



# Remanufacturingability Modeling Approach on Remanufacturing Conventional Machine into CNC Machine Tool

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## Author's contribution

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

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## ABSTRACT

**Aims:** Assess to find the most suitable remanufacturing portfolio alternatives to restore dovetail guide ways and saddles of machine tools.

**Study Design:** Comparative literature based analysis adoption to apply a series of assessments to find the remanufacturability of best restoration portfolio alternative where portfolios are developed by using scenario based analysis and results are optimized using remanufacturing experience based analysis.

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

### Methodology:

1. Literature survey aided remanufacturing assessment case studies elicitation.
2. Sample of published papers re-representation to highlight the findings of discussions and conclusions of these papers.
3. Graphical representation of results is also applied.
4. Study of published papers sample allows isolation of criteria, weighting of criteria, weighting of alternatives, global weights calculation and alternatives ranking of remanufacturing portfolio alternatives to restore dovetail guides ways and saddles of machine tools.

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**Conclusion:** Series of different assessments with different groups of criteria lead to propose hypotheses to be highlighted to continue application of comparative literature based assessment, proposed hypotheses include:

1. As much as uniform is the Rank-Global weights curve of portfolio alternatives the more consistent is the assessment matrix.
2. Technical viability of remanufacturing portfolio will lead to economic and environmental viabilities.
3. Economic and environmental viabilities necessarily can certain remanufacturability and will lead to social viability.
4. Technical, economic, environmental and social viabilities will lead to sustainability.
5. Integrated technical viability of a remanufacturing portfolio is an integration of derivatives of technical viabilities of processes consist the portfolio.
6. Comparative literature based assessment is a powerful tool under the mixture of remanufacturing experience based analysis and scenario based analysis.
7. Remanufacturability assessment, technical viability assessment and partial sustainability assessment can be mixed to develop comprehensive remanufacturing sustainability assessment.
8. Grinding-Mechanical Cladding is assembly based remanufacturing to improve machine tool remanufacturability and sustainability.

*Keywords: Remanufacturability assessment; machine tool remanufacturing; lathe machine remanufacturing-upgrading; CNC machine tool remanufacturing; milling machine remanufacturing-upgrading.*

## 1. INTRODUCTION

Quantification methods 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 machine tool remanufacturing-upgrading can include uncertainty of both of the machine tool 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 machine tool remanufacturing-upgrading.
- 2- Improve the performance of machine tool.
- 3- Achieve high value-added remanufacturing-upgrading.
- 4- Improve the success rate of machine tool remanufacturing-upgrading.

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 cores and upgrade the functionality and re-manufacturability of the products should be assessed. Remanufacturing-upgrading is a new manufacturing mode for high demands of productivity and energy efficiency. Original equipment manufacturers of products can conduct remanufacturing-upgrading as a new development strategy for gathering advantages of developing original brand based remanufacturing to be delivered in the form of human development and employment where technology, equipment, logistics and talented persons can be interacted to accumulate [2].

Cost, quality, time and service are performance assessment criteria of hybrid eco-social effects to highlight the integrated environmental effects of remanufacturing system as environmental conscious technology. Remanufacturing technology alternatives can be environmentally evaluated through means of different resource consumption and process emission evaluation criteria. Generally 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 candidate technologies under constraints of financial capital and human resources which represent remanufacturing-upgrading alternatives can be called remanufacturing technology portfolio. According to financial

capital and human resources, alternative with good singular benefit, highest synergistic benefit and lowest portfolio cost will be the best. Synergistic effects of a certain remanufacturing-upgrading technology can consider the overall enterprise benefit. Technology portfolio that produces significant synergistic benefit can be more attractive than a technology with high singular benefit [3].

Consideration of failure rate of remanufacturing portfolio to restore can be based on capability of remanufacturing portfolio and decay of machines and tools which both are affected by the quality of returned products so that all these factors can be used to model reliability. Remanufacturing process planning means that optimization process of decision making to select the optimum sequence of remanufacturing technology within a certain portfolio. Improve efficiency of remanufacturing portfolio and the reliability of remanufactured-upgraded machine tool and reduce process cost can be fulfilled by integrating the quality of returned cores within evaluation model of remanufacturing process [4].

To optimize the remanufacturability of a certain component, keeping costs low can maximize the resulting service life and efficiency. Damaged and worn components with varying level of damage will be of varying level of remaining life. Components need to be evaluated in terms of damage level and remaining life before determining the optimal value recovery options. Quantified damage condition based remaining life specifying of used components can be developed as a comprehensive evaluation to 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 individually components. Cost criterion can be modeled for selecting the remanufacturing portfolio alternative can be done based on the remaining life value recovery options for used components. Value recovery options for each component can include new, reuse and reconditioned scenarios to be forecasted by each valuable component which is combinatorial optimization problem. Value recovery options can help obtain the optimal remanufacturing portfolio alternative of valuable components and improve the economic benefits from remanufacturing which requires an evaluation criterion to be quantified within insights of damage level and remaining life of used components to identify value recovery options for each used component [5].

Cost, energy consumption and material consumption can be used to assess remanufacturing oriented design to accommodate used parts within structure of like new remanufactured-upgraded machine tool which require dynamic information transfer and feedback model. Powerful case studies are required to demonstrate the effectiveness of redesign and eco-design to exploit used components for remanufacturing of products which consist of valuable components with high added-value and full of assembly-disassembly. Fault feature analysis can be based on the failure mode, fault features and damage volume to predict the remaining service life of used components. Used components integration can led to that cost can be reduced up to 6.65%, energy consumption can be cut off up to 6.10% and material can be saved up to 13.1%. Dynamic information transfer and feedback can generalize reusing process through redesign and eco-design to highlight remanufacturing strategy so that components synergistically interact to combine reliability and quality. Reliability and quality can reduce remanufacturing cost, energy consumption and material consumption of remanufactured-upgraded machine tool [6].

Wear, corrosion, bending-torsion deformation and crack faults modes can be eliminated to restore the surface into its original state by using undercutting, thermal spray, submerged arc welding and grinding as a remanufacturing system portfolio. These processes are of different operating parameters so their closeness to optimum solution can be called the degree of similarity. Specification influence factors, influence factors and faults feature factors can be used to assess remanufacturing system portfolio remanufacturability based on different failures at different locations. Information and knowledge of remanufacturing is complex to cause uncertainty to be involved. Multi-sources remanufacturing information at different life cycle stages is relevant to provide a structured way to express and manage remanufacturing knowledge [7].

Remanufacturing can provide a great opportunity to increase market shares and aftermarket sales to deliver human development and employment as a social sub-sustainability. Comprehensive framework that includes all the major strategic factors is necessary to make earlier effective remanufacturing decisions in the conceptual stage of product development. Comparative literature based identified factors and academicians based innovative solutions can

help bridge the gap and provide an effective and transparent decision-making based remanufacturing modeling and assessment. Some techniques can be used to develop strength data base to be used for remanufacturing assessment such as [8]:

- 1- Case studies based experience and judgment elicitation.
- 2- Survey based current industry thinking reporting.
- 3- Expert panel survey to provide valuable feedback on the remanufacturing decision-making factors.
- 4- Industry executives and academicians based interesting enhancing and testing in real remanufacturing field.

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 unifying platform to enable process 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 degree and fault location. 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 in consideration during optimizing remanufacturing process planning [9].

The characteristics of remanufacturing service knowledge resources and the relatively better evaluation index attributes of remanufacturing service knowledge resources provide 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 of subjectivity, technological viability of

remanufacturing of machine tool 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. In such case, experts based indexes establishing can lead to weight value of criteria which consists of remanufacturability measures that can include criteria of:

- 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.

Environmental sub-sustainability can identify impacts of remanufacturing advanced restoring technologies by using criteria of Global Warming Potential, Primary Energy Demand, Abiotic Depletion Potential, Water Depletion, Acidification Potential, Eutrophication Potential and Particulate Matter. Thus environmental impacts assessment at various stages can help provide decision references that affect restoring technology and remanufacturing industry development. Scenario based analysis can be used to model environmental benefits of advanced remanufacturing technologies through comparing with traditional remanufacturing technologies. Major components and processes in remanufacturing can be included in the system boundary due to the availability of data. Establish an information sharing platform of energy consumption and air emissions during the whole supply chain to implement the green supply chain management and facilitate scientific assessment of environmental impacts and material efficiency. Empirical based remanufacturingability study can help applicability of the new technologies to be developed and analyzed and evaluate the

environmental and economic advantages of remanufactured components [10].

## 2. COMPRATIVE LITERATURE BASED ASSESSMENT METHODOLOGY

Methodology to apply comparative literature based analysis of remanufacturing assessment includes the following steps [1-20]:-

Step1: Literature in field of remanufacturing is reviewed and surveyed to conclude the assessment directions, the following assessment approaches are found out:-

- Remanufacturability, technical viability, remanufacturing portfolio or technological path assessment.
- Economic viability and environmental viability assessment.
- Economic viability, environmental viability and technical viability assessment.

According to tested sample of remanufacturing assessment literature, there is no comprehensive assessment approach of remanufacturing which includes economic, environmental, social and technical viabilities assessments. Most assessments are focused on technical viability or partial sustainability with very low consideration

of social viability of remanufacturing. Most studies such as [11] and [12] states that remanufacturing is a sustainable assessment which requires comprehensive assessment.

