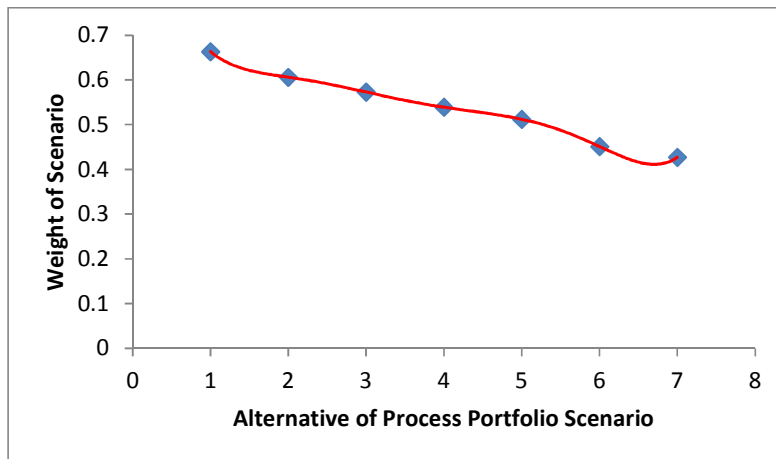

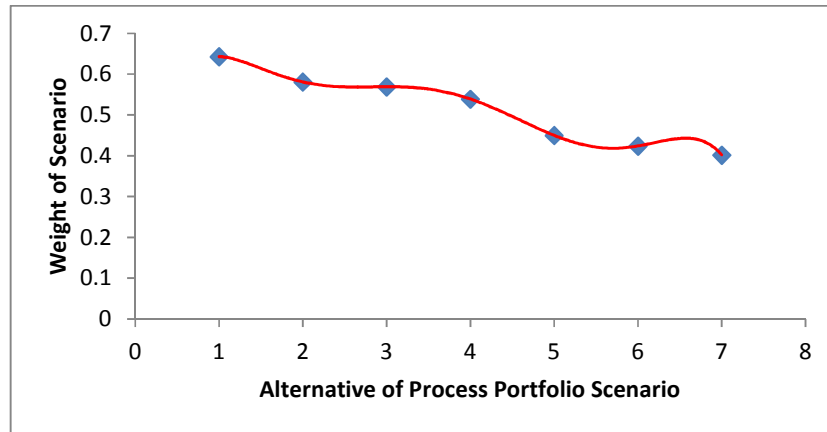**Fig. 7. Rejection rate of the product sub-criterion, scenario based weight variation representation**

Fig. 8. Process of internal quality audit of material sub-criterion, scenario based weight variation representation
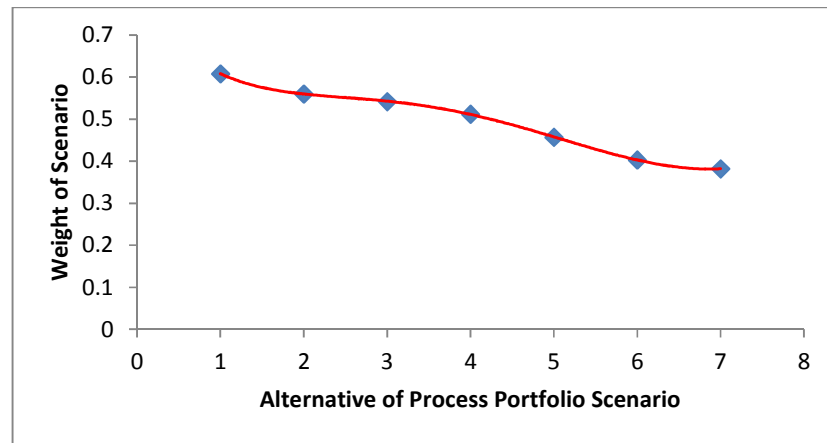

Fig. 9. Lead time flexibility criterion, scenario based weight variation representation

3.1.7 Delivery and services criterion - lead time flexibility sub-criterion

Lead time flexibility assessment philosophy states that Increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive sub-criterion of lead time flexibility toward very poor option due to increasing lead time due to increasing complexity of the remanufactured-upgraded system with increasing processing activities which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. Stable non-steady state attributes the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between highest weight of scenario 1 to continue until reaches the lowest weight of scenario 7. Weights values variation is of range of (0.38 and 0.6), Fig. 9.

3.1.8 Delivery and services criterion - after sales services sub-criterion

After sales services assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive criterion of after sales services toward very poor option due to increasing after sales services due to increasing complexity of the remanufactured-upgraded system with increasing processing activities which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. High stable non-steady state attributes the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between highest weight of scenario 1 to continue until reaches the lowest weight of scenario 7. Weights values variation is of range of (0.23 and 0.34), Fig. 10.

3.1.9 Delivery and services criteria - time to solve the complaint sub-criterion

Time to solve the complaint assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive sub-criterion of time to solve the complaint criterion toward very poor option due to increasing complaints due to increasing complexity of the remanufactured-upgraded system with increasing processing activities which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. Very high stable to be semi straight line of non-steady state attributes the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between the highest weight of scenario 1 to continue until reaches the lowest weight of scenario 7. Weights values variation is of range of (0.23 and 0.32), Fig. 11.

3.1.10 Delivery and services criteria - on time delivery criterion

On time delivery philosophy that states increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive criterion of on time delivery sub-criterion toward very poor option due to increasing time due to increasing complexity of the remanufactured-upgraded system with increasing processing activities which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. Stable with slight fluctuation non-steady state attributes the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between highest weight of scenario 1 to continue until reaches the lowest weight of scenario 7. Weights values variation is of range of (0.27-0.36), Fig. 12.
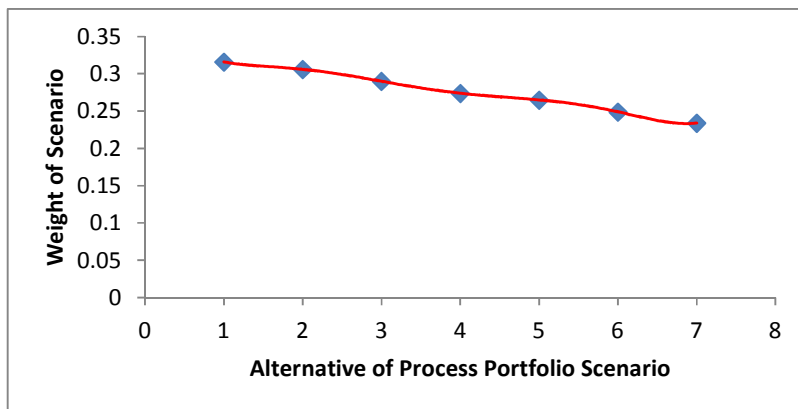

