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Remanufacturing Aided Upgrading of Universal Testing Machine through Sustainability Assessment Modeling

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Author's contribution

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

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ABSTRACT

Aims: Study sustainability of Remanufacturing Aided Upgrading of Universal Testing Machine Business.
Study Design: Sustainability assessment criteria are elicited, unified, normalized and weighted to find the mean global weights of economic, environmental, social, management and technical measures of sustainability.
Place and Duration of Study: Middle Technical University, Institute of Technology-Baghdad, Mechanical Techniques Department, between January 2020 and August 2020.
Methodology: Remanufacturing Aided Upgrading experience is used to project the suitable literature comparatively to construct sustainability assessment model. Remanufacturing Aided Upgrading are reviewed and modified to accommodate new changes that accompany the current case study.
Decision making for selection of remanufactured alternatives and remanufacturing alternative in field of machine tools remanufacturing is reviewed. Experience in field of machine tool remanufacturing is exploited to remodeling of existence models to optimize a remanufactured lathe into CNC machine case study.
Results: Remanufacturing Aided Upgrading of Universal Testing Machine can encounter four

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phases of upgradability so that Universal Testing Machine can be divided into:
1- Analog Display Universal Testing Machine
2- Digital Display Universal Testing Machine
3- Computer Display Universal Testing Machine
4- Electro-Hydraulic Servo Control Universal Testing Machine
Such classification cannot fulfill structural analysis to study sustainability through prospective of remanufacturing added upgradability so structural analysis is required to be applied. Structural analysis can show that mechanical structure and hydraulic sub-systems are developing slightly through these four phases so they are remanufacturing oriented while control and data acquisition system encounters dramatically changes so that Universal Testing Machines are classified based on their specifications in control and data acquisition. According to Remanufacturing Aided Upgrading based sustainability prospective, Universal Testing Machine components can be classified into :-
1- Remanufacturing Aided Upgrading based design components
2- Remanufacturing based design components
3- Upgrading based design components
4- General purposes based design components
Assessment matrices are of consistent weights with an error due to ambiguity, inexactness subjectivity, impreciseness and vagueness to an extent in some joints of the problem statement which requires future research.
Conclusion: Literature based analysis and experience based analysis can be used to develop alternatives based analysis to elicit potentials to apply Remanufacturing Aided Upgrading of Universal Testing Machine to develop sustainable business. Technically, remanufacturing is the viable to be followed by economic and environment viabilities. There is a need to enhance the social and management viabilities because they are low. Assessment based classification lead to that Universal Testing Machine can be divided into:
1- Remanufacturing based Design Components which include Upper Cross Head, Moveable Cross Head, Lead Screws, Driving Sub-system, Upper Cross Head and Table Alignment Columns, Table, Machine Base Foundation, Hydraulic Cylinder and Hydraulic Pump.
2- Remanufacturing Aided Upgrading based Design components which include Load Control Valve, hydraulic oil returning valve and Pump Electrical Motor.
3- Upgrading based Design components which include Analog Display, Pendulum Load Cell, Elongation Translation Mechanism, Pressure Sensor, Load Cell, Encoder, Extensometer, Data Acquisition Card, Data Acquisition-Control Card, Computer Display Data Acquisition Software and Computer Display Data Acquisition-Control Software.
4- General purposes based design components which include piping system, Upper Cross Head Grips and Moveable Cross Head Grip.

Keywords: Remanufacturing based sustainability modeling; universal testing machine structural analysis; universal testing machine remanufacturing; remanufacturing aided upgrading.

1. INTRODUCTION

Techniques for Order Preferences by Similarity to Ideal Solution can be extended under interval valued fuzzy environment to cope with uncertain information of sustainable alternative selection due to the subjective nature of human judgments. Fuzzy numbers sets have great ability to address strong fuzziness, ambiguity and inexactness during the decision-making process. Uncertain information of sustainable alternative selection can be captured and integrated through using such techniques where distance and similarity between alternatives and ideal solutions can be calculated concurrently to evaluate 24 sustainable performances of alternatives. The relative weights of evaluation criteria, which are independent and can interact with each other, can be determined by entropy measure method to avoid subjective judgments of decision makers. Mixed sustainability-resilience objective function can be introduced to select a resiliently sustainable alternative through the supporting techniques such as [1]:-

- Numerical examples can be applied to test the validated of the formulated model.
- Case study based demonstration can be used to test the applicability of solution method in practice.

- Sensitivity analysis can be carried out to show the merits of the aggregated sustainability-resilience objective function.

Subjectivity, impreciseness and vagueness can be reduced to a large extent by applying fuzzy sets based multi-criteria assessment techniques for assigning degrees to attributes. Increasing the number of attributes can lead to complexity issues while carrying out the digraph based analysis which requires using of matrix factorization as a helpful technique to be utilized in any industrial scenario to develop an upgraded product. Multi-criteria assessments can be applied for selecting the sustainable alternatives which can contain the following steps [2]:

- Identification all attributes of alternatives.
- Establishment interrelationships among various identified attributes and also their degree.
- Specifying degrees of interrelationships among various identified attributes.
- Synthesizing of sustainable alternative selection attributes structure graph based on the degree of interrelationships.
- Analyzing structure matrix developing.
- Sustainable alternative selection index development.
- Sustainability perspective analyzing to select best alternative.

Multi criteria and sub-criteria can provide an accurate optimization approaches to obtain a reliable sustainable ranking of alternatives to be validated through real world case studies and to be matured through research, theoretical findings, managerial insights and directions. Using such optimization approaches requires [3]:-

- A comprehensive literature survey should be conducted to identify the most crucial criteria and sub-criteria associated with economic, environmental and social sustainability dimensions.
- Final assessment criteria and sub-criteria are chosen according to aggregated opinions.
- Intuitionistic fuzzy approach can be used to select the most sustainable alternative.

Fuzzy inference system to find out fuzzy entropy can be used to determine the weights to prioritize sustainability criteria. Evaluating and selecting of optimal sustainable alternative can be based on hybrid consistent performance of sub-sustainability scale among the economic, environmental and social dimensions to be developed into comprehensive sustainability assessment approach [4].

Modified fuzzy Analytical Hierarchy Process is the integration of fuzzy preference programing with Technique for Order of Preference by Similarity to Ideal Solution to develop hybrid framework that can deal with inconsistency, uncertainty and calculation complexity to evaluate and determine the appropriate sustainable alternative according to the following procedure:

- Literature based analysis is used to develop a comprehensive list of sustainability criteria and sub-criteria.
- Criteria and sub-criteria are incorporating into a questionnaire and distributing the questionnaire to academics and practitioners for establishing the importance and applicability of these criteria and sub-criteria.
- Statistical tests are used to demonstrate the robustness of the data obtained from the questionnaire.

Sustainability assessment shows that the economic aspect is the most important aspect which is followed by environmental aspect and finally social aspect respectively [5].

Fuzzy multi objective optimization modeling can be based on the ratio analysis to evaluate the overall performance of sustainability of alternative. Multi objective mathematical model can be developed to alternative sustainability considering assessment to increase total profit and also decrease the amount of risks due to impose the sustainability [6].

Resilient based sustainable assessment framework can be based on criteria which can be weighted through modular fuzzy set theory to cope with the uncertainty and subjectivity that can be involved within alternative sustainability assessment procedure. A multi-methods approach based on quantitative empirical investigations and analytical modeling to utilize interval fuzzy sets to quantify inputs and extend efficiency of modeling to include desirable and undesirable inputs and outputs to evaluate alternatives. Comprehensive sustainable alternative modeling can be developed with any number of indicators and alternatives to be a modular data envelopment analysis to determine the weights of indicators and rank the alternatives [7].

Vague and subjective information often exist in evaluation procedure to select the sustainable alternative which requires fuzzy based approaches to be eliminated. Vagueness, subjectivity and randomness in raw information are required to be manipulated through extended Technique for Order Performance by Similarity to Ideal Solution method to develop sustainable alternative selection. An integrated weighting method considering both subjective and objective attributes can determine comprehensive weights of criteria to manipulate uncertainty of randomness and the merit of rough set theory in flexibly handling interpersonal uncertainty without extra information [8].

Incomplete information and high order imprecision can be encountered through a multi-criteria group decision making under triangular neutrosophic numbers environment. Such integrated technique of the analytical network process method can cope with linguistic variables based on opinions of experts. Sustainable alternative selection can be applied by using the following steps [9]:-

- Analytical network process can be used to calculate the weights of criteria and sub-criteria.
- Entropy method can be used to justify the weights of the criteria and sub-criteria.
- Genetic algorithm can be used to compute predicted weights of various economic, environmental and social criteria.

Logic importance and decision making contribution can be considered under mixed information environment and triangular intuitionistic fuzzy numbers to depict the fuzziness and hesitancy of expert knowledge to avoid information distortion. Combined analytic hierarchy process and the entropy theory can be used to compute index importance to develop expert experience and information content based analysis. The cumulative prospect theory can be introduced to rank alternatives with the assumptions of bounded rationality. Environmental measures can be the core competitiveness of sustainable alternative selection [10].

Voting Analytic Hierarchy Process based multi-criteria sustainability assessment can hierarch structures of assessment criteria to employ data envelopment analysis for deriving criteria weights from the ordinal preferences of experts. Simpler application cannot overcome the requirement of a strong convex order of the importance of weights and ordinal rank gradations and the choice of discrimination threshold for consecutive rank weights in the data envelopment analysis model. More robust tool can be developed to be exploited for sustainable alternative selection. Game theory can be used so that suffering issues can be overcome by pursuing an approach to elicit weights of criteria through removing subjectivity from rank discrimination [11].

Sustainable alternative can be developed in the form of multiple-criteria decision making methods which requires sorting of alternatives into classes to show the sustainability performance. Sorting method under a fuzzy environment with interval fuzzy sets can be developed for selecting representative points for priority of alternatives. It is a management improving of unclear class assignments by softening transitions between classes which facilitate the sustainable alternative selection. A significant reduction of comparisons and higher precision of priorities can be obtained which makes decisions become more in line with reality because of a better management of uncertainty and more accurate priorities [12].

Sustainable alternative management plays a great part in enterprise production operation management due to strict government regulations and increased public awareness. Selecting the best sustainable alternative requires:

1. A multi criteria decision making problem description.
2. Experience based decision making.
3. Utilizing linguistic terms for expressing evaluations based on fuzzy knowledge.

Multi criteria is an innovative model for sustainable alternative selection can be developed by integrating best-worst method to obtain the optimal weights of criteria and alternative queuing method within interval valued intuitionistic uncertain linguistic setting. Uncertainty and vagueness of judgments of decision makers can be captured with the aid of interval valued intuitionistic uncertain linguistic sets [13].

