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Review on Labour Productivity Analysis in the Manufacturing Industries Using Fuzzy Logic Algorithm

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Abstract- Manufacturing decisions inherently face uncertainties and imprecision. Fuzzy logic, and tools based on fuzzy logic, allow for the inclusion of uncertainties and imperfect information in decision making models, making them well suited for manufacturing decisions. In this study, we first review the progression in the use of fuzzy tools in tackling different manufacturing issues during the past two decades. We then apply fuzzy linear programming to a less emphasized, but important issue in manufacturing, namely that of product mix prioritization. The proposed algorithm, based on linear programming with fuzzy constraints and integer variables, provides several advantages to existing algorithm as it carries increased ease in understanding, in use, and provides flexibility in its application.

Keywords- Artificial intelligence, fuzzy logic, expert system, decision support system, tool selection; production; Industry 4.0

I. INTRODUCTION

As we know whenever we planned the manufacturing system we consider the design criteria such as the system efficiency, the system will be efficient in all the way in production. All such criteria cannot be achieved until the design production, planning scheduling and controlling steps work well.
A FMS can be defined as production system consisting of identical multipurpose numerically controlled machine (work stations).

FMS is manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes. FMS works for automated material and tools handling system load and unload stations, inspection stations, storage areas and a hierarchical control system.

Generally when time is being planned, the objective is to design a system which will be efficient in the production of the entire range of parts. A FMS provides the efficiency of automated high-volume mass production.

Scheduling in an FM environment is more complex and difficult than in conventional manufacturing environment. Scheduling of FMS determine an optimal schedule and controlling an FMS is considered as difficult task. Fuzzy set theory was introduced in 1965 by zadeh. Fuzzy logic approaches easily deal with uncertain and incomplete information and human experts, knowledge can be easily coded into fuzzy logic approaches for scheduling FMS is consider due to its ability to deal uncertain and incomplete information and with multi objective problem.

II. RESEARCH MOTIVATION

Smart Manufacturing System (SMS) is a vast field to be explored in the domain of Industry 4.0, even as it presents several advantages compared to conventional manufacturing systems. Thus, it is progressively being adopted by manufacturing industry players as a strategic method to enhance their performance, even when SMS is an expensive approach compared to the conventional system [**1**]. Many studies have been done in the past to explore

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the technical aspects in the development of a new SMS [**1**,**2**,**3**,**4**,**5**,**6**,**7**,**8**,**9**,**10**,**11**,**12**,**13**]. However, very limited studies have been conducted on investigating the configuration challenges when establishing new SMS [**7**,**14**,**15**,**16**] that requires pre-implementation planning and assessment. Specifying a correct SMS configuration prior to the costly implementation could assist industry players in planning and establishing a new SMS that minimizes the operational cost and time and improves efficient machine utilization.

In Industry 4.0, SMS is moving towards human-machine collaboration, and autonomous response is moving towards robot deployment to replace human intervention in smart manufacturing systems [**11**]. Extensive research was conducted in terms of having proper test methods for this smart manufacturing. This sheds light on the importance of evolving smart manufacturing systems involving adequate intelligent aspects to operate autonomously without human intervention [**11**]. The smart manufacturing environment can be envisioned as an environment that allows communication between humans and machines, and the system's success lies in the way the configuration is adopted.

Due to the increasing demand by consumers for continuously innovative and higher quality products and for affordable prices and product immediacy, market players constantly come under pressure to make well-informed decisions while establishing a new SMS that requires pre-implementation planning and assessment. This proper pre-implementation planning aspect has been given little attention, despite it being the core of the manufacturing success as former research works such as a hybrid simulation-based assessment and agent-based modeling framework for smart manufacturing systems (SMS) focused mainly on assisting decision-makers in designing better configurations based on the establishment of appropriate information messaging protocols between system components using hybrid simulation modeling [**7**].

This assessment should be based on measured values using systematic approaches to stay ahead in the industry with high sustainability constantly. Clear and concise evaluation factors play key roles in any Smart Manufacturing System's configurations as each contributes to the level of success of the manufacturing products.

Therefore, identifying evaluation factors to develop a coherent evaluation framework aids decision-makers in selecting the correct configuration.