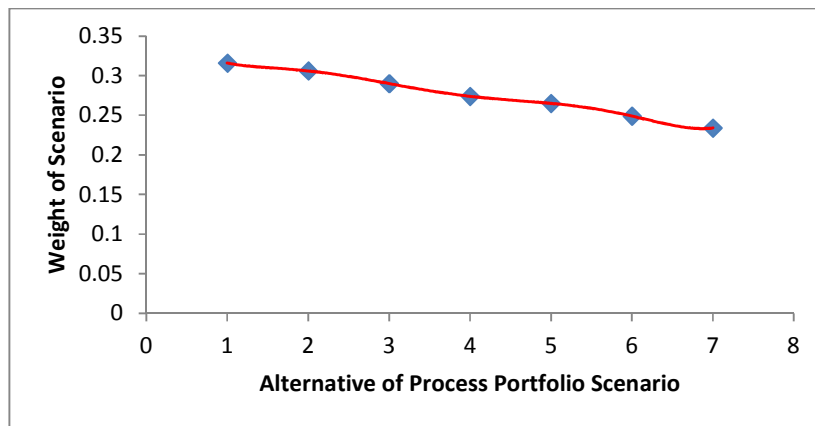**Fig. 10. After sales services criterion, scenario based weight variation representation**

Fig. 11. Time to solve the complaint sub-criterion, scenario based weight variation representation
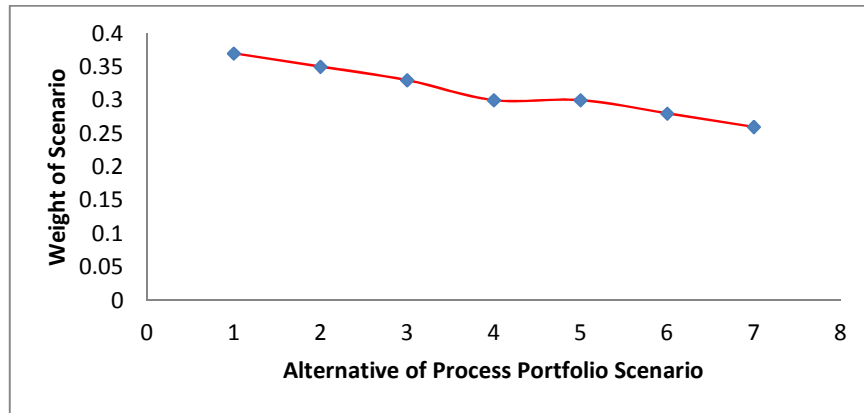
Fig. 12. On time delivery sub-criterion, scenario based weight variation representation
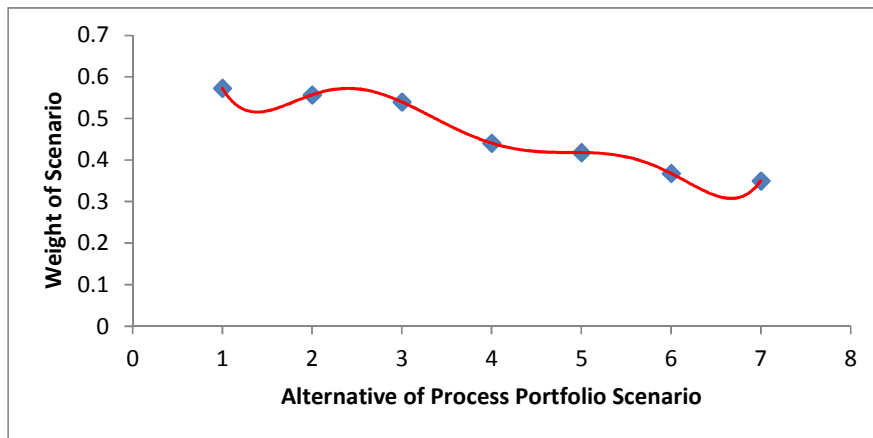

Fig. 13. Flexibility in giving discount, weight based scenario variation representation

3.1.11 Flexibility criterion - flexibility in giving discount sub-criterion

Flexibility in giving discount assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive criterion of flexibility in giving discount criterion toward very poor option due to increasing expenses due to increasing complexity of the remanufactured-upgraded system with increasing processing activities which limits flexibility of profit, while decreasing these activities will drive the sub-criterion toward very good option. Fluctuated non-steady state attributes the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between highest weight of scenario 1 to continue until reaches the lowest weight of scenario 7. Weights values variation is of range of (0.35-0.58), Fig. 13.

3.1.12 Flexibility criterion - flexibility in delivery time sub-criterion

Flexibility in delivery time assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive criterion of flexibility in delivering time criterion toward very poor option due to increasing complexity of the remanufactured-upgraded system with increasing processing activities which limits flexibility of delivery time , while decreasing these activities will drive the sub-criterion toward very good option. Fluctuated non-steady state attributes the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between highest weight of scenario 1 to continue until reaches the lowest weight of scenario 7. Weights values variation is of range of (0.26-0.44), Fig. 14.
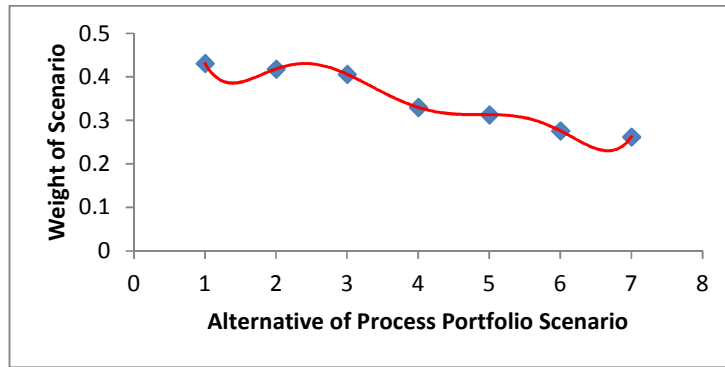
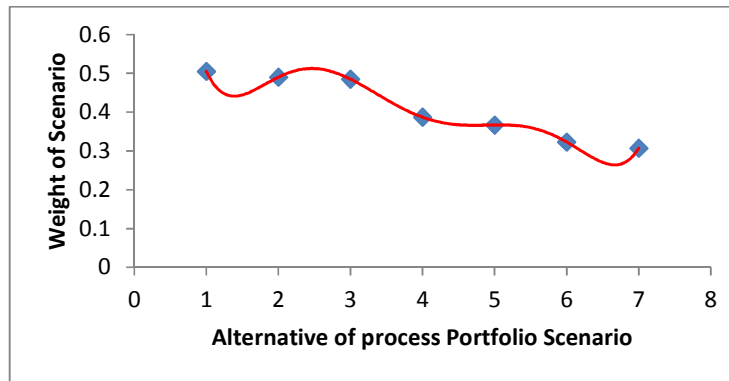**Fig. 14. Flexibility in delivery time sub-criterion, scenario based weight variation representation**