2. SUSTAINABILITY ASSESSMENT LITERATURE REVIEW

A multi-criteria methodology can be structured to take into account three to five dimensions of sustainability. An integrative approach for multi-criteria sustainability assessment can be built on the existing informational gap of lifecycle. Environmental, technical and economic multi-measure of sustainability can demonstrate significantly different sustainability behaviors based on the used lifecycles based scenario. The issue of low reliability should be endeavored to rank the different criteria categories which require highlighting the gaining of view to deeper insight on the controversial sustainability issue so that multi-criteria integrative approach based sustainability assessment can constitute a vital tool for possible interventions in complex production sectors[14].

Sustainability management estimation system with energy recovery requires choosing indicators to translate a comprehensive and meaningful assessment management and energy systems. Scenarios based sustainability assessment modeling can be based on energy and resources recovery as multi-criteria analysis through analytical hierarchy process method. Insufficient number of selected indicators to evaluate the sustainability can influence the sensitivity of the assessment so that several methodological steps can be encompassed to model prediction where an increased number of modeling criteria can increase the sensitivity of the assessment. Energy indicators and management indicators should be reviewed to identify criteria and facilitate weighting of criteria. Common used criteria can be mixed with new ones to select the most relevance indicators to illustrate how a model based on multi-criteria analytical hierarchy process method can be applied for selection of sustainability management scenario with bases of energy and resource recovery. Scenarios based sustainability analysis can easily show that the best sustainable management scenario can involve energy recovery and added-value recycling to correspond to zero waste to be the best ranked scenario in terms of sustainability if it leads to avoid relatively high costs and low revenues. Sustainability analysis can be satisfied through [15]:-

- Determining the optimal number of indicators for assessing the sustainability.
- Evaluation of quantitative indicators of sustainable development.
- Economic and social dimension highlighting.

Comprehensive sustainability evaluation model of remanufacturing system can be constructed by integrating criteria of technical, economic and environmental dimensions to evaluate the process of the remanufacturing sustainability of machinery. Remanufacturing can include process of cleaning and testing, surface repair and mechanical processing and upgrading which require adopting of remanufacturing alternatives that satisfy the standard parameters values of technical engineering characteristic such as accuracy, cost, energy consumption and carbon emissions [16].

Environmental integrated economic sub-sustainability can be quantified in term of carbon emissions based on an overall quality coefficient that reflects the quality distribution of faults in machinery which can be developed to set up a correlation between the carbon equivalent emissions and remanufacturing difficulty factor. Such overall complex quality coefficient can be measured under the conditions of multiple faults statutes to describe the uncertainty in the quality of remanufactured machinery. End-of-life technology routings can include whole machine remanufacturing, direct reuse of components, remanufacturing of components for cannibalization or scraping of components for materials. Matrix of step transition to denote the process step transition probability and the difficulty factor for each step and for each complete process flow overall quality coefficient can be constructed to reflect the quality distribution and perform a quantitative analysis of net environmental benefits and costs. Uncertainty of faults conditions quantifying can lead to determine overall quality coefficient which is exploited to select the most sustainable end-of-life strategy routing factor. Environmental benefits and uncertainty can be correlated to determine carbon emissions reduction in the real remanufacturing process so that the amount of reduction in carbon emissions increases with the increase in the overall complex quality coefficient. Optimal remanufacturing point can fulfill the environmental responsibility to dominate environmentally friendly remanufacturing-upgraded based on industrial activities scale [17].

Environmental impacts of remanufacturing and advanced restoring technologies can be identified through sub-sustainability evaluation by integrating 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 assessment system boundary based on the availability of data, information and knowledge. Establish an information sharing platform of energy consumption and air emissions to implement sub-sustainability management and facilitate scientific assessment of environmental impacts and material efficiency. Empirical based remanufacturing ability study can help applicability of the new technologies in both of remanufacturing and upgrading to be developed and analyzed to evaluate the environmental and economic advantages of remanufactured-upgraded machinery [18].

Remanufacturing can provide a great opportunity to increase market shares and aftermarket sales to deliver human development and employment as a social sub-sustainability. Lack of a comprehensive framework that includes all the major strategic factors to make effective remanufacturing alternative, social sub-sustainability assessment should be integrated in the conceptual stage of product development. Comparative literature based factors identified and academicians based innovative solutions can help bridge the gap and provide an effective and transparent weighting of criteria based remanufacturing modeling and assessment. Some technique can be used to develop strength data base to be used for remanufacturing assessment such as [19]:

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.

Technique for Order Preference by Similarity to Ideal Solution can be used to develop an effective and comprehensive multi-criteria decision-making based sustainability assessment model by considering the environmental impact, economic cost and technical property to optimize the remanufacturing alternative. Restoration technology can be ranking to get the order of brushing electroplating, plasma spray, plasma arc surfacing and laser cladding respectively. Processing parameters of brushing electroplating, plasma spray, plasma arc surfacing and laser cladding can be set constant and modeled in the form that ensures they can affect all the criteria of performance measures which include environmental impact, cost, and technical property to reach optimum. Faster processing speed can reduce environmental loads and economic cost but these can be got at the expense of surface quality which will be deteriorated. Optimal set of parameters oscillate in a trade-off manner among environmental impact, cost, and technical property measures which requires huge amounts of experiments and calculation with varying values of parameters to satisfy optimization and eliminate lacks of capability to universe application which shows specific occasions based effectiveness. Sustainability based remanufacturability assessment can include measures and criteria of [20]:-

1. Technology feasibility is a remanufacturability measure to be controlled by criteria of bonding strength, substrate deformation, hardness and porosity.
2. Economic feasibility is a remanufacturability measure to be controlled by criterion of cost which can be divided into processing cost and investment cost of restoring alternative.

3. Environmental feasibility is a remanufacturability measure to be controlled by criteria of material saving, energy saving and pollution reduction. Global Warming Potential Acidification Potential, Resource Depletion Potential, Water Eutrophication Potential and Respiratory Inorganics

Relative closeness values of ranking weight from optimum solution can get be precise by considering the combination of entropy method, the expert investigation method and the inclusion of imprecise value and parameters which could be expressed by fuzzy triangular numbers. Sustainability based remanufacturability assessment can ensure [20]:

1. Technically qualified remanufacturing.
2. Mandatory legislations implementation for energy conservation and emission reduction.
3. Environmental restoring alternative technology adopting to lower the environmental impacts and build a positive image.
4. Profit satisfaction.
5. Considerable cost-saving achievement by selecting appropriate restoring technologies.

Environmental integrated economic sub-sustainability can be based on fault conditions that critically decide the quality of returned cores of machinery. The quality uncertainty is a practical production and management difficulty which can be quantified in the form of a critical quality-environmental impacts coefficient which is a compound rejection threshold of to be passed by machinery cores to be remanufactured. Acquisition cost based environmental assessment model can prove that a linear relationship can gather an overall quality coefficient and the best conditions of acquired machinery cores which maximizes the overall environmental benefit. The complexity of remanufacturing system makes quantifying of the environmental impacts of the remanufacturing operations due to quality uncertainty to be difficult task. Probabilistic methods can be employed to establish the functional relation among quality coefficient of returned end-of-life machinery cores and remanufacturing indexes. The optimal solution of the acquisition quality coefficient should be based on the existence conditions of returned cores which require a closed form solution to quantify the optimal quality coefficient to maximize remanufacturing benefits. Thus theoretical basis can be provided for managers to devise optimal acquisition strategy for maximal remanufacturing efficiency with lower energy and resource input. Environmental efficiency assessment can consider the economic indexes in the remanufacturing as a multi-objective optimization system which is based on the literature based analysis to serve as potential directed efforts [21].

Remanufacturability based sustainability assessment can be realized through ecological performance evaluation to ensure emerging of remanufacturing industry based sustainable development. Energy saving rate, remanufacturing process cost and rate of remanufacturing can be identified as key assessment criteria. Remanufacturing portfolio alternatives should be optimized to improve remanufacturing ecological performance to the extent that satisfies public acceptability to be effective social measure of remanufacturing. Due to uncertainty the assessment of some criteria cannot be generalized and the findings will be constrained which require big data technology to be utilized to increase the objectivity and universality of the results and enhance the accuracy of remanufacturing assessment [22].

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 implementing of different criteria of resource consumption and process emission. 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 alternatives can be called remanufacturing technology portfolio. Financial capital and human resources of alternative is the best if is paired with good singular benefit, highest synergistic benefit and lowest portfolio cost. Synergistic effects of technologies considering can include [23]:-

- Technology portfolio cannot consider the overall enterprise benefit.
- Technology portfolio that produces significant synergistic benefits can be more attractive than a technology with high singular benefit.

Several remanufacturing alternatives should be studied since machinery 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 are 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 theatrically to be used as decision making method of remanufacturing and form a relatively optimal solution to help improve the comprehensive benefits of remanufactured-upgraded machinery. Many considerations allow the decision making technique 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 of machinery and literature adjusted information. Excessive uncertainty of remanufacturing process can alter process of definitive optimal alternative solution of remanufacturing. For simplifying purposes, criterion evaluation process may not quantify the uncertainty of the remanufacturing. 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 condition. Studies of remanufacturing can include uncertainty of both of the machinery to be remanufactured and the remanufacturing process to be used for remanufacturing. 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 [24]:-

- Reduce the cost of remanufacturing.
- Improve the performance of machinery through upgrading.
- Achieve high value-added remanufacturing.
- Improve the success rate of remanufacturing.
- Reduce the difficulty of remanufacturing

3. REMANUFACTURABILITY ASSESSMENT LITERATURE REVIEW

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 alternative planning. Reasoning rules and operation paths can be applied to generate remanufacturing alternative alternatives. Optimization model that considers quantification of fault features as a multi-objective optimization is more feasible and effective than other models. Faults features can be quantified and integrated within unified platform to enable process alternative planning optimization. Remanufacturing alternative optimization to release the maximum residual value of used components that satisfy lowest cost, energy consumption and time requires different restoring alternatives to be studied and practiced due to the different damage degree and fault location. Based on quantified fault features, environmental factors and remanufacturing knowledge, remanufacturing alternative planning process can be optimized [25].

Remanufacturing is an important approach to achieve sustainable development to close the manufacturing loop locally and globally. Industrial technologies are key factors to promote component based remanufacturing industry development. Design, market strategy, repair technology and talent quality can be used to assess re-manufacturability. Re-manufacturability needs to be propelled by related technology issues which are suitable for different industries with similar development stages and conditions. Advanced restoration techniques such as surface engineering can be used to restore the physical wear of components based on faults modes analysis and life assessment. Reconstruction or upgrading technology can be used to extend the service life of components that have reach technical or economical end-of-life [26].

