Green and Resilient Supplier Selection Model and Inventory Management under uncertainty for Cement Industry

By

Muhammad Imran

(Registration No: 00000327083)

Thesis Supervisor: **Dr. Afshan Naseem**

Department of Engineering Management

College of Electrical and Mechanical Engineering (CEME)

National University of Sciences and Technology (NUST)

Islamabad, Pakistan

(2024)

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Muhammad Imran Registration No. 00000327083 of MS (Engineering Management) has been vetted by undersigned, found complete in all respects as per NUST Statutes/ Regulations, is free of plagiarism, errors and mistakes and is accepted as partial fulfillment for award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature: ____________________

Name of Supervisor: Dr. Afshan Naseem

Dated: 19 Mar 2024

Signature: ____________________

Name of HOD: Dr. Yasir Ahmad

Dated: 19 Mar 2024

Signature (Dean/Principal): ____________________

Dated: 19 MAR 2024

Annex A to NUST letter No.0972/102/Exam/Thesis-Cert dated: 21 Dec 2016

DEDICATION

Dedicated to all those who read this complete thesis with determined resolve and persistence to provide input for improvement.

ACKNOWLEDGEMENTS

With great appreciation, I would want to thank everyone who helped me finish my master's thesis. First of all, I would like to express my sincere gratitude to my thesis advisor, for her essential advice and steadfast support during this trip. Their knowledge and support have been crucial in forming this work.

I am especially appreciative of the faculty members' insightful comments and helpful critiques, which considerably improved the caliber of this thesis.

I owe my family a debt of gratitude for their unending support, love, and tolerance during the trying times of this project.

I would want to express my gratitude to everyone who helped, no matter how tiny, to finish my thesis.

Muhammad Imran

ABSTRACT

The study explores two sections of supply chain management namely Inventory Management (IM) and Procurement Management (PM). Both have direct on profitability of firms. Profitability of an organization is influenced by Inventory Metrics. Inventory faces many risks that includes the impact of exchange rate fluctuations, high storage costs, obsolescence and poor demand forecasting. The Total Inventory Value is indirectly influenced by good supplier selection as well. The suppliers need to be cost as well time and quality conscious in order to positively impact inventory. In line with growing concern for the environmental impact as well growing global supply chain risks the supplier have to be green and resilient as well. The combination of good supplier materials entering inventory in correct forecasted quantity will lead to lower inventory costs.

First part of the study explores minimization of forecasted total inventory costs under exchange rate fluctuation scenarios. Total Inventory value forecasting is carried out using grey forecasting techniques by obtaining previous secondary historical data of 10 years. Forecasting/Estimation is carried out for next 5 years. GM (1, 1) Markov technique is used to obtain the initial forecast. The error in the forecast is optimized by using Markov Chain technique. The forecasted data is used as an input for inventory cost function with the assumption that all consumed inventory is replenished within the same year and prices of spares remains the same throughout the year. The overall inventory cost function includes the share of purchase cost in local currency and foreign currency as well as impact of insurance, obsolescence and storage costs. The cost function is analyzed by plugging in multiple scenarios of currency fluctuations and percentage share of local versus import spares in buying/replenishment. The forecast accuracy is high as per low MPE which is acceptable for implementation. The novelty of the research lies in adopting the attitude to use complete inventory value instead of demand forecasting for each spare part or raw material. Moreover, in previous studies, neither specific cement plant inventories have been studied in detail nor capacity utilization has been considered to improve forecasting. Impact of this approach on cement plants in Pakistan is discussed along with some recommendations for industrial practitioners. Cement plant management can plan and save accordingly by considering the findings.

The second part of the study explores Green and Resilient Supplier Selection. This evaluation is a considerable strategic solution for minimizing environmental impact, operational costs and continuously improving the resilience and competitive advantage of the supply chain of the organization. Adding green factors and resilience factors to supplier selection process will have a positive impact on manufacturing plant inventories. This research aims to develop a hybrid model for supplier selection while incorporating the environmental performance criteria and resilience requirements by integrating expert opinion. The framework is based on a business quintet of cost, quality, time, resilience, and green score. Cost and time objective functions includes the forecasted (GM (1, 1)-Markov Model) demanded quantities. Quality objective function is built upon fuzzy numbers, in our case triangular. Green and resilience objective functions are grounded on Quality Function Deployment using input from experts by utilizing Delphi Technique. All the objectives are converted to single objective using multi-objective fuzzy weighted goal programming, the relative weight of each is obtained from expert opinion by utilizing Delphi Technique. The originality of the research lies in adopting the method combining green and resilient criterion to use at cement plants that were previously are not well studied.

Keywords: Supplier Selection, Green supplier, Resilient Supplier, Inventory forecasting, Inventory Cost, Fuzzy Goal Programming, GM (1, 1)-Markov

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

SCM – Supply Chain Management

IM – Inventory Management

PM – Purchase Management

QFD – Quality Function Deployment

GM (1, 1) – Grey Forecasting, grey prediction model with incomplete structural information, single variable single order

MCMD – Multi Criterion Decision Making

CPEC - China-Pakistan Economic Corridor

PSDP - Public Sector Development Program

GSS – Green Supplier Selection

RSS – Resilient Supplier Selection

INS – Insurance

STO - Storage

OBS – Obsolescence

CHAPTER 1 INTRODUCTION

1.1.Background of the research/Purpose of the study

External pressure by Government Authorities in regards to environmental impact has started to compel Cement Plants to restructure and rethink their business activities for minimum possible impact on the environment. Among the main avenues of improvement is Supply Chain Operations, which is, least explored in the Cement Industry.

A hybrid approach is required that considers the overall Inventory as well supplier selection procedure to meet the challenges. Supplier choice, inventory forecasting and management are important considerations in Supply Chain Management. Separately these have been studied in great detail by researchers. In this study, we present a two-phase unified approach to the supplier selection and inventory planning problem. In the first phase, suppliers are tiered based on selected criteria comprising cost, quality, and time along with green and resilient factors. In the subsequent phase, total inventory cost equation/model is generated to simulate the impact of good supplier selection on overall inventory value. Next year inventory is forecasted under exchange rate fluctuations in order to meet the economic objectives of supply chain operation.

The first stage is development of Inventory Cost function that will include the demand factor considering the previous years' trend for forecasting. Individual spare or raw material demand as well as whole inventory value may be forecasted. Last ten years total inventory value is taken into account to forecast next 5 years inventory using Grey-Markov forecasting technique. All the relevant cost related to inventory are considered under changing exchange rates that impact the procurement process. The developed cost function is simulated under multiple scenarios of different currencies and different percentage of imported or local spares.

The second stage, Supplier assortment and assessment is a considerable tactical resolution for minimizing operational costs and continuously improving the competitive advantage of the organizations. Adding Green factors and Resilience to supplier selection for raw materials or spares will have a positive impact on Cement Plant Inventories in terms of indirect contribution to positive environmental impact. This research aims to develop supplier selection by combining the environmental performance criteria and resilience requirements along with traditional econometric factors. The selection is based on cost, quality, time, resilience and green score. Expert opinion is incorporated to study sub criterions for green and resilience. QFD technique is used to compute the weights of several green and resilient sub criterions. Expert opinion is also incorporated to rank the criterions in order of importance and assign a weightage to each criteria objective function. Fuzzy goal programming is selected to formulate and solve the single objective function.

The result is a procedure for Cement Industry experts for predicting Inventory and supplier performance based on a 3-5 year look ahead. The model is tested as a numerical case study by assessing errors and satisfaction levels. There is room for gaining significant advantage in terms of reduction in overall inventory costs.

For practitioners to effectively adopt the model it is important to visualize the overall economic advantage while gaining advantage of green and resilient supply chain in the long run.

1.2.Industry setting

There are more than 22 units operating in Pakistan with many more planned due to demand associated with projects related to Public Sector Development Program (PSDP), private housing societies growth and works related to China–Pakistan Economic Corridor (CPEC). These projects have huge demand for Cement in coming years. Statistics from APCMA shows that cement dispatches have been showing increasing trend since the mid-2010s. The rising development is mainly due to local sales. The sector will continue to grow in coming years. Pakistan is in the process of urbanization and Cement/construction sector growth will be continuous with positive trend.

Selecting green and resilient suppliers is crucial for the cement industry in Pakistan as it contributes to environmental sustainability and resilience. Green suppliers help reduce the industry's carbon footprint by providing eco-friendly raw materials and adopting sustainable practices, aligning with global environmental goals. Developing good relations with resilient suppliers will ensure a stable and reliable supply chain, minimizing disruptions caused by market-related disruption events or other unforeseen challenges, which is vital for the consistent production of cement. By prioritizing green and resilient supplier selection, the Pakistani cement industry can not only enhance its environmental performance but also fortify its resilience against the impacts of global changes and foster long-term sustainability. The changing market and customer demand will force plant management to improve reliability and reduce costs. One of the major components of these costs is the raw materials and spares that form major part of inventory. Available data shows inventories worth around 250 million USD in 2022 are kept by top 5 cement producing groups.

For maintaining the desired Inventory for Cement Plant operation, domain experts of cement plants manually set minimum and maximum stock levels same as used in Health Care Sector (Rushton et. al., 2023). This puts too much reliance on opinions of domain experts. The data driven time series approach may benefit the process by setting a benchmark for comparison and will aid in future decision making. The cost function will help procurement and planning departments to plan their respective process to attain favorable rates while order processing. With resilient supplier selection and development, the Supply Chain operation will be strengthened.

1.3.Research Rationale

The total inventory cost of Cement Plants has not been studied under exchange rate fluctuations while considering insurance, obsolescence and storage costs. Green and resilient supplier selection criterions included along with cost, quality and time criterions need to be studied to achieve a better supplier selection approach. It will be effective to utilize both overall Inventory cost minimization and Green/Resilient supplier selection to meet strategic objectives in challenging economic times.

1.4.Research Problem

There is a need to study total inventory cost of cement plants under exchange rate fluctuations and no specific study could be found which has incorporated the green and resilient supplier selection criterions in supplier selection approach in a comprehensive manner. Moreover, ss it is observed that cement industry has remained an untapped domain, devoid of significant research, the application of an integrated approach in the cement industry and the commencement of research within cement industry at large is required.

1.5.Problem Statement

Increasing trend to reduce environmental impact and possibility of global disruptions in Supply Chains combined with government policy pressures is compelling Cement Plant Management to come up with strategic solutions. A delicate balance between economic and sustainability factors needs to be maintained while being risk averse. These competing objectives need to be clearly understood to boost supply chain performance. With absence of effective supplier selection process and inventory management, integrating conflicting requirements may make the Organization prone to multiple risks like higher costs, fall in product quality, suboptimal plant operations, late deliveries, failure to meet project deadlines along with rising inventory values.

1.6.Thesis Structure

Chapter 1 is introduction and background that has already been covered in previous section. Cement Sector of Pakistan is covered in detail along with research rationale and questions.

Chapter 2 explores the literature meticulously examines two pivotal components within the domain of Supply Chain Management (SCM): Inventory Forecasting and Supplier Selection. Positioned under the Inventory Management and Purchase Management subsections of SCM, respectively, these components represent integral facets of managing and optimizing the flow of goods throughout the supply chain.