Fig. 15. Flexibility in ordering sub-criterion, scenario based weight variation representation

3.1.13 Flexibility criterion - flexibility in ordering sub-criterion

Flexibility in ordering assessment philosophy that states increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive criterion of flexibility in ordering toward very poor option due to increasing complexity of the remanufactured-upgraded system with increasing processing activities which limits flexibility of ordering, while decreasing these activities will drive the criterion toward very good option. Fluctuated non-steady state attributes the variation of weight values of alternative scenarios through the whole evaluation curve which is limited between highest weight of scenario 1 to continue until reaches the lowest weight of scenario 7. Weights values variation is of range of (0.3-0.5), Fig. 15.

3.2 Environmental Sub-sustainability Assessment

Comparative literature based weight analysis, scenario based analysis and experience based

remanufacturing-upgrading analysis. These analysis techniques are applied to model the effects of sub-criteria of criteria of environmental performance on decision making to select the most suitable remanufacturing-upgrading portfolio. It is comparative literature based matching of local weights with triangular fuzzy number to estimate the local weights corresponding to four sets of triangular fuzzy numbers for each of different seven scenarios to find out the global weight of each scenario. These sub-criteria are of direct effect on remanufacturing-upgrading processes portfolio which require further analysis to select the best alternative as following:-

3.2.1 Environmental management system criterion - environmental performance evaluation sub-criterion

Environmental performance evaluation assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive criterion of environmental performance

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evaluation toward very good option due to reduction of power and natural resource exhaustion and reduction of waste and emissions with increasing complexity of the remanufacturing-upgrading system. Even increasing remanufacturing activities will be accompanied with exhaustion of power and natural resources and waste and emissions generation but they cannot compared with recovered embodied power and its related saving of material, waste and emissions , while decreasing these activities will drive the criterion of environmental performance evaluation toward very poor option. Fully reusing is of the highest weight and represents scenario1 while fully remanufacturing represents scenario 7 which is of the lowest weight but the variation among scenarios is within the range of (0.4-0.54) to show slight variation between both scenarios, Fig. 16.

3.2.2 Environmental management system criterion - eco-labeling application sub-criterion

Eco-labeling application assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive sub-criterion of eco-labeling application toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option. Eco-labeling can encourage remanufacturing-upgrading to adopt environmental friendly raw materials, reused components, environmental conscious components and eco-design based eco-friendly modifications. So that fully remanufacturing is of the highest weight and represents scenario 7while fully reusing represents scenario 1 which

is of the lowest weight and the variation among scenarios is within the range of (0.18-0.44). Fluctuated non-steady state rising behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 17.

3.2.3 Environmental management system criterion – environmental friendly raw material sub-criterion

Environment-friendly raw material assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive criterion of environment-friendly raw material toward very good option since there is a big chance to embed environment-friendly raw material through eco-design within structure of remanufactured-upgraded conventional lathe into CNC machine , reduction of power and natural resource exhaustion and reduction of waste and emissions can be fulfilled through using of environment-friendly raw material which can be fulfilled through increasing complexity of the remanufacturing-upgrading system. Environment-friendly raw material using can be encouraged through remanufacturing activities so that fully remanufacturing is of the highest weight and represents scenario 7 while fully reusing represents scenario 1 which is of the lowest weight and the variation among scenarios is within the range of (0.07-0.32) to show variation between both scenarios. Non-steady state rising with low degree of fluctuation behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 18.
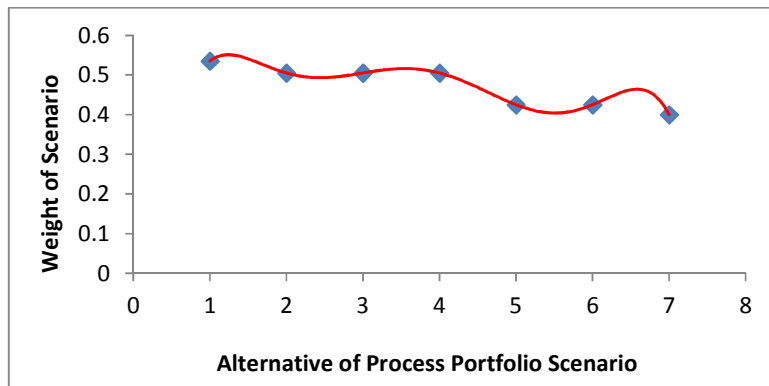

Fig. 16. Environmental performance evaluation sub-criterion, scenario based weight variation representation
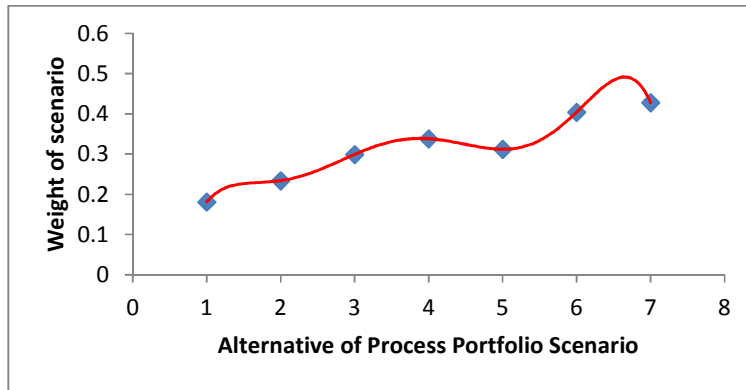
Fig. 17. Eco-labeling sub-criterion, scenario based weight variation representation
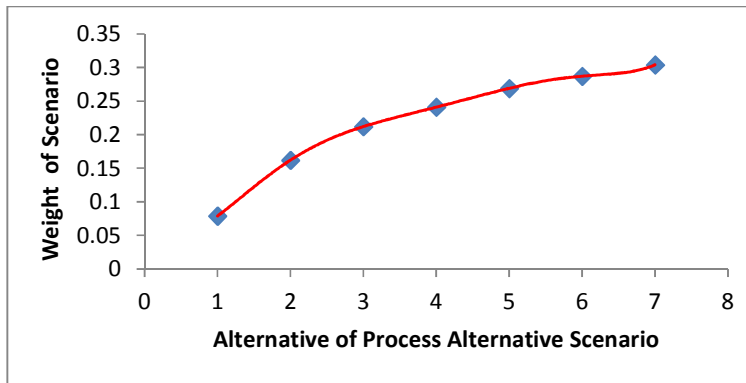

