DEM KNOWLEDGE PAPER

College of Electrical & Mechanical Engineering (CoEME),
National University of Sciences & Technology (NUST), Islamabad

DEPARTMENT OF ENGINEERING MANAGEMENT

Dem-1/Oct/2023

RISK IDENTIFICATION AND MITIGATION IN MANUFACTURING INDUSTRY: CURRENT STATUS AND FUTURE DIRECTIONS

Afshan Naseem & Muhammad Awais Akbar

1. BACKGROUND

With the industrial growth, manufacturing organizations are required to get ready to satisfy the demand of their customers with reliable, affordable, and quality products and services. Over the years, many manufacturing companies are continuously defamed by the recalls of their defective parts/ components which have been delivered to the customers (Lucky & Takim, 2015), like an un-wanted event when Honda Atlas Cars Pakistan limited launched 10th generation Civic (both 1.8 i-VTEC and 1.5 VTEC Turbo variants) car in 2016 with issues such as engine knocking (Turbo only), radiator leakage, steering rack jamming, AC compressor/ evaporator malfunctioning, and warning lights troubleshooting on meter, which brought the company where they had to re-launch the model after rectifying the defects/ errors and satisfying the customers by asking them to claim the under warranty parts, if the car model is already purchased. Automating the manufacturing process includes intelligent machines and the more equipped workforce to make better decisions in real time activities/ scenarios (Zhong, 2017). Similarly, Figure 1 shows the summary regarding total number of cases of requests for each hybrid car brand (Ugay, Kaminskiy, & Permyakova, 2019).

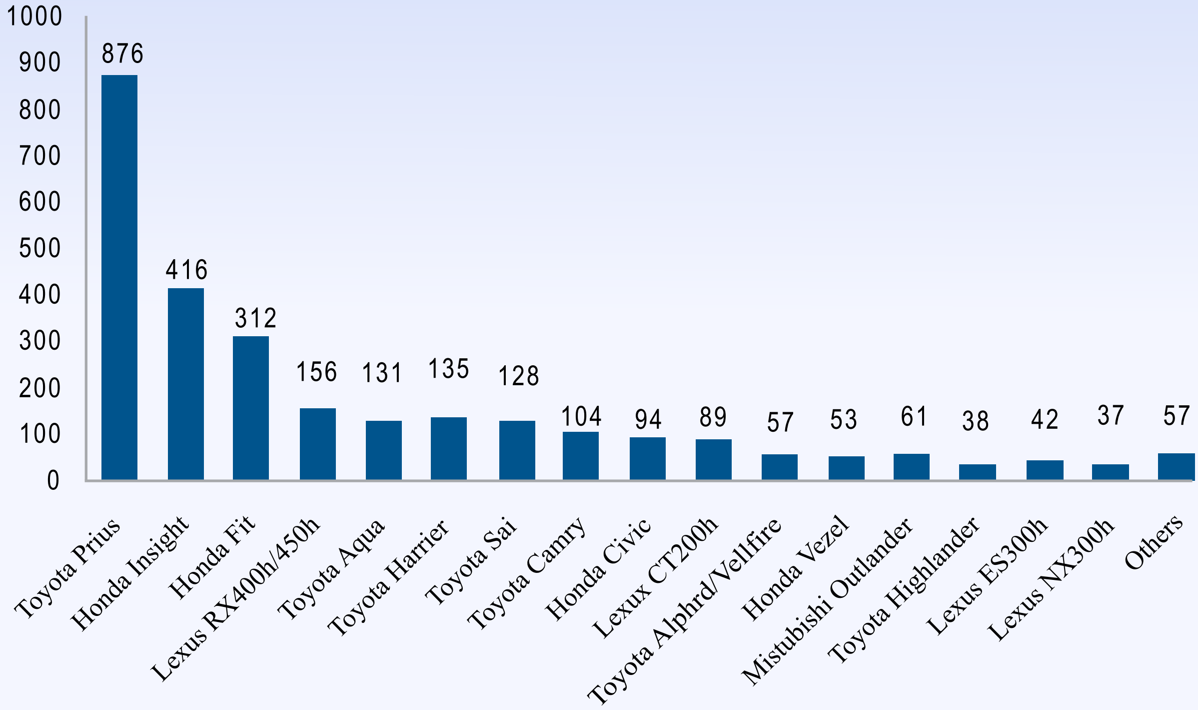


Figure 1: No. of hybrid cars' recalls (Ugay, Kaminskiy, & Permyakova, 2019)