Step2: Comparative literature based analysis application.

Step3: Classification of literature sample into:

- Remanufacturability Assessment.
- Remanufacturing-Sustainability Assessment.
- Partial Remanufacturing-Sustainability Assessment.

Step3: Re-representation of discussions and conclusions of papers included in literature sample.

Step4: Graphical representation of results.

Step5: Isolation of criteria.

Step6: Case study definition.

Step7: Weighting of criteria.

Step8: Weighting of alternatives.

Step9: Global weights calculation.

Step10: Alternatives ranking

Fig.1 shows comprehensive comparative literature based remanufacturing assessment methodology.

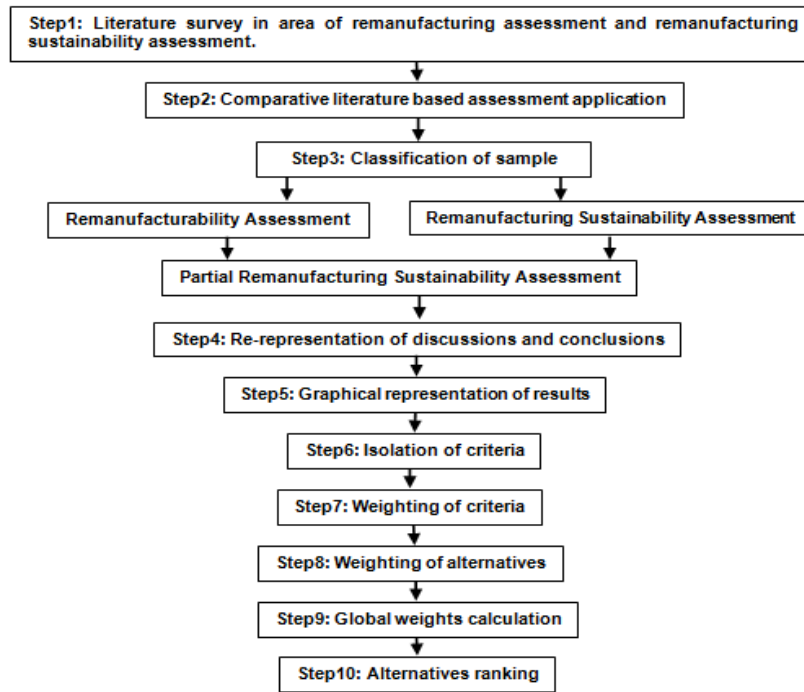


Fig. 1. Comparative literature based assessment application methodology

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 fuzzification grade of each criterion where local weights are used to put the criteria in an order and prepare them for fuzzification 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, remanufacturing experience based application and triangular fuzzy numbers based matrix mathematical modeling to find out local weights of criteria, local weights of alternatives and global weights of alternatives. Thus ranking can be conducted.

### 3. RESULTS AND DISCUSSION

#### 3.1 Case Study Definition

Dovetail guide ways and saddles are heavy and big parts of machine tool bulk and of high added-value so that they should be reused. Such components can suffer from wear, cracks or both. Remanufacturing can be done through replacing of worn component of machine tool to be material substituting remanufacturing which requires application of what is termed in this study as mechanical cladding which is using of flexible insert/mate/bolt to fulfill assembly of ball linear guide ways to machine tool body instead of fault dovetail guide ways and saddles.

Fault damage degree statute of dovetail guide ways and saddles ranges between low and medium to be remanufactured-upgraded by mechanical cladding. Pre-assessment of remanufacturing portfolio can include the following considerations:-

- 1- Profession.
- 2- Complexity.
- 3- Special equipment requirement.

The following remanufacturing portfolios are scenarios to be used to restore dovetail guide ways and saddles into their original statutes to be like new:-

#### **A<sub>1</sub>: Cold Welding-Grinding**

It is more suitable for low degree of damage of fault statute where few amount of metal can be added to dovetail guide ways and saddles to be followed by grinding to get high surface finish.

Good profession, high degree of complexity and special equipment are required.

#### **A<sub>2</sub>: Milling-Electrodeposited- Grinding**

It is more suitable for medium degree of damage of fault statute where amount of metal should be removed by milling then metal should be added to dovetail guide ways and saddles by electrodeposited process to be followed by grinding to get high surface finish. Very good profession, very high degree of complexity and special equipment are required.

#### **A<sub>3</sub>: Milling-Laser Cladding-Grinding**

It is more suitable for medium degree of damage of fault statute where amount of metal should be removed by milling then metal should be added to dovetail guide ways and saddles by laser cladding process to be followed by grinding to get high surface finish. Very good profession, very high degree of complexity and special equipment are required.

#### **A<sub>4</sub>: Milling - Plasma spray-Grinding**

It is more suitable for medium degree of damage of fault statute where amount of metal should be removed by milling then metal should be added to dovetail guide ways and saddles by plasma spray process to be followed by grinding to get high surface finish. Very good profession, very high degree of complexity and special equipment are required.

#### **A<sub>5</sub>: Milling- Plasma arc surfacing – Grinding**

It is more suitable for medium degree of damage of fault statute where amount of metal should be removed by milling then metal should be added to dovetail guide ways and saddles by plasma arc surfacing process to be followed by grinding to get high surface finish. Very good profession, very high degree of complexity and special equipment are required.

#### **A<sub>6</sub>: Milling- Brushing electroplating – Grinding**

It is more suitable for medium degree of damage of fault statute where amount of metal should be removed by milling then metal should be added to dovetail guide ways and saddles by brushing electroplating process to be followed by grinding to get high surface finish. Very good profession, very high degree of complexity and special equipment are required.

**A<sub>7</sub>: Milling -Cold Welding- Grinding**

It is more suitable for medium degree of damage of fault statute where amount of metal should be removed by milling then metal should be added to dovetail guide ways and saddles by cold welding process to be followed by grinding to get high surface finish. Very good profession, very high degree of complexity and special equipment are required.

**A<sub>8</sub>: Grinding-Mechanical Cladding**

It is more suitable for low to medium degree of damage of fault statute where metal can be removed by grinding to get high surface finish to be followed by insert/mate/screw assembly of ball guide ways to machine body. Medium profession, low degree of complexity and special equipment is not required.

Pre-assessment of remanufacturing portfolio cannot be of straight judgment. According to comparative literature based assessment (A<sub>6</sub>) is the best alternative comparing with (A<sub>3</sub>), (A<sub>4</sub>) and (A<sub>5</sub>) based on mean relative closeness of alternatives, Fig. 2 [16].

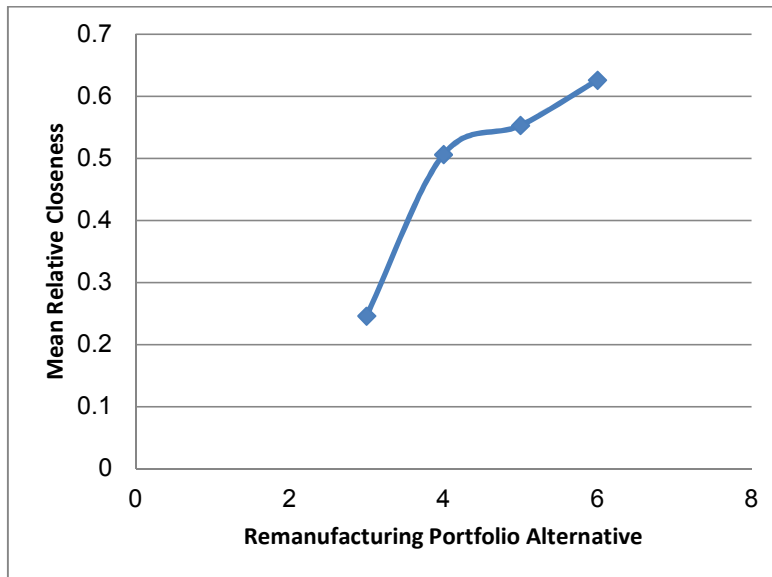
The assessment process based on the increasing rule which states that the increase in global weight will lead to decrease in rank of

alternative means the first best three alternatives are A<sub>8</sub> with weight of (0.142), A<sub>6</sub> with weight of (0.365) and A<sub>1</sub> with weight of (0.402).

**3.2 Remanufacturing of Dovetail Guide Ways and Saddles Performance Assessment**

Each single process that can contribute the formation of single remanufacturing portfolio can be assessed as following:-

- 1- Cold welding can be of manual based operation or robotics based operation such technology of:
  - High to extremely high difficulty.
  - Average to high investment.
  - Above average to extremely high localization ability.
  - Average to high training applicability.
- 2- Grinding can be automatic machine based technology or CNC machine based technology so such technology of:
  - Above average to high difficulty.
  - Average to very high investment.
  - High to extremely high localization ability.
  - Average to high training applicability.