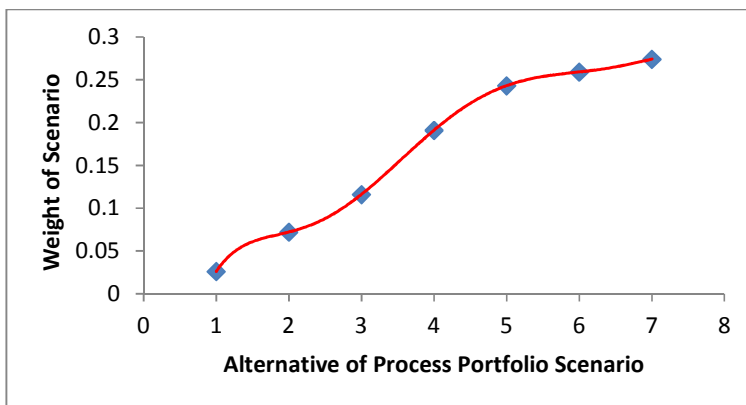**Fig. 18. Environmental Friendly raw material sub-criterion, scenario based weight variation representation**

Fig. 19. Reuse sub-criterion, scenario based weight variation representation

3.2.4 Green products criterion - reuse sub-criterion

Reuse assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of reuse toward very poor option, while decreasing these activities will drive the criterion of reuse toward very good option. Even there is chance to embed environment-friendly raw material including reused components through eco-design

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application through remanufacturing-upgrading activities to embed reused components within structure of remanufactured-upgraded CNC lathe but this should be done without limitation of upgrading functionality of CNC machine . So that fully remanufacturing is of the highest weight and represents scenario 7while fully reusing represents scenario 1 which is of the lowest weight and the variation between both scenarios is within the range of (0.02-0.27) to show variation among scenarios. Fluctuated non-steady state rising behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 19.

3.2.5 Green products criterion – green packaging sub-criterion

Green packaging assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of green packaging toward very poor option since full remanufactured lathe will be like new which required traditional non-green packaging to be used, while decreasing these activities will drive the sub-criterion toward very good option since there will be no need for packaging. So that fully remanufacturing is of the lowest weight and represents scenario 7while fully reusing represents scenario 1 which is of the highest weight and the variation among scenarios is within the range of (0.04-0.71) to show variation among scenarios. Highly fluctuated non-steady state decreasing behavior attributes the variation

of weight values of alternative scenarios through the whole evaluation curve, Fig. 20.

3.2.6 Green products criterion – air emission sub-criterion

Air emission assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of air emission toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option due to reduction of power and natural resource exhaustion and reduction of waste and emissions with increasing complexity of the remanufacturing-upgrading system. Increasing remanufacturing-upgrading activities are accompanied with exhaustion of power and natural resources and generation of waste and emissions but they cannot be compared with recovered embodied power and related saving of material, waste and emissions according to consideration of performance assessment comprehensively. So there is low variation of weights among scenarios even fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.23-0.3) to show environmental conscious scenarios. Low fluctuated non-steady state with increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 21.
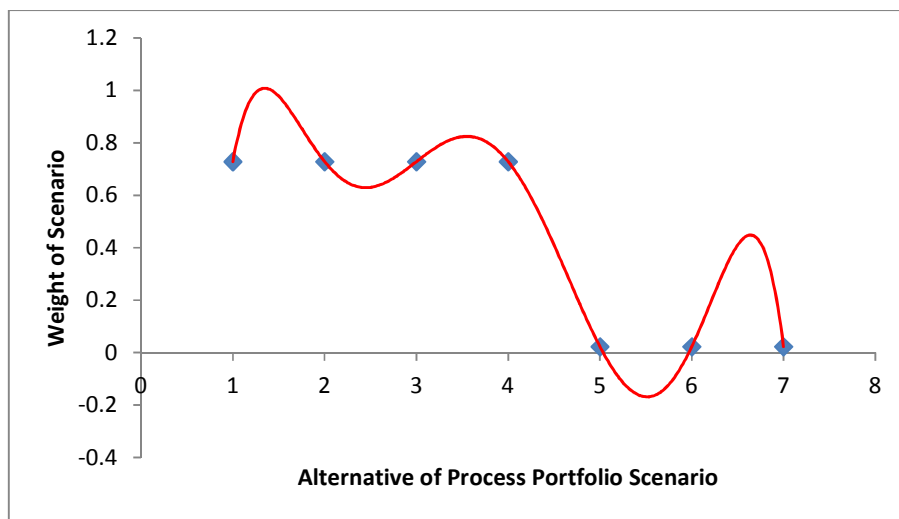

Fig. 20. Green packaging sub-criterion, scenario based weight variation representation
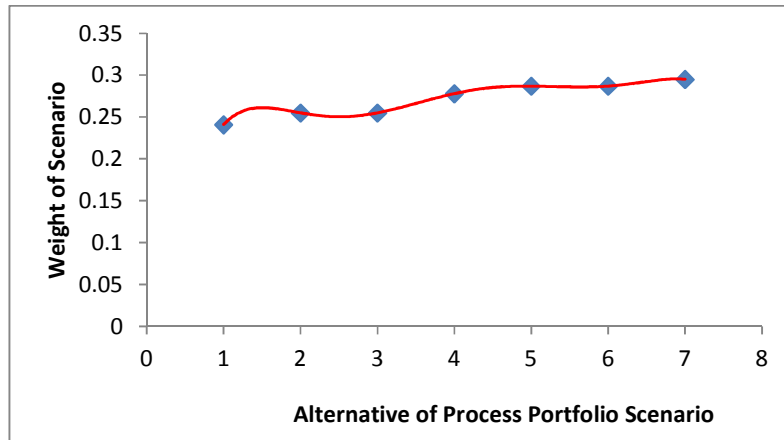
Fig. 21. Air emission sub-criterion, scenario based weight variation representation
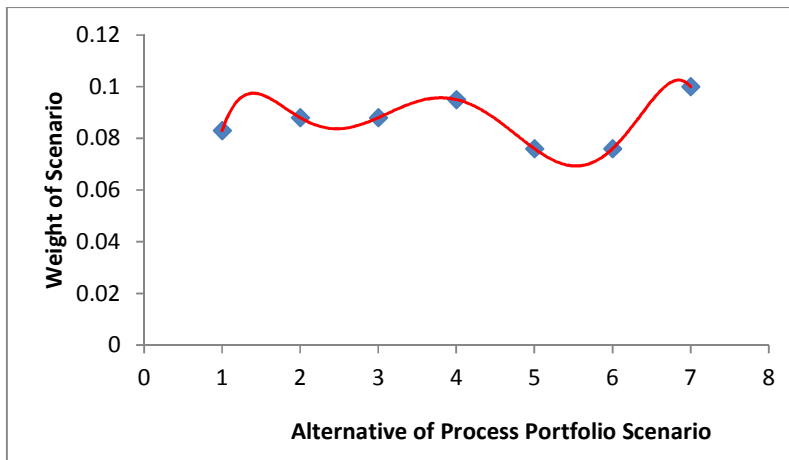