Inventory forecasting methods are discussed in detail. The output of which will help in development of Total Inventory Cost function. The function needs to be minimized. Grey Forecasting Technique and modelling of exchange rate fluctuations are explored in detail. Additionally, inventory cost such as storage, insurance and obsolescence is also discussed.

Supplier Selection falls under Purchase Management subsection of Supply Chain Management. Criterions and sub criterions of supplier selection are explored along with popular techniques. Conventional econometric factors like Cost, Time and Quality have been studied in great detail. Green supply chain management is discussed in detail followed by resilient supply chain management. Delphi and Quality Function deployment are explored to incorporate expert opinion into the process of Green and Resilient criterions weight assignment. Fuzzification and defuzzification are discussed followed by their application in Goal Programming to create one Objective Function.

Chapter 3 is Methodology; first part of this chapter contains forecast procedure for one spare followed by total inventory value forecasting. This is to show that all spares individually and spares as a whole may be estimate/forecasted using Gray Markov Method. Procedure to forecast single spare or total inventory value from historical data by utilizing Gray-Markov technique is discussed in detail. Step by step breakdown is given for next 5 years forecast based on last 10 years historical data

Second part of this chapter contains the necessary steps needed to carry out supplier selecting process. The development of individual objective function of cost, quality and time are discussed. In order to develop objective function of Green and Resilience, we need to first explore their sub criterions. The weightage of sub criterions is obtained by Delphi techniques from experts and then analyzed by using Quality Function Deployment. After having all the objective function, we need to combine all to obtain single objective function to optimize it. The relative weight of each is found using Delphi techniques from experts as well. Finally fuzzy goal programming is used to obtain minimum solution to the single objective function.

Chapter 4 and beyond discussed results, conclusion and future directions of research. The implication of the process on cement plant supply chains is discussed along with tips for practitioners. Error analysis is carried to validate the numerical analysis.

CHAPTER 2 LITERATURE REVIEW

2.1. Evaluation of the existing body of knowledge on the topic

Supply Chain Management involves activities such as designing, planning, procurement, inventory management, and execution, manufacturing and final supply of the finished goods through cost-effective transport and storage as per consumer's demands. Supply chain has a crucial role in company productivity. SCM comprises of forecasting, procurement, distribution, production, logistic and inventory (Warren Liao & Chang, 2010). The literature review meticulously examines two pivotal components within the domain of SCM: Inventory Forecasting and Supplier Assessment. Positioned under the Inventory Management and Purchase Management subsections of SCM, respectively, these components represent integral facets of managing and optimizing the flow of goods throughout the supply chain. Supply chain impact on company operation is positive based on following significant competitive advantages, increase in profit up to 15%, reduction of inventory up to 40%; reduction of procurement costs up to 15% as discussed by Akhmatova et al., (2022).

Inventory Management is ordering, storing, consuming and selling inventory. The main aim is to carry out all processes efficiently with least amount of cost incurred. Reducing the total cost of logistics, including inventory holding and ordering cost is possible during replenishment (Mohammaditabar & Ghodsypour, 2016). Inventory management and inbound transportation are the main procurement activities which are closely related to suppliers (Saputro et al., 2019). Inventory conversion period has an inverse relationship with firms‟ profitability (Panigrahi 2013). The inventory conversion period estimates the period that it takes to convert on hand inventory to sales. One may calculate it as inventory divided by average sales or cost of sales and multiply by 365 to understand the inventory conversion into sales exact days. The high conversion duration estimates the delayed cash conversion cycle and money block in inventory. A shorter conversion period, on the other hand, reduces cash conversion cycles and unneeded money blockage and takes into account the average amount invested in the stock. Janjua et al., (2016) concludes that liquidity ratio affects the profitability ratios. Higher the level of inventories kept, lower the rate of returns (Koumanakos, 2008).

Inventory Forecasting is an important area of research for all major manufacturing industries. Inventory is all materials held to utilize in business processes. Inventory management is considered to be one of the most critical components of supply chains and logistics systems

(Khakbaz et al., 2023). Accurate prediction of inventory is necessary for its efficient management and can also help in reducing the risks associated with the inventory.

The simple average, weighted average, Bayesian model averaging (BMA), and meta-learning methods are some of the methods that can be used for forecasting. Other techniques are also available for Stationary demand processes including linear regression, Auto-Regressive, Moving Average and ARMA (1, 1). Simple exponential smoothing methods was developed by Brown (1959), Holt (1957) and Winters (1960). In 1970s, ARIMA models were developed and have been studied extensively by many researchers. These are extensions on work by Box and Jenkins (1970) and later by Box et al. (1994). Some researchers have studied the scale of inventory savings according to the degree of improvement in forecasting accuracy (Ali et al., 2011). Multiple techniques have been used for forecasting with varying accuracy and underlying assumptions. Previous literature shows that Exponential smoothing is the most popular approach used for forecasting, followed by simple moving averages, Croston-like methods (also exponential smoothing-based) and ARIMA (Thanos et al., 2022). Another method of imperfect demand forecasting is based on Advance Demand Information (ADI), involves equipment inspections and yields around 51% saving (Zhu et al., 2020). This method is suitable for forecasting for shorter periods as it relies heavily on inspector experience and judgment. Recently data driven and machine learning methods are gaining popularity for forecasting but these methods have limitation related to complexity and black box approach (difficulty in justifying results). Scholars have used Deep learning and random forest-based ensemble method for forecasting (Punia et al., 2022). In case of availability and usage of transactional data of unique products in inventory, time series models can be utilized. These may include Linear regression, Exponential smoothing, Holt Winters Seasonal Additive, and Holt Winters Seasonal Additive+ damped (Rushton, 2023; Virtanen et al., 2020). Swapnil et al. (2021) in their study stated that initially spare parts need to be classified and then forecasting should be done. A review of demand forecasting techniques carried out for energy supply chain from 2000 to 2020 showed top three methods as Neural network, Metaheuristic algorithms and Grey model (Nia et al., 2021). Grey forecasting has gained significant attention of the researchers worldwide. One of the advantage of grey forecasting is that model can be built using limited samples that can perform better forecasting for short and long-term problems (Chen et al., 2012). Application of grey forecasting ranges from healthcare to energy sector, from long term to short term problems with limited data (Misra et al 2022). The grey forecasting models can be further improved by incorporating multiple techniques such as the Markov Chain error classes (Jia et al., 2020). The grey prediction model requires less historical data, while Markov focuses on the data with strong randomness, and the advantages of both can be used to improve forecasting accuracy (Yao et al., 2023). In the past, scholars have used Grey-Markov forecasting method. Fan (2022) used it for the forecasting of production material, Liu (2022) forecasted individual spare parts for specific equipment in aviation industry using GM (1, 1). Markov and Li (2020) used improved Grey Markov for forecasting of set of spares of specific weapon system.

A gap has been found in literature regarding the application of Grey Markov Method. The method has not been used for forecasting the complete inventory especially in case of cement plant. The current study aims to bridge this gap by considering the complete inventory value as opposed to estimating individual SKUs in the inventory whose count may be significantly high when it comes to large manufacturing plants.

Majority of the cement plant spare part inventories are affected by **currency exchange rate risk**. Recently the entire economy of Pakistan and specifically the manufacturing sector has been adversely affected due to exchange rate fluctuations (Akbar et al., 2021; Ebrahimi.et al., 2021). Research has been carried out considering exchange rate increases from 0.2 to 0.6 (Huet. al. 2021). Exchange rate uncertainty has been studied for different scenarios by the researchers (Hammami et al., 2012; Hammami et al., 2014). It has been studied in the context of price discounts (Zarindast et al., 2017) and order quantity variance (Fateme et al., 2021). Research has also been carried out on the impact of contract parameters on expected profit under uncertain demand and currency exchange rate (Gbemileke et al., 2021).

Another objective of this research work is to measure the cost impact of exchange rate fluctuation, insurance, obsolescence, plant capacity utilization and storage on forecasted cement plant spare part inventories. Developing countries like Pakistan are greatly affected by currency exchange rate risk. Existing research on this particular topic is limited and insufficient to provide a comprehensive understanding of the subject. The aim of this study is twofold; Firstly, we aim to forecast the Spare Parts inventory for one of the Plants for the next 5 years and secondly, we aim at using this forecasted data for our cost function that incorporates varying levels of imported spares that are impacted by the currency exchange rate risk to calculate the overall cost. This cost will include storage, insurance and obsolescence cost.

Table 1 summarizes some of the research that has been done on multiple industries/sectors. The overall literature review provides very little insight into cement plant inventories forecast and management.

Table 1 Sector wise Studies

Techniques	Reference	Error	Industry
Linear regression for forecast accuracy	Rachel et al. (2023)	RMSE	Pharmaceutical
Time series forecasting in production planning	Vithitsoontorn (2022)	RMSE MAE	Dairy products
Time Series for demand forecasting in SC	Falatouri et al. (2022)	MAPE RMSE	Retail
Forecasting consumption of urban people using ANN optimized with backward search algorithm	Zubaidi et al. (2020)	RMSE	Water consumption
Forecast using hybrid wavelet decomposer and the ARDL-SVR ensemble model	Zhao et al. (2023)	RMSE MAPE	Crude Oil
Forecast of humanitarian medical items using Crostons, SBA, SES and Markov methods	Bahman et al. (2022)	MSE	Humanitarian medical Items

Table 2 summarizes some of the research related to the grey system that has been conducted on various industries/sectors. The overall literature review gives very little insight into cement plant inventories forecast and management indicating that this area requires attention of the researchers.

Table 2 Studies based on gray systems

Techniques	Reference	Error	Industry/Sector
Urban electricity consumption based on grey system	Meng (2023)	MAPE	Electricity
Demand forecasting for fashion products	Kritica (2023)	Multiple	Fashion
Adaptive grey model (AGM) forecasting in short-term manufacturing demand	Mishra (2022)	MSE MAPE	Manufacturing
Air passenger flow forecasting with grey prediction	Hu (2023)	RMSE MAPE	Aviation
Gray model for forecasting the quarterly natural gas production in China	Li (2022)	MAE MAPE	Oil and Gas
Prediction models of demand in supply chain	Zougagh (2020)	Multiple	Supply Chain
Novel grey forecasting model for logistic demand	Xu (2024)	APE MAPE	Cold Storage

Supplier Selection is one of significant processes for SCM. Supplier selection is the practice of identifying the right suppliers with right quality products at the right price, quantities who will deliver at right time (Tijo et al., 2023). Purchasing has a strong influence on a company's profitability and the total cost of products (Pazhani et al., 2016). For that reason, making correct decisions about purchasing will reduce production costs, including the inventory cost of a company. However, the purchasing operation is not an easy task since there are many aspects in consideration, namely, the supplier selection, the order cycle frequency, the number of orders assigned to each supplier, and the number of units per order (Monczka et al., 2015). Consequently, when the manufacturer requires distinct materials to produce a single product, the available suppliers, offered items, different prices, lead times, production capacities, shipping costs, etc., must be considered as part of the total cost. These are decision variables that provide an infinite number of possible solutions, even for a single purchasing material (Mendoza et al., 2013). It is noted that, manufacturers spend more than 60% of its total sales on purchased items (Ghodsypour et al., 1998). In addition, their purchases of goods and services constitute up to 70% of product cost (Onut et al., 2009). Therefore, selecting the right supplier significantly reduces purchasing costs, improves competitiveness in the market and enhances end user satisfaction (Liao et al., 2011). The literature on conventional econometric factors of supplier selection is very extensive. Ali M.R. et al., (2023) has summarized 18 articles with 30 criterions including cost, quality and time. Jing Li et al., (2019) have also studied classical economic criterions.