Reasoning can allow define the cause and possible failure process mechanisms that could be occurred after remanufacturing. Literature and industrial comparing and evaluating are required to identify the most serious causes of faults based on failure type that can occur after remanufacturing process. The cause of failure should be defined in order to improve the quality and reliability of remanufactured machinery. Remanufacturing alternative and after remanufacturing failure relationship can be studied by analyzing a variety of failures that could be occurred after remanufacturing. Failure modes and remanufacturing alternative relationship identification can be obtained through noise based expert opinions analysis which can reduce failure rate and process defect rate [27].

Various failure types and failure degree can lead to that remanufacturability should be evaluated to determine the remanufacturing value. Remanufacturability is usually evaluated based on multi-process routes and multi-parameters process to form portfolio alternatives to conduct a decision making assessment. Quality, resource consumption and environmental emission can be used as remanufacture ability assessment criteria which can lead to more efficient and cleaner remanufacturing. Remanufacturability can be defined as the suitability of the machinery to be remanufactured. Due to the different faults conditions, machinery can be restored according to multiple process remanufacturing portfolios so they have different remanufacturability even the have the same structure but of different faults conditions [28].

Selection and planning of the reconditioning processes can be enabled through sustainability and remanufacturability assessment based on the fault conditions. Criticality of faults, synergistic effects and the nature of selected technology are crucial steps in the reconditioning process sequence planning to be engineering requirements based reliability. Reconditioning based remanufacturing portfolio operations can process core components with varying conditions and different faults which need for reconditioning processes to be planned according to paths of certain sequence to each component in the core. Reconditioning process sequence for a core component depends on fault conditions to determine the optimal reconditioning process sequence [29].

Selection of remanufacturing technologies should be based on the principle of uncertainties reduction which requires generalizing expert thinking based decision making. Economic value, technical adequacy and environmental effects criteria can be used to assess remanufacturability based sustainability. The performance of assessing using guiding criteria should be elaborated to accommodate and enhance knowledge contribution in field of selection of technology. Remanufacturing technology portfolio selection can suffer from managerial significant due to human being ambiguity in decision making which requires uncertainty to be moderated in evaluating , ranking and selecting appropriate technology. Purchasing cost, disposal cost, operating cost and flexibility impact technology performance largely which require experience based experts complementation. Diversity of criteria can help management to conduct thorough analysis and make informed decisions that accommodate ambiguity of experts in decision making [30].

Remanufacturability based sustainability assessment can be expertise opinion enabled decision making so that quantitative and qualitative attributes of end of life machinery can be incorporated . Technical, economic, resource utilization and the environmental criteria can be combined to form an overall remanufacturability based sustainability measures. Time, fault statute can cause impact the whole remanufacturing system which require detailed remanufacturing process analysis to be carried out to find weights of assessing remanufacturability criteria. Remanufacturability based sustainability assessment can be resulted in the form of multi-products evaluations comparisons to develop indexes. Comprehensive comparative literature approach is required to incorporate aspects of remanufacturing such as reverse logistics, government legislation, take back polices and alternative technology development within a comprehensive remanufacturability based sustainability assessment modeling [31].

Partial sustainability evaluation index attributes of remanufacturing service knowledge resources can provide referential based evidences. 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 which increase resilience. Technological viability of remanufacturing of machinery needs the basic knowledge of material, size of components, pretreatment parameter information, the basic information of tools, the knowledge of repair technology principle and the knowledge of post-processing to be involved within selection, evaluation and modeling of evaluation criteria of such remanufacturing service. Experts based indexes establishing can lead to weight of criteria of partial remanufacturing sustainability measures which can include [32]:

- 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.

Fastener accessibility, disassembly complexity, disassemblability and recoverability criteria can be used to assess remanufacturability based computer aided product prototypes. Dimensional and positional tolerances can also be analyzed based on design features through assessing recoverability [33].

Machinery 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 successfully as a cost saving conscious solution instead of new purchasing. Such high added-value requires remanufacturability to be evaluated before remanufacturing where assessment measures and criteria can include [34]:-

Wear, corrosion, bending-torsion deformation and crack faults modes can be eliminated to restore the surface into its original state by using undercutting, thermal spry, submerged arc welding, grinding and grinding as a remanufacturing system portfolio which 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 sustainability based on different failures at different locations. Information and knowledge of remanufacturing is complex which causes uncertainty. Relevant Multi-sources remanufacturing information at different life cycle stages can provide a structured way to express and manage remanufacturing knowledge [35].

Machinery remanufacturing requirement can include [36]:

- Easy to disassemble.
- Disassembly stability.
- Damage resistance.
- Clear wear conditions.
- Upgraded.
- Reliability, stability and safety.
- Clear working life.
- Easily identifiable.

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

1. Ease of disassembly criterion.
2. Ease of Reassembly criterion.

Product non-destructive disassembly is an important guarantee of the remanufacturing process. Disassemblability can be analyzed to solve all problems during design stage by checking:

1. If the component can be reduced.
2. If disassembly costs can be reduced.
3. If disassembly time is short.

Optimization of remanufacturing processes through keeping costs low can maximize the resulting service life and efficiency. Damaged and worn components are of varying level of damage and remaining life which need to be evaluated in terms of damage level and remaining life before determining the optimal value recovery options. The wear failure mode can be measured by analyzing and imaging processing of component to be remanufactured based on comparison of new products. Quantified damage level can be used to measure the remaining life of components. Quantified damage condition based remaining life of used components can be developed comprehensively evaluation and identifying 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 components individually. Cost criterion can be modeled for selecting the remanufacturing portfolio alternative based on the remaining life value recovery options for used components. Extend remaining useful life of a product can be through recovering of valuable components to reduce production cost by reusing components application of remanufacturing. Value recovery options for each component can include new, reuse and reconditioned scenarios to be forecasted by each valuable component of a returned product so that value recovery process is combinatorial optimization problem. To obtain the optimal remanufacturing valuable components reusing alternative and improve the economic benefits from remanufacturing require an evaluation criteria to be quantified within insights of damage level and remaining life of used components to identify value recovery options for each reused component [37].

Remanufacturing 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 and upgrade the functionality and remanufacturability. Remanufacturing is a new manufacturing mode for high demands of productivity and energy efficiency. Original equipment manufacturers of machines can conduct remanufacturing and 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 and accumulate [38].

Remanufacturing performance of machinery can be assessed by using criteria of reliability and cost. Remanufactured machinery can cost only (40%-60%) of new ones and better operating efficiency can be offered. Remanufacturing process capability and decay of machines and tool are affected by the quality of returned products which can be used to model reliability. Remanufacturing process planning is the application of optimization process to select the optimum sequence of remanufacturing technology within a certain portfolio. Improve efficiency of remanufacturing portfolio and the reliability of remanufactured product and reduce process cost can be fulfilled by integrating the quality of returned cores within evaluation model of remanufacturing process [39].

4. SUSTAINABILITY ASSESSMENT METHODOLOGY

Fig. 1 is an illustration of study methodology which contains twelve steps to direct the current article through hybrid insights of literature based analysis, remanufacturing aided upgrading experience analysis and alternatives differentiation based analysis to elicit potentials of Remanufacturing Aided Upgrading of Universal Testing Machine that can lead to sustainable development.

5. UNIVERSAL TESTING MACHINE STRUCTURAL CHARACTERISTICS ANALYSIS

Hydraulic Universal Testing Machine is a multi-disciplines electromechanical testing equipment which required concurrent engineering analysis, design structure matrix or semi technique such as structural analysis.

Structural analysis can show that mechanical structure and hydraulic system are developed slightly through the four configuration alternatives of Universal Testing Machine while control and data acquisition system encounters dramatically changes so that Universal Testing Machines are classified based on their specifications in control and data acquisition. Four configuration of Universal Testing Machine includes:-

1. Analog Display Universal Testing Machine.
2. Digital Display Universal Testing Machine.
3. Computer Display Universal Testing Machine.
4. Electro-Hydraulic Servo Control Universal Testing Machine

Hydraulic Universal Testing machine applies force on testing sample through single action hydraulic cylinder (piston). Whether the test is for tension, compression or bending, the hydraulic piston moves upward so the position of test sample fixture will decide the type of force if tension, when test sample is fixed between upper cross head and moveable cross head, or compression, when the test sample is fixed between movable cross head and table. Pre-test preparation includes the moving of moveable cross head upward in case of tension or downward in case of compression so that the distance between grips will be enough to fix the test sample.

Hydraulic returning vale should be closed to prevent oil returns to tank during test. The pump should be rotating so that load control valve is opened gradually to allow the oil enters the piston and force the piston to expand and exert load on test sample.

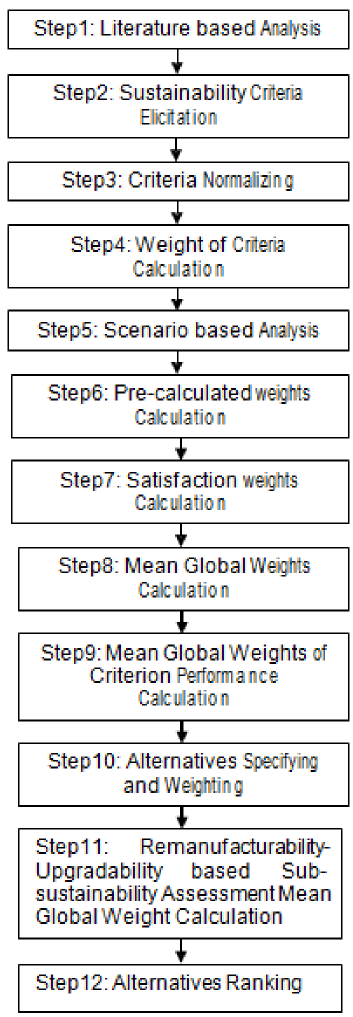

Fig. 1. Sustainability assessment methodology

Structural components of conventional Universal Testing Machine can be divided into:

1. Moveable cross head driving system which includes lead screws, chain, sprockets and electrical motor.
2. Test sample fixing system which includes mechanical or hydraulic grips.
3. Hydraulic piston driving system which includes hydraulic cylinder, pump, electrical motor, load control value, piping system and oil returning valve.
4. Data acquisition system which includes pendulum, mechanical extension translator and mechanical plotter.
5. Machine rigidity and alignment maintaining system which includes main host base and foundation, table, moveable cross head, upper cross head and columns.

Such classification will be ineffective to analyze the structural characteristics of Universal Testing Machine so Remanufacturing Aided Upgrading potentials based classification should be applied which contains:-

5.1 Mechanical Structure System Alternative

Fig. 2 shows mechanical structure system alternative of Universal Testing Machine. Upper Cross Head, Table Upper and Cross head Alignment Columns, Moveable Cross Head Lead Screws, Table, Moveable Cross Head and Moveable Cross Head Driving Sub- system are of high added-value sub-system with lower contribution weight of upgradability so they are most suitable for remanufacturing oriented sustainability.