**Fig. 2. Mean relative closeness ranks of additive remanufacturing portfolio alternatives, (1): Laser Cladding, (2): Plasma Arc Surfacing, (3): Brushing electroplating, (4): Plasma spray [16]**

- 3- Electrodeposited can be manual-automatic hybridity so such technology of:
  - Extremely High to exceptionally high difficulty.
  - Very high to extremely high investment.
  - Extremely High to exceptionally high localization ability.
  - High to extremely high training applicability.
- 4- Brushing electroplating can be manually only so such technology of:
  - Average to high difficulty.
  - Below average to above average investment.
  - Very low to average localization ability.
  - High to extremely high training applicability.
- 5- Plasma spray can be of manual based operation or robotics based operation such technology of:
  - High to very high difficulty.
  - Average to very high investment.
  - Average to high localization ability.
  - Average to high training applicability.
- 6- Plasma arc surfacing can be of manual based operation or CNC machine based operation so such technology of:
  - High to very high difficulty.
  - Average to very high investment.
  - Average to high localization ability.
  - Average to high training applicability.
- 7- Laser Cladding can be of manual based operation or CNC machine based operation so such technology of:
  - High to very high difficulty.
  - Average to very high investment.
  - Average to high localization ability.
  - Average to high training applicability.
- 8- Milling can be automatic machine based technology or CNC machine based technology so such technology of:
  - Above average to high difficulty.
  - Average to very high investment.
  - High to extremely high localization ability.
  - Average to high training applicability.
- 9- Mechanical cladding
  - Very low to average difficulty.
  - Very low to average investment.
  - Low to above average localization ability.
  - Very low to average training applicability.

### 3.3 Comparative Literature Based Rough Fuzzy Based Assessment Application

Impact is termed as the harmful effect on economic, environment, society and technology. As high as the environmental impact, economic impact or social impact, as low as the assigned value. Chart 1 is a quantitative values assigned attributes to be used for rough fuzzy assessment of remanufacturing portfolios which include:

Grinding-Mechanical Cladding additive remanufacturing portfolio will contain grinding of fault dovetail guide ways or saddles then magnetic Neodymium Pot Magnets will be used to develop flexible insert/mate/bolt system to enable assembly of ball linear guide ways to machine tool body. So any further process will not be required so that the alternative ( $A_8$ ) will contribute very high in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and processing cost will be very low so this alternative will contribute extremely high in reduction of economic impacts and technically, extremely high performance can be gotten even Bonding Strength and Hardness are low comparing with other portfolios but they will be more than enough to provide high machining performance by remanufactured conventional machine into CNC machine tool. Porosity and Substrate Deformation are of very low contribution to after remanufacturing defects since no material or heat is added so that such portfolio is of very high remanufacturability. Such technology is a little hard to be localized nationally and can be of medium hard to be practiced by training since heavy duty grinding machine is required to process dovetail guide ways and saddles so that application of such technology can certain employment and human development and will contribute very high in reduction of social impacts.

Milling- Brushing Electroplating - Grinding additive remanufacturing portfolio will contain milling of failed dovetail guide ways or saddles then metal should be added by using Brushing Electroplating to be followed by grinding to remove the unwanted metal and certain fit-to-size profile of dovetail guide ways or saddles. Alternative ( $A_6$ ) will contribute above average in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and



processing cost will be low so this alternative will contribute high in reduction of economic impacts and very high in enhancing technical performance to provide high machining performance by remanufactured conventional machine into CNC machine tool. Porosity and Substrate Deformation are of very low contribution to after remanufacturing defects since no melting technique is used to add materials which can maintain mechanical properties of machine bed unchanged so that such portfolio is of high remanufacturability. Such technology is above medium hard to be localized nationally since light duty Brushing Electroplating machine and heavy duty milling machine or gantry type milling machine should be added to heavy duty grinding machine to be of medium complexity to be practiced by training so that application of such technology can certain employment and human development and will contribute high in reduction of social impacts.

Cold Welding-Grinding additive remanufacturing portfolio will contain add metal by heat to cover the failed dovetail guide ways or saddles to be followed by grinding to remove the unwanted metal and certain fit-to-size profile of dovetail guide ways. Alternative (A<sub>1</sub>) will contribute average in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and processing cost will be low so this alternative will contribute above average in reduction of economic impacts and high in enhancing technical performance to provide high machining performance by remanufactured conventional lathe into CNC machine tool. Porosity and Substrate Deformation can be involved due to unsuitable application so that contribution to after remanufacturing defects due to such melting technique can change mechanical properties of

machine bed so that such portfolio is of above average remanufacturability. Such technology is medium hard to be localized nationally since light duty cold welding machine and heavy duty grinding machine are required to be of medium complexity to be practiced by training so that application of such technology can certain employment and human development and will contribute high in reduction of social impacts.

Milling-Cold Welding-Grinding additive remanufacturing portfolio will contain milling of failed dovetail guide ways or saddles then metal to be added by heat through Cold Welding to cover the failed dovetail guide ways or saddles to be followed by grinding to remove the unwanted metal and certain fit-to-size profile of dovetail guide ways. Alternative (A<sub>7</sub>) will contribute average in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and processing cost will be low so this alternative will contribute average in reduction of economic impacts and high in enhancing technical performance to provide high machining performance by remanufactured conventional lathe into CNC machine tool. Porosity and Substrate Deformation can be involved due to unsuitable application so that contribution to after remanufacturing defects due to such melting technique can change mechanical properties of machine bed so that such portfolio is of above average remanufacturability. Such technology is hard to be localized nationally since light duty cold welding machine and heavy duty milling machine or gantry type milling machine should be added to heavy duty grinding machine to process dovetail guide ways or saddles to be of medium complexity to be practiced by training so that application of such technology can certain employment and human development and will contribute high in reduction of social impacts.

**Chart 1. Quantitative values assigned attributes [4]**

<b>Qualitative measure of attributes</b>	<b>Assigned Value</b>
Exceptionally low	1
Extremely low	2
Very low	3
Below average	4
Average	5
Above average	6
High	7
Very high	8
Extremely high	9
Exceptionally high	10

Milling - Plasma spray – Grinding additive remanufacturing portfolio will contain milling of failed dovetail guide ways or saddles then metal to be added by heat through Plasma Spray to cover the failed dovetail guide ways or saddles to be followed by grinding to remove the unwanted metal and certain fit-to-size profile of dovetail guide ways. Alternative (A<sub>4</sub>) will contribute average in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and processing cost will be low so this alternative will contribute below average in reduction of economic impacts and above average in enhancing technical performance to provide high machining performance by remanufactured conventional lathe into CNC machine tool. Porosity and Substrate Deformation can be involved due to unsuitable application so that contribution to after remanufacturing defects due to such melting technique can change mechanical properties of machine bed so that such portfolio is of above average remanufacturability. Such technology is above medium hard to be localized nationally since heavy duty plasma spray machine and heavy duty milling machine or gantry type milling machine should be added to heavy duty grinding machine to process dovetail guide ways or saddles to be of above medium complexity to be practiced by training so that application of such technology cannot certain employment and human development and will contribute average in reduction of social impacts.

Milling-Plasma arc surfacing-Grinding additive remanufacturing portfolio will contain milling of failed dovetail guide ways or saddles then metal to be added by heat through Plasma Arc Surfacing to cover the failed dovetail guide ways or saddles to be followed by grinding to remove the unwanted metal and certain fit-to-size profile of dovetail guide ways. Alternative (A<sub>5</sub>) will contribute average in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and processing cost will be low so this alternative will contribute below average in reduction of economic impacts and below average in enhancing technical performance to provide high machining performance by remanufactured conventional lathe into CNC machine tool. Porosity and Substrate Deformation can be involved due to unsuitable application so that contribution to after

remanufacturing defects due to such melting technique can change mechanical properties of machine bed so that such portfolio is of above average remanufacturability. Such technology is above medium hard to be localized nationally since heavy duty plasma arc surfacing machine and heavy duty milling machine or gantry type milling machine should be added to heavy duty grinding machine to process dovetail guide ways or saddles to be of high complexity to be practiced by training so that application of such technology cannot certain employment and human development and will contribute average in reduction of social impacts.

Milling-Laser Cladding-Grinding additive remanufacturing portfolio will contain milling of failed dovetail guide ways or saddles then metal to be added by heat through Laser Cladding to cover the failed dovetail guide ways or saddles to be followed by grinding to remove the unwanted metal and certain fit-to-size profile of dovetail guide ways. Alternative (A<sub>3</sub>) will contribute average in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and processing cost will be low so this alternative will contribute below average in reduction of economic impacts and below average in enhancing technical performance to provide high machining performance by remanufactured conventional lathe into CNC machine tool. Porosity and Substrate Deformation can be involved due to unsuitable application but heat distribution and quantity are controlled to be uniform so that contribution to after remanufacturing defects due to such melting technique cannot change mechanical properties of machine bed so that such portfolio is of high remanufacturability. Such technology is very hard to be localized nationally since heavy duty laser cladding machine and heavy duty milling machine or gantry type milling machine should be added to heavy duty grinding machine to process dovetail guide ways or saddles to be of high complexity to be practiced by training so that application of such technology cannot certain employment and human development and will contribute below average in reduction of social impacts.

