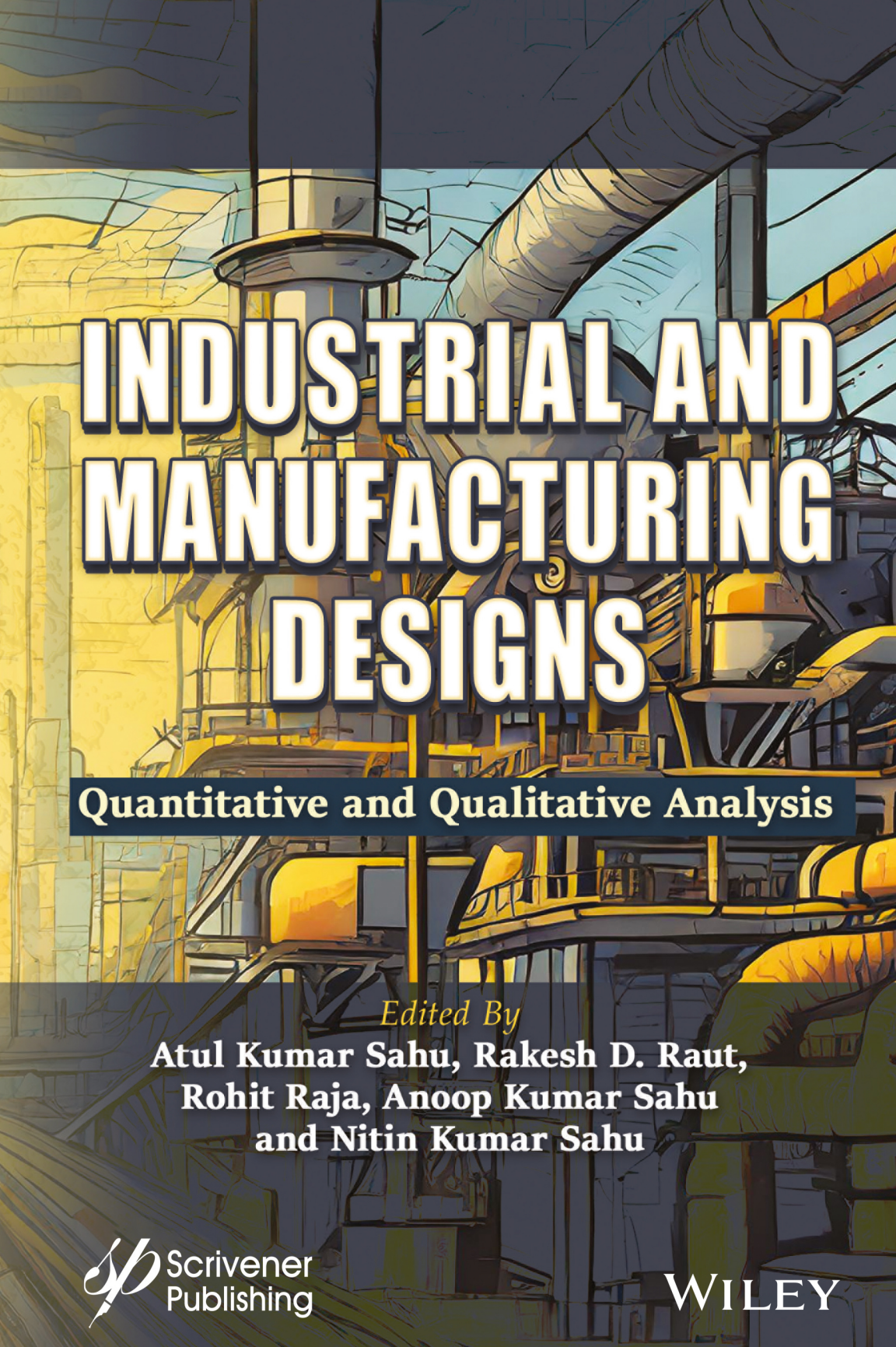
INDUSTRIAL AND MANUFACTURING DESIGNS
Quantitative and Qualitative Analysis
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Phillip Carmical (pcarmical@scrivenerpublishing.com)