The main failures (malfunctions) of these hybrid cars are categorized into six groups as shown in Figure 2, in accordance with the main damage. The highest peak is faults with 852 electrical equipment and electronics, out of which 569 are premature loss of HVB capacity, 102 are the inverter circuit faults, 59 are explosion of HVB elements, 55 are oxidation of the battery contacts, 34 are short circuit (water condensation in the battery case), 17 are ECU inverter chip de-soldering, and 16 are HVB control unit. The second highest peak of faults is with 675 hybrid systems, out of which 506 were inverter cooling pump, 76 are power module (IGBT transistor failure), 32 are freezing of HS antifreeze, 31 are DC/DC converter failure, 14 are short circuit of inverter high-tension part and 16 others.

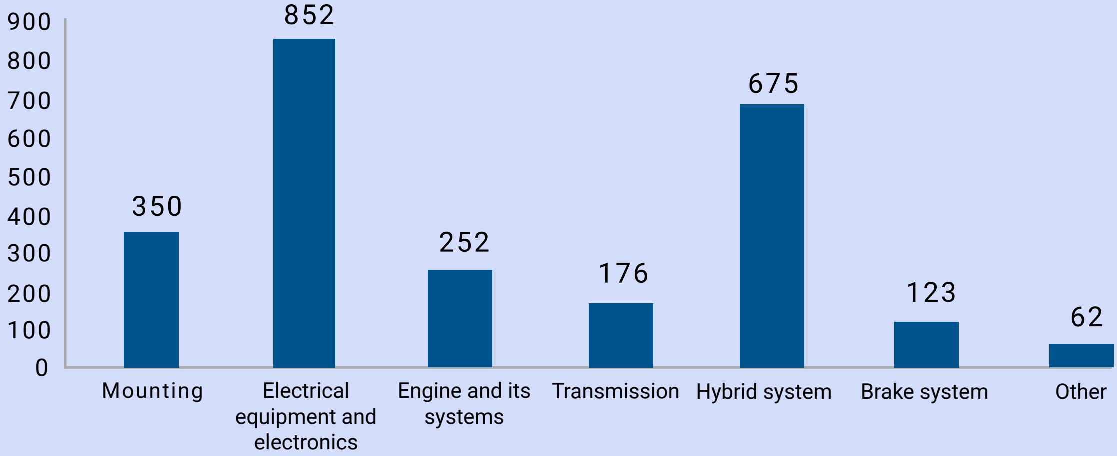


Figure 2: Main types of faults of hybrid vehicles (Ugay, Kaminskiy, & Permyakova, 2019)

2. INTRODUCTION

The growth of developing economies heavily depends upon the automation of manufacturing processes and well-trained workforce help to overcome the problems in manufacturing processes (Misiurek & Misiurek, 2017). Now, the organizations are adopting intelligent machines to prevent such defects/ errors so to continuously improve their profits and competitiveness by optimizing the resources (Kuriqi, Pinheiro, Sordo-Ward, & Garrote, 2019).
Risk Management in mechanical & manufacturing engineering aims to minimize time/ costs and maximize the quality. It is a holistic approach to ensure quality by reducing defects through predictive, preventive, and corrective techniques, using mostly data-driven technologies, which guarantee that no defective product leaves the production floor. Currently, fourth industrial revolution referred as Industry 4.0, utilizes data from the past as well as the present to help in data driven decision making process (Psarommatis & Kiritsis, 2022). Globally, there are different techniques such as six sigma (6σ), Lean Manufacturing (LM), Total Quality Management (TQM), zero-defect-manufacturing (ZDM) use data to assess and improve the quality in a manufacturing setup.