Moveable Cross Head Driving Motor is of low added-value local weight and low contribution to upgrading local weight so that this sub-system is of no to very low effect on sustainability. Moveable Cross Head Driving Motor is a three phases (380v) electrical motor can be replaced easily when it will be broken and it is attached to Moveable Cross Head Driving Sub-system by sprocket to transmit motion through chain to pair of sprockets which are assembled with lead screw that are responsible on upward and downward motion of movable cross head. After replacing the tight and slack tension of chain is adjusted by vertical sliding sprocket of ability to be fixed to foundation of machine by bolt.

During test conduction, Moveable Cross Head Driving Sub-system are useless which are used to set the test sample inside machines grips before test where length of sample should be taken into consideration to no exceed the design specification of machine space.

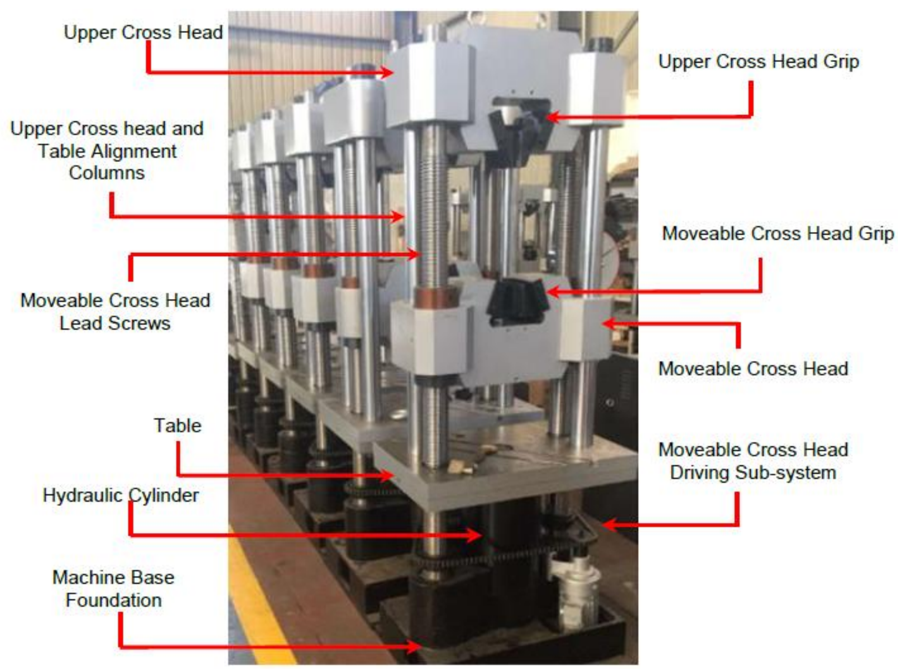

Fig. 2. Mechanical structure system alternative of universal testing machine

Fig. 3. Control and data acquisition sub-system of analog display type

5.2 Control and Data Acquisition Sub-system Alternative

Variety of control and data acquisition sub-systems make this alternative as an effective reservoir of innovative potentials of Remanufacturing Aided Upgrading oriented sustainability. Fig. 3 shows control and data acquisition sub-system of analog display type.

Load Control Valve is of medium local weight added-value since it represents precious emerged technology and can be remanufactured and of very high contribution to upgrading local weight since it can be replaced with electro-hydraulic servo valve to control the linear velocity of upper cross head and table which are related functionally through alignment columns. Controlling linear velocity of test sample is a powerful method to study the behavior of metallic samples at elevated temperature where the strain-rate is predominated. Load Control Value is Remanufacturing Aided Upgrading based design since it will appear in a developed version in the new generations of Universal Testing Machine.

Hydraulic Oil Returning Valve is of medium local weight added-value since it represents precious emerged technology and can be remanufactured. Low contribution to upgrading local weight since it cannot be used for automated Universal Testing Machine. Hydraulic Returning Valve is remanufacturing based design since it will not appear in a developed version in the new generations of Universal Testing Machine.

Analog Load Display, Elongation Translator Mechanism and Mechanical Plotter are old fashion data acquisitions system and even they are precious emerged technology but they are out of date and not easy to be remanufactured or even maintained so they are of low local weight added-value and low contribution to upgrading local weight since it will not appear in a developed version in the new generations of Universal Testing Machine.

Digital display universal testing machine is equipped with digital plotter to plot the test data on piece of paper. Most important point of testing curve can be plotted but with limitations which let the recorded data is not enough for research and development of engineering materials. According to previous description, potentials of Remanufacturing Aided Upgrading can lead sustainability assessment to flow the analysis of that Digital Display unit is of low local weight added-value since it represents precious emerged technology but cannot be remanufactured and of high contribution to upgrading local weight since it will not appear in a developed version in the new generations of Universal Testing Machine. Fig. 4 shows control and data acquisition sub-system of digital display type. Flexibility of recorded data is very limited so such displaying method is more suitable for quality control purposes rather than engineering materials developing. Sensor of pressure, load cell and extensometer, which is sensor of elongation, are attached to digital display unit to enable load-displacement and stress-strain curves plotting so that load-displacement and stress-strain curves can be drawn on a piece of paper as show in Fig. 5.

Fig. 6 shows control and data acquisition sub-system of computer display type. Data Acquisition Card and Computer Display Data acquisition Software are of very high local weight added-value since they represent precious

Fig. 4. Control and data acquisition sub-system of digital display type

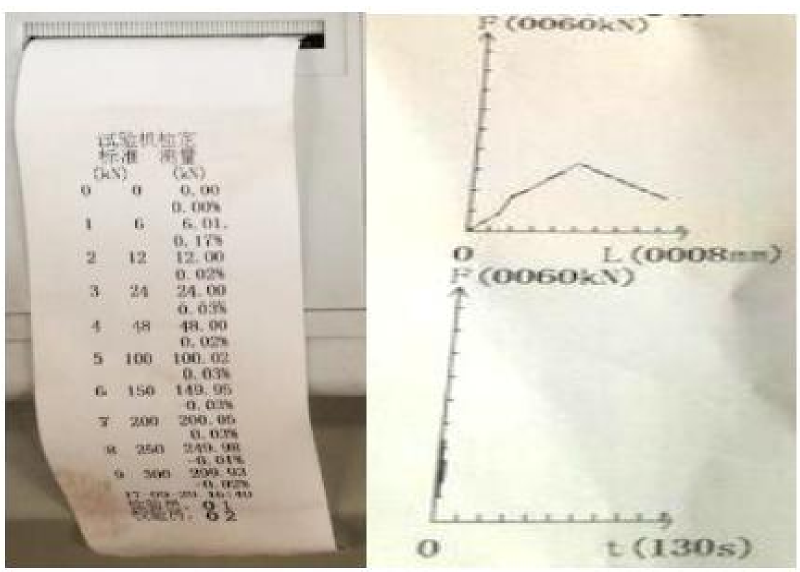

Fig. 5. Data acquisition output form of digital display type

emerged technology. Data Acquisition Card cannot be remanufactured and of very high contribution to upgrading local weight since it can be replaced by Control Data Acquisition Card and Computer Display and Control-Data acquisition Software to appear as a developed version.

According to Fig. 7 which shows Data Acquisition Software, Data can be manipulated in different ways based on registered load, extension and time such as load-displacement curve, stress-strain curve, modulus of elasticity, modulus of rigidity, proportional limit, elastic limit, proof stress, yielding points, ultimate strength and fracture point.

Computer control electro-hydraulic servo system, Fig. 8, offers more flexibility to control activities of universal testing machine where there is no manual valves to control the load and instead it is equipped with Data Acquisition-Control Card and Data Acquisition-Control Software to enable controlling the velocity in an automated manner where visual buttons are built-in to software interface with differentiation of velocity values to be written on each button, Fig. 9 control-data acquisition software.