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Edited by

Atul Kumar Sahu

Department of Industrial and Production Engineering, SOSE&T, Guru Ghasidas Central University, Bilaspur, India

Rakesh D. Raut

Department of Operations and Supply Chain Management, Indian Institute of Management, Mumbai, India

Rohit Raja

Department of Information Technology, SOSE&T, Guru Ghasidas Central University, Bilaspur, India

Anoop Kumar Sahu

Department of Mechanical Engineering, SOSE&T, Guru Ghasidas Central University, Bilaspur, India

and

Nitin Kumar Sahu

Department of Industrial and Production Engineering, SOSE&T, Guru Ghasidas Central University, Bilaspur, India

WILEY

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Contents

Preface

The main aim of this book is to disseminate creative thinking to leading academics, scientists, researchers, and research scholars to enhance their experiences and work on qualitative and quantitative analysis for reinforcing engineering designs related to industrial and manufacturing boundaries. The book provides a platform for researchers, practitioners, and educators to learn about and understand many dimensions, recent innovations, trends, and concerns, as well as the practical challenges encountered and solutions adopted in the fields of industrial and manufacturing engineering.

The present book:

- Explains of qualitative and quantitative research for exploiting system characteristics and attaining system efficiency, as well as what decision-making tools are available for attaining sustainability in industrial fields;
- Discusses the utility of qualitative and quantitative models and analytical frameworks for enduring sustainability and the exploration of new ideas, critical theories, and methods related to qualitative and quantitative research;
- Disseminates industrial and manufacturing knowledge and allied boundaries, and demonstrates of case studies and sustainable ways to retain excellence in industrial and manufacturing domains based on qualitative and quantitative analysis;
- Presents critical aspects related to lean manufacturing and lean management tools, and demonstrates pure research and practical solutions to manufacturing problems;
- Offers theoretical content and demonstrations of manufacturing applications, as well as critical thinking and methodological support for optimizing resources and consumption;
- Reviews the development of supply chain network designs based on qualitative and quantitative aspects.

By focusing on the development of the theoretical foundations, applications of diverse tools, and support techniques for evaluating the design and operation of systems in manufacturing industries and businesses, this book meets the demands of scenarios, stakeholders, and markets under the sphere of manufacturing management. It discusses the utility of integration of critical components and systems engineering for effective systems design. The book presents research directions and can be used as a tool to understand in-depth possible ways related to the management of industrial and manufacturing activities, processes, actions, benchmarks, and so on. The new ideas, theories, and methods related to qualitative and quantitative research that are presented herein will improve manufacturing knowledge linked to the manufacturing process.

This book is intended for students in the areas of industrial engineering, manufacturing engineering, supply chain management, qualitative analysis, quantitative analysis, and to practitioners working under allied boundaries of industrial and manufacturing practices. Additionally, individuals with interdisciplinary knowledge of statistical quality control, production planning, and control, performance measurement, mathematical modeling, decision-making approaches, and framework development with the generation of performance index will find value in this book. Application developers, business professionals, and researchers who seek information on industrial and manufacturing dimensions can utilize this book, as well.

We are deeply grateful to everyone who helped with this book and greatly appreciate the dedicated support and valuable assistance rendered by Martin Scrivener and the Scrivener Publishing team during its publication.

Dr. Atul Kumar Sahu
Dr. Rakesh D. Raut
Dr. Rohit Raja
Dr. Anoop Kumar Sahu
Dr. Nitin Kumar Sahu

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Demonstrating the Role of Qualitative and Quantitative Information in Industrial and Manufacturing Designs

Nitin Kumar Sahu[1]*, Sanju Kumar Nishad[1], Atul Kumar Sahu[1] and Anoop Kumar Sahu[2]

[1]Department of Industrial and Production Engineering, Guru Ghasidas Central Vishwavidyalaya, Bilaspur, India
[2]Department of Mechanical Engineering, Guru Ghasidas Central Vishwavidyalaya, Bilaspur, India