ISO 31000 is an international standard which defines risk as "the effect of uncertainty on objectives" (ISO, 2018). Project Management Body of Knowledge (PMBOK) defines risk management as "a series of efforts undertaken to increase the probability and/ or impact of positive risks and to decrease the probability and/ or impact of negative risks" (PMI, 2018). Manufacturing organizations are initiating steps in the digitalization of their working mechanism to manage, control and improve their setups, instead of existing tools such like Enterprise Resource Planning (ERP) (Magnanini, Colledani, & Caputo, 2020).

Risk identification depends on early detection of the manufacturing risks which helps to save extra time and cost which is required to produce a component within specifications with allowed tolerances, whereas risk assessment/ analysis is the evaluation of risk occurrence including an estimation of its probability and impact on the manufacturing process, providing in-depth information about risks' antecedents and key vulnerabilities of risks (El-Baz & Ruel, 2021).

Risk mitigation depends upon database/ data management based upon history of the manufacturing practices, to take appropriate measures before any disruption occurs (El-Baz & Ruel, 2021). Once the quality event analysis has calculated the defect information, rectification activity is triggered by suggesting all possible ways to mitigate the errors. It determines the rectification/ repairing plan by calculating the operational time for every task per machine/ equipment with respect to required material and the operator. For multiple defects/ errors, the mitigation system works in series by prioritizing the risks (Psarommatis & Kiritsis, 2022).

Toyota Production System (TPS) is a first ever system on the globe as a safety related company focusing the quality and volume of their manufactured cars (Monden, 2012). On the other hand, Toyota has faced serious quality related problems in their manufacturing line, cost the consumers' lives (Southworth, 2010). This led to massive recalls coming as a trial to the renowned "The Toyota Way" production philosophy (Joshi, 2013).

Manufacturing errors have the potential to tragic accidents costing human lives like happened in San Diego, California in 2009 in which the Saylor's family (Mark Saylor himself, his wife, his daughter, and brother-in-law) lost their lives, when they were travelling in a Lexus car which careened out of control at ~160 km/hour and plunged into a ravine after massive collision with an oncoming car. This unwanted event brought Toyota to the public glare with issues of "defects" leading to utmost recalls. Toyota brought its production error upon its own head, also assuming that manufactured cars with "defective" brakes and accelerators or any other recall is a common phenomenon in a production facility. Therefore, there is an ultimate need to develop a system to identify and mitigate defects/ errors in any manufacturing industry to prevent those severe threats impacting human lives. So, this knowledge brief discusses relevant studies which can be adopted to propose some remedy to minimize such risks.

3. SUSTAINABLE PRODUCT DEVELOPMENT IN MANUFACTURING INDUSTRY

Manufacturing companies increasingly recognize the importance to enhance capabilities for sustainability integration and implementation in product/ process development for their survival (to gain lion's share) in the industry by meeting demands of the customers/ consumers. Sustainable product development means that "a strategic economic, social and environmental perspective is integrated and implemented into the early phases of the product innovation process, including life-cycle thinking" as shown for nested interdependence system in Figure 3 (Schultea & Knuts, 2022).