Fig. 22. Waste water sub-criterion, scenario based weight variation representation

3.2.7 Green products criterion – waste water sub-criterion

Waste water assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive sub-criterion of waste water toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option. Reduction of power and natural resource exhaustion and reduction of waste and emissions with increasing complexity of the remanufacturing-upgrading system can be obtained. With increasing processing activities accompanied exhaustion of power and related water and natural resources and generated waste and emissions can be reduced. So that there fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.08-0.1) to show environmental conscious scenarios. Fluctuated non-steady state with increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 22.

3.2.8 Green products criterion – hazardous waste sub-criterion

Hazardous waste assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of hazardous waste toward very good option emissions, while decreasing these activities will drive the sub-criterion toward very poor option. They are environment conscious scenarios due to reduction of hazardous waste and emissions with

increasing complexity of the remanufacturing-upgrading system with increasing processing activities. Accompanied waste and emissions due to remanufacturing-upgrading activities cannot be compared with related saving of material, waste. With increasing processing activities accompanied exhaustion of power and related water and natural resources and generated waste and emissions can be reduced. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.1-0.12) to show environmental conscious scenarios. Non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 23.

3.2.9 Green warehousing criterion – inventory of non-hazardous substances sub-criterion

Inventory of non-hazardous substances assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of inventory of non-hazardous substances toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option. There is a big chance to embed non-hazardous substances through eco-design within structure of remanufactured-upgraded CNC lathe. Reduction of power and natural resource exhaustion and reduction of waste and emissions can be fulfilled through using of non-hazardous substances with increasing complexity of the remanufactured-upgraded system. Increasing processing

activities are environmental conscious procedure. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.14-0.118) to show environmental conscious scenarios. Fluctuated non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 24.

3.2.10 Green warehousing criterion – warehouse management sub-criterion

Warehouse management assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of warehouse management toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option. since there is a big chance to use green packaging, eco-labeling and embed environmental friendly raw materials and non-hazardous substances to be embedded through eco-design through the structure of remanufactured-upgraded CNC lathe. Developed structural characteristics reduce power and natural resource exhaustion and reduction of waste and emissions can be fulfilled. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.14-0.18) to show environmental conscious scenarios. Fluctuated non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 25.
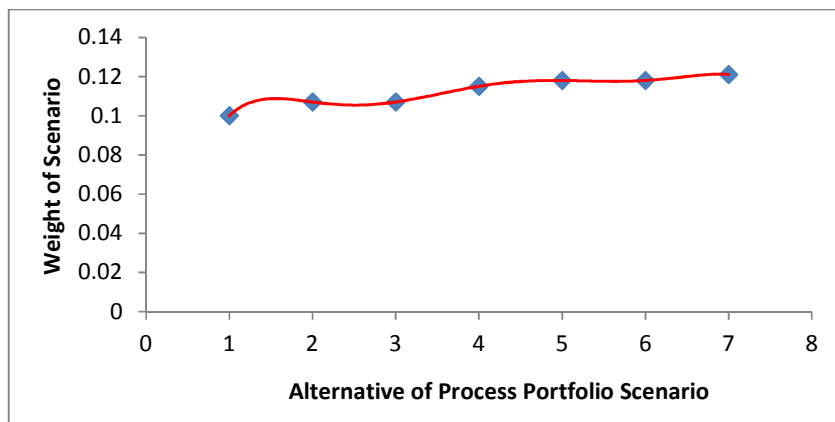

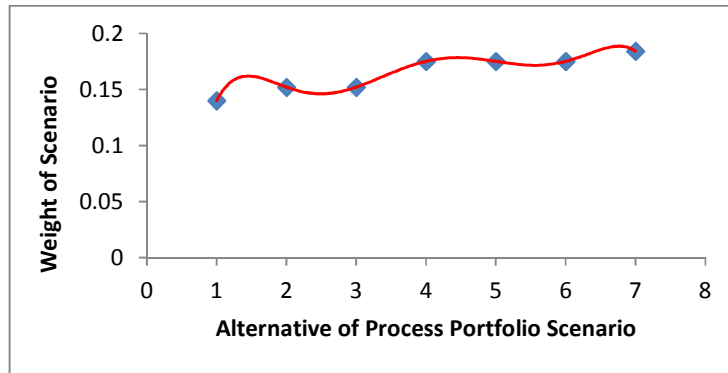**Fig. 23. Hazardous waste sub-criterion, scenario based weight variation representation**

Fig. 24. Inventory of non-hazardous substances sub-criterion, scenario based weight variation representation
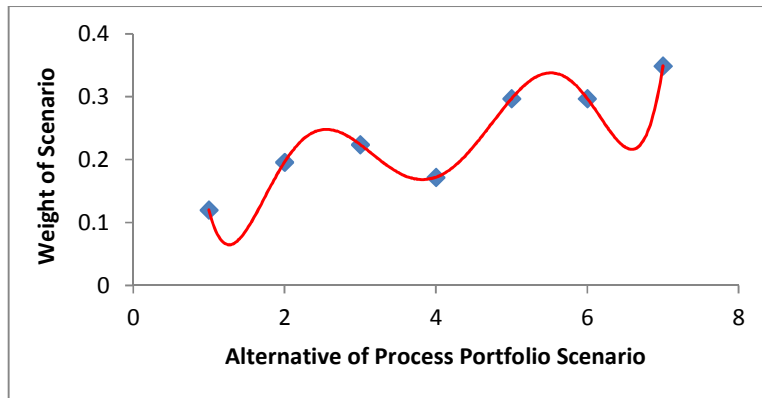