Milling-Electrodeposited-Grinding additive remanufacturing portfolio will contain milling of failed dovetail guide ways or saddles then metal to be added through Electrodeposited to cover the failed dovetail guide ways or saddles to be

followed by grinding to remove the unwanted metal and certain fit-to-size profile of dovetail guide ways. Alternative (A<sub>2</sub>) will contribute below average in reduction of environmental impacts of Depletion Potential, Global Warming Potential, Respiratory Inorganics, Acidification Potential, and Water Eutrophication Potential. Investment and processing cost will be very high so this alternative will contribute below average in reduction of economic impacts and below average in enhancing technical performance to provide high machining performance by remanufactured conventional lathe into CNC machine tool. Porosity and Substrate Deformation cannot be involved so that contribution to after remanufacturing defects due to such melting technique cannot change mechanical properties of machine bed so that such portfolio is of high remanufacturability. Such technology is above very hard to be localized nationally since Electrodeposited factory scale unit, heavy duty milling machine or gantry type milling machine should be added to heavy duty grinding machine to process dovetail guide ways or saddles to be of very high complexity to be practiced by training so that application of such technology cannot certain employment and human development and will contribute below average in reduction of social impacts.

### 3.4 Comparative Literature Based Assessment Application

Shitong Peng et al. [16] after above by process assessment description in paragraph (3.3), comparative literature based assessment

application contains ten criteria to be used to differentiate among the proposed eight additive remanufacturing portfolios of conventional machine tool into CNC machine. The assessment analysis results are contained in Table 2 and shown in Fig. 3, assessment procedure contains:

- C<sub>1</sub>: Resource depletion potential.
- C<sub>2</sub>: Global warming potential.
- C<sub>3</sub>: Respiratory inorganics.
- C<sub>4</sub>: Acidification potential.
- C<sub>5</sub>: Water eutrophication potential.
- C<sub>6</sub>: Processing cost.
- C<sub>7</sub>: Bonding strength.
- C<sub>8</sub>: Hardness.
- C<sub>9</sub>: Porosity.
- C<sub>10</sub>: Substrate deformation.

Yanbin Du et al. [1] Comparative literature based assessment can be applied by using seven criteria to differentiate among the proposed eight additive remanufacturing portfolio of conventional machine tool into CNC machine. Criteria and their AHP-weights are contained in Table 3 and shown in Fig. 4, assessment process is as the following:-

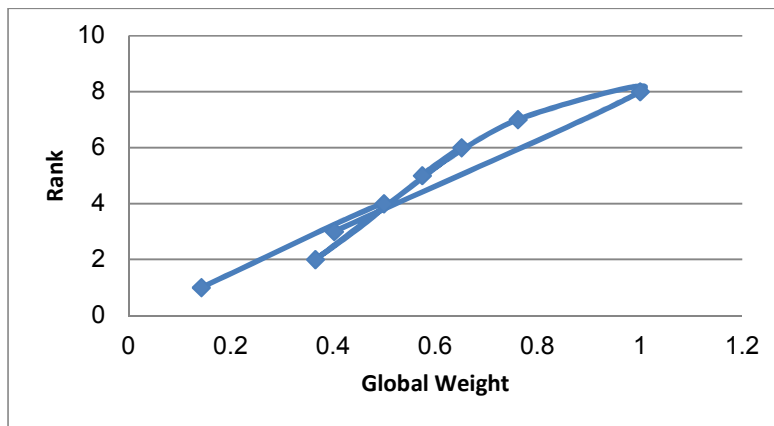
- C<sub>1</sub>: Remanufacturing cost.
- C<sub>2</sub>: Remanufacturing time.
- C<sub>3</sub>: Accuracy.
- C<sub>4</sub>: Reliability.
- C<sub>5</sub>: Processing efficiency.
- C<sub>6</sub>: Processing range.
- C<sub>7</sub>: Ergonomics.

**Table 2. The weighted importance of each criterion**

Alternative	Criterion	C <sub>1</sub> (0.303)	C <sub>2</sub> (0.260)	C <sub>3</sub> (0.116)	C <sub>4</sub> (0.154)	C <sub>5</sub> (0.167)	C <sub>6</sub> (0.309)
A <sub>1</sub> : Cold Welding-Grinding		0.210	0.146	0.157	0.163	0.157	0.1203
A <sub>2</sub> :Milling Electrodeposited-Grinding		0.635	0.571	0.533	0.559	0.635	0.6358
A <sub>3</sub> :Milling-Laser Cladding-Grinding		0.571	0.533	0.385	0.533	0.571	0.2107
A <sub>4</sub> :Milling-Plasma spray-Grinding		0.210	0.146	0.157	0.163	0.157	0.1205
A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.385	0.385	0.345	0.345	0.385	0.2496
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.157	0.0982
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.146	0.120	0.098	0.087	0.120	0.3854
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.0471

**Table 2. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>7</sub> (0.367)	C <sub>8</sub> (0.204)	C <sub>9</sub> (0.156)	C <sub>10</sub> (0.273)	Normalized global weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.385	0.345	0.120	0.375	0.402	3
A <sub>2</sub> :Milling-Electrodeposited-Grinding		0.533	0.571	0.559	0.571	1	8
A <sub>3</sub> :Milling-Laser Cladding-Grinding		0.533	0.571	0.559	0.098	0.761	7
A <sub>4</sub> :Milling-Plasma spray-Grinding		0.279	0.533	0.262	0.533	0.574	5
A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.279	0.533	0.262	0.635	0.651	6
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.385	0.345	0.262	0.210	0.365	2
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.345	0.533	0.279	0.559	0.499	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.157	0.120	0.047	0.047	0.142	1



**Fig. 3. Rank- global weight curve of additive remanufacturing portfolio alternatives**

**Table 3. The weighted importance of each criterion**

Alternative	Criterion	C <sub>1</sub> (0.256)	C <sub>2</sub> (0.256)	C <sub>3</sub> (0.151)	C <sub>4</sub> (0.151)	C <sub>5</sub> (0.091)	C <sub>6</sub> (0.038)
A <sub>1</sub> : Cold Welding-Grinding		0.157	0.146	0.120	0.163	0.157	0.098
A <sub>2</sub> :Milling Electrodeposited-Grinding		0.635	0.571	0.533	0.559	0.635	0.635
A <sub>3</sub> :Milling-Laser Cladding-Grinding		0.571	0.533	0.385	0.533	0.571	0.210
A <sub>4</sub> :Milling-Plasma spray-Grinding		0.279	0.262	0.345	0.385	0.279	0.249
A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.385	0.385	0.345	0.345	0.385	0.249
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.210	0.146	0.157	0.163	0.157	0.120
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.210	0.146	0.157	0.163	0.157	0.120
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047

**Table 3. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>7</sub> (0.057)	Global Weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.385	0.160	3
A <sub>2</sub> :Milling-Electrodeposited-Grinding		0.533	0.586	8
A <sub>3</sub> :Milling-Laser Cladding Grinding		0.533	0.512	7
A <sub>4</sub> :Milling-Plasma spray-Grinding		0.279	0.299	5
A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.279	0.362	6
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.345	0.141	2
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.385	0.180	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.157	0.075	1

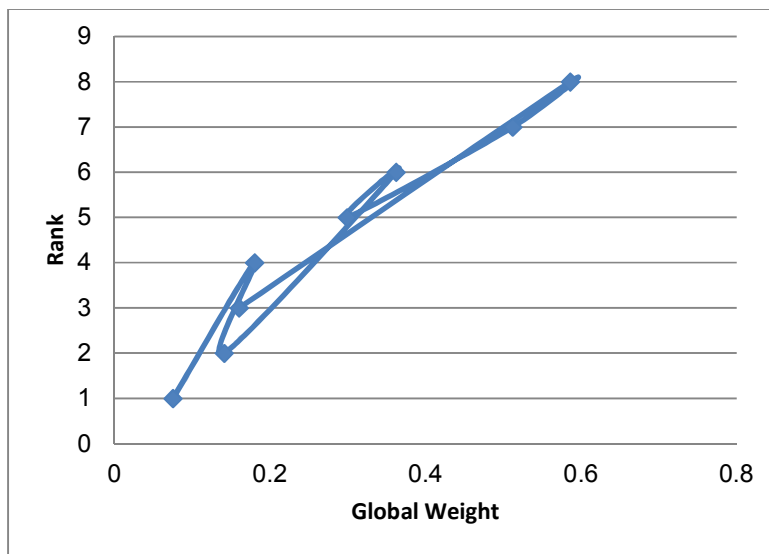
Yanbin Du et al. [17] another remanufacturing assessment approach can include the using of weights of new nine criteria to differentiate among the proposed eight additive remanufacturing portfolio of conventional machine tool into CNC machine. Fig. 5 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 4. Criteria include:-

- C<sub>1</sub>: Ease of disassembly
- C<sub>2</sub>: Feasibility of cleaning
- C<sub>3</sub>: Feasibility of inspection and sorting
- C<sub>4</sub>: Feasibility of part reconditioning
- C<sub>5</sub>: Feasibility of machine upgrading
- C<sub>6</sub>: Ease of reassembly
- C<sub>7</sub>: Material saving
- C<sub>8</sub>: Energy saving

- C<sub>9</sub>: Pollution reduction
- C<sub>10</sub>: Economic feasibility

Zhigang Jiang et al. [3]Another remanufacturing assessment approach can include the following weighted six criteria which are used to differentiate among the proposed eight additive remanufacturing portfolio alternatives of conventional machine tool into CNC machine. Fig. 6 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 5. Criteria include:-