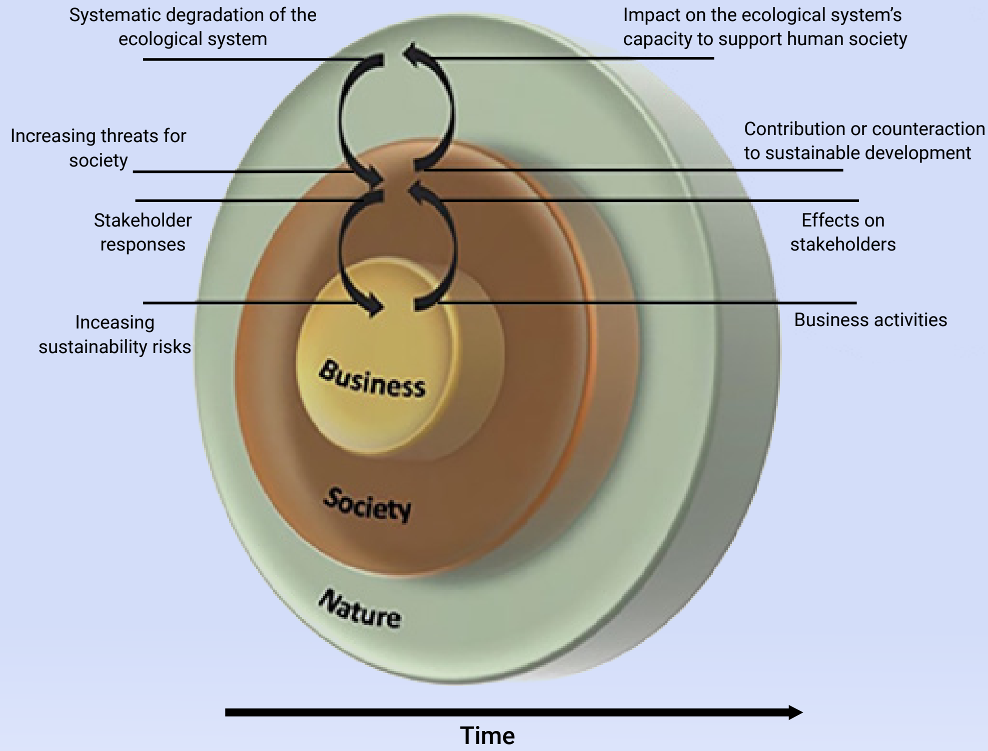
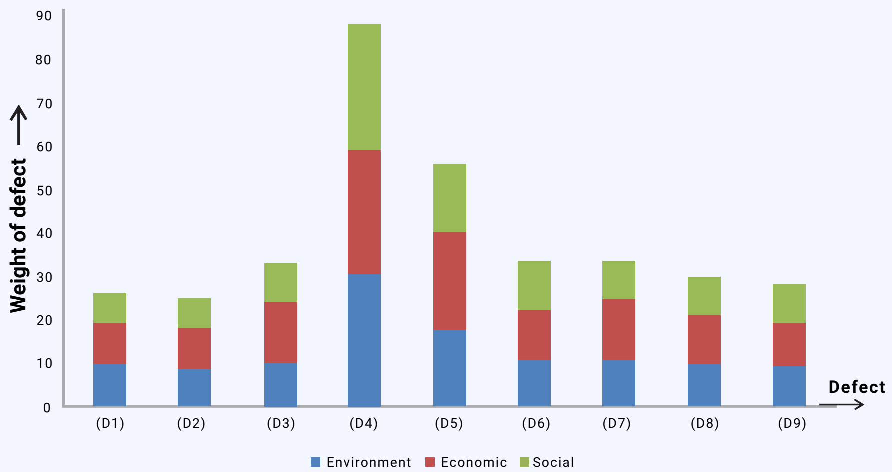


Figure 3: Nested interdependent system view of sustainability and its implications for risk management (Schultea & Knuts, 2022)

Goyal (2019) implemented 6σ in a manufacturing process at his workstation for zero defects. One day, whole lot of his products was rejected just because of a single defect occurred in very early stage of production line. He pondered over it and realised that single defect appearing insignificant may have the potential to ruin whole product despite robust quality management system (QMS). So, he conducted a study in which the respondents (from Quality department, Insulation engineering department, Product engineering department, Insulation production department, Stress grading production department, Assembly area, and Production planning department) were asked to assign weight (based on their experience, knowledge, expertise, and company objectives) on the Likert scale of 1-5 for each defect on each dimension (environmental, economic, and social) of sustainability. The steep rise in defects per million opportunities (DPMO) or fall in σ-level indicates presence of highly impactful defect i.e., D4 as evident in Figure 4. So, to lessen overall defect rate in his production setup, he started rectifying defects (starting from D4, D5, D7, D6, D3 and so on) as per the priority directed by the survey (Goyal, Agrawal, & Saha, 2019).