There are several factors upon which supplier may be evaluated. Dickson (1966) has identified 23 different criteria for vendor selection including quality, delivery, performance history, warranties, price, technical capability, and financial position. Siguaw (2004) has further identified a more comprehensive list of 84 supplier evaluation items. Supplier selection criterion has been studied for decades with various factors and objectives. One objective alone cannot make the supply chain efficient and effective given so many factors. The need to consider multi objective solution is necessary. MCDA models consider multiple criteria, both quantitative and qualitative, to make supplier selection decisions. Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and Multi-Attribute Utility Theory (MAUT) are examples of MCDA methods. Various Models have been developed and studied in detail from statistical, linguistic to machine learning. One of the popular methods is VIKOR which was further explored by Oliveira et al., (2023). Machine learning and MARCOS was used by Ahmad et al., (2023). TOPSIS was further explored by Hajiaghaei K.M et al., (2023) to study supplier selection in food industry. Huseyin 2020 integrated goal programming with other methods to study supplier selection. Bartosz et al.,

(2022) carried out assessment of five methods namely TOPSIS, VIKOR, COMET, SPOTIS, and MARCOS. Multiple approaches for supporting sustainable supplier selection have been studied by Schramm et al., (2020) which mentioned AHP and ANP among the most studied. Global trends for Supplier selection are now focused on green and resilient supplier's selection with integration of multiple techniques.

Green supply chain management seeks to reduce the harmful effects of the supply chain's activities on the environment. One of the most critical topics in GSCM is supplier selection since about 70% of the cost of the final product arises from component parts and raw material (Ghodsypour and O'Brien 2001). A recent study carried out by Mirzaee et al., (2023) on Green Supplier has considered non-green measures that affect GSCM. Green design, Green Production, Green management and Green Image were discussed in detail by Fang Zhou et al., (2023). Below factors were discussed by Mirzaee et al., (2023) in detail

- Environmental management system: the suppliers' policies for making the production process environmentally friendly (e.g., the ISO 14001 certificate)
- Pollution production: the amount of pollution created by a manufacturer
- Recyclability: the capability of suppliers in using recycled material in their manufacturing process
- Green product: the ability of suppliers in using green technology as well as environmentally friendly material
- Product toxicity: the level of toxic substance used in suppliers' products

Another 27 factors were studied by Hajiaghaei K.M et al., (2023) when selecting green supplier.

Resilient Supply chain management is the ability to bounce back, adapt to new policies and develop ways of mitigating risk. Due to the unpredictable and changing world, most organizations emphasize resilience to cope with the uncertain business environment (Rajesh, 2017). The advantages of being a resilient supply chain are anticipating and acting on the changes in the market and minimizing the demand risk (Sharma et al., 2020). Resilience has been one of the most researched topics in the supply chain domain since gaining attention in early 2000. Resilience, in the context of a supply chain, deals with the prevention, response and management of risks at multiple stages of supply chain process as discussed by Ponomarov et al., (2009). Jothi et al., (2023) have reviewed recent literature on Supply Chain resilience with focus on the phases such as anticipation phase, resistance phase, and response & recovery phase.

Green design, Green Production, Green management and Green Image were discussed in detail by Fang Zhou et al., (2023). Below factors were discussed by Mirzaee et al., (2023) in detail

- Environmental management system e.g. ISO 14001
- Pollution production is amount of pollution created
- Recyclability is willingness to use recycled material
- Green product is green technology and environmentally friendly material
- Product toxicity is level of toxic substance handled

Another 27 factors were studied by Hajiaghaei K.M et al., (2023) when selecting green supplier for food industry. Shirkouhi S.N. et al., (2023) studied resiliency in supplier selection for pharmaceutical industry. Resiliency factors like Risk awareness (R1), Adaptive capability (R2), Vulnerability (R3) and Responsiveness (R4) were studied. Factors like Agility, Flexibility, Visibility, Collaboration and Information Sharing were discussed by Hosseini et al. (2019b). They explained that Absorptive, Adaptive and Restorative capacities influence the whole supply chain resilience. Mohammad et al. (2018) stated that 4 pillars of resilience need to be considered i.e. robustness, agility, leanness and flexibility. Rajesh and Ravi, (2015) studied 13 resilience factors clubbed under Primary performance factors, Supplier's responsiveness, Supplier's risk reduction, Supplier's technical support and Supplier's sustainability. Below factors were discussed by Goodarzi et al., (2022).

- Visibility is ability to see threats and disorder across the chain.
- Technological Capabilities to adapt technologically to the innovation and technological disorders.
- Flexibility to adapt to changes required in the minimum time and effort, as well as the flexibility in the suppliers, production system, distribution channels, transportation methods and multi-skill staff.
- Agility is responding quickly to the unexpected changes in supplying or demand.
- Vulnerability is having resilient sales and operations plans to identify and responding to the different sources of vulnerability.
- Risk management culture within the company.
- Adaptability to temporary disruptive events and recover to better conditions.

Some of the techniques which are used in green supplier selection are mentioned in Table 3.

Table 3 Studies on Green Supplier Selection

Methodology	Reference
fuzzy TOPSIS	(Cao et al., 2015)
Interval type-2 fuzzy TODIM	(Qin et al., 2017)
VIKORSORT	(Demir et al., 2018)
Fuzzy COPRAS	(Lu et al., 2021)
Q-rung Ortho-pair fuzzy set	(Tian et al., 2020)
EDAS method	(G. Wei et al., 2021)
Fuzzy voting model	(Sharafi et al., 2022)
Pythagorean cubic fuzzy Hama-char aggregation operators	(Abdullah et al., 2022)
Pythagorean Fuzzy TOPSIS	(Hajiaghaei K.M et al., 2023)

Table 4 Studies on Resilient Supplier Selection

Methodology	Reference
Hybrid ANP and TOPSIS	(Shyur and Shih, 2006)
Mixed-integer programming	(Sawik, 2013)
Integrated fuzzy group TOPSIS	(Haldar et al., 2014)
Bi-objective mixed possibilistic model	(Torabi et al., 2015)
Grey relational analysis method	(Rajesh and Ravi, 2015)
Multi-Criteria Decision Analysis (MCDA)	(Mühlbacher et al., 2016)
Analytical Hierarchy Process (AHP)-VIKOR	(Prasad et al., 2016)
Integrated modelling based on AHP, TOPSIS, and QFD methods	(Pramanik et al., 2017)
Interval-valued fuzzy possibilistic statistics	(Foroozesh et al., 2017)
(MCDM) with grey numbers, Grey DEMATEL and Grey Simple Additive Weighting (GSAW)	(Parkouhi et al.,2019)
Integrated model based on DEA and principal components analysis (PCA) methods	(Davoudabadi et al., 2020)
Hybrid MCDM model based on AHP and VIKOR in a fuzzy environment	(Zarei et al., 2021)

Cost and income criteria based fDEA model	(Tsai et al., 2021)
Hybrid approach using Z-number DEA model and Artificial Neural Network	(Nazari et al., 2023)

Supplier selection and expert opinion must go hand in hand to avoid pitfalls in overall goal attainment for specific industries. **Expert opinion** is very important when specific industries must be studied. Data from 12 experts was analyzed by Sonar et al., (2022) to model a strategic tool to select a supplier who considers lean, agile, resilient, green, and sustainable criteria simultaneously to increase supply chain efficiency and effectiveness. Expert selection has been studied by Hallowell and Gambatese, (2010) by providing specific criterions to define an expert. Murry and Hammons, (1995) recommended sample size of 5 to 15 experts to obtain a quality result. Hallowell and Gambatese, (2010) have studied the point system of expert selection. Tushar et al., (2022) used expert opinion of 10 experts (who are graduates with at least 5 years work experience). Ghosh et al., (2022) used expert opinion based on subject knowledge and 7 years professional experience. Bari et al., (2022) used expert opinion base on subject knowledge, graduate, and 10 years of working experience. In this study, a purposive or judgmental sampling method was carried out to select the experts (Belay et al., 2022). Purposive sampling is a non-probabilistic technique where the researcher's judgment is utilized to select the experts for gathering qualitative feedback to achieve the research objective, rather than using random sampling (Cash et al., 2022). Hallowell and Gambatese, (2010) proposed flexible point system for Qualification of Expert Panelists. For the purpose of this paper, we use ranking expert opinions by use of aggregate and normalized fuzzy number as per Imran et al., (2018).

Sharma et al., (2016) applied AHP technique for green supplier selection of Indian Cement Sector using **Delphi approach**. Singh and Modgil, (2020) applied SWARA and WASPAS technique for green supplier selection of Indian Cement Sector using Delphi approach. Delphi method (DM) to filter and rate unneeded factors for Green Supplier Selection according to their relevance (Mabrouk, 2021).

QFD technique is a useful tool for transforming the customer requirements into technical specifications. It is a good tool for organizations that focus on tuning the voice of clients and fulfilling their requirements. QFD method is used to develop HOQ for solving the problem. This technique considers the customer requirements as "What" and the design features or technical specifications as "How". The main body of the house is the correlation matrix of "How" with each of the "What". The ranking between these two can be done using the values of 0, 3, 6, and 9 showing the weak, moderate, and strong relationships respectively. The total of these values in every column is a relative importance rating of each technical specification. This information is valuable for positioning each of the "How" and to choose where to designate the greater part of the assets. The HOQ matrix contains the What, How, the interrelationship matrix between what and how, weights of what, and weights of How. This method has been explained in detail by Tang et al., (2005).

Fuzzification is the process of mapping crisp input $x \in U$ into fuzzy set $A \in U$. This is achieved with three different types of fuzzifier, including singleton fuzzifiers, Gaussian fuzzifiers, and trapezoidal or triangular fuzzifiers. Talon et al., (2017) have studied multiple de-fuzzification methods and compared them. Siddiquee et al., (2024) have an opinion that best method of defuzzification is center of area COA. A standard representation of a Triangular Fuzzy Number (TFN) takes the form (l, m, and u), where l represents the lower limit, m is the most probable value, and u stands for the upper limit. The process of transforming a fuzzy number into distinct real numbers is called defuzzification. **Defuzzification** involves determining the best non fuzzy Performance (BNP) value. There are numerous approaches that can be used to achieve this goal. Among the most popular methods are the Mean-of-Maximum, Center-of-Area, and α-cut Method (Zhao & Govind, 1991). In this study, we use the following definition, for the triplet of a triangle fuzzy number, to compare the performance of two triangular fuzzy numbers. This approach (Chen, 1996) was selected since it is straightforward and does not necessitate the analyst's subjective opinion. The notion of the removal of a fuzzy number serves as the foundation for the approach, which is based on Kaufmann and Gupta's (1988) method to compare fuzzy numbers.