III. LITERATURE REVIEW

Mirko Mazzoleni et al.[1] Since the introduction of the industry 4.0 paradigm, manufacturing companies are investing in the development of algorithmic diagnostic solutions for their industrial equipment, relying on measured data and process models. However, process and fault models are not usually available for complex productions plants and production data are usually unlabeled. Thus, to classify machine status, unsupervised approaches such as anomaly detection and signal processing strategies have to be employed. Due to the unsupervised nature of the problem, it is meaningful to apply several diagnostic algorithms to cover most of the process anomalous behaviors. Additionally, in some contexts, the experience of process operators in grasping the correct functioning of machines as well as their ability in understanding early signs of deterioration is relevant for the diagnosis of incoming failures.

However, seldom this information can be included in failure diagnosis algorithms. In this paper, we propose a diagnostic scheme for condition monitoring of mechanical components. The proposed scheme combines anomaly detection algorithms, envelope analysis of vibration data, and eventually additional qualitative information on machine functioning. The combination of all the fault indicators is obtained leveraging on a fuzzy inference system. The proposed scheme is experimentally validated on a steel making plant with real process data, making use of heuristic information such monitoring reports of machine health status.

Anita Susilawati et al.[2] Lean manufacturing is gaining popularity as an approach that can achieve significant performance improvement in the industry. However, the application of lean manufacturing is not an easy process. To reach the level of full implementation of lean manufacturing takes a long time and during that time the continuous improvement must be made. In the process of continuous improvement, lean manufacturing assessment is required. One form of assessment is to measure the degree of lean implementation. However, it is the complexity involved in the measure of degree of leanness. This complexity arises due to (a) the inherent multi-dimensional concept of leanness (b) unavailability manufacturing practice database that can be used as a benchmark in assessing the degree of leanness and (c) the necessity for the application of subjective human judgement on lean practices which involve vagueness and bias due to variation of evaluator's knowledge and experience. In this paper a method to deal with the multi-dimensional concept, unavailability benchmark and uncertainty, which arises from the subjective and vague human judgement for the measurement of degree of leanness, is proposed.

The multi-dimensional concept involving a variety of components of lean practices is measured in order to arrive at a measure for the lean activity of a given organization. It is constructed from primary and secondary data involving a comprehensive literature review and validated with interviews with a set of sample organizations representing the entire spectrum of the industry.

The vagueness of subjective human judgement on degree of application of lean practices is modelled by fuzzy number in conjunction with an additional consideration related to the length of lean practice implementation and the use of multi-evaluators. Value stream mapping is used in scoring the degree of implementation of lean so the use of benchmark is not necessary. Some results from an initial survey from a sample of respondents from the manufacturing industry in Indonesia are presented to illustrate the applicability and potential strength of the proposed method.

Ifeyinwa Juliet Orji et al.[3] Globally, supply chains compete in a complex and rapidly changing environment. Hence, sustainable supplier selection has become a decisive variable in the firm’s financial success. This requires reliable tools and techniques to select the best sustainable supplier and enhance understanding about how supplier behavior evolves with time. System dynamics (SD) is an approach to investigate the dynamic behavior in which the system status alterations correspond to the system variable changes. Fuzzy logic usually solves the challenges of imprecise data and ambiguous human judgment. Thus, this work presents a novel modeling approach of integrating information on supplier behavior in fuzzy environment with system dynamics simulation modeling technique which results in a more reliable and responsible decision support system.

Supplier behavior with respect to relevant sustainability criteria in the past, current and future time horizons were sourced through expert interviews and simulated in Vensim to select the best possible sustainable supplier. Simulation results show that an increase in the rate of investment in sustainability by the different suppliers causes an exponential increase in total sustainability performance of the suppliers. Also, the growth rate of the total performance of suppliers outruns their rate of investment in sustainability after about 12 months. A dynamic multi-criteria decision making model was presented to compare results from the systems dynamics model.

Taha Al-Saadi et al.[4] Since the development of the Fuzzy Logic theory by Zadah (1965), motivated by the human-level understanding of systems for the development of computational and mathematical frameworks, it has become an active research field for a broad spectrum of research in academia and the industry, from systems modelling to systems monitoring and control. In this research, the authors intend to highlight the use of Fuzzy Logic theory in metal additive manufacturing processes. The modelling of such processes has a lot of uncertainties due to the large underlying physics during the operation, which makes the Fuzzy Logic Controller a promising tool to deal with such a process. This work will provide a survey of the previous efforts and a case study to illustrate the approach's effectiveness in such a complex manufacturing technique.