Defects ID	Description
D1	Rough finishing of conducting paint
D2	Wrong overlapping of coatings with each other
D3	Surface dents
D4	Disconnection of stress grading area with grounding
D5	Wrong length of coatings
D6	Low resistivity on surface
D7	High resistivity on surface
D8	Trapping of humidity in between coating layers
D9	Insufficient mixing of components in paint

Figure 4: Defects with weight for each dimension of sustainability in a stress grading process in a manufacturing industry (Goyal, Agrawal, & Saha, 2019)

4. CASE STUDIES

4.1 Automotive Leaf Spring Manufacturing in Sheikhupura, Pakistan

A study is conducted in manufacturing industry where they manufacture leaf springs for original equipment manufacturers (OEMs) like Toyota, Pak Suzuki, Master Motors, and Sazgar. Severity, occurrence, detectability, and risk priority number (RPN) are used to evaluate failure mode and effect analysis (FMEA). Severity guides about the volume of the potential failure in such a way that if severity is marked as '1' it means no effect whereas score '10' means a serious risk for manufacturing process. Occurrence guides about the probability of the failure occurrence such as if it is marked as '1' it means that it is likely very rare event, and if scored '10' it means failure is almost inevitable and risk has potential to harm the system. And detectability guides the controls which can have failure detection such as if it is marked as '1' it means system will certainly detect the failure/ error and scored '10' means system does not have the ability to predict/ detect the failure/ error (Aized, et al., 2020). RPN can be found by multiplying severity, occurrence, and detectability (Down, et al., 1988) as:

$$RPN = SxOxD$$

In this case study, FMEA is applied on product or process to reduce failures, to increase quality, reliability, and safety to gain customers satisfaction in a much better way. It is implemented for 42 potential failures/ errors in concept, designing, and manufacturing process of a leaf spring. For more better results, hybrid approach combining FMEA with process capability analysis or grey relational analysis (GRA) can also be used (Aized, et al., 2020). As shown in Table 1, this study only identified and prioritized associated risks in a system.

Table 1: RPN (Aized, et al., 2020)

RPN = Severity × Occurrence × Detection		
S. No.	**RPN**	**Response**
1	401-1000	Top priority (Requirement of immediate measures)
2	250 - 400	High priority (Implement rectification measures quickly)
3	101 - 249	Moderate priority (Monitor failure mode occurrence and implement measures accordingly)
4	11 -100	Low priority (Implement measures when time and resources permit)
5	1 - 10	Accept as a remaining risk (No further measures are required)

4.2 Home Appliances Manufacturing – Dawlance Pakistan

This study demonstrates the practical use of the 6σ: Define, Measure, Analyse, Improve and Control (DMAIC) cycle where the potential problem was the external leakage defect in the refrigerators during its production stage. Due to the increasing rate of defects from the calculation of service call rate (SCR) as shown in Figure 5, company wanted to reduce the manufacturing defects to sustain its competitive position in a red-ocean market in the country. The objective to implement DMAIC approach was to identify the root causes of weak brazing and to guide the action plan to control. Based on the historical data, the external leakage of gas in refrigerator was having highest defect rate of 26% in refrigerator model no. 9166 (Wassan, et al., 2022).

Based on the database as shown in Figure 5, there were 709 external leakage defects in a year, which means ~2.8 defects per working day. After the implementation of mitigation actions during the improve and control phases of the DMAIC cycle, the defects rate per day reduced by 0.84 defects per working day, which cumulatively makes ~30% defects (i.e., 210 defects) reduction per annum. Lower number of the defects of external leakage in production at brazing stations on production floor reduced customer's complaints, ultimately improved the SCR (Wassan, et al., 2022). This case study not only identified and prioritized risks, but also mitigated the associated risk in the manufacturing system.