- C<sub>1</sub>: Time
- C<sub>2</sub>: Quality
- C<sub>3</sub>: Cost
- C<sub>4</sub>: Service
- C<sub>5</sub>: Process emission
- C<sub>6</sub>: Resource consumption



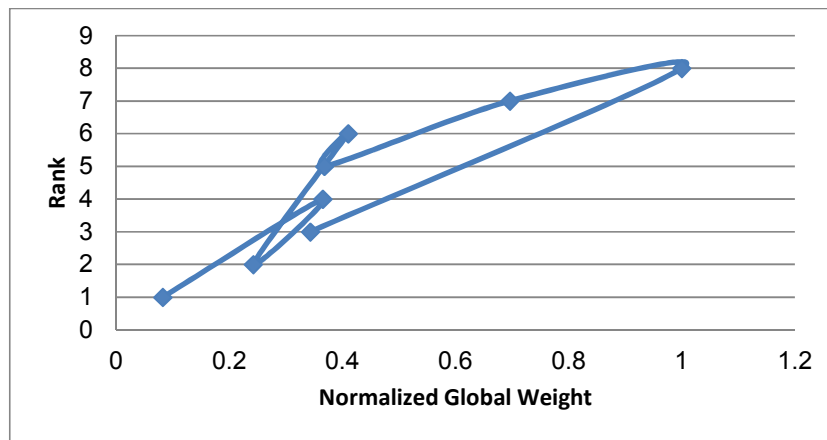
**Fig. 4. Rank- global weight curve of additive remanufacturing portfolio alternatives**

**Table 4. The weighted importance of each criterion**

Alternative	Criterion	C <sub>1</sub> (0.8)	C <sub>2</sub> (0.74)	C <sub>3</sub> (0.8)	C <sub>4</sub> (0.84)	C <sub>5</sub> (0.92)	C <sub>6</sub> (0.778)
A <sub>1</sub> : Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.279	0.249
A <sub>2</sub> :Milling-Electrodeposited-Grinding		0.635	0.571	0.533	0.559	0.635	0.635
A <sub>3</sub> :Milling-Laser Cladding-Grinding		0.157	0.146	0.120	0.163	0.157	0.098
A <sub>4</sub> :Milling-Plasma spray-Grinding		0.571	0.533	0.385	0.533	0.571	0.210
A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.146	0.120	0.098	0.087	0.120	0.385
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.210	0.146	0.157	0.163	0.157	0.120
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.385	0.385	0.345	0.345	0.385	0.249
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047

**Table 4. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>7</sub> (0.54)	C <sub>8</sub> (0.297)	C <sub>9</sub> (0.163)	C <sub>10</sub> (0.8)	Normalized global weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.279	0.533	0.262	0.533	0.343	3
A <sub>2</sub> :Milling-Electrodeposited-Grinding		0.533	0.571	0.559	0.571	1	8
A <sub>3</sub> :Milling-Laser Cladding-Grinding		0.385	0.345	0.262	0.210	0.696	7
A <sub>4</sub> :Milling-Plasma spray-Grinding		0.533	0.571	0.559	0.098	0.368	5
A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.345	0.533	0.279	0.559	0.410	6
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.385	0.345	0.120	0.375	0.242	2
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.279	0.533	0.262	0.635	0.365	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.157	0.120	0.047	0.047	0.082	1



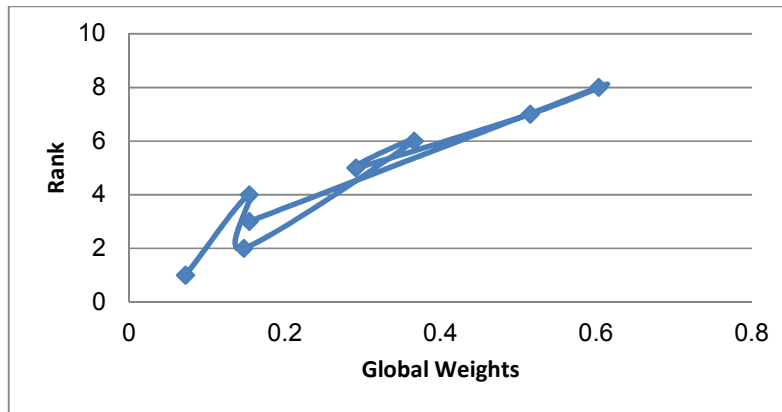
**Fig. 5. Rank- global weight curve of additive remanufacturing portfolio alternatives**

**Table 5. The weighted importance of each criterion**

Alternative	Criterion	C <sub>1</sub> (0.046)	C <sub>2</sub> (0.268)	C <sub>3</sub> (0.084)	C <sub>4</sub> (0.129)	C <sub>5</sub> (0.403)	C <sub>6</sub> (0.068)
3A <sub>1</sub> : Cold Welding-Grinding		0.210	0.146	0.157	0.163	0.157	0.120
8A <sub>2</sub> :Milling Electrodeposited-Grinding		0.635	0.571	0.533	0.559	0.635	0.635
7A <sub>3</sub> :Milling-Laser Cladding-Grinding		0.571	0.533	0.385	0.533	0.571	0.210
5A <sub>4</sub> :Milling-Plasma spray-Grinding		0.210	0.146	0.157	0.163	0.157	0.120
6A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.385	0.385	0.345	0.345	0.385	0.249
2A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.157	0.098
4A <sub>7</sub> : Milling -Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.279	0.249
1A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047

**Table 5. The weighted importance of each criterion, continued**

Alternative	Criterion	Global weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.154	3
A <sub>2</sub> :Milling-Electrodeposited-Grinding		0.603	8
A <sub>3</sub> :Milling-Laser Cladding Grinding		0.515	7
A <sub>4</sub> :Milling-Plasma spray-Grinding		0.291	5
A <sub>5</sub> : Milling- Plasma arc surfacing - Grinding		0.366	6
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.147	2
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.154	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.072	1



**Fig.6. Rank- global Weight curve of additive remanufacturing portfolio alternatives**

**3.5 Continued Comparative Literature Based Assessment Application**

Several hypotheses can be highlighted to continue comparative literature based assessment include:

- 1- Technical viability of remanufacturing portfolio will lead to economic and environmental viabilities.
- 2- Economic and environmental viabilities necessarily can certain remanufacturability and will lead to social viability.

3- Technical, economic, environmental and social viabilities will lead to sustainability.

Most remanufacturing portfolios that can be of technical viability include A<sub>1</sub>, A<sub>6</sub>, A<sub>7</sub> and A<sub>8</sub> and thus comparative literature based assessment can be continued as following:

Integrated technical viability of a remanufacturing portfolio is an integration of derivatives of technical viabilities of processes that consists the portfolio. Technical and economic viabilities of a single process can be described as following:

1- Brushing electroplating can be done manually only so such technology of:

- Average to high difficulty.
- Below average to above average investment.
- Very low to average localization ability.
- High to extremely high training applicability.

2- Cold welding can be of manual based operation or robotics based operation such technology of:

- High to extremely high difficulty.
- Average to high investment.
- Above average to extremely high localization ability.
- Average to high training applicability.

3- Milling can be automatic machine based technology or CNC machine based technology so such technology of:

- Above average to high difficulty.
- Average to very high investment.
- High to extremely high localization ability.
- Average to high training applicability.

4- Grinding can be automatic machine based technology or CNC machine based technology so such technology of:

- Above average to high difficulty.
- Average to very high investment.
- High to extremely high localization ability.
- Average to high training applicability.

5- Mechanical cladding can be done manually so such technology of:

- Very low to average difficulty.
- Very low to average investment.
- Low to above average localization ability.
- Very low to average training applicability.

Xu-Hui Xia et al. [18]Another remanufacturing assessment approach can include the following weighted criteria which are used to differentiate among the proposed eight additive remanufacturing portfolio alternatives of conventional machine tool into CNC machine. Fig. 7 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 6. Criteria include:-

- C<sub>1</sub>: Response time
- C<sub>2</sub>: Execution time
- C<sub>3</sub>: Reverse logistics transport time
- C<sub>4</sub>: Rental prices for integrated platforms
- C<sub>5</sub>: Cost of knowledge services
- C<sub>6</sub>: Cost of processing and testing
- C<sub>7</sub>: Default fine
- C<sub>8</sub>: Service resources
- C<sub>9</sub>: Service module
- C<sub>10</sub>: Network operation
- C<sub>11</sub>: Information storage
- C<sub>12</sub>: Knowledge transfer
- C<sub>13</sub>: Scheme
- C<sub>14</sub>: Craft
- C<sub>15</sub>: Knowledge
- C<sub>16</sub>: Technology
- C<sub>17</sub>: Scale

**Table 6. The weighted importance of each criterion**

Alternative	Criterion	C <sub>1</sub> (0.327)	C <sub>2</sub> (0.380)	C <sub>3</sub> (0.293)	C <sub>4</sub> (0.246)	C <sub>5</sub> (0.257)	C <sub>6</sub> (0.275)	C <sub>7</sub> (0.222)
A <sub>1</sub> : Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.279	0.385	0.533
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.157	0.163	0.385
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.571	0.533	0.385	0.533	0.571	0.533	0.385
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047	0.157