Nedra Abbes et al.[5] The implementation of the Lean Six Sigma (LSS) in the textile and clothing industries is a successful strategy to reduce the defects produced along the production line in these industries. Lean Six Sigma readiness knowledge is a pre-requisite for a successful LSS implementation. Yet, the literature on Lean Six Sigma implementation and the readiness evaluation model in small and medium-sized textile and clothing are very limited. The purpose of this study is to develop a model of LSS readiness assessment for the clothing industries (LSRACI) using fuzzy logic. The present model is based largely on both the critical success factors (CSFs) of LSS and the LSS factors (enablers, criteria, and attributes) derived from the literature. The CSFs

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are identified using a questionnaire distributed to 85 small-medium clothing industries, and integration with the evaluation model.

The outcome of this process is the identification of 5 enablers, 6 criteria, and 46 attributes which are finally ready to be used. The use of CSFs from the clothing industries gives a specification to our evaluation model and makes the LSRACI model original and specified to clothing SMEs. This model is developed for assessing the readiness level of the clothing and textile industries and it helps as well as to improve the readiness level for successful implementation of LSS. The present study aims to contribute to the knowledge of readiness for the LSS implementation in clothing industries.

The readiness level of this company is average ready with (3.28; 4.9; 6.7). Using a fuzzy performance importance index (FPII), 20 from 46 attributes were identified as weaker attributes and therefore necessary corrective actions were recommended to improve the readiness level. The proposed model helps managers and practitioners to find out the potential of the clothing and textile industries by evaluating the company readiness before implementation in order to overcome problems and achieve a successful LSS implementation.

Rongxu Xu et al.[6] Construction sites remain highly perilous work environments globally, exposing employees to numerous hazards that can result in severe injuries or fatalities. To resolve this several solutions based on quantitative approaches have been developed. However the wide adoption of preexisting solutions is hindered by lack of accuracy. To this aim the development of an efficient fuzzy inference system has become a de-facto necessity. In this paper, we propose an edge inference framework based on multi-layered fuzzy logic for safety of construction workers.

The proposed system employs an edge computing-based framework where IoT devices collect, store, and manage data to offer safety services. Multi-layer fuzzy logic is applied to infer the worker safety index based on rules that consist of construction environment factors. The multi-layer fuzzy logic is fed with weather, building and worker data collected from IoT nodes as inputs. The safety risk assessment process involves analyzing various factors. Weather information, such as temperature, humidity, and rainfall data, is considered to assess the risk to safety. The condition of the building is evaluated by analyzing load, strain, and inclination data. Additionally, the safety risk to workers is analyzed by taking into account their heart rate and location information.

The initial layer's outputs are utilized as inputs for the subsequent layer, where an integrated safety index is inferred. Ultimately, the safety index is generated as the final outcome. The system's results are conveyed through warnings and an error measurement on a safety scale ranging from 1 to 10. Furthermore, web service is developed to allow the construction management to check the worker safety condition of the construction site in real-time, while also monitoring the operational status of the IoT devices, allowing for the early detection of sensor malfunction and the subsequent guarantee of worker safety. Extensive evaluations conducted to test the performance of the developed framework verify its efficiency to provide improved risk assessment, real-time monitoring, and proactive safety actions, encouraging a safer and more productive work environment.

Belen Maria Moreno-Cabezali et al.[7] Experts from industry and academics have highlighted Additive Manufacturing (AM) as a technology that is revolutionizing manufacturing. AM is a process that consists of creating a three-dimensional object by incorporating layers of a material such as metal or polymer. This research studies risks associated with AM R&D Project Management. A significant set of risks with a potential negative impact on project objectives in terms of scope, schedule, cost and quality are identified through an extensive literature review. These risks are assessed through a survey answered by ninety academics and professionals with noteworthy sector expertise.

This process is made by the measurement of two parameters: likelihood of occurrence and impact on project objectives. According to the responses of the experts, the level of relevance of each risk is calculated, innovatively, through a fuzzy logic-based model, specifically developed for this study, implemented in MATLAB Fuzzy Logic Toolbox. The results of this study show that the risks “Defects occurring during the manufacturing process”, “Defective design”, “Poor communication in the project team” and “Insufficient financing” are determined as the most critical in AM R&D Project Management. The proposed model is presented as a powerful new tool for organizations and academics, to prioritize the risks that are more critical to develop appropriate response strategies to achieve the success of their projects.