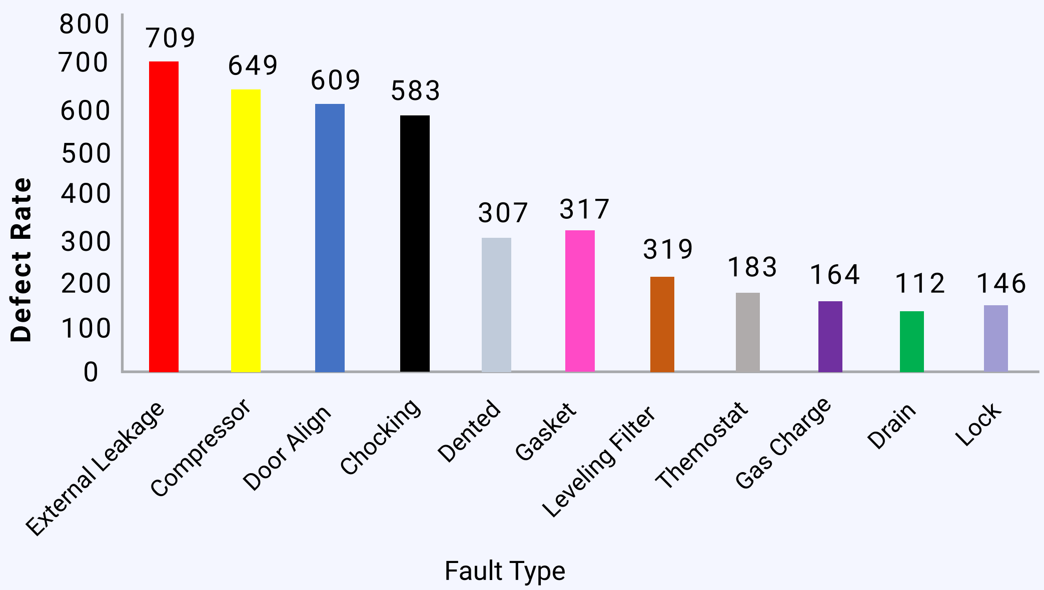


Figure 5: Bar Chart of the Fault Group (Wassan, et al., 2022)

5. AUTOMATED MANUFACTURING THROUGH HYBRID-DECISION SUPPORT SYSTEM (DSS)

In a Swedish research study for a hybrid-DSS for automating decision making to detect and its rectification in the event of defects in the era of ZDM, wherein the with-DSS simulation, manufacturing errors were detected and the DSS was activated for 1,321 times in a specific period. In the without-DSS simulation, 1,309 defects were recognized. For both the with-DSS and without-DSS scenarios, the categorized decisions are demonstrated in Figure 6, in which the proposed DSS required 6.1458 seconds on average to recognize an error/ defect whereas the manual decision-making time on average was 1756.38 seconds.