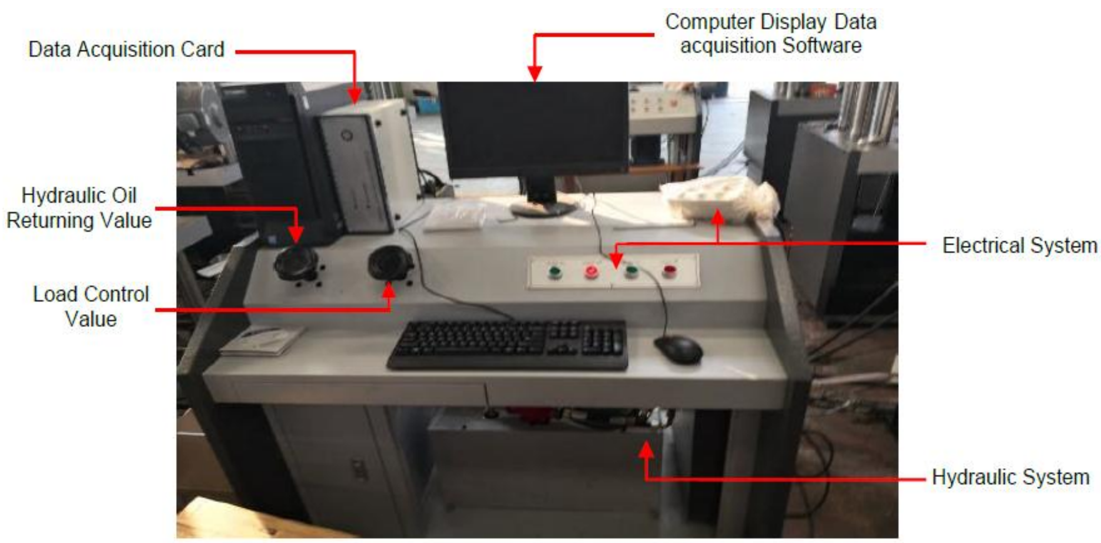

Fig. 6. Control and data acquisition sub-system of computer display type

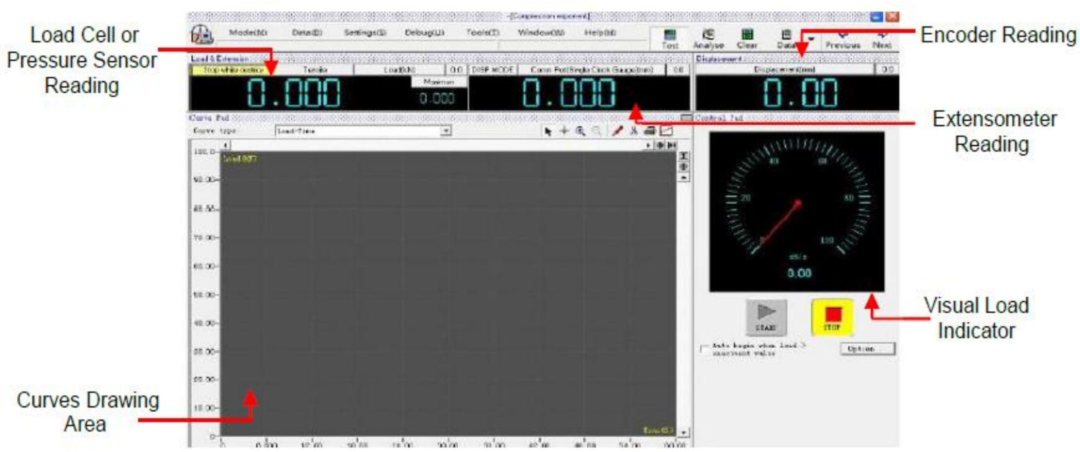

Fig. 7. Data acquisition software interface

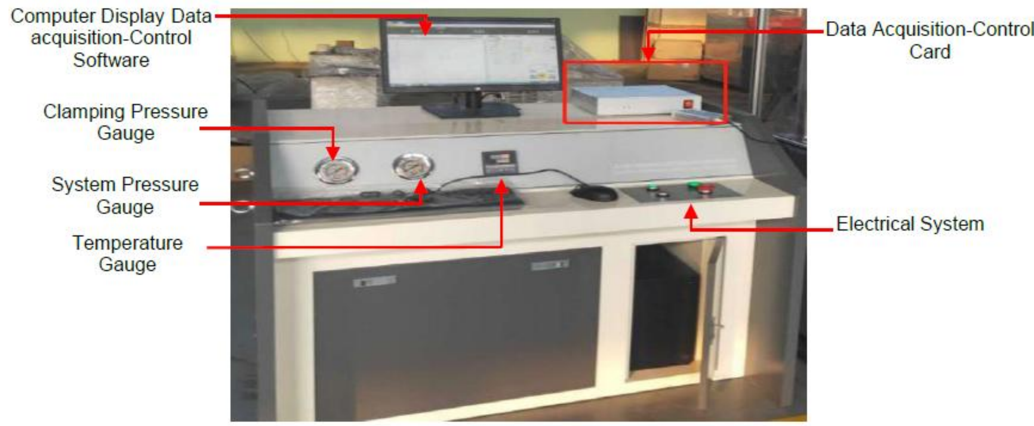

Fig. 8. Control and data acquisition sub-system of electro-hydraulic servo type

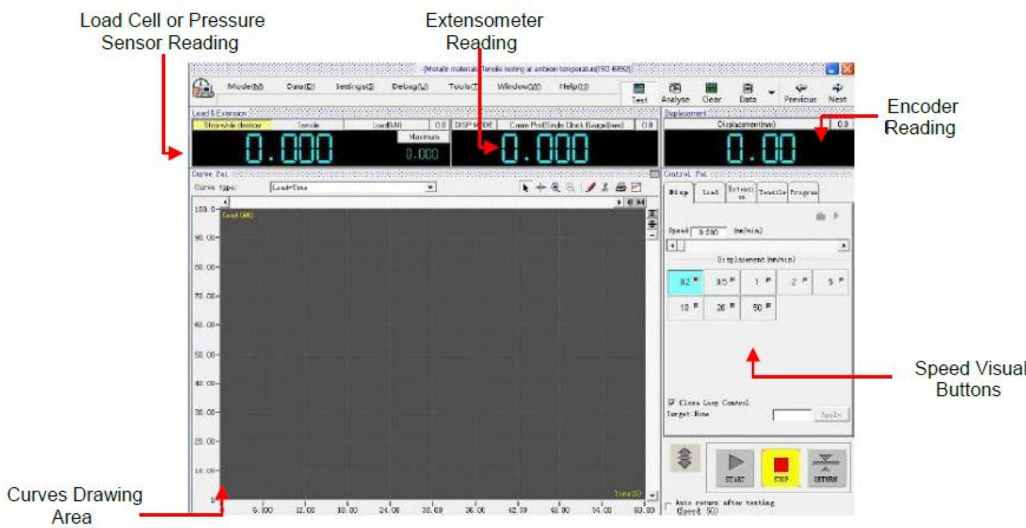

Fig. 9. Control-data acquisition software interface

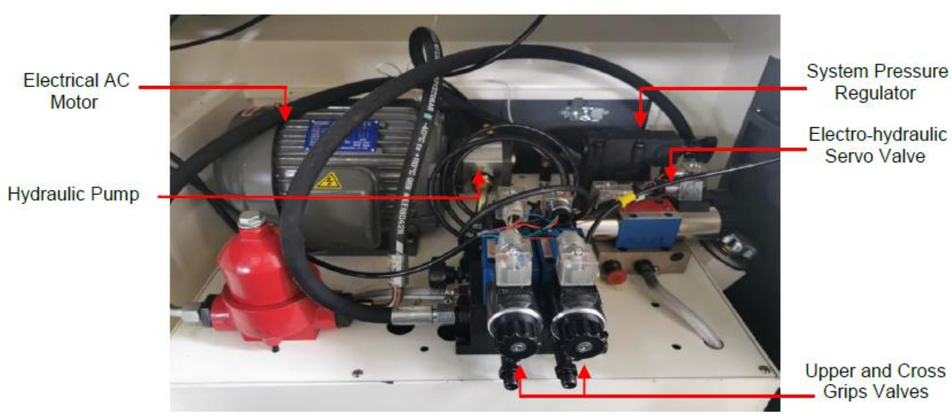

Fig. 10. Hydraulic system, front view

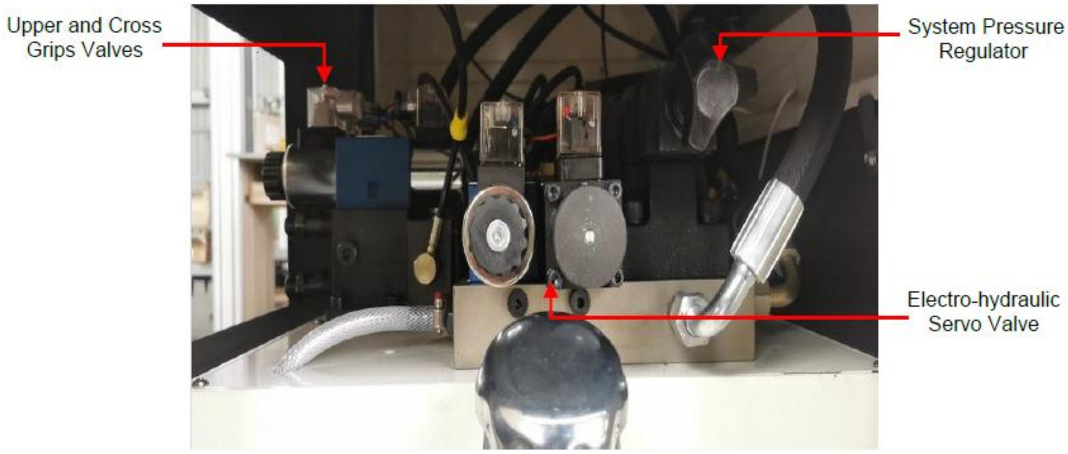

Fig. 11. Hydraulic system, side view

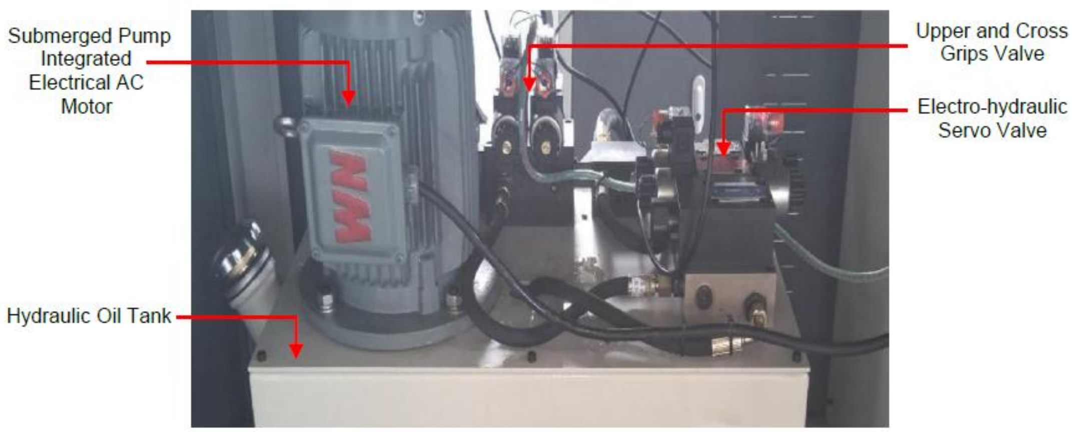

Fig. 12. Hydraulic system, submerged pump

Fig. 13. Hydraulic system, pressure sensor location

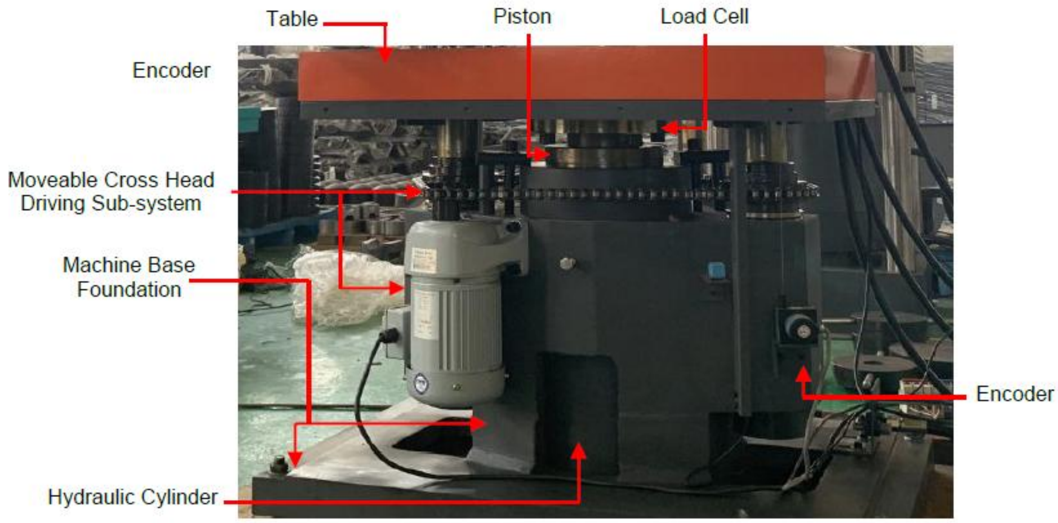

Fig. 14. Hydraulic cylinder assembly to machine base foundation

5.3 Hydraulic System Alternative

Figs. 10, 11 and 12 show Hydraulic System. Hydraulic Cylinder, Piping Sub-system, Load Control Valve, Hydraulic Returning Value, Backward Cylinder Realizing Valve, Hydraulic Pump, Pump Electrical Motor and Foundation are sub-systems which constitute the Hydraulic System Alternative.