Aswin Ramaswamy Govindan et al.[8] Workers in the modular construction industry are frequently exposed to ergonomic risks, which may lead to injuries and lower productivity. In light of this, researchers have proposed a number of ergonomics risk assessment methods to identify design flaws in work systems, thereby reducing ergonomic discomfort and boosting workplace productivity. However, organizations often disregard ergonomics risk assessments due to a lack of convenient tools and knowledge. Therefore, this study proposes a fuzzy logic-based decision support system to help practitioners to automatically and comprehensively assess the ergonomic performance of work systems.

For comprehensive assessment of ergonomic risk, the proposed decision support system considers physical, environmental, and sensory factors. Specifically, the decision support system comprises eight fuzzy expert systems that output a composite risk score, called an “ergonomic risk indicator”, that indicates the overall level of ergonomic risk present in a given work system. The performance of the proposed decision support system is then evaluated using a real-world case study in a modular construction facility by comparing the results of the decision support system with the facility's occupational injury reports. The results prove the effectiveness of the decision support system. Overall, the decision support system is capable of generating a composite risk score, the ergonomic risk indicator, and the proposed high-level architecture and design represent significant contributions for the enhancement of health and safety in the modular construction industry.

Hiluf Reda et al.[9] Lean manufacturing is a profound system designed to enhance every manufacturing industry's efficiency by reducing waste through internationally recognized tools and techniques. Manufacturing industries strive to adopt lean concepts to maximize their resources like staff, facilities, materials, and schedules to be economically effective. However, managers face difficulty selecting the appropriate lean tools out of the many available LM tools for successful lean implementation. This study suggests an innovative approach to choose suitable lean tools to maximize these essential resources.

Herein the Value Stream Mapping and plant layout are considered for waste identification. Fuzzy QFD and FMEA prioritize the crucial resources concerning the defined wastes and determine the risk associated with each failure mode's sub-element for lean application. It saves time by analyzing only the most critical resources for a successful lean implementation since its focus only on the most important resources. The applicability of the proposed approach is demonstrated through a case study of an Ethiopian shoe manufacturing firm. With the aid of future state plant layout and value stream map, total cycle time is reduced by 56.3%, lead-time is reduced by 69.7%, materials transportation distance and transportation activities are reduced by more than 75%, and workers required are reduced from 202 to 200.

Saadat Ali Rizvi et al.[10] In this article, a grey-based fuzzy logic algorithm was proposed as a soft computing method to optimize the metal inert gas (MIG) welding process parameters during the joining of stainless steel (AISI) 304. In welding, welding process parameters play a significant role to evaluate the weld quality i.e. mechanical properties. Input parameters selected for examination referred to as welding current, voltage, wire feed speed and gas flow rate were optimized. The grey-based fuzzy logic algorithm was used to obtain a grey fuzzy reasoning grade (GFRG) and it was observed from result that experiment number seven have the highest value of MPCI. In this experimental work arc voltage play a major role on the determination of MPCI and it was also observed that the grey-based fuzzy method is very helpful for the continuous enhancement of the product quality and on fractrography mode of fracture was ductile observed.

Tom Drews et al.[11] This paper presents an approach for the integration of lean methods and manufacturing process objectives through the usage of a fuzzy logic controller. The fuzzy logic controller comprises twelve common lean methods, three manipulated variables (setup time, error rate and technical availability) and five manufacturing process objectives, which are operationalized through the target variables Every Part Every Interval (EPEI), Overall Equipment Effectiveness (OEE), Lead Time (LT), Quality Grade (QG) and Delivery Service (DS). The basic structure of the fuzzy logic controller design and the modeling of the optimization effect on the manufacturing process level are shown.

Dan Su et al.[12] Since 2008, many academics have increasingly paid attention to block chain technology from different perspectives. In general, researchers desire to achieve global block chain systems within a sustainable manufacturing domain; however, a number of technical challenges have come to exist in the recent decade, for instance, consensus algorithms and computing paradigms that can meet the privacy protection requirements of manufacturing systems. Therefore, an integrated decision-making framework called Pythagorean fuzzy-entropy-rank sum-Combined Compromise Solution (PF-entropy-RS-CoCoSo) is developed in this study, including two main phases.

In the first phase, the PF-entropy-RS method is applied to obtain the subjective and objective weights of criteria to evaluate the technical challenges of transforming block chain technology for a sustainable manufacturing paradigm in the Industry 4.0 era. The PF-CoCoSo model is then utilized in the second phase to assess the preferences of organizations over different technical challenges of the block chain technology transformation for the sustainable manufacturing paradigm in the Industry 4.0 era. An empirical case study is taken to assess the main technical challenges of blockchain technology transformation for the sustainable manufacturing paradigm. Furthermore, a comparison analysis and a sensitivity investigation are made to demonstrate the superiority of the developed framework.