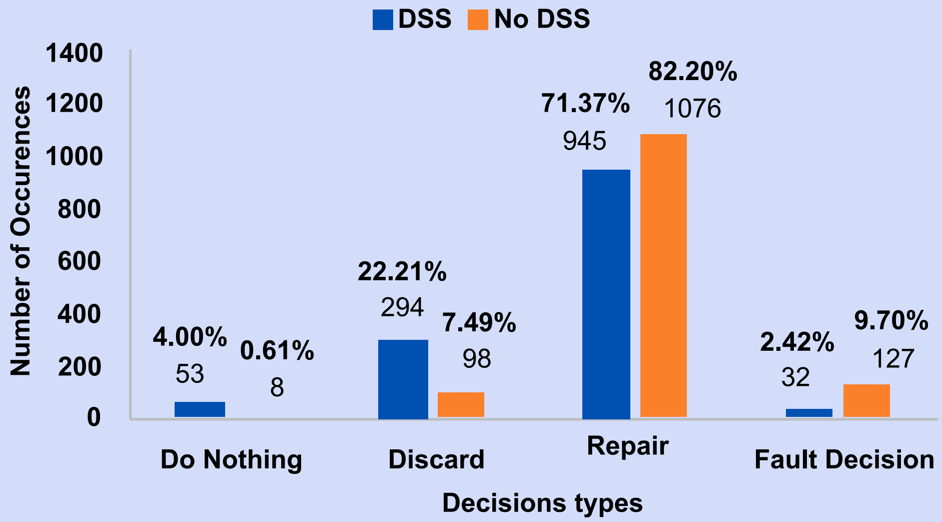


Figure 6: Decisions break down for with-DSS and without-DSS situations (Psarommatis & Kiritsis, 2022)

The goal of the DSS is to improve production performance in terms of the iron triangle (time, cost, and quality). The developed DSS managed to improve overall performance by 7.21% (Psarommatis & Kiritsis, 2022). Therefore, for every manufacturing company, it is highly recommended to develop a DSS or Manufacturing Execution System (MES) with the ability to not only identify risks, but also prioritize risks along with the mitigation actions to enhance the quality (lowering time and cost).

6. CONCLUSION AND FUTURE DIRECTIONS

Industrialization in the world has brought rapid manufacturing of all kinds of equipment, household items, spares, automobiles, and machinery etc. And with the rapid growth to produce completely or semi-knocked down (CKD/ SKD) products, many errors/ defects have been observed during manufacturing, creating many risks for the manufacturing industry for growth. There are many reputed manufacturing firms which have been affected in past due to potential risks existing in their system. Activities in the process industry contain several hazards associated from harmful chemicals to mechanical risks, which are addressed as originating from the product, process, human and working environment, and the associated risks are evaluated, prioritized, and mitigated as well. To cater these risks, risk identification and its mitigation is the utmost challenge for the manufacturing industry to utilize iron triangle concept in such a way that to minimize their production time and cost to ultimately maximize their production quality. There are many techniques to enhance the manufacturing quality through DSS or other automated manufacturing systems approaching towards 6σ, LM, TQM, or ZDM.

A combination of model-driven and data-driven decision-making support systems has become a trend in the research published in recent years. The quality of model-based decision-making support strongly depends on data, its completeness, validity, consistency, and timely availability. The hybrid DSS provide machine operators with all information they need for the better decision-making process in real time operations. In the existing literature, already developed system for these kinds of solutions are process-oriented ones, some are developed to identify risks, some for their mitigations, and very few for both risk identification and mitigation. Therefore, all existed models have limitations in such a way that a knowledge gap exists to develop a system for identification and mitigation risks simultaneously involved in manufacturing industry. Industry 4.0 give boost to data analytics applications to reach new horizons of decision-making support to manage severe disruptions in manufacturing sector. The combination of simulation (for verification of the model) and optimisation (to reach globally optimum solution), with data analytics constitute a digital twin: a novel data-driven framework to manage potential risks, followed by its sensitivity analysis (to check model's robustness) provides a complete solution to risk management in manufacturing industry. It also guides to constantly improve its framework (based upon internal data by the operator) as per guidance by reinforcement-learning and continuous-quality-improvement with the help of manufacturing data gathered for knowledge/ data base in a system.

BIBLIOGRAPHY

Aized, T., Ahmad, M., Jamal, M. H., Mahmood, A., Rehman, S. U., & Srai, J. S. (2020). Automotive leaf spring design and manufacturing process improvement using failure mode and effects analysis (FMEA). ***International Journal of Engineering Business Management.***

Down, M., Brozowski, L., Younis, H., Benedict, D., Feghali, J., Schubert, M., Haughery, W. (1988). Potential Failure Mode and Effect Analysis (FMEA). ***Chrysler Corporation, Ford Motor Company, General Motors Corporation***.