Abstract

In the present chapter, the role of qualitative and quantitative (Q&Q) information for evaluating industrial and manufacturing designs is presented, where a group of application cases to reveal the importance of Q&Q analysis is demonstrated. Here, application cases related with the selection of solar panels, evaluation of automatic/robotic welding system, selection of smart alloys, identification of logistic service provider, evaluation of machine tool, and election of industrial robot are presented to represent the utility and importance of aforesaid information in evaluation. Various cases under aforesaid aspects are presented to report the importance of Q&Q information. The chapter will help readers in understanding the worth and values of Q&Q information in analysis. The chapter describes the developed multi-criteria decision-making (MCDM) methods that can be used for reinforcing industrial and manufacturing practices based on the utilization of Q&Q information. The present chapter will assist in creating a learning atmosphere and developing capabilities in effectively evaluating decisions that involve multiple criteria and factors. Additionally, the chapters will assist learners in prioritizing and ranking different alternatives based on their alignment with specific criteria and objectives. The understanding of Q&Q information to quantify and incorporate subjective preferences into decision-making and the ability to analyze complex

**Corresponding author*: nitin83sahu@gmail.com

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data related to multiple criteria for making better decisions with a large amount of information can be attained through the present chapter. The chapter will help in understanding how Q&Q criteria values impact the final decision outcomes and can help in enhancing your ability to make robust choices. Familiarization with different MCDM methods to choose the most suitable approach for different decision contexts can be attained through this chapter. The chapter will help in handling decision complexity related toward analyzing and addressing complex decision challenges, especially in scenarios where there are conflicting objectives or numerous alternatives. Moreover, the chapter will assist in modeling a structured framework for strategic planning to enable learners to align your decisions with long-term objectives based on Q&Q information.

***Keywords*:** Qualitative and quantitative, decision-making, industrial and manufacturing designs, multi-criteria decision-making (MCDM), evaluation

1.1 Introduction

In the present scenario, manufacturers around the world are moving toward manufacturing their product in sustainable manner. Moreover, sustainable practices are highly demandable to be inculcated in the manufacturing activities for streamlining manufacturing operations. In addition, various regulatory norms, regulation policies, acts, etc., are imposed on manufacturing organizations to produce their products via proper utilization of resources and minimal waste generation for respecting environmental structure. Manufacturing is the wide expression and is typically used to illustrate machining of materials to attain desired workpiece. It comprises various activities like metal forming, customized operations, cutting, grinding, unconventional machining, foundry practices, and sheet metal working. Nowadays, modern manufacturing facilities are incorporating computer software platforms in manufacturing information systems to produce desired shapes with ease and effectiveness. The same are incorporating to facilitate the manufacturing managers and judgment makers to appraise and assess the conditions of the production process and assist in understanding "how the production system can be optimized and enhanced". Today, there is a need for manufacturing information systems with real-time data and feedback support with miscellaneous information related with the process, machines, inputs, personnel, and many more. Similarly, it will help in monitoring the tendency of faults, operational accuracy, precision, fruitful utility of production time, worker time, right repairs, and quality concerns, as well as in increasing safety and in

decreasing business threats throughout the operation, which demands the exploitation of Q&Q factors.

The available data with the manufacturing systems are needed to evaluate for observing effectiveness, organizing inventory, and goods; taking action against consumer demands; developing financial execution; and delivering essential and judicious information to banks, associates, sponsors, and key stakeholders. Thus, it is needed to capture more data from the manufacturing system characteristics that can be supported by qualitative and quantitative (Q&Q) measures. The more data will be collected, the more accuracy will be attained by the system. It is found that categorization of the data can be done by considering two aspects, i.e., primary data or secondary data based on the source of collection. Primary data are directly gathered from the main source, i.e., experiments, monitoring, inspection, surveys, and questionnaires. Secondary data are the data that were gathered by other indirect sources, i.e., government organization records, research foundation reports, previous investigations, manuscripts, journals, newspapers, reporters, publications, data records, and catalogs. Moreover, one can say that data are the spirit and essence to monitor and evaluate the system, and it only provides information when it is in the structured form. The Q&Q data play a significant role in evaluating and understanding the behavior of any systems. The authentic, accurate, and trustworthy data help in revealing and enhancing the performance of your intrusion and support the decision-making (DM) process.