Abinash Jena et al.[13] Recently, Indian manufacturing industries have undergone a significant transformation emphasising customer-centric objectives to meet the dynamic market's demands. To achieve this, existing industries must upgrade their existing infrastructure to a smart environment driven by automatic data exchange, transparency, and interconnected digital systems. These are the key enabling elements of Industry 4.0. As a result, many Indian industries are developing various sophisticated implementation strategies for adopting it. However, few research works and strategies contribute to its effective and successful implementation. This paper proposes two types of implementation strategies for implementing Industry 4.0 enabling technologies based on the requirements and adaptability of India's commercial vehicle manufacturing industry.

The first strategy identifies various aspects of implementing Industry 4.0 enabling framework elements and categorizes it for developing implementation strategies based on India's commercial vehicle manufacturing industry. The significance of each was determined using fuzzy-AHP analysis and ranked accordingly based on the linguistic responses of the industry experts. The most significant framework element is found to be ‘Decision Making and Management Skills’. The second strategy emphasizes long-term sustainable implementation objectives. The framework elements are reconstructed and developed into a novel, customized sustainable framework based on six dimensions of sustainability.

Using the Fuzzy-DEMATEL method, the causal relationships among these elements are investigated to determine a sustainable implementation strategy. ‘Central Database Server’ is determined to be the most significant sustainable framework element, while the maximum number of casual relationships is obtained from the group, ‘Skill upgradation of the workforce’. This paper proposes a novel research direction for implementing Industry 4.0 technologies into the existing industry. The findings provide several insights and strategies for technological upgradation in other industries in this geographical region. The findings of the work enhance the implementation process of I4.0 technologies, transitioning it from a conventional approach to a futuristic sustainable implementation that is economical and effective.

L. Maretto et al.[14] The presence of Industry 4.0 national plans and the ever-increasing international competition are forcing companies to embark on digitalization projects of their industrial plants. Time and money, however, are a constraint and, in addition to that, there is a considerable lack of works in the academic literature with regards to specific models for the selection of digital technologies. Starting from our methodological framework, we developed a multi-criteria decision-making model for the digitalization of industrial plants. The model is based on both Fuzzy Logic and AHP and is combined with an existing hierarchical classification of digital technologies in an attempt to highlight the advantage of adopting similar and easily interconnect able technologies. Finally, the model is applied to a simple case study to test its validity.

Yongzhe Li et al.[15] The deposition process of wire and arc additive manufacturing (WAAM) is usually planned based on a bead geometry model (BGM), which represents the relationship between bead geometries (e.g. width, height) and required deposition parameters. However, the actual deposition situation may deviate from the one in which the BGM is built; such as varied heat dissipation conditions, resulting in morphological changes of deposited beads and geometrical errors in the formed parts. In this paper, a novel control mechanism for enhancing the fabrication accuracy of WAAM based on fuzzy-logic inference is proposed.

It considers the geometrical errors measured on already deposited layers and deposition context to adjust deposition parameters of beads in the subsequent layer, forming an interlayer closed-loop control (ICLC) mechanism. This paper not only presents the theoretical fundamentals of the ICLC mechanism but also reports the technical details about utilizing this mechanism to control the forming height of multi-layer multi-bead (MLMB) components.

A fuzzy-logic inference machine was applied as the core component for calculating speed change of bead deposition based on height error and previously applied change. In terms of validation, the effectiveness of the proposed control mechanism and the implemented controller was investigated through both simulative studies and real-life experiments. The fabricated cuboid blocks showed good accuracy in height with a maximum error of 0.20 mm. The experimental results implied that the proposed ICLC approach facilitates deposition continuity of WAAM, and thus enables process automation for robotic manufacturing.

IV. CONCLUSION

In summary, our work here provides two contributions to the literature. First, despite the increasing application of fuzzy logic to manufacturing challenges during the past two decades, a review of the uses of fuzzy logic suggests that the depth and breadth of applications of fuzzy logic can be enhanced. Second, we demonstrate the strength of fuzzy logic in tackling specialized problems in manufacturing by developing an easy to use and flexible algorithm for product mix issues, an area of lesser focus in applying fuzzy logic.

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