Karimi et al., (2022) have concluded that **Goal Programming** is most trending among Fuzzy multi-objective programming. Kumar et al., (2004) solved 3 fuzzy goals with more effective than the deterministic methods for handling the real situations of supplier selection. Ku et al., (2010) effectively used fuzzy AHP and fuzzy Goal programming to solve supplier selection problem.

Considering all the above discussions regarding Econometric, Green and Resilient factors and techniques used in supplier selection, a procedure/methodology needs to be set up. The methodology should incorporate Delphi and Quality Function Deployment while proposing suitable multi criterion decision making technique to successfully propose a supplier selection model.

2.2. Research Gap

Gray-Markov technique has not been used for overall inventory value forecasting. Overall inventory cost has not been considered under currency fluctuation for Cement Plant Inventory. Green and resilient supplier selection has not been studied for Cement plant supply chains.

2.3. Theoretical framework

Multiple-criteria supplier evaluation and selection framework adapts both qualitative and quantitative approach. The framework integrates 2 qualitative criterions (green and resilience including sub criterions) and 3 quantitative measures (Cost, Quality and Time) as criteria for supplier evaluation and selection. Inventory value forecasting and Cost minimization framework adapts quantitative approach including scenario analysis.

2.4. Research Questions

- What are the relevant criteria and sub-criteria for Supplier Selection?
- What is the weightage of each criterion and their interaction?
- Developing a supplier selection procedure
- How to model exchange rate fluctuations?
- What is impact of exchange rate fluctuation on Inventory cost?
- Developing a Total inventory cost model
- What is the effect of interaction of Total Inventory Cost and Supplier Selection on Cement Plant Supply Chain?

2.5 Research Objectives

- To develop a supplier selection model with appropriate criterion
- To effectively weigh each criterion to include in model
- To effectively forecast complete inventory value
- To model exchange rate fluctuation for inclusion in inventory cost
- To model total inventory cost under exchange rate fluctuation.

CHAPTER 3 METHODOLOGY/MATHEMATICAL MODEL

3.1. Research paradigm

The research is based on Supply Chain Management with focus on Inventory Management by accurate forecasting resulting in lower inventory costs. It also relates to Supply Chain Management section purchase management by efficiently selecting green and resilient supplier. The research is mixed type (Qualitative and Quantitative) with expert selection and questionnaires-based approach to collect data.

3.2. Research Settings

The population is Cement Plant experts with cement plants inventories of Pakistan. The sampling technique is expert selection based on expert criterion of experience and academic qualifications. Data collection technique is via questionnaires.

3.3. Research Methods/Design

Our work begins by collecting historical data on consumption of specific spare or raw material. Once selected and collected. It is fed to the forecast technique i.e. Gray Markov which will give us a reasonably accurate forecast for coming years. Now we want to know the impact on our inventory just based on selected spare or raw material by plugging the values into inventory cost function. Now we move onto making our supply chain green and resilient by ranking and selecting appropriate supplier for said spare or raw material.

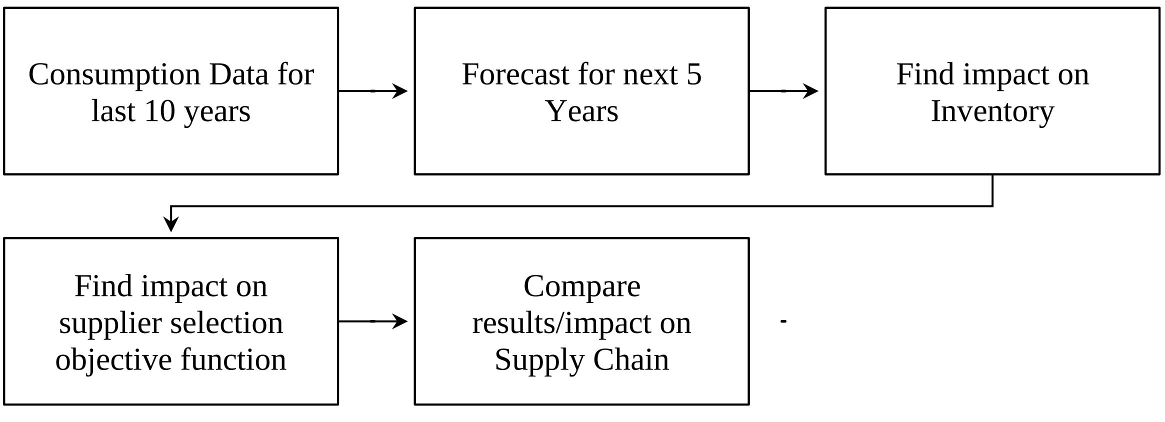

Figure 1 Overall Process

In Figure 1 the overall process that begins with forecasting, goes through inventory cost and ends at supplier selection. In Figure 2 the steps that were carried out for finding the forecasted impact of exchange rate fluctuations, insurance, obsolescence, plant capacity utilization and storage costs for Cement Plants.

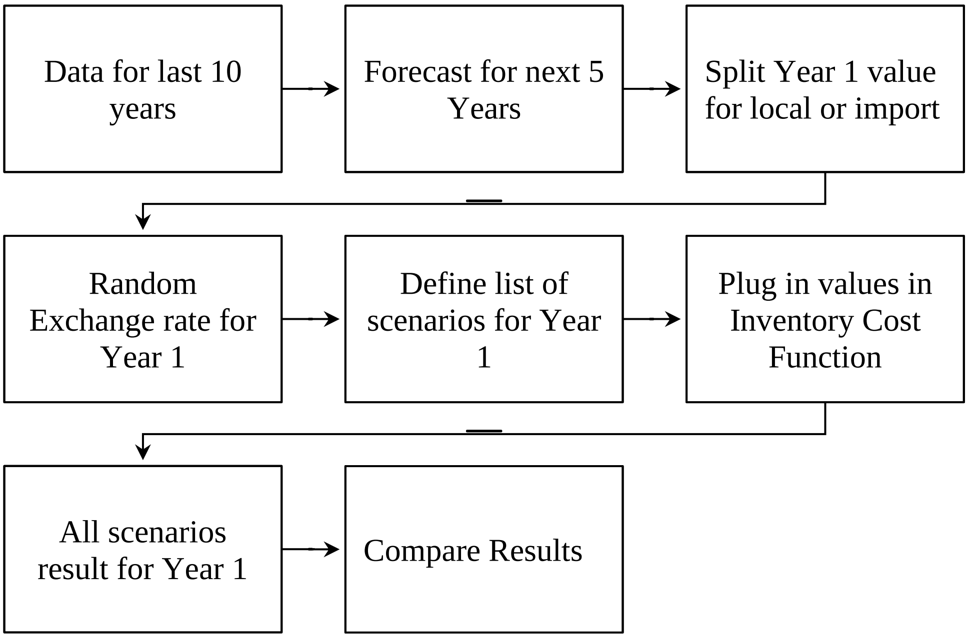

Figure 2 Phase One: Forecasting and Inventory Cost

In Figure 3, the steps are shown that were carried out for Green and Resilient Supplier selection for Cement Plants

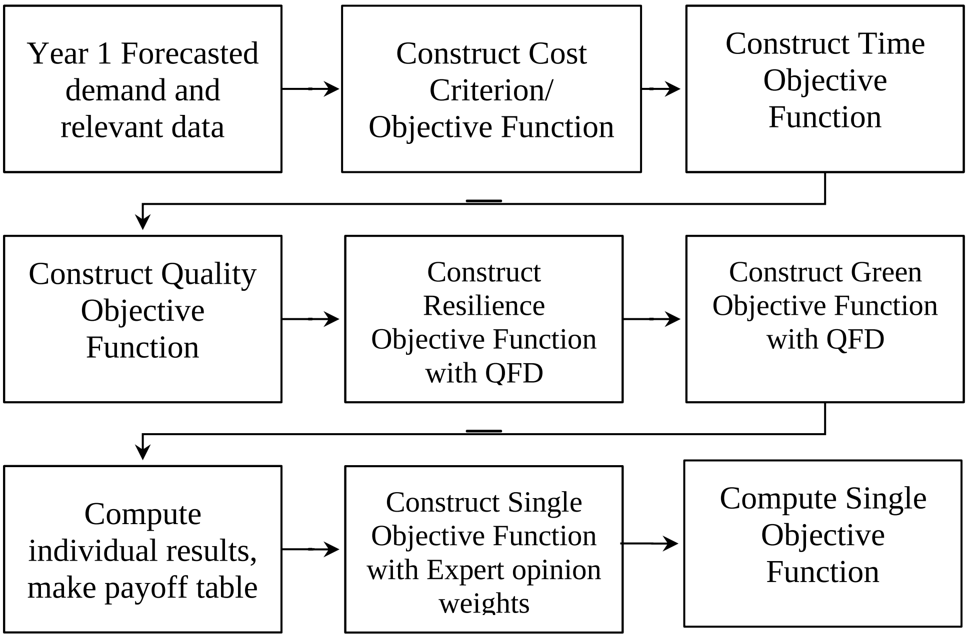

Figure 3 Phase Two: Supplier Selection

Figure 4 shows the overall model with all above step combined. This is further elaboration on Figure 1.