It is ascertained that the utilization of the combination of Q&Q data can improve the evaluation and DM process by assuring that the restrictions of one type of data are influenced by the potency of another data. Qualitative data collection incorporates intangible factors like knowledge, judgment, inspiration, behaviors, and explanations of activity, occasion, or a particular significant situation. Hence, in further expressions, one can say that a qualitative approach uses public chronicle as well as their knowledge and outlooks to evaluate transformation; is more open, informal, and unstructured; and supplies more freedom toward the data collection. The frequent qualitative data gathering means and equipments are unrestricted surveys, unrestricted interviews, society interviews/gathering, centred assembly discussions, case learning, examination/surveillance, techno science, visual procedures, literature, document review, spoken history, etc. The quantitative methodology is more prearranged, uncomplicated, clear-cut, and always prescribed and employed to derive responses for multiple locations assessment that engage huge group of respondents. Typical quantitative data collection approaches comprise experiments, collecting appropriate facts from management information systems, administering

surveys with closed-ended queries, as well as monitoring and recording clear described events. It is easier to collect and analyze quantitative data, and there are fewer chances of biasness in the interpretation of results. Results of the quantitative data are mathematical, goal-oriented, decisive, and, to the point, easier to conclude and helpful for building comparative analysis. The frequent quantitative data gathering approaches are structured closed-ended interview, investigations and opinion polls, investigational research, correlation study, comparative analysis, statistical data examination, laboratory testing, etc.

The process of data collection for Q&Q methods has its own advantages. Moreover, modern industrial and manufacturing practices are complex as well as intricate and cannot be disentangled through one method alone. Therefore, integration of Q&Q methods is too important to enable researchers to gain a more holistic understanding of the intervention. Mixed methods introduce precision in the monitoring and assessment. Accordingly, it is advocated to develop Q&Q methods toward focusing on the deficiencies and restrictions of each method in order to provide more logical, consistent, and constructive conclusions that augment the overall confidence in the soundness of the assessment outcomes. Accordingly, in the present chapter, the role of Q&Q information for evaluating industrial and manufacturing designs is presented, where a group of application cases to reveal the importance of Q&Q is presented. Various cases are presented to report the importance of Q&Q information. The chapter will help readers in understanding the worth and values of Q&Q information in analysis.

1.2 Literature Review

Today, it is needed to explore new opportunities in industrial and manufacturing designs for crucially satisfying the dynamic needs of world, which requires mental and physical abilities to make vital DM. The same is needed to explore different solutions for handling the manufacturing situation and to receive elevated outcomes. A dignified decision in manufacturing is needed to purposely select a best answer from a set of substitutes to attain organizational or managerial objectives. Many researchers are continuously analyzing and evaluating their engineering domain in order to increase their business benefit. A successful DM plays a decisive responsibility in constructing the long period associations and augments profitability. Moreover, DM for reinforcing industrial and manufacturing designs needs engineering principles, technological tools, and information for processing and requires a specialized form of management

skills, which is sometimes called as engineering management to determine the right choice and integrated DM structure. Various researchers have applied diverse multi-criteria decision-making (MCDM) techniques for tackling various manufacturing applications, where Hernández *et al.* [1] have applied analytic hierarchy process (AHP) and analytic network process (ANP) techniques under qualitative study to determine the influence of reverse logistics (RL) practices in automotive corporate performance of Brazilian automotive sector. Huang *et al.* [2] have proposed the concept of key performance indicator (KPI) under qualitative information to evaluate RL practices based on the collection of studies and expert interviews and used ANP to obtain relative weights of KPI to form the final performance evaluation model. Sahu *et al.* [3] have explored the TOPSIS (Technique for Ordering Preference by Similarity to Ideal Solution) technique in conjunction with the trapezoidal fuzzy number set to evaluate computer numerical control (CNC) machine tool under qualitative information. Here, the authors have determine the preference orders considering the decreasing value of the "collective index" and identified that the elevated value of "collective index" under qualitative premises is crucial and replicates the elevated extent of performance by the machine tool, which, in turn, assisted in enabling advanced manufacturing environment toward the organization and helped the organization toward attaining sustainability and competitiveness worldwide. Sheu [4] utilized quantitative information to develop a multi-objective optimization approach using a linear multi-objective optimization model to optimize the operations of nuclear power generation and the accompanying RL process. A cluster approach based on ratio analysis, reference point analysis, and full multiplication form under type-2 fuzzy sets to handle the right selection of industrial robot (IR) for manufacturing based on multiple qualitative measures is found built for DM under Q&Q information [5]. Here, the authors have utilized qualitative and quantitative approach considering 59-dimensional measures to select IRs for manufacturing firms operations. Additionally, many approaches like Simple Additive Weighting (SAW) and TOPSIS methodology under quantitative information for examining turning operations in CNC lathe machine to evaluate the impact of manufacturing process parameters, i.e., cutting speed, feed, and depth of cut, are found [6]. Sahu *et al.* [7] presented a replacement model combined with straight-line depreciation method to determine the economic life of the productive machines and equipments under quantitative medium. The proposed methodology enables the organization to impart efficiency to operators, machines, equipment, parts, etc. Their approach determined the replacement period of machines considering quantitative information under uneconomic circumstances,