Hydraulic Cylinder is of very high local weight added-value since it represents precious technology and can be remanufactured. Low contribution to upgrading local weight since it cannot contribute automation of Universal Testing Machine. Hydraulic Cylinder is remanufacturing based design since it will not appear in a developed version in the new generations of Universal Testing Machine.

Pressure sensor can be used to transmit pressure of Hydraulic Cylinder into Data Acquisition Card or Data Acquisition-Control Card, Fig. 13. Load cell can be used instead of Pressure sensor to transmit pressure of Hydraulic Cylinder, Fig. 14.

6. RESULTS AND DISCUSSION

6.1 Mean Global Weights of Measures Calculation

Literature in field of sustainability assessment can be classified into macro-scale literature which assesses sustainability based on general criteria in field of business sustainability assessment and micro-scale literature which assesses sustainability based on specified criteria in field of remanufacturing based sustainability assessment.

A sample of (56), [1-56], published articles is used to elicit criteria of measures of sustainability assessment and their weights to be normalized and unified. Local weight of each criterion is calculated by dividing the sum of local weights of the criterion on the number of articles where different criterion local weights are mentioned through the target literature. Equation (1) is used as literature based calculation to find the value of local weight of criterion (W_{LC}):-

$$W_{LC} = \sum_{n=1}^{k}(W)/k \quad (1)$$

Where,

W_{LC}= Criterion local weight,
W= Local weight of criterion per article,
n=Number of article where the criterion is mentioned,
k= Total number of articles.

Satisfaction local weight of each criterion is calculated to express performance index that may be satisfied by Remanufacturing Aided Upgrading of Universal Testing Machine business in accordance to the criterion. Remanufacturing Aided Upgrading and experience based assignment are used to find the value of local weight of criterion satisfaction (W_{LCS}) where experts can use pre-calculated weights to assign them to show criterion satisfaction by Remanufacturing Aided Upgrading of Universal Testing Machine business.

Pre-calculated weights values are determined by using fuzzy linguistic scale to describe four sub-degrees of several scenarios of satisfaction degree of a criterion based on considerations of remanufacturing business application.

Triangular fuzzy numbers are used to differentiate each sub-degree and then by multiplying, one triangular fuzzy number can be resulted. Criterion weight is described as triangular fuzzy number also to describe the importance of the criterion then the local weight of satisfaction can be obtained by multiplying both triangular fuzzy numbers of satisfaction and importance. By taking the mean of the new triangular fuzzy number pre-calculated weight can be obtained.

Satisfaction local weight represents to which extent the process of Remanufacturing Aided Upgrading of Universal Testing Machine can satisfy a certain criterion. Global weight (W_{GM}) of a certain criterion of sustainability can be obtained by multiplication of satisfaction local weight by criterion local weight, equation(3), while mean global weight can be obtained by dividing the summation of global weights of all criteria of a certain measure on the number of criteria:-

$$W_{GM} = W_{LC} \times W_{LCS} \quad (2)$$

$$W_{MGM} = \sum_{k=1}^{n}(W_{GM})/n \quad (3)$$

Where,

W_{GM}= Criterion global weight,
W_{LC} = Local weight of criterion,
W_{LCS}= Local weight of criterion satisfaction,
W_{MGM}=Mean global weight of criterion,
K= Number of criteria per certain measure,
n=Total number of criteria per certain measure.

Mean global weights (W_{MGM}) of a certain measure represent the importance of a certain measure through the process of sustainability assessment, equation (3).

Table1 shows mean local weights of measures of sustainability of economic, environmental, social, management and technical of macro-scale and micro-scale based literature.

6.2 Mean Global Weights of Measures of Remanufacturability-Upgradability based Sub-sustainability Assessment Calculation

Remanufacturability-upgradability based sub-sustainability assessment global weight can be calculated by using equation (4):-

$$W_{GRUS} = W_{LV} \times W_{LU} \times W_{GESS} \quad (4)$$

While remanufacturability-upgradability based sub-sustainability assessment mean global weight can be calculated by using equation (5):-

$$W_{MGRUS} = [(W_{LV} \times W_{LU} \times W_{MGM})_{k=1} + \ldots\ldots\ldots\ldots + (W_{LV} \times W_{LU} \times W_{MGM})_{k=n}]/n \quad (5)$$

Where,

W_{LV}= Added-value local weight,
W_{LU}= Contribution to upgrading local weight,
W_{MGM}= Mean Global weights of a certain measure of sustainability,
WMGM= Mean global weights of a certain measure of sustainability,
W_{GM}=Global weight of remanufacturability-upgradability based sub-sustainability assessment measure,
WMGM=Mean global weight of remanufacturability-upgradability based sub-sustainability assessment measure,
K= Number of Criteria (k=1…….n)
n=Number of Last Criterion

6.2.1 Economic sub-sustainability modeling

Universal Testing Machine economic sub-sustainability performance of remanufacturability based upgradability system can be assessed based on the three alternatives scenarios of Remanufacturing Aided Upgrading potentials which include mechanical structure system alternative, control and data acquisition system alternative and hydraulic system alternative.

Assessment matrices of alternatives are shown in Tables 2, 3 and 4 where each matrix is (3xN) dimensions where added-value local weight (W_{LV}), contribution to upgrading local weight (W_{LU}) and mean global weight of economic measure (W_{MGMEC}) to be assigned in three columns.

Mechanical structure sub-system alternative can be divided into nine components of Upper Cross Head, Moveable Cross Head Lead Screws, Movable Cross Head, Moveable Cross Head Driving Mechanism, Upper Cross Head and Table Alignment Columns, Table, Moveable Cross Head Grip, Upper Cross Head Grip and Machine Base Foundation. Literature based analysis, Remanufacturing Aided Upgrading and experience based analysis are used to assigned pre-determined weights of added-value local weight (W_{LV}), contribution to upgrading local weight (W_{LU}) and mean global weight of economic measure (W_{MGMEC}).

Control and data acquisition sub-system alternative can be divided into thirteen components of Analog Load Display, Electrical Circuit, Pendulum Load Cell, Elongation translator Mechanism, Digital Display Control Unit, Pressure Sensor, Load Cell, Encoder, Extensometer, Data Acquisition Card, Data Acquisition-Control Card, Computer Display Data Acquisition Software and Computer Display Data Acquisition-Control Software.

Hydraulic sub-system alternative can be divided into six components of Hydraulic Cylinder, Piping, Load control Valve, Hydraulic Oil Returning Valve, Hydraulic Pump and Pump Electrical Motor.

Remanufacturability-Upgradability based economic sub-sustainability global weight (W_{GRUS}) can be calculated by using equation (4) for each sub-system alternative, while Remanufacturability-Upgradability based economic sub-sustainability mean global weight (W_{MGRUS}) can be calculated by using equation (5) for each sub-system alternative.

6.2.2 Environmental sub-sustainability modeling

Assessment matrices of alternatives are shown in Tables 5, 6 and 7 where each matrix is (3xN) dimensions where added-value local weight (W_{LV}), contribution to upgrading local weight (W_{LU}) and mean global weight of environmental measure (W_{MGEM}) to be assigned in three columns.

Remanufacturability-Upgradability based environmental sub-sustainability global weight (W_{GRUS}) can be calculated by using equation (4) for each sub-system, while Remanufacturability-Upgradability based environmental sub-sustainability mean global weight (W_{MGRUS}) can be calculated by using equation (5) for each sub-system alternative.

6.2.3 Social sub-sustainability modeling

Assessment matrices of alternatives are shown in Tables 8, 9 and 10 where each matrix is (3xN) dimensions where added-value local weight (W_{LV}), contribution to upgrading local weight (W_{LU}) and mean global weight of economic measure (W_{MGSM}) to be assigned in three columns.

Remanufacturability-Upgradability based social sub-sustainability global weight (W_{GRUS}) can be calculated by using equation (4) for each sub-system, while Remanufacturability- Upgradability based social sub-sustainability mean global weight (W_{MGRUS}) can be calculated by using equation (5) for each sub-system alternative.

6.2.4 Management sub-sustainability modeling

Assessment matrices of alternatives are shown in Tables 11, 12 and 13 where each matrix is (3xN) dimensions where added-value local weight (W_{LV}), contribution to upgrading local weight (W_{LU}) and mean global weight of economic measure (W_{MGMM}) to be assigned in three columns.

Table 1. Mean global weights of economic, environmental, social, management and technical

Measure	Local weight of importance, macro literature based assessment	Local weight of importance, micro literature based assessment	Mean local weight of importance
Economic	0.294	0.215	0.255
Environmental	0.170	0.294	0.232
Social	0.105	0.105	0.105
Management	0.154	0.154	0.154
Technical	0.288	0.288	0.288

Table 2. Remanufacturability-upgradability based economic sub-sustainability assessment, mechanical structure system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of economic feasibility measure (W_{MGMEC})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Upper cross head	0.900	0.542	0.255	0.143
Moveable cross head lead screws	0.900	0.542	0.255	0.143
Movable cross head	0.900	0.542	0.255	0.143
Moveable cross head driving mechanism	0.900	0.542	0.255	0.143
Upper cross head and table alignment columns	0.900	0.542	0.255	0.143
Table	0.900	0.542	0.255	0.143
Moveable cross head grip	0.526	0.675	0.255	0.104
Upper cross head grip	0.526	0.526	0.255	0.071
Machine base foundation	0.900	0.542	0.255	0.143
Remanufacturability-upgradability based sustainability mean global weight (W_{MGRUS})				0.131

Table 3. Remanufacturability-upgradability based economic sub-sustainability assessment, control and data acquisition system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of economic feasibility measure (W_{MGMEC})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Analog load display	0.254	0.858	0.255	0.056
Electrical circuit	0.254	0.254	0.255	0.016
Pendulum load cell	0.254	0.858	0.255	0.056
Elongation translator mechanism	0.254	0.858	0.255	0.056
Digital display control unit	0.254	0.858	0.255	0.056
Pressure sensor	0.542	0.858	0.255	0.119
Load cell	0.817	0.817	0.255	0.170
Encoder	0.542	0.858	0.255	0.119
Extensometer	0.817	0.817	0.255	0.170
Data acquisition card	0.900	0.900	0.255	0.207
Data acquisition-control card	0.900	0.900	0.255	0.207
Computer display data acquisition software	0.900	0.900	0.255	0.207