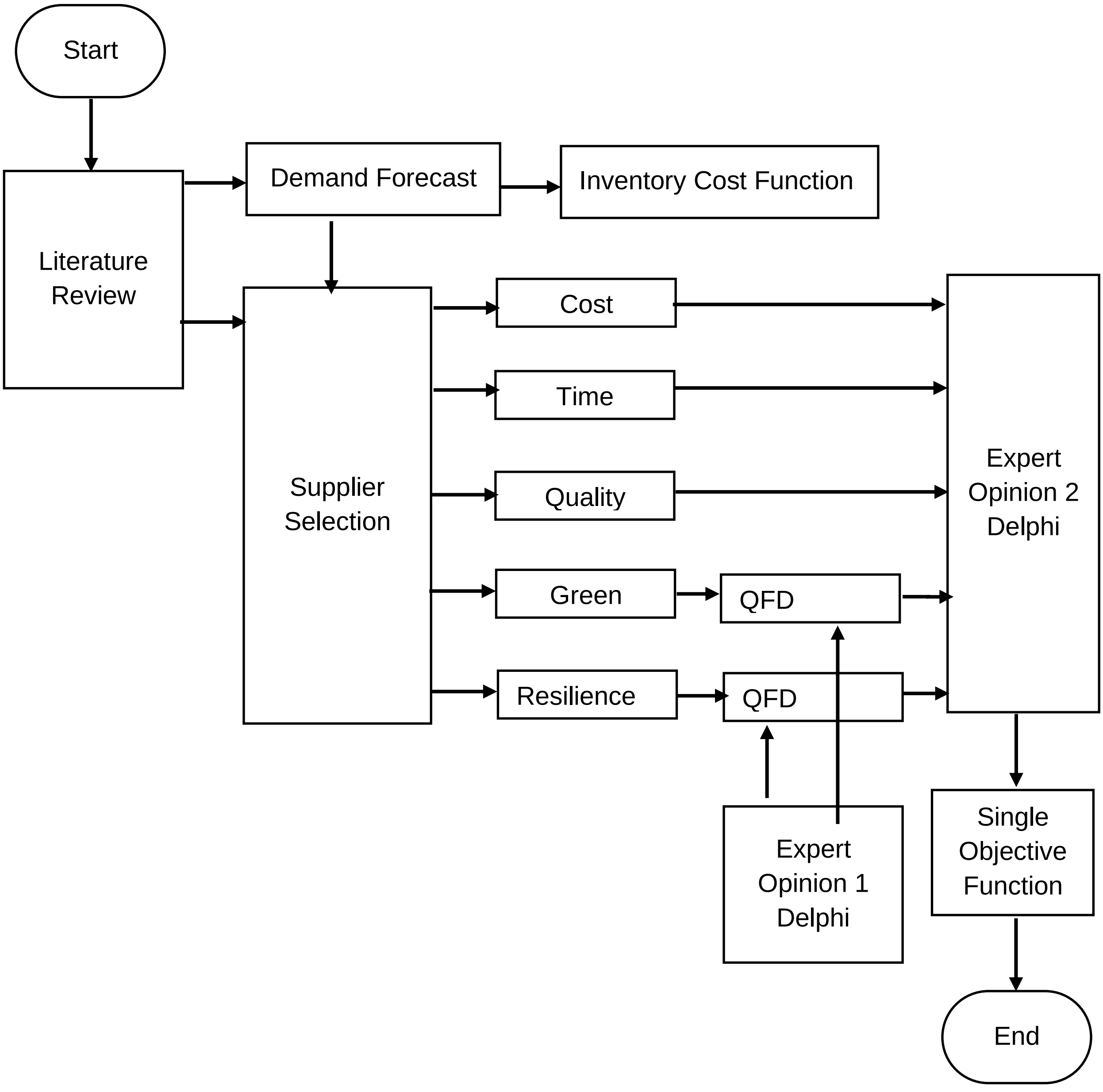

Figure 4 Overall Flow

3.3.1. Total Inventory Cost Model

A stochastic process whose amplitudes vary with time is referred to as a grey process. GM (1, 1) type of grey model is the most widely used in the literature, pronounced as "Grey Model First Order One Variable." GM (1, 1) model is a time series forecasting model, which is able to make accurate predictions for forecasting of the monotonous type of processes. Markov chain is a mathematical system that experiences transitions from one state to another according to certain probabilistic rules. The defining characteristic of a Markov chain is that no matter how the process arrived at its present state, the possible future states are fixed. This may be used to reduce errors in the GM (1, 1) model by defining error classes. The current state is forecast of previous year and next year state can be calculated so that the average value of the defined error class can be added or subtracted to improve the accuracy of the next year forecast. The method given in Jia et al., (2020) and Zhan-li et al. (2011) is utilized for this study.

3.3.1.1. Forecast Procedure

Below is the forecasting procedure for GM (1, 1)–Markov chain (MC) model or MCGM (1, 1) model with capacity utilization incorporation for Cement Plants

1) X (0) (k), original data sequence, historical data to construct the model
2) X (1) (k), 1-AGO sequence, historical data accumulated sequence
3) Z (1) (k), consecutive neighbor sequence, take average of 2 consecutive numbers in 1-AGO sequence, i.e. Z (1) (1) = (x (1) (1) + x (1) (2))/2
4) Construct data matrices B and Yn
5) Input values in exact GM 11 model to compute "a" development coefficient and "b" grey input/ action amount, x (0) k+ a z (1) k = b
6) Use least square method to find a and b, using linear algebra
7) Compute a least-squares solution let B be an m×n matrix and let b be a vector in Rn. Here is a method for computing a least-squares solution of Ax=b:
8) Compute the matrix BTB and the vector BTYn.
9) Form the augmented matrix for equation BTBx= BTYn, and row reduce.
10) This equation is always consistent, and any solution Kx is a least-squares solution
11) Obtain Prediction Model by plugging in "a" and "b" into x (1) (k+1) =(x (0) (1)-b/a) e-ak + b/a
12) Apply Model correction by Markov by defining error classes
    i. Calculate error

ii. Divide error into classes

iii. Calculate transition probability matrix

iv. Calculate state matrix

v. Use last state vector and multiply with transition probability matrix to get next state of predicted error class

13) Find GM 11 predicted value by subtracting from n-1 term

14) Use error median to correct the GM 11 value

15) Use capacity utilization to further adjust the forecast

16) Carry out error testing

This procedure will be used to yield the next 5 years forecasted inventory value as well as specific spare or raw material in question. The results can be an input into Data matrices.

In order to improve the accuracy of the inventory cost we need to consider the fact that spares are being procured from local and imported sources. The percentage of local to import spares may vary greatly from plant to plant. In order to see all the possibilities, we may consider some scenarios like 10% local and 90% import spares, 20% local and 80% import spares and so on.10 scenarios with increments of 10% rise in import inventory are shown in table 3. Each column shows year wise forecasted imported inventory from 2022-2026. We define another data matrices D2ij where “i” is percentage share of imported spares and “j” is forecast year. The top row D21j shows 10% of forecasted inventory is imported. The columns show forecasts amounts in million PKR for respective years considering 100 % capacity utilization

For Cement Industry in Pakistan, US dollar and Euro are main currencies that are used to perform business. Therefore, for our study we will be considering USD and Euro only.

Since we have 2 foreign currencies USD and Euros, the total number of scenarios in the stochastic model are 3^2=9 for one period (one year). Multiple forecast values can be obtained by first fixing the fluctuation percentage as per the process of Hammami et al. (2014). The scenario-based process has also been utilized by Zarindast et al. (2017) and Shih et al. (2022). We used random real functions in Mathamatica software generate the values. USD and Euro exchange rates were calculated considering the conditional probability of USD rise/fall/stability vs. Euro rise/fall/stability. This can be seen in figure 5.

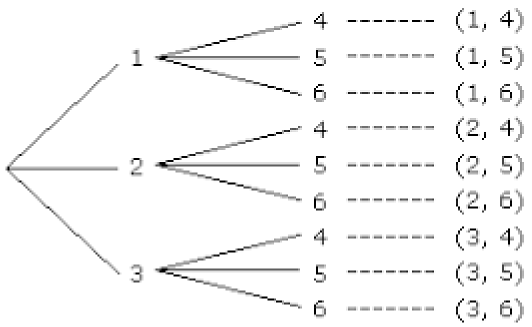

Figure 5 Exchange rate fluctuation possibilities

Figure 5 shows three scenarios for USD rise (1), stays the same (2) falls (3) with reference to base currency here taken as PKR. This is followed by 3 scenarios: Euro rise (4), stays the same (5) and falls (6). We get a total of 9 scenarios in one year for 02 currencies. In case we consider 03 currencies the total scenarios will go up to 27.

Once we obtain values of Inventory, exchange rate and local/import percentage, we may **create scenarios** for plugging into our cost forecast model. Among the scenarios, one can be taken as USD stays same while Euro goes up and we will be replenishing 20% imported spares from total change in inventory value. In respective scenario variable will be plugged in cost function.

3.3.1.2. Total Inventory Cost Function

The cost estimation function is given below.

Total Cost = $\sum_{i=1}^{1} \quad \sum_{j=1}^{1} \quad ((INV_i - INV_{i-1}) * LOCAL_{5-j}) +$

$(\alpha * (\frac{((INV_i - INV_{i-1})}{FXUSD_{i-1}}) * IMPORT_j * FXUSD_i) +$

$(\beta * ((\frac{(INV_i - INV_{i-1})}{FXEURO_{i-1}}) * IMPORT_j * FXEURO_i) +$

$$INV_{i-1} * (INS + OBS + STO)$$

Where

INV_i is inventory for current year

INV_{i-1} is inventory for previous year

$LOCAL_{5-j}$ is proportion of inventory being procured from local source

$IMPORT_j$ is proportion of inventory being procured from Import source

$FXEURO_i$ is euro exchange rate for PKR for current year

$FXUSD_i$ is dollar exchange rate for PKR for current year

$FXEURO_{i-1}$ is euro exchange rate for PKR for previous year

$FXUSD_{i-1}$ is dollar exchange rate for PKR for previous year α – binary variable for selection of dollar for order placement

β– Binary variable for selection of euro for order placement

INS – Insurance cost

OBS – Obsolescence cost

STO – Storage cost

- The **first term** simply takes into account the cost of locally procured spares. The difference in inventory (inventory this year minus inventory last year) is simply expressed in base currency.
- The **second term** takes into account the difference of inventory divided by exchange rate of last year as those spares were procured in the last period. The resulting value is multiplied by the forecasted exchange rate. The alpha component is a binary variable that is zero if USD is not selected as purchasing currency, one in case USD is used in the procurement process as its value is less than Euro when comparing with base currency.
- The **third term** uses the same principle as the second term with only difference of Euro exchange rate and beta component dictating buying currency and decision of procurement when compared with USD.
- The **last term** expresses all other associated cost of inventories. Same has been adapted from study conducted by Chouhan et al. (2021) where the researcher expressed storage, tax, obsolescence, insurance etc. for cement plant inventories.

3.3.2. Green and Resilient Supplier Selection

One of popular directions of research areas in supply chain is integration of LARG supply chain paradigms. LARG (Lean, agile, resilient and green) has been applied by Jamali et al., (2017) for Iranian Cement sector. Interested reader are directed there.

3.3.2.1. Supplier Selection Procedure

Below steps describe the implementation of the model for **green and resilient supplier selection with expert opinion** as under. The main steps are followed by detailed explanations on each step

1) Obtain relevant data for set of suppliers to be tested and ranked along with demand of spare or raw material being studied
2) Construct Cost Objective Function with product price, demanded quantity, electricity, labor, inventory holding, order management, transport and inspection costs

3) Construct Time Objective Function with production, transport and inspection times.
4) Quality Objective Function with observations and rejections on previous suppliers adjusted by fuzzy triangular numbers due to its nature
5) Apply QFD/HOQ for Green Factors by using Expert Opinion 1 and construct Green Objective Function
6) Apply QFD/HOQ for Resilient Factors by using Expert Opinion 1 and construct Resilience Objective Function
7) Define Constraints, Obtain optimal solutions for all the objective functions
8) Construct payoff table
9) Compute aggregate and normalized fuzzy numbers of Cost, Quality, Time, Green and Resilient as per Expert Opinion 1 by Delphi technique
10) Compute fuzzy membership function to get satisfaction levels on all objective functions as per Expert Opinion 1 by Delphi technique
11) Compute Single Objective Function and rank suppliers by using fuzzy goal programming technique
12) Compare results for each supplier by varying each factor while keeping all other factors same

Data Collection from expert was carried out using questionnaires for **Steps 5, 6, 9 and 10 shown in Table 6**

Table 5 Survey Data Forms

Sr #	Link	Title	Purpose
1	https://forms.gle/hhv6mS4e7tk11LNS8	Expert Opinion 2 on Green/ Resilient Supplier Selection	Weights of Cost, Quality, Time, Green and Resilience
2	https://forms.gle/DQ1uYvjW9UnSdgha9	Expert Opinion 1 on Green/Resilience Sub Factors	Weights Green and Resilience sub criterions

Below technique will be used to compute weights of expert opinions to incorporate those in single objective function as per **step 10** in above procedure.