breakdowns, sudden failures, and gradual deterioration with the passage of time. Thus, one can say that the collection of Q&Q information n is crucial.

Moreover, the MCDM techniques have also been applied with Q&Q, which is generally a process of selecting the right choice from available alternatives or ranking of alternatives under Q&Q conflicting criteria. Under MCDM, a performance appraisement platform under chain of mixed green-lean-agile (G-L-A) logistic activities is found, and fuzzy performance index model is developed with qualitative medium to estimate the overall performance of organization [8]. Here, the authors have fruitfully used centroid method with fuzzy number set considering Q&Q information for understanding ill and strong G-L-A metrics. Guo *et al.* [9] fabricated a novel integrated computational approach under manufacturing to operate a mild steel plate workpiece for optimizing weld bead geometry in MIG (metal inert gas) welding. Here, the authors have investigated optimum setting of MIG welding process parameters to attain high tensile strength with quality characteristics, i.e., bead width, reinforcement, penetration, and dilution. It is found that a zone of various prominent methods, i.e., Simple Additive Weighting (SAW) method [10], compromise programming [11], AHP method [12], Technique for Ordering Preference by Similarity to Ideal Solution (TOPSIS) method [13], Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method [14], DEMATEL [15], Elimination and Choice Expressing Reality (ELECTRE) method [16], Complex Proportional Assessment (COPRAS) method [17], VIKOR (Visekriterijumska optimizacijai Kompromisno Resenje in Serbian, means Multicriteria Optimization and Compromise Solution) method [18], Additive Ratio Assessment (ARAS) method [19], Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) method [20], and ANP [21], is developed by the researchers for attaining quality facts and outputs by the processes, whose implication depends on the attainment of Q&Q information. It is found that various academic researchers, decision-makers, and experts have applied these methods in supply chain management (SCM), logistics management, supplier selection, machine tool selection, and on various other fields. Additionally, researchers has also stated concentrating on the application of these methods on the production and manufacturing arena, which will facilitates in the DM process. The same is demonstrated in this chapter, where application cases related with the selection of solar panels (SPs), evaluation of automatic/robotic welding system (WS), selection of smart alloys, identification of logistic service provider, evaluation of machine tool, and election of IR are presented to represent the utility of Q&Q information

in evaluation. Various cases under aforesaid aspects are presented to report the importance of Q&Q information.

It is admired that the multi-level MCDM algorithmic technique for appraising the economic values of the material handling system under qualitative and quantitative information is applied to build robust selection decision [22]. Here, the authors have evaluated the performance of logistic activities in the realm of industrial management. He *et al.* [23] developed the decision support framework (DSF) under qualitative premises to evaluate the case of polar robot evaluation, where the authors measured the overall economic worth of advanced manufacturing machines under quantitative information and reported the effectiveness of Q&Q information in making effective decision. The implication of four MCDM techniques under Q&Q is reported for making effective decision-making (DM) framework. It is found significant to utilize qualitative information to explore DM capabilities and to establish a link between digital transformation and firms and supply chains' capabilities [24]. Here, the authors have suggested to utilize Q&Q information under STRATH (strategies and threats)–based modeling to reinforce capabilities of supply chains (SCs). The authors have used qualitative measure to define SWOT (strength, weakness, opportunity, and threats) architectures for elevating the fertility in SCM.