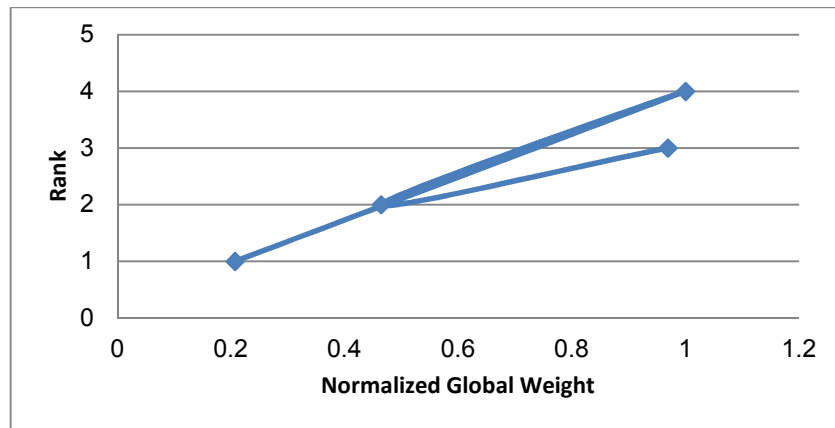


**Table 6. The weighted importance of each criterion, continued**

Alternative	Criterion	<b>C<sub>8</sub></b> <b>(0.503)</b>	<b>C<sub>9</sub></b> <b>(0.497)</b>	<b>C<sub>10</sub></b> <b>(0.333)</b>	<b>C<sub>11</sub></b> <b>(0.347)</b>	<b>C<sub>12</sub></b> <b>(0.320)</b>	<b>C<sub>13</sub></b> <b>(0.338)</b>	<b>C<sub>14</sub></b> <b>(0.325)</b>
A <sub>1</sub> : Cold Welding-Grinding		0.571	0.559	0.571	0.249	0.279	0.279	0.279
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.345	0.120	0.345	0.098	0.157	0.157	0.157
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.345	0.262	0.345	0.210	0.571	0.571	0.571
A <sub>8</sub> : Grinding-Mechanical Cladding		0.120	0.047	0.120	0.047	0.098	0.098	0.098

**Table 6. The weighted importance of each criterion, continued**

Alternative	Criterion	<b>C<sub>15</sub></b> <b>(0.338)</b>	<b>C<sub>16</sub></b> <b>(0.525)</b>	<b>C<sub>17</sub></b> <b>(0.475)</b>	<b>Normalized global weight</b>	<b>Ranking</b>
A <sub>1</sub> : Cold Welding-Grinding		0.249	0.249	0.249	0.969	3
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.098	0.098	0.098	0.464	2
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.210	0.210	0.210	1	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.047	0.047	0.047	0.207	1



**Fig. 7. Rank- normalized global weight curve of additive remanufacturing portfolio alternatives**

Guangdong Tian et al. [19] another remanufacturing assessment approach can include the following weighted criteria which are used to differentiate among the proposed eight additive remanufacturing portfolio alternatives of conventional machine tool into CNC machine. Fig. 8 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 7. Criteria include:-

- C<sub>1</sub>: Remanufacturability design
- C<sub>2</sub>: Market strategy

- C<sub>3</sub>: Disassembly technology
- C<sub>4</sub>: Cleaning technology
- C<sub>5</sub>: Inspection technology
- C<sub>6</sub>: Repair technology
- C<sub>7</sub>: Process technology
- C<sub>8</sub>: Reassembly technology
- C<sub>9</sub>: Testing technology
- C<sub>10</sub>: Talent quality
- C<sub>11</sub>: Standard performance
- C<sub>12</sub>: Quality certification
- C<sub>13</sub>: Information management
- C<sub>14</sub>: Recovery network
- C<sub>15</sub>: Sale mode

**Table 7. The weighted importance of each criterion**

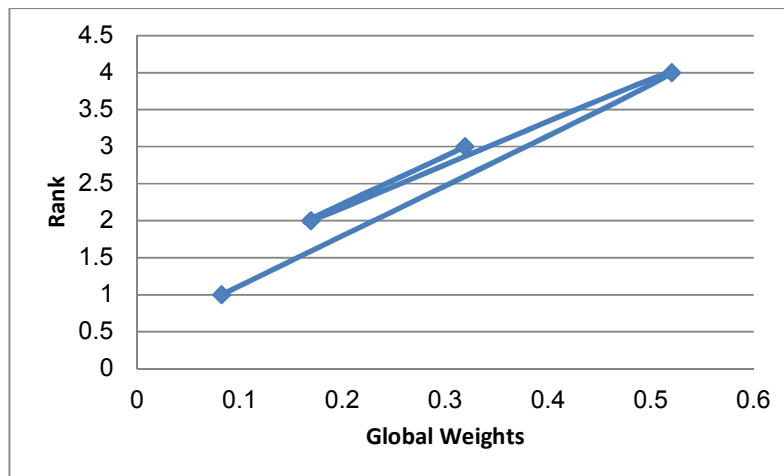
Alternative	Criterion	C <sub>1</sub> (0.467)	C <sub>2</sub> (0.156)	C <sub>3</sub> (0.047)	C <sub>4</sub> (0.036)	C <sub>5</sub> (0.023)	C <sub>6</sub> (0.099)	C <sub>7</sub> (0.019)
A <sub>1</sub> : Cold Welding-Grinding		0.571	0.533	0.385	0.533	0.571	0.533	0.385
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.157	0.163	0.385
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.279	0.385	0.533
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047	0.157

**Table 7. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>8</sub> (0.009)	C <sub>9</sub> (0.007)	C <sub>10</sub> (0.055)	C <sub>11</sub> (0.033)	C <sub>12</sub> (0.026)	C <sub>13</sub> (0.016)	C <sub>14</sub> (0.007)
A <sub>1</sub> : Cold Welding-Grinding		0.571	0.559	0.571	0.249	0.279	0.279	0.279
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.345	0.120	0.345	0.098	0.157	0.157	0.157
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.345	0.262	0.345	0.210	0.571	0.571	0.571
A <sub>8</sub> : Grinding-Mechanical Cladding		0.120	0.047	0.120	0.047	0.098	0.098	0.098

**Table 7. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>15</sub> (0.005)	Global weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.210	0.319	3
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.249	0.169	2
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.210	0.520	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.047	0.0822	1



**Fig. 8. Rank- global weight curve of additive remanufacturing portfolio alternatives**

Ramesh Subramoniama et al. [8] another include the following weighted criteria criteria are remanufacturing assessment approach can used to differentiate among the proposed eight

additive remanufacturing portfolio of conventional machine tool into CNC machine. Fig. 9 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 8. Criteria include:-

- C<sub>1</sub>: Impact of remanufacturing
- C<sub>2</sub>: Core management
- C<sub>3</sub>: Protection of intellectual property
- C<sub>4</sub>: Green perception
- C<sub>5</sub>: Original equipment product specifications
- C<sub>6</sub>: Government regulations

- C<sub>7</sub>: Integrated organizational alignment
- C<sub>8</sub>: Design for remanufacturing
- C<sub>9</sub>: Brand erosion

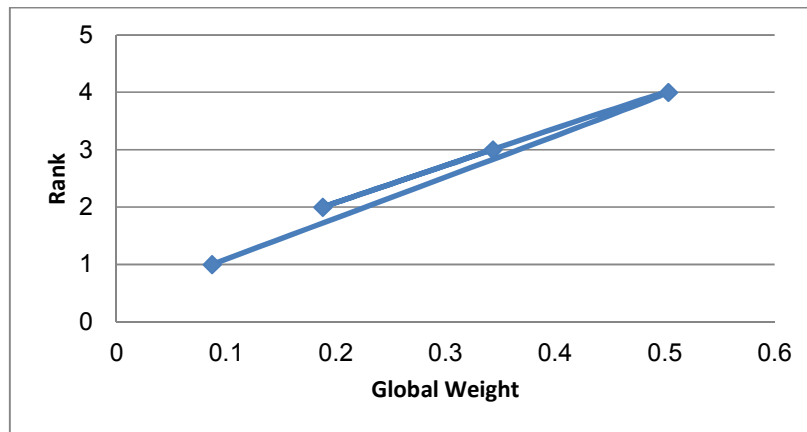
Zhigang Jiang et al. [13] another remanufacturing assessment approach can include the following weighted criteria ten criteria are used to differentiate among the proposed eight additive remanufacturing portfolio of conventional machine tool into CNC machine. Fig. 10 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 9. Criteria include:-

**Table 8. The weighted importance of each criterion**

Alternative	Criterion	C <sub>1</sub> (0.300)	C <sub>2</sub> (0.175)	C <sub>3</sub> (0.115)	C <sub>4</sub> (0.083)	C <sub>5</sub> (0.081)	C <sub>6</sub> (0.078)	C <sub>7</sub> (0.069)
A <sub>1</sub> : Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.279	0.385	0.533
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.157	0.163	0.385
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.571	0.533	0.385	0.533	0.571	0.533	0.385
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047	0.157

**Table 8. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>7</sub> (0.061)	C <sub>8</sub> (0.035)	Global weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.533	0.571	0.343	3
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.385	0.345	0.188	2
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.385	0.345	0.503	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.157	0.120	0.087	1



**Fig. 9. Rank- global weight curve of additive remanufacturing portfolio alternatives**

- C<sub>1</sub>: Cost of purchasing end-of-life product.
- C<sub>2</sub>: Transportation cost.
- C<sub>3</sub>: Inventory cost.
- C<sub>4</sub>: Remanufacturing processing cost.
- C<sub>5</sub>: Cost of purchasing replaced parts.
- C<sub>6</sub>: Energy saving rate.
- C<sub>7</sub>: Industrial wastewater.
- C<sub>8</sub>: Industrial exhaust fumes.
- C<sub>9</sub>: Industrial solid waste.
- C<sub>10</sub>: The utilization rate of environmental friendly materials.
- C<sub>11</sub>: Rate of remanufacturing of end-of-life products.
- C<sub>12</sub>: Electrical energy consumption.
- C<sub>13</sub>: Rate of materials reuse.
- C<sub>14</sub>: Rate of materials recovery.
- C<sub>15</sub>: Material resource consumption.