El-Baz, J., & Ruel, S. . (2021). n supply chain risk management practices mitigate the disruption impacts on supply chains' resilience and robustness? Evidence from an empirical survey in a COVID-19 outbreak era. ***International Journal of Production Economics,*** 233: 107972.

Goyal, A., Agrawal, R., & Saha, C. (2019). Quality management for sustainable manufacturing: Moving from number to impact of defects. ***Journal of Cleaner Production,*** 241: 118348.

ISO. (2018). Risk Management: ISO 31000. ISO.
Joshi, A. (2013). Product recalls: A failure of Toyota production system. ***ASM'S International E-Journal of on-going Research in Management and IT.***

Kuriqi, A., Pinheiro, A., Sordo-Ward, A., & Garrote, L. (2019). Flow regime aspects in determining environmental flows and maximising energy production at run- of-river hydropower plants. ***Appl Energy.***

Lucky, B. O., & Takim, S. (2015). Manufacturing defects in the automobile industry, a case study of the remote causes and effects of Toyota's transmission malfunctions in cars. ***International Journal of Engineering and Applied Sciences (IJEAS),*** Volume-2, Issue-8.

Magnanini, M. C., Colledani, M., & Caputo, D. (2020). Reference architecture for the industrial implementation of Zero-Defect Manufacturing Strategies. ***53rd CIRP Conference on Manufacturing Systems (pp. 646-651). Elsevier.***

Misiurek, K., & Misiurek, B. (2017). Methodology of improving occupational safety in the construction industry on the basis of the TWI program,". ***Safety Science***, Vol. 92, pp. 225–231.

Monden, Y. (2012). ***Toyota Production System: An Integrated Approach to Just-In- Time.*** 4th edn. New York: Taylor and Francis.

PMI. (2018). ***A guide to the Project Management Body of Knowledge (PMBOK guide)*** (6th Edition, Ed.). ***Project Management Institute***.
Psarommatis, F., & Kiritsis, D. (2022). A hybrid DSS for automating decision making in the event of defects in the era of ZDM. ***Journal of Industrial Information Integration.***

Schultea, J., & Knuts, S. (2022). Sustainability impact and effects analysis - A risk management tool for sustainable product development. ***Sustainable Production and Consumption,*** 737-751.

Southworth, T. (2010). Printing Lean: ***The 800-Pound-Gorilla. Label and Narrow Web.***

Ugay, S. M., Kaminskiy, N. S., & Permyakova, O. G. (2019). Study of Faults in Hybrid Vehicles. International science and technology conference "Earth science". ***IOP Conf. Series: Earth and Environmental Science***.

Wassan, R. K., Hulio, Z. H., Gopang, M. A., Sarwar, U., Akbar, A., & Kaka, S. (2022). Practical Application of Six Sigma Methodology to Reduce Defects in a Pakistani Manufacturing Company. ***Journal of Applied Engineering Science,*** 20(2022)2, 961, 552-561.
Zhong, R. Y. (2017). Intelligent Manufacturing in the Context of Industry 4.0: A Review. ***Engineering,*** 3(5), 616–630.

DEPARTMENT BRIEF

Engineering Management (EM) is a specialized field of management concerned with the engineering sector. By its very nature, EM is a multi-disciplinary subject, so the scope of topics available for specialization is broad within engineering and management, as well as some topics that blend both fields. Through the combination of business and management acumen with technical expertise, EM degrees are expected to play a key role in preparing the next generation of managers for public (including defense) and private sectors. Department of Engineering Management (DEM) was established in Colllege of Electrical and Mechanical Engineering (CoEME) under National University of Science and Technology (NUST) in 2006 for Masters and Doctoral programs. Total of 327 scholars have completed their Masters' degree and 16 scholars have completed their PhD degrees from the department so far.

EDITOR
DR. YASIR AHMAD

DESIGNED BY
MUHAMMAD RIZWAN