Lee *et al.* [25] developed dynamic location and allocation models under Q&Q medium to handle the issues related with RL network configurations and various associated factors, where an extended two stage stochastic programming is used to develop RL network design. Here, elevated outcomes in terms of sustainable indicators are demonstrated to underline the utility of the developed stochastic model. A DSF based on qualitative factors is found significant to select robust supplier under the boundaries of Lean-Agile-Resilient-Green (LARG) practices for developing capabilities of an Indian automotive manufacturing company [26]. A gray set–based scorecard model is found admired to measure the performances of fruit supply bazaars [27]. Here, the advanced hierarchical structural model is constructed on the basis of the chain of Q&Q macro-micro parameters among fruit retailers. Accordingly, one can say that Q&Q information can discharge fruitful results in exploiting system characteristics.

Today, the manufacturing capabilities of large industries require the introduction and adoption of highly automated and computer-controlled strategies to satisfy the ever-changing market requirement [28]. The same is needed to economically operate manufacturing systems efficiently and to receive elevated pay back and to demonstrate the success of these manufacturing systems and machines, which depends on selection of a range of decisive parameters in the form of Q&Q factors [29]. The right judgment

depends on the right selection of Q&Q information. Moreover, it is also needed to develop efficient techniques to analyze these Q&Q information, where many researchers have started focusing and taking initiatives to develop tools, critical ways, and techniques under industrial and manufacturing fields in diverse engineering areas such as welding, SCM, agile manufacturing, production planning, and quality control. The same is required in industrial and manufacturing domains for attaining sustainable industrial manufacturing practices. Sahu *et al.* [30] have developed one DM tool based on quantitative experimental information for machining nickel-based super alloy for optimizing output responses, i.e., power consumption, machining time, and material removal rate. Here, the authors have integrated two DM techniques with Taguchi technique and found imperative to develop tools, critical ways, and techniques under manufacturing sphere to receive eminence outputs. A decision support system (DSS) under qualitative factors to extract customer's preferences is found fruitful to prevent replacement of mobiles and e-waste generation for supporting green issues [31]. Here, qualitative factors are analyzed by exploring generalized interval-valued trapezoidal fuzzy numbers with a degree of similarity approach to attain sustainability. Arya *et al.* [32] have examined manufacturing characteristics, i.e., tensile strength, bead width, bead height, penetration, and Heat Affected Zone (HAZ) in MIG welding to ascertain the synergy among inputs such as wire diameter, welding current, arc voltage, welding speed, and gas flow rate by using Signal to Noise (S/N) ratio and ANOVA analysis to find significant input parameter, where the role of quantitative information is appraised by the authors. Additionally, Mukhraiya *et al.* [33] have examined the torsional rigidity of weld in MIG welding in respect to ascertain the synergy among inputs such as wire feed rate, welding voltage, and welding current by using S/N ratio and ANOVA analysis to find significant input parameter. Moreover, Sivasakthivel *et al.* [34] have examined tensile strength of weld in MIG welding in respect to ascertain the synergy among inputs such as speed, current, and voltage by using S/N ratio and ANOVA analysis to find significant input parameter. Thus, one can say that quantitative information is desired to obtain the precise understanding of optimum process parameters. The study conducted by Perumal *et al.* [35] utilized quantitative information to examine the effect of pulse on duration, wire tension, and wire feed on metal removal rate and surface roughness (SR) for machining. Here, grey relational approach (GRA) is used there to analyze the collected quantitative information with the intension to receive significant facts and to review the process parameters for sustainable outcomes. Nas *et al.* [36] utilized quantitative information to machine AISI D2 cold work tool steel

and thrust to utilize GRA to categorize the influence of machining parameters on output parameters, where it is found that machining parameters, i.e., amperage and pulse on time, significantly influence the SR and hole diameter in electric discharge machining (EDM). Considering quantitative information, Abed *et al.* [37] proposed a sequential discharge model for EDM machining, and Guo *et al.* [38] also utilized quantitative information to machine Ti-6Al-4V work material considering compressed air, kerosene, and water-based emulsion as a dielectric medium to investigate the material removal process in machining, where results are experimentally validated and a need is found to develop appropriate mathematical modeling to minimize the extent of errors from machining parameters and to receive elevated characteristics in output materials. Accordingly, it is investigated that the extraction of quantitative information is needed to receive the right understanding of optimum process parameters.