Qingtao Liu et al. [20] another remanufacturing assessment approach can include the following weighted criteria ten criteria are used to differentiate among the proposed eight additive remanufacturing portfolio of conventional

machine tool into CNC machine. Fig. 11 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 10. Criteria include:-

- C<sub>1</sub>: Economic remanufacturability indicator
- C<sub>2</sub>: Quality remanufacturability indicator
- C<sub>3</sub>: Resource consumption indicator
- C<sub>4</sub>: Environmental emission indicator

Thomas A. Omwando et al. [15] another remanufacturing assessment approach can include the following weighted criteria which are used to differentiate among the proposed eight additive remanufacturing portfolio of conventional machine tool into CNC machine. Fig. 12 shows Rank- Global Weight curve of additive remanufacturing portfolio alternatives where the weighted importance of each criterion and assessment values are registered in Table 11. Criteria include:-

**Table 9. The weighted importance of each criterion**

Alternative	Criterion	C <sub>1</sub> (0.774)	C <sub>2</sub> (0.759)	C <sub>3</sub> (0.769)	C <sub>4</sub> (0.777)	C <sub>5</sub> (0.776)	C <sub>6</sub> (0.779)	C <sub>7</sub> (0.762)
A <sub>1</sub> : Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.279	0.385	0.533
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.157	0.163	0.385
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.571	0.533	0.385	0.533	0.571	0.533	0.385
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047	0.157

**Table 9. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>8</sub> (0.759)	C <sub>9</sub> (0.762)	C <sub>10</sub> (0.764)	C <sub>11</sub> (0.775)	C <sub>12</sub> (0.770)	C <sub>13</sub> (0.769)	C <sub>14</sub> (0.770)
A <sub>1</sub> : Cold Welding-Grinding		0.571	0.559	0.571	0.249	0.279	0.279	0.279
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.345	0.120	0.345	0.098	0.157	0.157	0.157
A <sub>7</sub> : Milling -Cold Welding-Grinding		0.345	0.262	0.345	0.210	0.571	0.571	0.571
A <sub>8</sub> : Grinding-Mechanical Cladding		0.120	0.047	0.120	0.047	0.098	0.098	0.098

**Table 9. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>15</sub> (0.764)	Normalized global weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.249	0.774	3
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.098	0.418	2
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.210	1	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.047	0.188	1

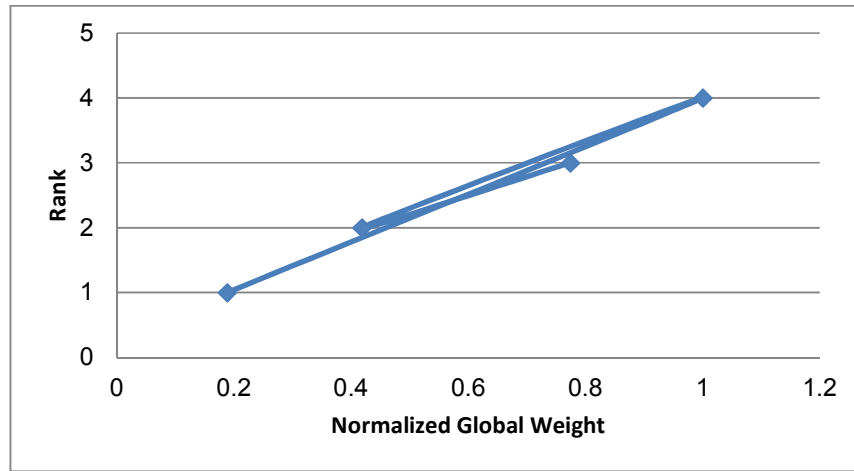


Fig. 10. Rank- normalized global weight curve of additive remanufacturing portfolio alternatives

Table 10. The weighted importance of each criterion

Alternative	Criterion	C <sub>1</sub> (0.333)	C <sub>2</sub> (0.333)	C <sub>3</sub> (0.167)	C <sub>4</sub> (0.167)	Global Weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.302	3
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.148	2
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.571	0.533	0.385	0.533	0.521	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.069	1

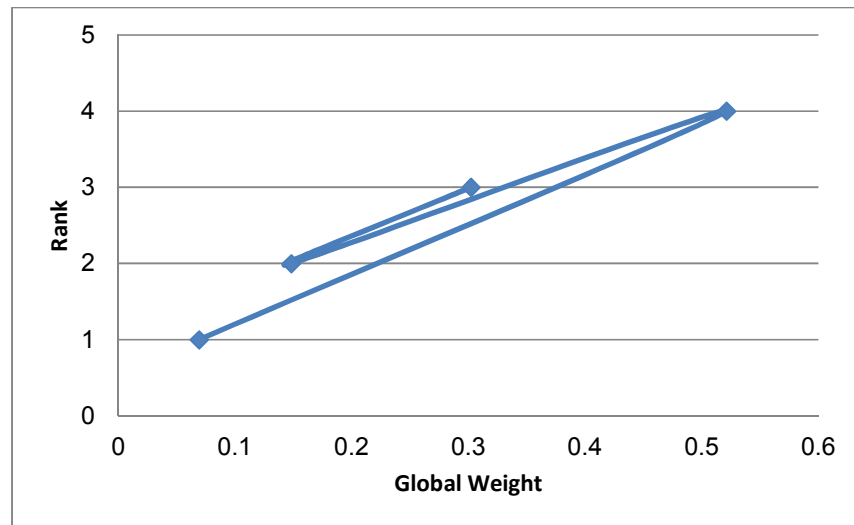


Fig. 11. Rank- Global Weight curve of additive remanufacturing portfolio alternatives

- C<sub>1</sub>: Inspection and sorting.
- C<sub>2</sub>: Cleaning.
- C<sub>3</sub>: Disassembly.
- C<sub>4</sub>: Diagnostic testing.
- C<sub>5</sub>: Repair and upgrade.
- C<sub>6</sub>: Reassembly.
- C<sub>7</sub>: Functional cost.

- C<sub>8</sub>: Quality of returned cores.
- C<sub>9</sub>: Products acquisition costs.
- C<sub>10</sub>: Remanufacturing cost.
- C<sub>11</sub>: Overheads.
- C<sub>12</sub>: Component salvage rate.
- C<sub>13</sub>: Equipment utilization.

**Table 11. The weighted importance of each criterion**

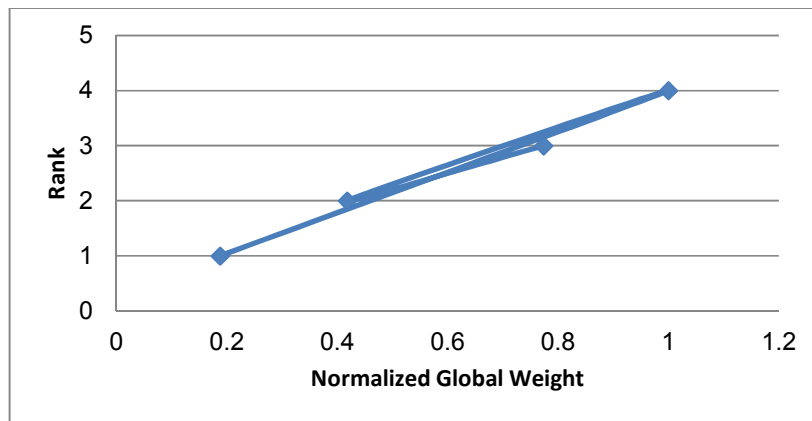
Alternative	Criterion	C <sub>1</sub> (0.567)	C <sub>2</sub> (0.427)	C <sub>3</sub> (0.563)	C <sub>4</sub> (0.877)	C <sub>5</sub> (0.595)	C <sub>6</sub> (0.789)	C <sub>7</sub> (0.659)
A <sub>1</sub> : Cold Welding-Grinding		0.279	0.262	0.345	0.385	0.279	0.385	0.533
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.157	0.146	0.120	0.163	0.157	0.163	0.385
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.571	0.533	0.385	0.533	0.571	0.533	0.385
A <sub>8</sub> : Grinding-Mechanical Cladding		0.098	0.047	0.075	0.047	0.098	0.047	0.157