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of economic feasibility measure (W_{MGMEC})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Computer display data acquisition – control software	0.900	0.900	0.255	0.207
Remanufacturability-upgradability based sustainability mean global weight (W_{MGRUS})				0.127

Table 4. Remanufacturability-upgradability based economic sub-sustainability assessment, hydraulic system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of economic feasibility measure (W_{MGMEC})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Hydraulic cylinder	0.900	0.254	0.255	0.058
Piping	0.254	0.254	0.255	0.019
Load control valve	0.462	0.9	0.255	0.122
Hydraulic oil returning valve	0.462	0.254	0.255	0.034
Hydraulic pump	0.758	0.817	0.255	0.182
Pump electrical motor	0.254	0.758	0.255	0.058
Remanufacturability-upgradability based sustainability mean global weight (W_{MRUS})				0.079

Table 5. Remanufacturability-upgradability based environmental sub-sustainability assessment, mechanical structure sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of environmental feasibility measure (W_{MGEM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Upper cross head	0.900	0.542	0.232	0.113
Moveable cross head lead screws	0.900	0.542	0.232	0.113
Movable cross head	0.900	0.542	0.232	0.113
Moveable cross head driving mechanism	0.900	0.542	0.232	0.113
Upper cross head and table alignment columns	0.900	0.542	0.232	0.113
Table	0.900	0.542	0.232	0.113
Moveable cross head grip	0.526	0.675	0.232	0.082
Upper cross head grip	0.526	0.526	0.232	0.064

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of environmental feasibility measure (W_{MGEM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Machine base foundation	0.900	0.542	0.232	0.113
Remanufacturability-upgradability based sustainability mean global weight (W_{MGRUS})				0.104

Table 6. Remanufacturability-Upgradability based environmental sub-sustainability assessment, control and data acquisition sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of environmental feasibility measure (W_{MGEM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Analog load display	0.254	0.858	0.232	0.051
Electrical circuit	0.254	0.254	0.232	0.015
Pendulum load cell	0.254	0.858	0.232	0.051
Elongation translator mechanism	0.254	0.858	0.232	0.051
Digital display control sub-system	0.254	0.858	0.232	0.051
Pressure sensor	0.542	0.858	0.232	0.108
Load cell	0.817	0.817	0.232	0.155
Encoder	0.542	0.858	0.232	0.108
Extensometer	0.817	0.817	0.232	0.155
Data acquisition card	0.900	0.900	0.232	0.188
Data acquisition-control card	0.900	0.900	0.232	0.188
Computer display data acquisition software	0.900	0.900	0.232	0.188
Computer display data acquisition – control software	0.900	0.900	0.232	0.188
Mean remanufacturability-upgradability based sustainability global weight (W_{MGRUS})				0.115

Remanufacturability-Upgradability based management sub-sustainability global weight (WGRUS) can be calculated by using equation (4) for each sub-system, while Remanufacturability-Upgradability based management sub-sustainability mean global weight (WMGRUS) can be calculated by using equation (5) for each sub-system alternative.

6.2.5 Technical sub-sustainability modeling

Assessment matrices of alternatives are shown in tables 14, 15 and 16 where each matrix is of (3xN) dimensions where added-value local weight (W_{LV}), contribution to upgrading local weight (W_{LU}) and mean global weight of economic measure (W_{MGTM}) to be assigned in three columns.

Remanufacturability-Upgradability based technical sub-sustainability global weight (W_{GRUS}) can be calculated by using equation (4) for each sub-system, while Remanufacturability-Upgradability based technical sub-sustainability mean global weight (W_{MGRUS}) can be calculated by using equation (5) for each sub-system alternative.

Comprehensive sustainability performance assessment of remanufacturability based upgradability system of Universal Testing Machine can be shown in Fig. 15, alternative-sustainability measures weights illustration. According to (1) economic, (2) environmental and (5) technical dimensions, there are a good signs of that sustainability is forwarded in the way of development, while according to (3) social and (4) management dimensions, there are high efforts are needed to be done to forward sustainability to be high performance development.

Table 7. Remanufacturability-upgradability based environmental sub-sustainability assessment, hydraulic sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of environmental feasibility measure (W_{MGEM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Hydraulic cylinder	0.900	0.254	0.232	0.053
Piping	0.254	0.254	0.232	0.015
Load control valve	0.462	0.9	0.232	0.096
Hydraulic oil returning valve	0.462	0.254	0.232	0.027
Hydraulic pump	0.758	0.817	0.232	0.144
Pump electrical motor	0.254	0.758	0.232	0.045
Mean remanufacturability-upgradability based sustainabilityglobal weight (W_{MRUS})				0.063

Table 8. Remanufacturability-upgradability based social sub-sustainability assessment, mechanical structure sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of social feasibility measure (W_{MGSM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Upper cross head	0.900	0.542	0.105	0.051
Moveable cross head lead screws	0.900	0.542	0.105	0.051
Movable cross head	0.900	0.542	0.105	0.051
Moveable cross head driving mechanism	0.900	0.542	0.105	0.051
Upper cross head and table alignment columns	0.900	0.542	0.105	0.051
Table	0.900	0.542	0.105	0.051
Moveable cross head grip	0.526	0.675	0.105	0.037
Upper Cross head grip	0.526	0.526	0.105	0.029

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of social feasibility measure (W_{MGSM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Machine base foundation	0.900	0.542	0.105	0.051
Remanufacturability-upgradability based sustainability mean global weight (W_{MGRUS})				0.047

Table 9. Remanufacturability-upgradability based social sub-sustainability assessment, control and data acquisition sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to Upgrading local Weight(W_{Lu})	Mean global weight of social feasibility measure (W_{MGSM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Analog load display	0.254	0.858	0.105	0.023
Electrical circuit	0.254	0.254	0.105	0.007
Pendulum load cell	0.254	0.858	0.105	0.023
Elongation translator mechanism	0.254	0.858	0.105	0.023
Digital display control sub-system	0.254	0.858	0.105	0.023
Pressure sensor	0.542	0.858	0.105	0.049
Load cell	0.817	0.817	0.105	0.070
Encoder	0.542	0.858	0.105	0.049
Extensometer	0.817	0.817	0.105	0.070
Data acquisition card	0.900	0.900	0.105	0.085
Data acquisition-control card	0.900	0.900	0.105	0.085
Computer display data acquisition software	0.900	0.900	0.105	0.085
Computer display data acquisition – control software	0.900	0.900	0.105	0.085
Remanufacturability-upgradability based sustainability global weight (W_{MGRUS})				0.052

Table 10. Remanufacturability-upgradability based social sub-sustainability assessment, hydraulic sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of social feasibility measure (W_{MGSM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Hydraulic cylinder	0.900	0.254	0.105	0.024
Piping	0.254	0.254	0.105	0.007
Load control valve	0.462	0.900	0.105	0.044
Hydraulic oil returning valve	0.462	0.254	0.105	0.012

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of social feasibility measure (W_{MGSM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Hydraulic pump	0.758	0.817	0.105	0.065
Pump electrical motor	0.254	0.758	0.105	0.020
Remanufacturability-Upgradability based Sustainability Global Weight(W_{MRUS})				0.029

Table 11. Remanufacturability-upgradability based management sub-sustainability assessment, mechanical structure sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of management feasibility measure (W_{MGMM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Upper cross head	0.900	0.542	0.154	0.075
Moveable cross head lead screws	0.900	0.542	0.154	0.075
Movable cross head	0.900	0.542	0.154	0.075
Moveable cross head driving mechanism	0.900	0.542	0.154	0.075
Upper cross head and table alignment columns	0.900	0.542	0.154	0.075
Table	0.900	0.542	0.154	0.075
Moveable cross head grip	0.526	0.675	0.154	0.055
Upper cross head grip	0.526	0.526	0.154	0.029
Machine base foundation	0.900	0.542	0.154	0.075
Remanufacturability-upgradability based sustainability mean global weight (W_{MGRUS})				0.068

Table 12. Remanufacturability-upgradability based management sub-sustainability assessment, control and data acquisition sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of management feasibility measure (W_{MGMM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Analog load display	0.254	0.858	0.154	0.034
Electrical circuit	0.254	0.254	0.154	0.010
Pendulum load cell	0.254	0.858	0.154	0.034
Elongation translator mechanism	0.254	0.858	0.154	0.034
Digital display control sub-system	0.254	0.858	0.154	0.034

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of management feasibility measure (W_{MGMM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Pressure sensor	0.542	0.858	0.154	0.072
Load cell	0.817	0.817	0.154	0.103
Encoder	0.542	0.858	0.154	0.072
Extensometer	0.817	0.817	0.154	0.103
Data acquisition card	0.900	0.900	0.154	0.125
Data acquisition-control card	0.900	0.900	0.154	0.125
Computer display data acquisition software	0.900	0.900	0.154	0.125
Computer display data acquisition – control software	0.900	0.900	0.154	0.125
Remanufacturability-upgradability based sustainability global weight (W_{MGRUS})				0.077

Table 13. Remanufacturability-upgradability based management sub-sustainability assessment, hydraulic sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of management feasibility measure (W_{MGMM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Hydraulic cylinder	0.900	0.254	0.154	0.035
Piping	0.254	0.254	0.154	0.007
Load control valve	0.462	0.900	0.154	0.044
Hydraulic oil returning valve	0.462	0.254	0.154	0.012
Hydraulic pump	0.758	0.817	0.154	0.095
Pump electrical motor	0.254	0.758	0.154	0.020
Remanufacturability-upgradability based sustainability global weight (W_{MRUS})				0.036

Table 14. Remanufacturability-upgradability based technical sub-sustainability assessment, mechanical structure sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of technical feasibility measure (W_{MGTM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Upper cross head	0.900	0.542	0.288	0.140
Moveable cross head lead screws	0.900	0.542	0.288	0.140
Movable cross head	0.900	0.542	0.288	0.140
Moveable cross head driving	0.900	0.542	0.288	0.140

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of technical feasibility measure (W_{MGTM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
mechanism				
Upper cross head and table alignment columns	0.900	0.542	0.288	0.140
Table	0.900	0.542	0.288	0.140
Moveable cross head grip	0.526	0.675	0.288	0.102
Upper cross head grip	0.526	0.526	0.288	0.080
Machine base foundation	0.900	0.542	0.288	0.140
Mean remanufacturability-upgradability based sustainability mean global weight (W_{MGRUS})				0.129