Manufacturing is the keen driver for the economy and for its sustainability in the present scenario; manufacturing is every day facing new challenges for the never-ending upcoming demands. Moreover, due to various constraints, i.e., design complexity, material hardness, cost, production efficiency, government laws, and environmental responsibility, it is also not possible to manufacture the components in cost effective manner by traditional manufacturing methods, and, hence, manufacturing organizations are evolving, changing, and shifting from conventional manufacturing methods to modern manufacturing practices and trying to becoming cleaner, leaner, and greener for gaining competitive advantage, but that demands DSF, which relies on the Q&Q information. Today, the whole manufacturing world is looking for the possibilities for becoming progressive manufacturing companies with the perspective of future growth. Now, industrial and manufacturing practices are shifting to take advantage of the better operational efficiencies, better utilization of resources, minimal wastage, waste reduction, effective and environmental production, etc., for the overall societal development. Accordingly, it is imperative to extract quality information from the ocean of Q&Q characteristics to receive progression and success.

1.3 Decision-Making (DM) and Framework

The DM is always crucial and involves a procedure that is systematically used for evaluating options, taking factors into account, and chooses the best from available alternatives. DM process collects and gathers the information for defined objectives and performs brainstorming and assessment

for the available options against the each selected criteria. Afterward, selection of the best option among the available options is carried out with respect to the goals and criteria. Thereafter, the selected alternatives are implemented into the action and continuous monitoring and tracking of the implemented outcomes has to be assessed in order to recognize the impact of the chosen alternative on organizational performance. A schematic representation of the DM procedure is depicted in Figure 1.1. It is important to note that the intricacy of the DM procedure can vary on the basis of the nature of the decision, the amount of available information, the risk involved, and the number of people or stakeholders affected by the decision. Additionally, DM can be influenced by cognitive biases, emotions, and external pressures. Developing a structured approach to DM helps to minimize these influences and make more informed choices.

It is highlighted that the MCDM framework is typically composed of several key elements, which are explored by the decision-maker in situations having multiple criteria and alternatives. The complexity of MCDM frameworks can vary, and they can encompass diverse mathematical models and techniques tailored to the precise context and demands of the decision. The selection of a MCDM framework is contingent upon factors like the quantity of alternatives, the number of criteria, data availability, and the inclinations of the decision-makers, where Q&Q information plays a

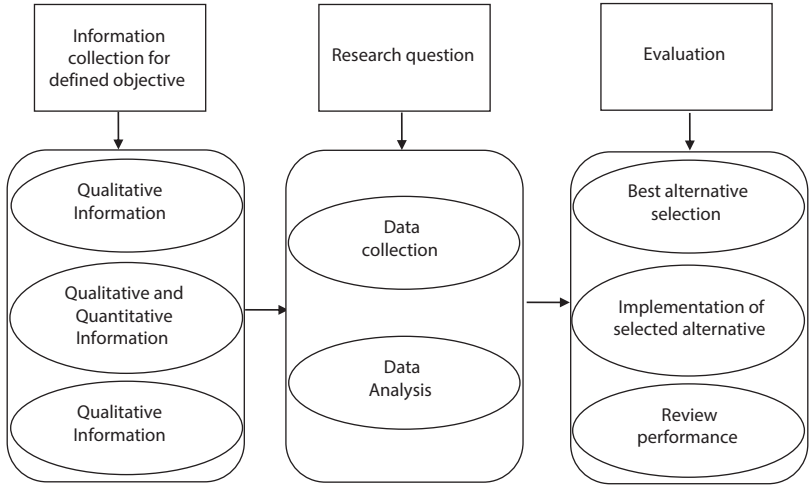

Figure 1.1 Decision-making procedure.