Fig. 25. Warehouse management sub-criterion, scenario based weight variation representation
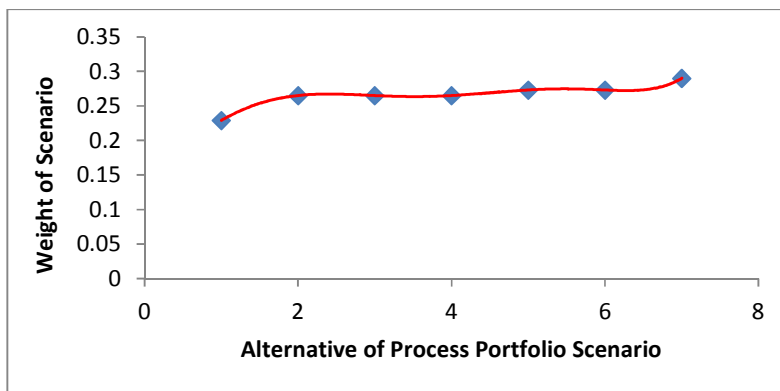

Fig. 26. Remanufacturing of product when design sub-criterion, scenario based weight variation representation

3.2.11 Eco-design criterion -remanufacturing of product when design sub-criterion

Remanufacturing of product when design assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of remanufacturing of product when design toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option. There is a big chance to embed non-hazardous substances

and using more used components through eco-design within structure of remanufactured-upgraded CNC lathe. Thus reduction of power and natural resource exhaustion and reduction of waste and emissions can be fulfilled through exploration of potentials of remanufacturing of product when design with increasing complexity of the remanufactured-upgraded system. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.22-0.28) to show environmental conscious scenarios. Non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 26.

3.2.12 Eco-design criterion - reduction of the use of hazardous materials sub-criterion

Reduction of the use of hazardous materials when design assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive sub-criterion of reduction of the use of hazardous material when design toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option. Since there is a big chance to embed non-hazardous materials through eco-design within structure of remanufactured-upgraded CNC lathe , reduction of power and natural resource exhaustion and reduction of waste and emissions can be fulfilled through using of non-hazardous

substances with increasing complexity of the remanufacturing-upgrading system. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.06-0.25) to show environmental conscious scenarios. Non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 27.

3.2.13 Eco-design criterion - ability to alter process and product for reducing the impact on natural resources sub-criterion

Ability to alter process and product for reducing the impact on natural resources assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC machine will drive sub-criterion of ability to alter process and product for reducing the impact on natural resources toward very good option, while decreasing these activities will drive the sub-criterion toward very poor option. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.1-0.25) to show environmental conscious scenarios. Fluctuated non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 28.
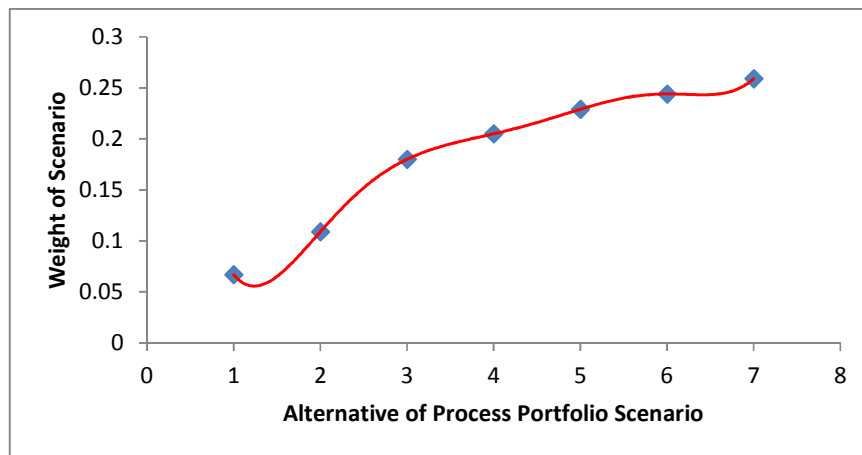

Fig. 27. Reduction of the use of hazardous materials sub-criterion, scenario based weight variation representation
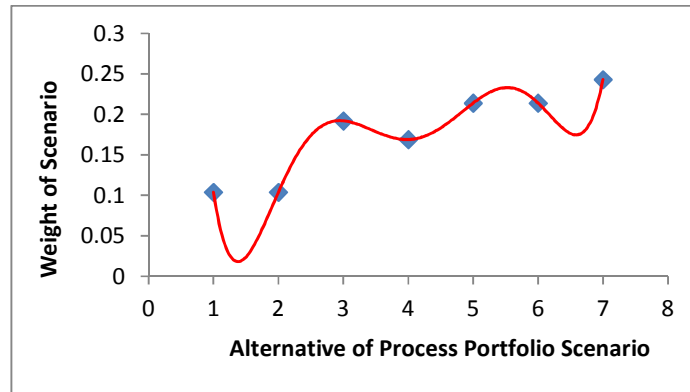
Fig. 28. Ability to alter process and product for reducing the impact on natural resources sub-criterion, scenario based weight variation representation
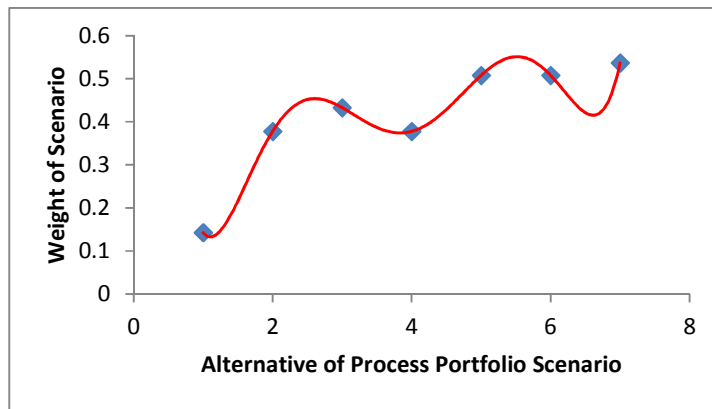

Fig. 29. Material used in the supplied components that reduce the impact on natural resources sub-criterion, scenario based weight variation representation

3.2.14 Eco-design criterion - material used in the supplied components that reduce the impact on natural resources sub-criterion

Material used in the supplied components that reduce the impact on natural resources assessment philosophy states that increasing activities of remanufacturing-upgrading of conventional lathe into CNC will drive sub-criterion of material used in the supplied components that reduce the impact on natural resources toward very good option , while decreasing these activities will drive the sub-criterion toward very poor option. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.15-0.53) to show environmental conscious scenarios. Fluctuated non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 29.