Table 15. Remanufacturability-Upgradability based technical sub-sustainability assessment, control and data acquisition sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of technical feasibility measure (W_{MGTM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Analog load display	0.254	0.858	0.288	0.063
Electrical circuit	0.254	0.254	0.288	0.019
Pendulum load cell	0.254	0.858	0.288	0.063
Elongation translator mechanism	0.254	0.858	0.288	0.063
Digital display control sub-system	0.254	0.858	0.288	0.063
Pressure sensor	0.542	0.858	0.288	0.134
Load cell	0.817	0.817	0.288	0.192
Encoder	0.542	0.858	0.288	0.134
Extensometer	0.817	0.817	0.288	0.192
Data acquisition card	0.900	0.900	0.288	0.233
Data acquisition-control card	0.900	0.900	0.288	0.233
Computer display data acquisition software	0.900	0.900	0.288	0.233
Computer display data acquisition – control software	0.900	0.900	0.288	0.233
Mean remanufacturability-upgradability based sustainability global weight (W_{MGRUS})				0.144

Table 16. Remanufacturability-upgradability based technical sub-sustainability assessment, hydraulic sub-system alternative

Alternative	Added-value local weight (W_{Lv})	Contribution to upgrading local weight (W_{Lu})	Mean global weight of technical feasibility measure (W_{MGTM})	Remanufacturability-upgradability based sustainability global weight (W_{GRUS})
Hydraulic cylinder	0.900	0.254	0.288	0.066
Piping	0.254	0.254	0.288	0.019
Load control valve	0.462	0.900	0.288	0.120
Hydraulic oil returning valve	0.462	0.254	0.288	0.034
Hydraulic pump	0.758	0.817	0.288	0.173
Pump electrical motor	0.254	0.758	0.288	0.055
Mean remanufacturability-upgradability based sustainability global weight (W_{MRUS})				0.077

Control and data acquisition system alternative is of highest preference weight to develop Remanufacturing Aided Upgrading of Universal Testing Machine as a sustainability contributor since it is directly related to performance of Universal Testing Machine and responsible on machine accuracy and reliability and ergonomics. So it is dependent variable of upgrading function to develop upgrading based sustainability.

Mechanical structure system alternative is of second highest preference weight to develop Remanufacturing Aided Upgrading of Universal Testing Machine as sustainability contributor since it is responsible on energy and material saving and waste and emission prevention. So it is dependent variable of remanufacturing function to develop remanufacturing based sustainability.

Hydraulic system alternative is of lowest preference to develop Remanufacturing Aided Upgrading of Universal Testing Machine as sustainability and it is dependent variable of upgrading function to develop upgrading based sustainability.

Mean sustainability weight of Mechanical structure system alternative is (0.337), mean sustainability weight of Control and data acquisition system alternative is (0.524) and mean sustainability weight of Control and data

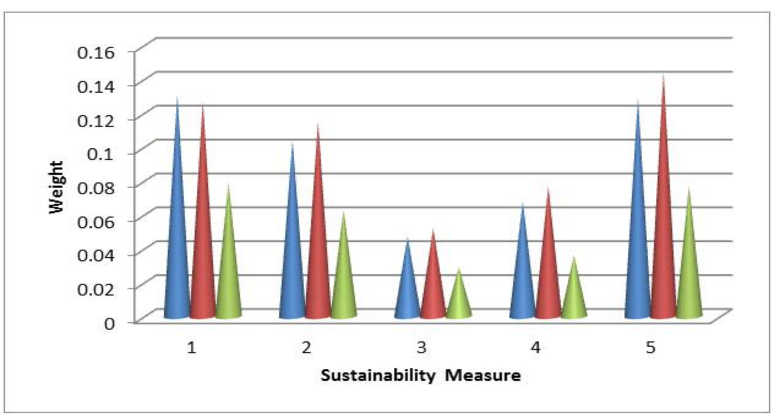

Fig. 15. Sustainability performance assessment of remanufacturability based upgradability system of Universal Testing Machine, alternative-sustainability measures weights illustration, (1): Economic measure, (2): Environmental measure, (3): Social measure, (4): Management measure, (5): Technical measure

acquisition system alternative is (0.237), Fig. 16 is an alternative weights prospective, so that A_2 is sustainable than A_1 and A_1 is sustainable than A_3.

Alternatives weights and sustainability measures weights values are consistent with error value of (27.8%) due to ambiguity, inexactness subjectivity, impreciseness and vagueness. Technical feasibility is of the highest weight. According to Fig. 17, sustainability measures weights illustration, environmental and technical feasibilities are very close to being identical. Mean lowest weight of social feasibility is followed by management feasibility to show the weak interrelation between these two feasibilities which reflect as shortages of polices and legislations that can regulate Remanufacturing Aided Upgrading activities of Universal Testing Machine to be adopted as sustainable business. Polices and legislations are required to unify the scattered and manifold efforts and experience through individual businesses to develop sustainable circular economy of Remanufacturing Aided Upgrading which can lead to employment and human development as a successful management practiced sustainability conscious business.

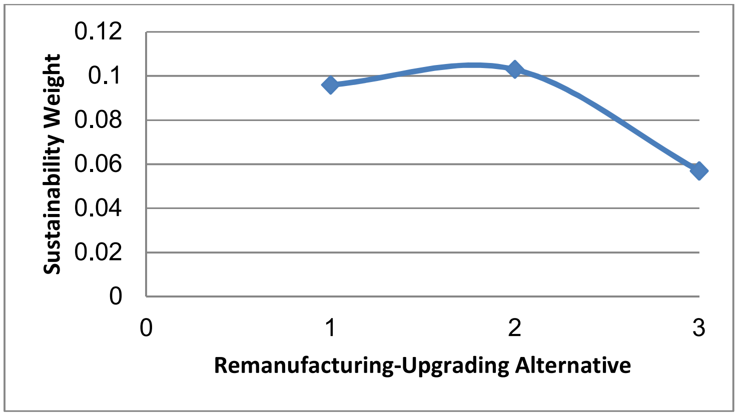

Fig. 16. Sustainability performance assessment of remanufacturability based upgradability system of Universal Testing Machine, alternative weight prospective, (1): Sustainability potentials contribution weight of mechanical structure sub-system alternative, (2): Sustainability potentials contribution weight of control and data acquisition sub-system alternative, (3): Sustainability potentials contribution weight of hydraulic sub-system alternative

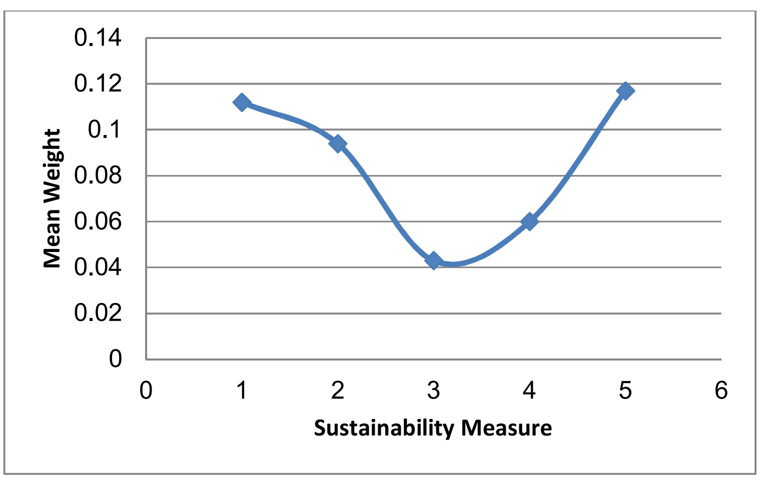

Fig. 17. Sustainability performance assessment of remanufacturability based upgradability system of Universal Testing Machine, sustainability measures weights prospective, (1): Economic measure, (2): Environmental measure, (3): Social measure, (4): Management measure, (5): Technical measure

7. CONCLUSION

Structural characteristics of Universal Testing Machine can be studied through classification of machine structure components. It is seen that dividing components of Universal Testing Machine functionally into three alternatives to generate sub-systems of Remanufacturing Aided Upgrading potentials contribution scenarios can be a powerful tool to assess sustainability of Remanufacturing Aided Upgrading models. Literature based analysis, Remanufacturing Aided Upgrading experience based analysis and alternatives based analysis are used to develop and analysis the sustainability of Remanufacturing Aided Upgrading of alternatives. The three alternatives of Remanufacturing Aided Upgrading potentials include:

1. Mechanical structure sub-system alternative.
2. Control and data acquisition sub-system alternative.
3. Hydraulic sub-system alternative

Sustainability measures include environmental, economic, social, management and technical feasibilities. For each measure of sustainability, the three alternatives should be assessed to find the index value which is called Remanufacturability-Upgradability based Sustainability Mean Global Weight (W_{MRUS}). This index value is the mean of multiplication of Added-Value Local Weight (W_{Lv}), Contribution to Upgrading local Weight (W_{Lu}) and Global Economic Sub-sustainability Assessment Weight (W_{GESS}) for each component in each viability measure. Thus five Remanufacturability-Upgradability based Sustainability Mean Global Weights (W_{MRUS}) can be obtained for each alternative and sustainability can be assessed within insights of remanufacturability aided upgrading potentials.

Three alternatives weights of economic feasibility show that mechanical structure sub- system alternative is the best to satisfy added-value restoration to be followed by control and data acquisition sub-system alternative while the performance of hydraulic sub-system alternative is low since general purposes based design components are of high content percentage in this sub-system.

Environmental feasibility weights of alternatives show that control and data acquisition sub-system alternative is of the best environmental performance to be followed by mechanical structure sub-system alternative while the performance of hydraulic sub-system alternative is low due to two reasons. The first is that Mean Global Weight of Environmental feasibility Measure (W_{MGEM}) is high and the second reason is the effective upgrading-remanufacturing based design components which are included in control and data acquisition sub-system alternative.

Social feasibility weights of alternatives are of the lowest values comparing with other feasibilities but the same performance behavior is kept comparing with weights of environmental feasibility of alternatives, where control and data acquisition sub-system alternative is of the best social performance to be followed by mechanical structure sub-system alternative while the social performance of hydraulic sub-system alternative is low. More potentials of experience accumulation which lead to employment and human development are the important contributions of social development that can be delivered through control and data acquisition sub-system alternative.

The behavior of management feasibility is the same as social feasibility but with higher weight to be accounted for management feasibility since managerial insights policies are applied based on internal institutional scale comparing with social development policies which should be more branched since they should be applied to include local remanufacturing section or could be of global extensions.

The highest weights are of technical feasibility since the Mean Global Weight of technical feasibility Measure (W_{MGEM}) is the highest and technology is mature enough especially for control and data acquisition sub-system alternative where automation is also introduced to control test parameters.

Findings can include conclusion of that analysis of result can lead to classify components of Universal Testing Machine into upgrading-remanufacturing based design components which contribute the both of upgrading and remanufacturing in particular and general manners, remanufacturing based design components which contribute remanufacturing process individually, upgrading based design components which contribute upgrading process individually and general purposes based design components which have no effect on both of upgrading and remanufacturing processes.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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