**Table 11. The weighted importance of each criterion, continued**

Alternative	Criterion	C <sub>8</sub> (0.9)	C <sub>9</sub> (0.762)	C <sub>10</sub> (0.734)	C <sub>11</sub> (0.764)	C <sub>12</sub> (0.963)	C <sub>13</sub> (0.823)
A <sub>1</sub> : Cold Welding-Grinding		0.571	0.559	0.571	0.249	0.279	0.279
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.345	0.120	0.345	0.098	0.157	0.157
A <sub>7</sub> : Milling -Cold Welding- Grinding		0.345	0.262	0.345	0.210	0.571	0.571
A <sub>8</sub> : Grinding-Mechanical Cladding		0.120	0.047	0.120	0.047	0.098	0.098

**Table 11. The weighted importance of each criterion, continued**

Alternative	Criterion	Normalized global weight	Ranking
A <sub>1</sub> : Cold Welding-Grinding		0.774	3
A <sub>6</sub> : Milling- Brushing electroplating - Grinding		0.418	2
A <sub>7</sub> : Milling -Cold Welding- Grinding		1	4
A <sub>8</sub> : Grinding-Mechanical Cladding		0.188	1



**Fig. 12. Rank- normalized global weight curve of additive remanufacturing portfolio alternatives**

**4. CONCLUSION**

Comparative literature based assessment application includes classification of sample of literature in field of remanufacturing assessment. Literature survey found that remanufacturing assessment can be divided into

remanufacturability assessment and remanufacturability-sustainability assessment which both are partial remanufacturing sustainability assessments. Sample of published papers are re-represented to highlight the findings of discussions and conclusions of these papers. Graphical representation of results is

also applied. Study of published papers sample allows isolation of criteria, weighting of criteria, weighting of alternatives, global weights calculation and alternatives ranking of remanufacturing portfolio to restore dovetail guides ways and saddles of machine tools.

Comparative literature based assessment is mixed with remanufacturing experience based analysis and scenario based analysis to propose group of portfolio alternatives and analyze them to mature a solution. Eight assessment scenarios which represent remanufacturing portfolio alternatives to restore dovetail guides ways and saddles of machine tools include:

- A<sub>1</sub>: Cold Welding-Grinding
- A<sub>2</sub>: Milling Electrodeposited-Grinding
- A<sub>3</sub>: Milling-Laser Cladding-Grinding
- A<sub>4</sub>: Milling-Plasma spray-Grinding
- A<sub>5</sub>: Milling- Plasma arc surfacing - Grinding
- A<sub>6</sub>: Milling- Brushing electroplating - Grinding
- A<sub>7</sub>: Milling -Cold Welding- Grinding
- A<sub>8</sub>: Grinding-Mechanical Cladding

Series of different assessments with different groups of criteria lead to propose hypotheses to be highlighted to continue application of comparative literature based assessment, proposed hypotheses include:

- 1- As much as uniform is the Rank-Global weights curve of portfolio alternatives the more consistent is the assessment matrix.
- 2- Technical viability of remanufacturing portfolio will lead to economic and environmental viabilities.
- 3- Economic and environmental viabilities necessarily can certain remanufacturability and will lead to social viability.
- 4- Technical, economic, environmental and social viabilities will lead to sustainability.
- 5- Most remanufacturing portfolios that can be of technical viability include A<sub>1</sub>, A<sub>6</sub>, A<sub>7</sub> and A<sub>8</sub> and thus comparative literature based assessment can be reduced and continued.
- 6- Integrated technical viability of a remanufacturing portfolio is an integration of derivatives of technical viabilities of processes consist the portfolio.
- 7- Comparative literature based assessment is a powerful tool under the mixture of remanufacturing experience based analysis and scenario based analysis.
- 8- Remanufacturability assessment, technical viability assessment and partial

sustainability assessment can be mixed to develop comprehensive remanufacturability sustainability assessment.

- 9- Grinding-Mechanical Cladding is assembly based remanufacturing to improve machine tool remanufacturability and sustainability.

Emerged CNC technology is supposed to be integrated within each scenario to fulfill upgrading. Due to reduction of power and natural resource exhaustion and reduction of waste and emissions with increasing complexity of the remanufacturing-upgrading system will satisfy remanufacturability-sustainability 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 related saving of material.

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## COMPETING INTERESTS

Author has declared that no competing interests exist.

## REFERENCES

1. Yanbin Du, Yashi Zheng, Guoao Wu, Ying Tang. Decision-making method of heavy-duty machine tool remanufacturing based on AHP-entropy weight and extension theory. *Journal of Cleaner Production*. 2019;252. (In press)
2. Yanbin Du, Congbo Li. Implementing energy-saving and environmental-benign paradigm: Machine tool remanufacturing by OEMs in China. *Journal of Cleaner Production*. 2014;66:272-279.
3. Zhigang Jiang, Hua Zhang, John W. Sutherland. Development of multi-criteria decision making model for remanufacturing technology portfolio selection. *Journal of Cleaner Production*. 2011;19:1939-1945.
4. Zhigang Jiang, Tingting Zhou, Hua Zhang, Yan Wang, Huajun Cao, Guangdong Tian. Reliability and cost optimization for remanufacturing process planning. *Journal of Cleaner Production*; 2016. (In press)

5. Zhigang Jiang, Han Wang, Hua Zhang, Gamini Mendis, John W. Sutherland. Value recovery options portfolio optimization for remanufacturing end of life product. *Journal of Cleaner Production*. 2019;210: 419-431.
6. Han Wang, Zhigang Jiang, Hua Zhang, Yan Wang. A dynamic information transfer and feedback model for reuse-oriented redesign of used mechanical equipment. *Procedia CIRP*. 2019;80:15-20.
7. Yan He, Chuanpeng Hao, Yulin Wang, Yufeng Li, Yan Wang, Lingyu Huang, Xiaocheng Tiana. An ontology-based method of knowledge modelling for remanufacturing process planning. *Journal of Cleaner Production*. 2020;258. (In press)
8. Ramesh Subramoniama, Donald Huisingh, Ratna Babu Chinnam, Suresh Subramonia. Remanufacturing decision-making framework (RDMF): Research validation using the analytical hierarchical process. *Journal of Cleaner Production*. 2013;40:212-220.
9. Han Wang, Zhigang Jiang, Xugang Zhang, Yanan Wang, Yan Wang. A fault feature characterization based method for remanufacturing process planning optimization. *Journal of Cleaner Production*. 2017;161:708-719.
10. Handong Zheng, Enzhong Li, Yan Wang, Peijing Shi, Binshi Xu, Shanlin Yang. Environmental life cycle assessment of remanufactured engines with advanced restoring technologies. *Robotics and Computer-Integrated Manufacturing*. 2019;59:213-221.
11. Ziyad Tariq Abdullah, Shun Sheng Guo, Sheng Bu Yun. Remanufacturing aided added-value creation, innovations meeting to deliver sustainable manufacturing. *IOP Conf. Ser.: Mater. Sci. Eng.* 2015;83:012-021.
12. Ziyad Tariq Abdullah, Guo Shun Sheng, Sheng Bu Yun. Conventional milling machine into CNC machine tool remanufacturing, eco-comparison ratio based analysis. *Current Journal of Applied Science and Technology*. 2018;28(6):1-18.
13. Zhigang Jiang, Zhouyang Ding, Hua Zhang, Wei Cai, Ying Liu. Data-driven ecological performance evaluation for remanufacturing process. *Energy Conversion and Management*. 2019;198: 118-144.
14. Yong-Sung Jun, Hyun-Jung Jo, Young-Chun Kim, Hong-Yoon Kang, Yong-Woo Hwang, Young-Won Kim. Analysis of potential economic and environmental effects through remanufacturing of construction equipment in Korea. 2020;43:620-626.
15. Thomas A. Omwando, Wilkistar A. Otieno, Sajjad Farahani, Anthony D. Ross. A Bi-level fuzzy analytical decision support tool for assessing product remanufacturability. 2018;174:1534-1549.
16. Shitong Peng, Tao Li, Mengyun Li, Yanchun Guo, Junli Shi, George Z. Tan, Hongchao Zhang. An integrated decision model of restoring technologies selection for engine remanufacturing practice. 2018;174:1534-1549.
17. Yanbin Du, Huajun Cao, Fei Liu, Congbo Li, Xiang Chen. An integrated method for evaluating the remanufacturability of used machine tool. *Journal of Cleaner Production*. 2012;20:82-91.
18. Xu-Hui Xia, Yi Zeng, Lei Wang, Jian-Hua Cao, Xiang Liu. The selection method of remanufacturing service knowledge resource based on DANP-GS. *Procedia CIRP*. 2019;80:560-565.
19. Guangdong Tian, Jiangwei Chu, Hesuan Hu, Hongliang Li. Technology innovation system and its integrated structure for automotive components remanufacturing industry development in China. *Journal of Cleaner Production*; 2014. (In press)
20. Qingtao Liu, Ziyu Shang, Kai Ding, Lei Guo, Lu Zhang. Multi-process routes based remanufacturability assessment and associated application on production decision. *Journal of Cleaner Production*. 2019;240:118-144.

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