3.3 Social Sub-sustainability Assessment

The attributes of the social measures include criteria of Rights of Workers Green Product, Health and Safety and Supportive Activities .These criteria are divided into sub-criteria which are of direct effect on remanufacturing-upgrading processes portfolio that include seven scenarios to fulfill remanufacturing-upgrading of conventional lathe into CNC machine which require further analysis to select the best alternative. Comparative literature based weight analysis, scenario based analysis and experience based remanufacturing-upgrading analysis. These analysis techniques are applied to model the effects of sub-criteria of criteria of environmental performance on decision making

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to select the most suitable remanufacturing-upgrading portfolio. It is comparative literature based matching of local weights with triangular fuzzy number to estimate the local weights corresponding to four sets of triangular fuzzy numbers for each of different seven scenarios to find out the global weight of each scenario. These sub-criteria are of direct effect on remanufacturing-upgrading processes portfolio which require further analysis to select the best alternative as following:-

3.3.1 Social performance criteria - work place design sub-criterion

Work place design assessment philosophy states that productivity is key factor of business development which of positive consequences on social performance, so that as good as design of work place as good as the work flow. Remanufacturing-upgrading activities requires lower number of work stations then the sub-criterion will be led toward very good option while occupation of all work stations in the same time

will lead to drive sub-criterion towards very poor option. So that fully remanufacturing is of the lowest weight and represents scenario 7and fully reusing represents scenario 1 which is of the highest weight. The variation among scenarios is within the range of (0.18-0.8) to show environmental conscious scenarios. Non-steady state decreasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig 30.

3.3.2 Social performance criteria - ergonomics and safety sub-criterion

Ergonomics and safety assessment philosophy states that since there is no poison waste and emission during remanufacturing process , so increasing remanufacturing activities will lead to use machinery and handling of heavy parts to drive the process toward very poor option while reduction such activities will lead to drive the alternative toward very good option.So that fully remanufacturing is of the lowest weight and represents scenario 7and fully reusing
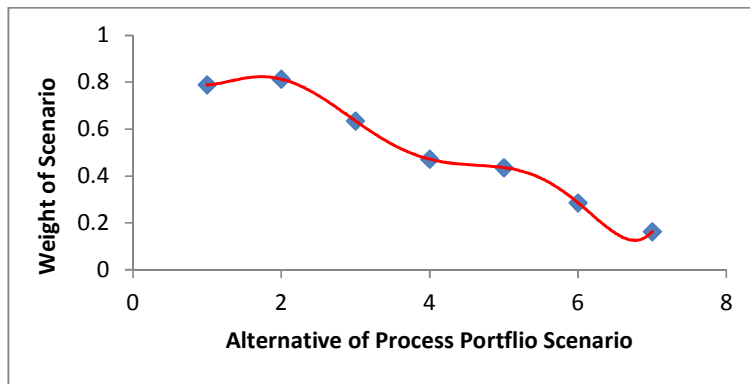

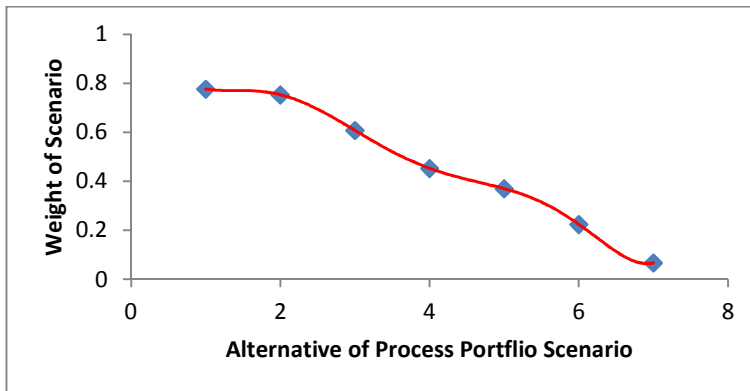**Fig. 30. Work place design sub-criterion, scenario based weight variation representation**

Fig. 31. Ergonomics and Safety sub-criterion, scenario based weight variation representation

represents scenario 1 which is of the highest weight. The variation among scenarios is within the range of (0.2-0.78) to show environmental conscious scenarios. Stable non-steady state decreasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 31.

3.3.3 Social performance criteria - training and development of employee sub-criterion

Training and development of employee assessment philosophy states that practicing remanufacturing-upgrading of conventional lathe into CNC machine can simulate training and will

lead to development of employee. Increasing remanufacturing activities will drive the sub-criterion of training and development of employee toward very good option, while decreasing such activities will lead to drive the alternative toward very poor option. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.02-0.8) to show environmental conscious scenarios. Fluctuated non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 32.
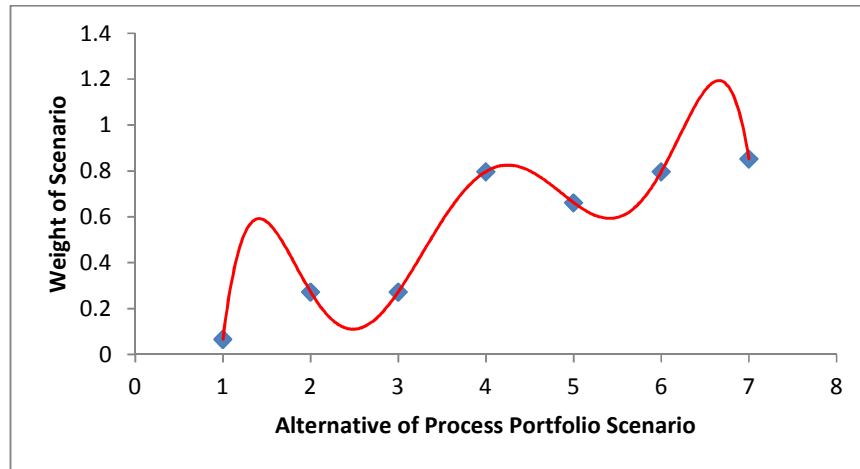