Step 10.1: The importance of expert opinion is found by dividing experts' number of years of experience by total number of years of experience of all experts as:

〖$Weight$ assigned to $Expert$〗 i= ($years\ of\ experience\ of$ Ei) / ($years\ of$ experience of ∑Ei)

Where Ei experience of expert "i"
IEi importance of opinion of expert "i"

〖AFN = ($Weight$ assigned to $Expert$〗 $i * Opinion$) / $Total\ number\ of\ responses$

Step 10.2: Now we need to AFN, aggregate the fuzzy number as:
Where Woi - weightage of objective "o" given by expert "i"

Step 10.3: Now we need to normalize the fuzzy number

$NFW=AFN$ / $\sum AFN$

Step 10.4: Forming a table to note down all details as:
Note opinion has been obtained using Likert Scale with below assigned values
Most Important assigned weight +2
More Important assigned weight +1
Important assigned weight 0
Less Important assigned weight -1
Least Important assigned weight -2
An example of the process is given below in Table 7

Table 6Example of expert opinion work

Expert #	Experience	Weight	Cost	Quality	Time	Green	Resilience
Expert 1	7	0.029	More Important	More Important	Most Important	Less Important	Less Important
Expert 2	12	0.049	More Important	Most Important	More Important	Most Important	Most Important
Expert 3	20	0.082	Most Important	Most Important	Important	More Important	Important
Expert 4	20	0.082	Most Important	Most Important	Most Important	Most Important	More Important
Expert 5	3	0.012	Important	Most Important	Most Important	More Important	More Important
Expert 6	1	0.004	More Important	Most Important	Important	Important	Less Important
Expert 7	61	0.250	Important	Most Important	Important	Important	Important
Expert 8	15	0.061	Most Important	Most Important	Most Important	Important	Important
Expert 9	6	0.025	More Important	Most Important	More Important	Most Important	Important
Expert 10	7	0.029	Important	Important	Less Important	More Important	Important
Expert 11	3	0.012	Important	Most Important	Important	More Important	Important
Expert 12	20	0.082	Important	Most Important	Important	Least important	More Important
Expert 13	10	0.041	Most Important	Important	Important	Important	Important
Expert 14	10	0.041	More Important	More Important	Important	Important	Less Important
Expert 15	31	0.127	More Important	Most Important	Important	Important	Important

Expert 16	12	0.049	Important	Most Important	Important	Important	Important
Expert 17	3	0.012	Important	More Important	More Important	Important	Important
Expert 18	3	0.012	Important	Most Important	Important	Important	Important
	244						
AFN			0.81	1.78	0.43	0.25	0.20
NFW			0.23	0.51	0.12	0.07	0.06

Further details on **Step 5 and 6** in above procedure, taking input from experts we can construct QFDs each for green and resilient factors and sub factors

- QFD1a: HOQ links stakeholder with the requirements of sub green factors/sub dimensions
- QFD1b: HOQ links green sub factors with green parameter/main factor
- QFD2a: HOQ links stakeholder with the requirements of resilient factors/sub dimensions
- QFD2b: HOQ links resilient factors/sub dimension with resilient parameter/primary dimension

3.3.2.2. Multiple Objective Functions

Below Objective functions are constructed and utilized as per **Steps 2, 3, 4, 5 and 6**

$$F(Cost) = \sum_{s}\sum_{p} (P_{ps}+LC+EC+CE_{h+}INV_{h+}OMC)*Q_{psrg} + \sum_{s}\sum_{p} ((TR+CE_{t})*DIST_{su}+IC_{ps})*Z_{p} \qquad 1.\ .$$

Quality Function is mentioned below

$$F(Quality) = \sum_{s}\sum_{p} ((QC_{ps}/U_{ps})*1{,}000{,}000)*Z_{psrg} \qquad 2.$$

Green Function is mentioned below

$$F(Green) = \sum_{s}\sum_{p}(\sum W_{gf}G_{gf})*Z_{psrg} \quad 3.$$

Resilience function is mentioned below

$$F(Resiliant) = \sum_{s}\sum_{p}(\sum W_{rf}R_{rf})*Z_{psrg} \quad 4.$$

Time function is mentioned below

$$F(Time) = \sum_{s}\sum_{p}(PT_{ps}/BS_{ps})*Q_{psrg} + \sum_{s}\sum_{p}((DIST_{su}/V)+IT_{ps})*Z_{psrg} \quad 5.$$

Further on **equation 2 and Step 4**, simple 3 step process is followed to get accurate data on complaints. First is assigning membership function, here triangular fuzzy number is selected. Second apply fuzzification, convert function using membership function. Third defuzzify the function, here in this study, we use the following definition, for the triplet of a triangle fuzzy number, to compare the performance of two triangular fuzzy numbers. This approach (Chen, 1996) was selected since it is straightforward and does not necessitate the analyst's subjective opinion. The notion of the removal of a fuzzy number serves as the foundation for the approach, which is based on Kaufmann and Gupta's (1988) method to compare fuzzy numbers.

Assumptions

- Demand is forecasted based on previous years data and may vary depending on internal policy change
- Price of spare remains fixed throughout the year
- Quality inspection cost remains fixed
- When an uncertain input is considered, triangular fuzzy number is used.

List of Notations

- Indices
    - S Index of Supplier S=1,2,3,4,5
    - P Index of Products P=1,2,3,------
    - I Index of Expert I=1,2,3----
    - O Index of Objectives O=1,2,3,4,5

- G Index of Green Criterion G=1,2,3
- R Index of Resilient Criterion R=1,2,3

- Decision Variables
  - Z_{psrg}
  - Q_{psrg}
- Parameters
  - Pps – product price
  - LC – Labor cost
  - EC – electricity cost
  - CEh – Carbon emission during holding
  - INVh – Inventory holding cost
  - OMC – order management cost
  - TR – Transportation cost
  - CEt – Carbon emission during transport
  - DISTsu – distance from supplier to plant/production unit
  - ICps – inspection cost
  - PTps – Production Time
  - BSps – Batch size
  - V – Speed of transport vehicle
  - ITps – Inspection time
  - QC – Quality complaints
  - Ups – Total units received
  - Wgf – weight of green factor
  - Ggf – Green factor
  - Wrf – Weight of resilient factor
  - Rrf – Resilient factor

3.3.2.3. Single Objective Function

Payoff data is obtained as per **Step 8** in above procedure in section

Fuzzy membership functions are found as per below details, this is further to Step 11 given in above procedure

The fuzzy membership functions for all objectives are:

$\mathbf{Ø_{green}}$ = (achieved - $F_{(Green)}$/upper limit – lower limit)

$\mathbf{Ø_{resilient}}$ = (achieved - $F_{(Resilient)}$/ upper limit – lower limit)

$\mathbf{Ø_{cost}}$ = (achieved - $F_{(Cost)}$/ upper limit – lower limit)

$\mathbf{Ø_{time}}$ = (achieved - $F_{(Time)}$/ upper limit – lower limit)

$\mathbf{Ø_{quality}}$ = (achieved - $F_{(Quality)}$/ upper limit – lower limit)

$\mathbf{NFW_{green}}$ = $AFN_{green}/ \sum AFN$

$\mathbf{NFW_{resilient}}$= $AFN_{resiliant}/ \sum AFN$

$\mathbf{NFW_{cost}}$ = $AFN_{cost}/ \sum AFN$

$\mathbf{NFW_{time}}$ = $AFN_{time}/ \sum AFN$

$\mathbf{NFW_{quality}}$= $AFN_{quality}/ \sum AFN$

Single Objective Function Construction is given below further to **Step 11** in above procedure

Function = $\mathbf{NFW_{green}} * \mathbf{Ø_{green}} + \mathbf{NFW_{resilient}} * \mathbf{Ø_{resilient}} + \mathbf{NFW_{cost}} * \mathbf{Ø_{cost}} + \mathbf{NFW_{time}} * \mathbf{Ø_{time}} + \mathbf{NFW_{quality}} * \mathbf{Ø_{quality}}$

3.4. Limitations of the research design

There are some assumptions in the model that include constant prices throughout the year neglecting the impact of inflation or discounted rates where applicable. Generally, the spares or raw materials with demand figures each year are most suitable for this approach. Although applicable to lumpy and erratic demand items but more suitable for smooth and intermittent demand. The forecast accuracy will vary based on available historical data. Lean and Agile Paradigm has not been explored.

CHAPTER 4 FINDINGS, RESULTS AND DISCUSSIONS

4.1. Total Inventory Cost Model

The Gray Markov forecasting process is first used to estimate one spare i.e. buckets for bucket elevator. Here we use quantity figures to get quantity forecasts. We use the same method given above.

Forecasting procedure will be used to yield the next 5 years forecasted spare/raw material requirement. The results are shown below in Figure 6

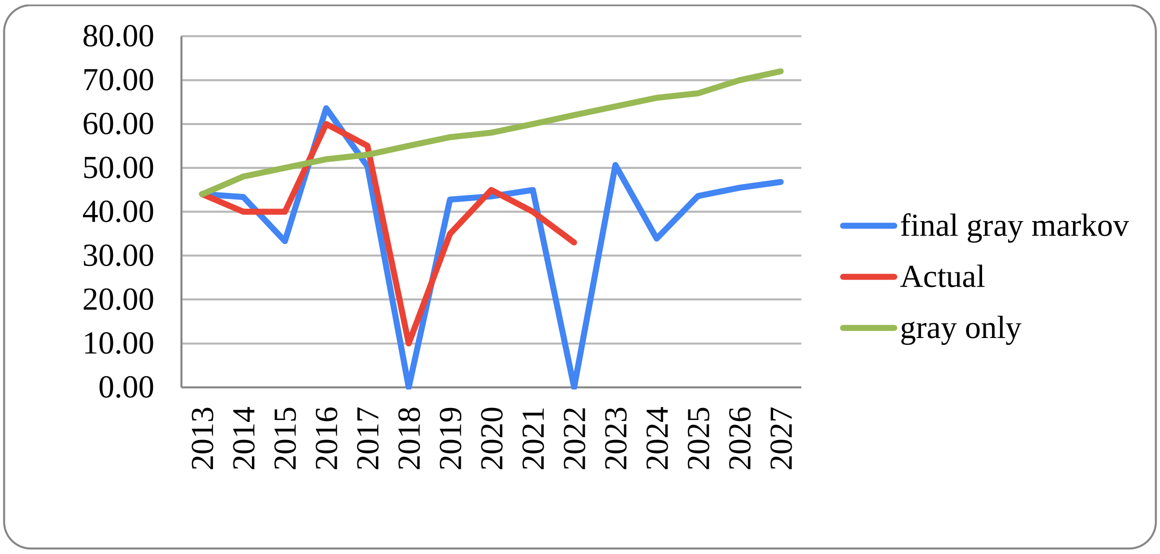

Figure 6 Forecasting single item

The result is 20.77 kg/bucket x 50 number of buckets = 1040 kgs forecast for Year 2023. These figures will be used in the supplier selection process.