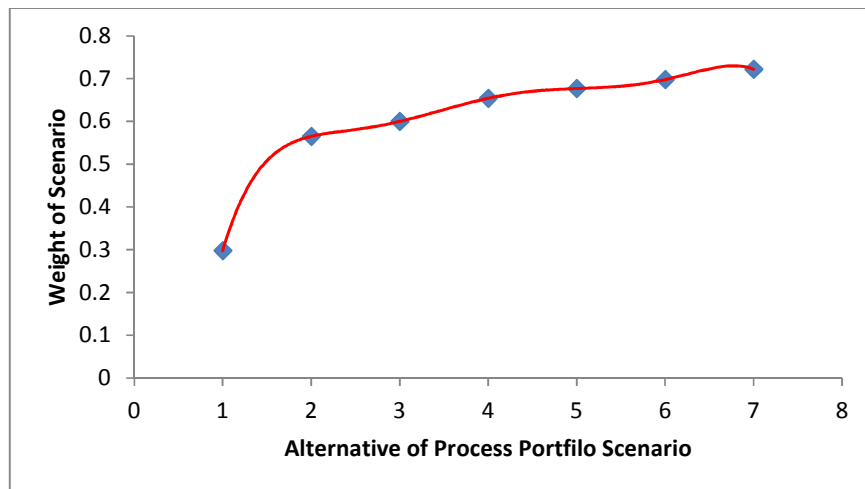**Fig. 32. Training and development of employee sub-criterion, scenario based weight variation representation**

Fig. 33. Innovation management sub-criterion, scenario based weight variation representation
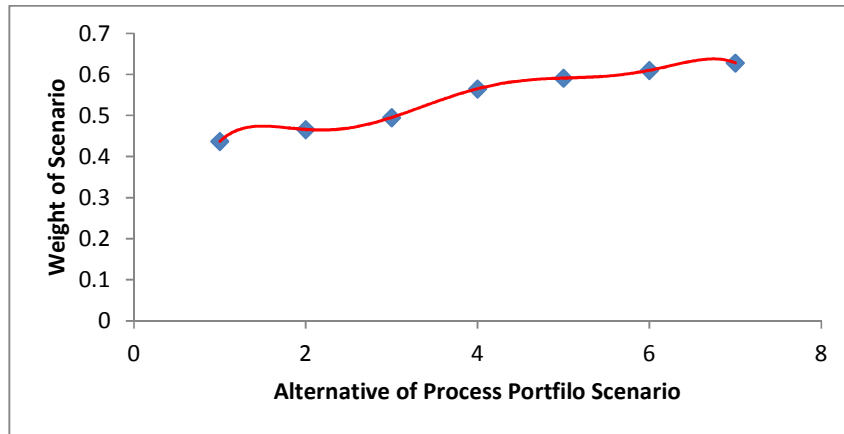
Fig. 34. Corporate image sub-criterion, scenario based weight variation representation

3.3.4 Social performance criteria - innovation management sub-criterion

Innovation management assessment philosophy states that increasing remanufacturing-upgrading activities will drive sub-criterion of innovation management toward very good option since such processes will induce potentials of innovation to be planted within structure of remanufactured-upgraded conventional lathe into CNC machine. Reduction of such activities will limit innovation management directives and drive sub-criterion toward very bad option. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.3-0.72) to show environmental conscious scenarios. Smooth non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 33.

3.3.5 Social performance criteria - corporate image sub-criterion

Corporate image assessment philosophy states that increasing remanufacturing-upgrading activities will drive sub-criterion of corporate image toward very good option since such processes will increase green activities through remanufactured-upgraded conventional lathe into CNC activities. Reduction of such activities will drive corporate image sub-criterion toward very bad option. So that fully remanufacturing is of the highest weight and represents scenario 7and fully reusing represents scenario 1 which is of the lowest weight. The variation among scenarios is within the range of (0.42-0.62) to show

environmental conscious scenarios. Smooth non-steady state increasing behavior attributes the variation of weight values of alternative scenarios through the whole evaluation curve, Fig. 34.

3.4 Overall Conventional Lathe into CNC Machine Tool Sustainability Assessment

Overall ranking of A_1 is (0.45) and of A_7 is (0.56), even alternative (A_1) is the best economically but it exhibits secondly preference according to the overall sustainability assessment where the alternative (A_7) is the best to remanufacture-upgrade conventional lathe into CNC machine which effect remanufacturing portfolio that includes spindle, gearbox and guide rail remanufacturing scenario. Tables 1, 2 and 3 show a conclusion of the best alternative based sub-sustainability assessments.

Table 1. Economic sub-sustainability based alternatives ranking

Sub-Criteria	Alternative of the Best Rank
C_{EC1}	A_1
C_{EC2}	A_1
C_{EC3}	A_1
C_{EC4}	A_1
C_{EC5}	A_1
C_{EC6}	A_1
C_{EC7}	A_1
C_{EC8}	A_1
C_{EC9}	A_1
C_{EC10}	A_1
C_{EC11}	A_1
C_{EC12}	A_1
Weight	$A_1=_1$, $A_7=0$

Table 2. Environmental sub-sustainability based alternatives ranking

Sub-Criteria	Alternative of the Best Rant
C_{E1}	A_1
C_{E2}	A_7
C_{E3}	A_7
C_{E4}	A_7
C_{E5}	A_1
C_{E6}	A_7
C_{E7}	A_7
C_{E8}	A_7
C_{E9}	A_7
C_{E10}	A_7
C_{E11}	A_7
C_{E12}	A_7
C_{E13}	A_7
C_{E14}	A_7
Weight A_1=0.14, A_7=0.86	

Table 3. Social sub-sustainability based alternatives ranking

Sub-Criteria	Alternative of the Best Rant
C_{S1}	A_1
C_{S2}	A_1
C_{S3}	A_7
C_{S4}	A_7
C_{S5}	A_7
Weight A_1=0.2, A_7=0.82	

4. CONCLUSION

Comparative literature based analysis, remanufacturing experience based analysis and scenario based analysis can form together a powerful comprehensive remanufacturing based sustainability assessment techniques. Literature is surveyed to specify large scale of criteria which include (12) economic sub-criteria, (14) environmental sub-criteria and (5) social sub-criteria as a comparative literature based analysis application. Weights of different scales of sub-criteria are normalized and remanufacturing experience based analysis is used to modify these weights and keep reasonable and strong relations of importance among sub-criteria so that final local weights can be obtained. Alternatives are constructed through scenario based analysis application to simulate conventional lathe remanufacturing-upgrading into CNC machine tool. Fuzzy linguistics expressions are used to describe alternatives and construct alternatives preference matrices. Fuzzy triangular are applied to find local weights

of alternatives. Global weights of alternatives are calculated through matrices of criteria and alternatives construction. Global weight based ranking analysis are applied to specify the order of alternatives ranks. Even (A_7) ranks the first to be followed by (A_1) to be the second but there is acceptable variation among different alternatives of remanufacturing-upgrading portfolio scenarios to be adopted as environment conscious end-of-life strategies which they are mixture of convention and emerged technology that can include reusing, restoring and buying procedures as environment conscious scenarios.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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