Next, the forecasting procedure is used to yield the next 5 years forecasted total inventory value. Here we use previous inventory values to estimate future inventory values.

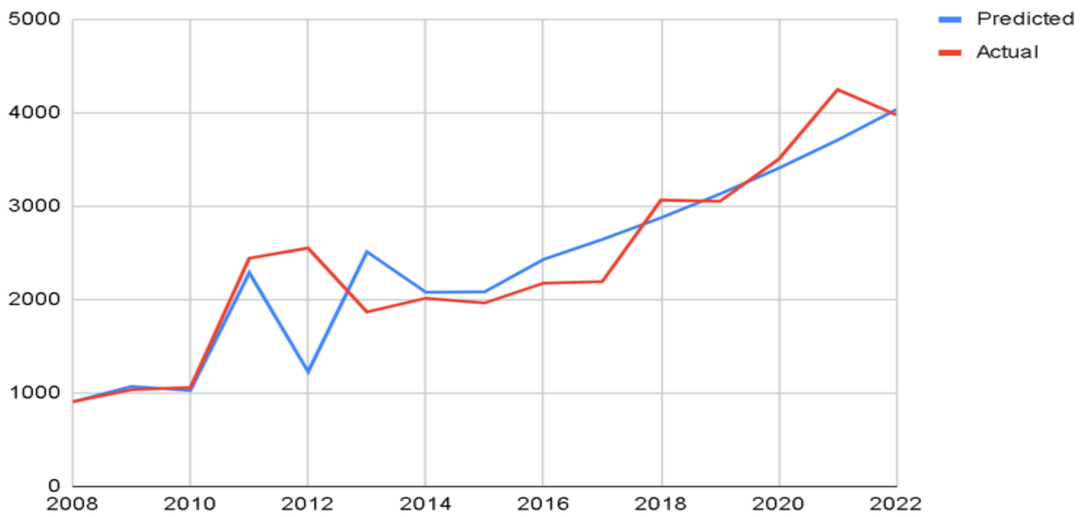

Figure 7 Forecasting complete inventory value

The forecasted results can be an input into Data matrice D1. These figures will be utilized in computing the overall cost function. Table 9

Table 7 Inventory value forecast

Year	Forecasted Values in Million PKR
2022	4,037.74
2023	4,393.97
2024	4,781.66
2025	5,203.39
2026	5,662.51
2027	6,161.97

Table 8 Accumulated values error calculation

Year	Actual accumulated Data	Forecast accumulated Data	MAPE	APE	RE	PE	RMSE
2009	1,945.67	2,271.80		0.168		-0.168	106361.4
2010	3,006.20	3,755.90		0.249		-0.249	562047.1
2011	5,450.38	5,370.90		0.015		0.015	6316.3
2012	8,004.81	7,128.40		0.109		0.109	768091.0
2013	9,874.73	9,040.90		0.084		0.084	695267.5
2014	11,891.06	11,122.20		0.065		0.065	591150.3
2015	13,856.47	13,387.10		0.034		0.034	220312.0
2016	16,033.84	15,851.80		0.011		0.011	33138.9
2017	18,228.29	18,533.80		0.017		-0.017	93335.1
2018	21,295.98	21,452.50		0.007		-0.007	24499.8
2019	24,351.02	24,628.70		0.011		-0.011	77107.8
2020	27,856.83	28,085.00		0.008		-0.008	52063.4
2021	32,107.58	31,846.30		0.008		0.008	68267.2
2022	36,087.30	35,939.30		0.004		0.004	21902.7
2023		40,393.40	0.056	0	0	0	487.0
2024		45,240.50		0	0	0	
2025		50,515.10		0	0	0	

In order to increase the precision of the inventory cost function we need to consider the fact that spares are being procured from local and imported sources. The percentage of local to import spares may vary greatly from plant to plant. In order to see all the possibilities, we may consider some scenarios like 10% local and 90% import spares, 20% local and 80% import spares and so on.
10 scenarios with increments of 10% rise in import inventory are shown in table 3. Each column shows year wise forecasted imported inventory from 2022-2026. We define another data matrice D2ij where "i" is percentage share of imported spares and "j" is forecast year. The top row D21jshows 10% of forecasted inventory is imported. The columns show forecasts amounts in million PKR for respective years considering 100 % capacity utilization

Table 9 Actual Import Local Percentage as per forecast

% age of imported inventory	**2022 year 0 Amount in millions PKR**	**2023 year 1**	**2024 year 2**	**2025 year 3**	**2026 year 4**
10%	403.8	439.4	478.2	520.3	566.3
20%	807.5	878.8	956.3	1,040.7	1,132.5
30%	1,211.3	1,318.2	1,434.5	1,561.0	1,698.8
40%	1,615.1	1,757.6	1,912.7	2,081.4	2,265.0
50%	2,018.9	2,197.0	2,390.8	2,601.7	2,831.3

The above data matrice is for imported percentage share, same can be done for local. The forecasted local inventory matrice can also be used for scenarios making. Above data shows that for each year 5 scenarios are added per year. We can add more scenarios considering 5% change in local/import proportion. In that case we will have 10 scenarios per year. In our inventory value calculations, we have utilized figures of year 1 and year 0 only.

For Cement Industry in Pakistan, US dollar and Euro are main currencies that are used to perform business. Therefore, for our study we will be considering USD and Euro only. We have two international currencies US Dollars and Euros, the total number of scenarios in the stochastic model are $3^2=9$ for one period (one year). Multiple forecast values can be obtained by first fixing the fluctuation percentage as per the process of Hammami et al. (2014). The scenario-based process has also been utilized by Zarindast et al. (2016) and Shih et al. (2022). We used random real functions in Mathematica to generate the values. USD and Euro exchange rates were calculated considering the conditional probability of USD rise/fall/stability vs. Euro rise/fall/stability. The possible scenarios can be seen below in Table 12.

Table 10 Exchange Rate Scenarios

	Exchange rate USD, year 0	**Exchange rate USD, year 1**	**Exchange rate EURO, year 0**	**Exchange rate EURO, year 1**
scenario 1.1	277.81	280.826	296.55	302.885
scenario 1.2	277.81	280.826	296.55	296.55
scenario 1.3	277.81	280.826	296.55	291.799
scenario 1.4	277.81	277.81	296.55	313.833

scenario 1.5	277.81	277.81	296.55	296.55
scenario 1.6	277.81	277.81	296.55	290.985
scenario 1.7	277.81	272.558	296.55	306.999
scenario 1.8	277.81	272.558	296.55	296.55
scenario 1.9	277.81	272.558	296.55	287.689

We get a total of 9 scenarios in one year for 02 currencies. In case we consider 03 currencies the total scenarios will go up to 27.

Once we obtain values of Inventory, exchange rate and local/import percentage, we may create scenarios for plugging in our cost forecast model. Among the scenarios, one can be taken as USD stays same while Euro goes up and we will be replenishing 20% imported spares from total change in inventory value. We will plug in respective scenario variable in cost function. The cost estimation function is given below

Total Cost = $\sum_{i=1}^{1} \quad \sum_{j=1}^{1} \quad ((INV_i - INV_{i-1}) * LOCAL_{5-j}) +$

$(\alpha * (\frac{((INV_i - INV_{i-1})}{FXUSD_{i-1}}) * IMPORT_j * FXUSD_i) +$

$(\beta * ((\frac{(INV_i - INV_{i-1})}{FXEURO_{i-1}}) * IMPORT_j * FXEURO_i) +$

$$INV_{i-1} * (INS + OBS + STO)$$

Where

INV_i is inventory for current year

INV_{i-1} is inventory for previous year

$LOCAL_{5-j}$ is proportion of inventory being procured from local source

$IMPORT_j$ is proportion of inventory being procured from Import source

$FXEURO_i$ is euro exchange rate for PKR for current year

$FXUSD_i$ is dollar exchange rate for PKR for current year

$FXEURO_{i-1}$ is euro exchange rate for PKR for previous year

$FXUSD_{i-1}$ is dollar exchange rate for PKR for previous year

α – binary variable for selection of dollar for order placement

β– Binary variable for selection of euro for order placement

INS – Insurance cost

OBS – Obsolescence cost

STO – Storage cost

Table 11 Input parameters for Inventory Function

Parameter	Values	Units or Ref
Demand of buyer	1000	Kgs
Demand of buyer	50	Nos
Demand of buyer	20	Kg/nos
INV_{i-1} (Year 0)	3818	MPkr
INV_i (Year 1)	4109	MPkr
Exchange rate USD and EURO	From Table	Table 10
Local Inventory %age	100-Import	
Imported Inventory %age	From Table	Table 9
Base Curency PKR	1	
Insurance cost	3%	
Obsolescence cost	2%	
Storage cost	5%	
Alpha	(0 or 1)	
Beta	(0 or 1)	

We use forecasted inventory value for year 2022 and 2023 to run scenarios of 5%, 10% and 15 % USD and EURO fluctuation. For the method given above we fixed the percentage variation and varied inputs of local/import inventory replenishment percentages, alpha and beta.

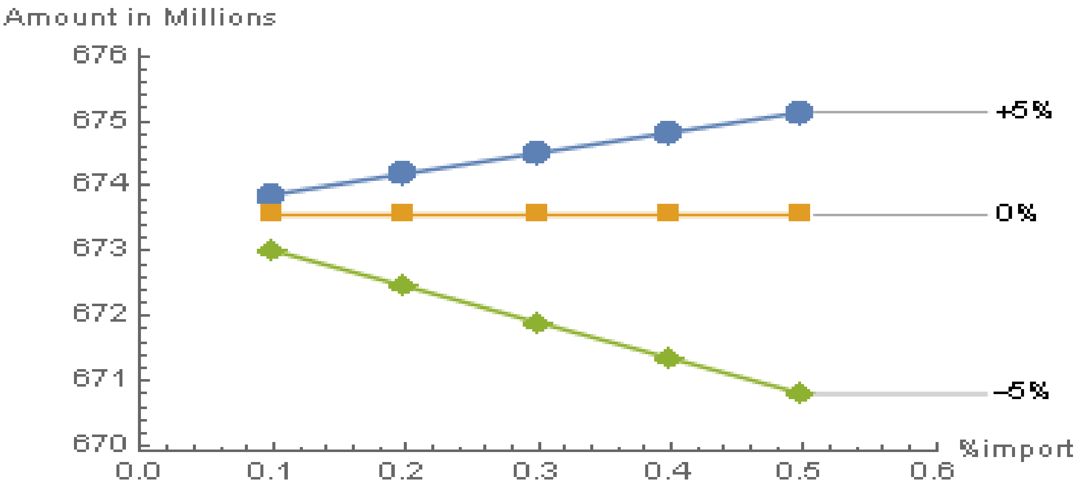

Figure 8 5% variation in USD

Figure 8 shows the plot of the total inventory cost when ±5% variation of USD is studied in isolation. The x axis shows varying import inventory replenishment percentages. The y axis shows incurred total inventory cost.

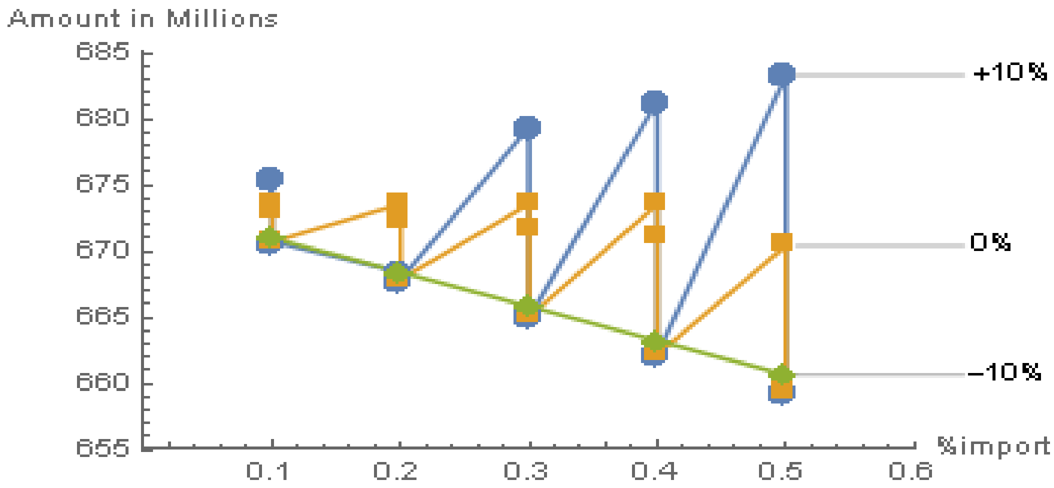

Figure 9 10% variation in USD

Figure 9 shows the plot of total variation when 10% variation of USD is studied in isolation. Here we see dips in total incurred total inventory cost due to binary variable beta being preferred over alpha as dollar exchange rate is higher than euro exchange rate thus euro is preferred for order placement.

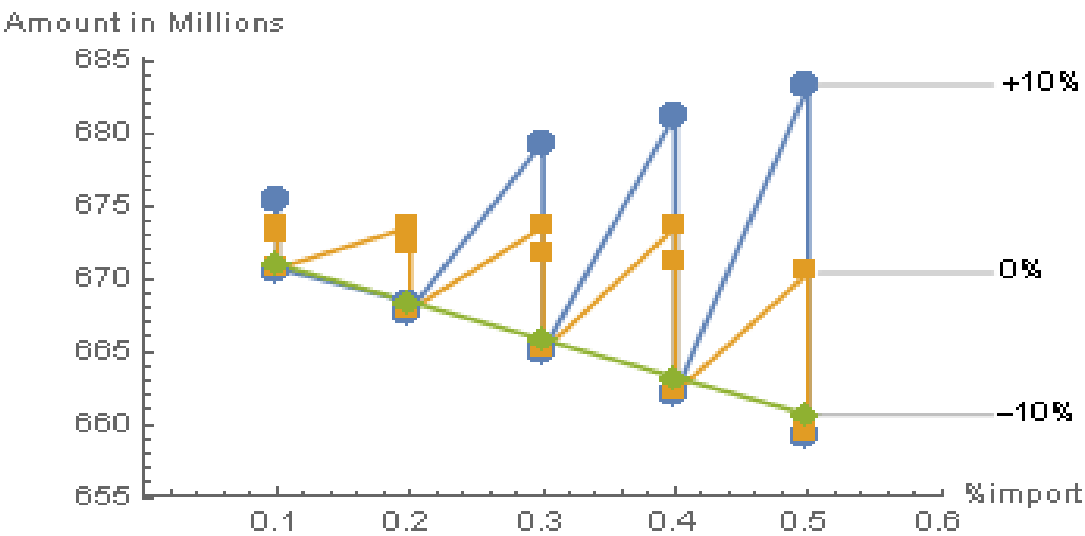

Figure 10 15% variation in USD

Figure 10 shows the plot of total variation when 15% variation of USD is studied in isolation. Analysis of the above graphs shows that when variation is low then all orders tend to be placed in USD but as variation changes to 10-15% we see the impact of Euro on ordered quantities shifting from USD to EURO. This is indicated by amount points in each % import value.

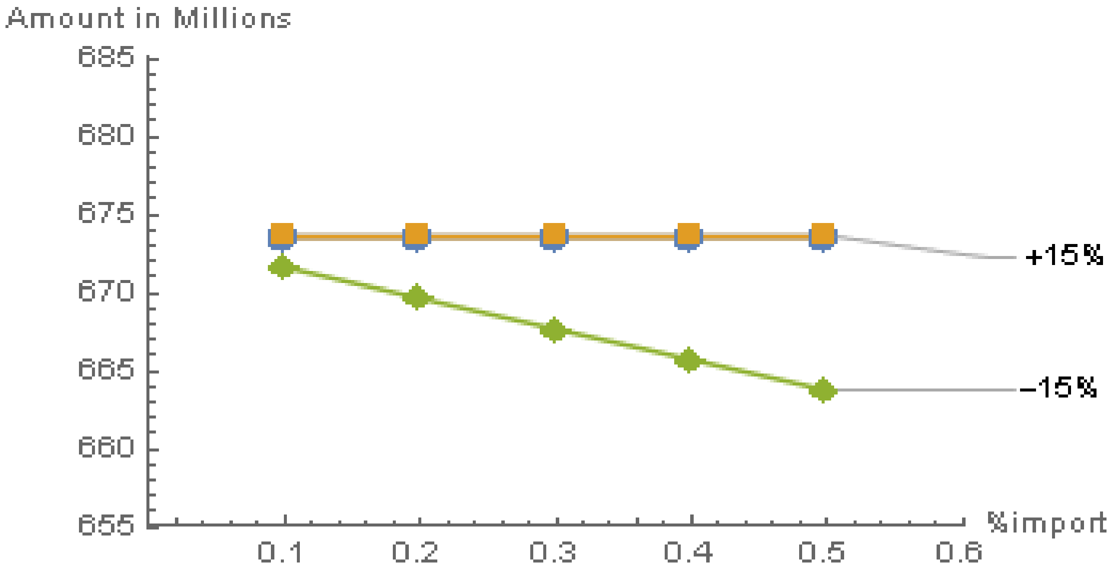

Figure 11 USD remains fixed while Euro changes

In Figure 11, we can see this impact when EURO rise/fall when USD remains constant.

Figure 12 shows the results of the scenario when 5 %, 10% and 15% increase in currency fluctuation of USD is assumed and order is placed in USD.

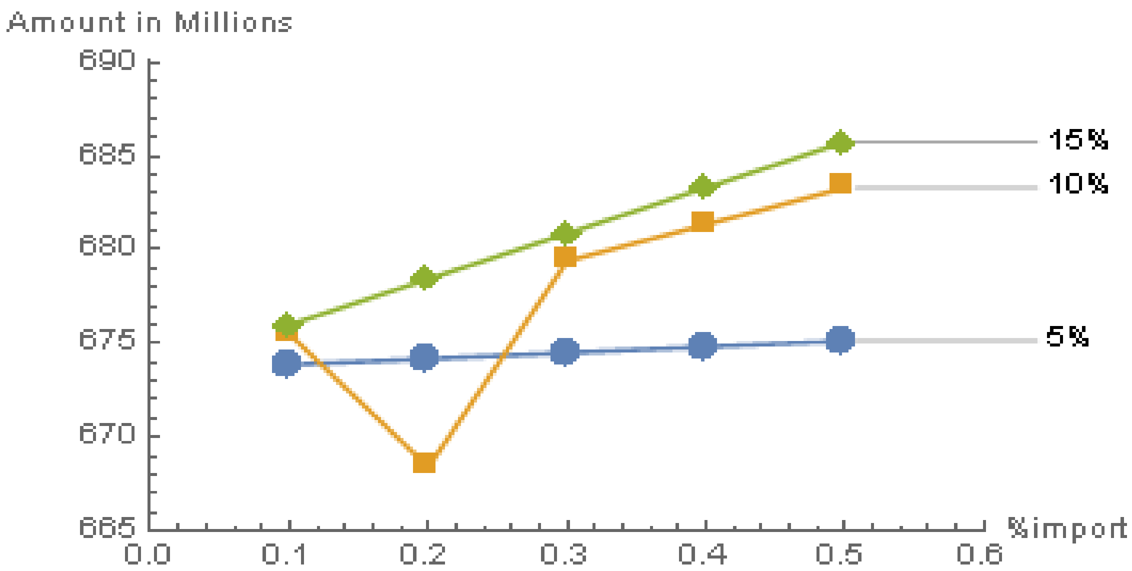

Figure 12 USD increase impact

Figure 13 shows the results of the scenario when 5%, 10% and 15% decrease in currency fluctuation of USD is assumed and order is placed in USD.

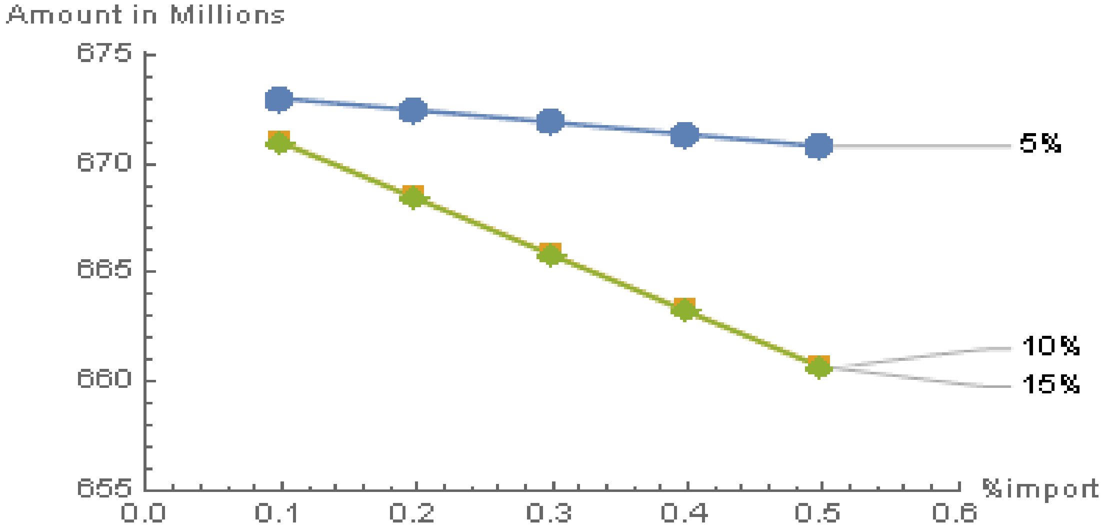

Figure 13 USD decrease impact

Table 12 shows the statistical analysis of all of the above-mentioned scenarios.

Table 12 Statistical Analysis

%age variation in EURO/USD	5%	10%	15%
Minimum	670.80	659.36	660.65
Maximum	675.14	683.29	685.74
Average	673.31	669.70	670.48
Standard Deviation	1.21	6.37	5.69
Variance	1.46	40.61	32.35

Figure 14 shows the histogram data of the total cost obtained when all 90 scenarios were considered altogether. It can be concluded that the most common overall cost lies between 670-675 million PKR while with careful consideration in order placement we may attain an overall cost as low as 655 million PKR. An overall saving of more than 20 million PKR or 70,000 USD.

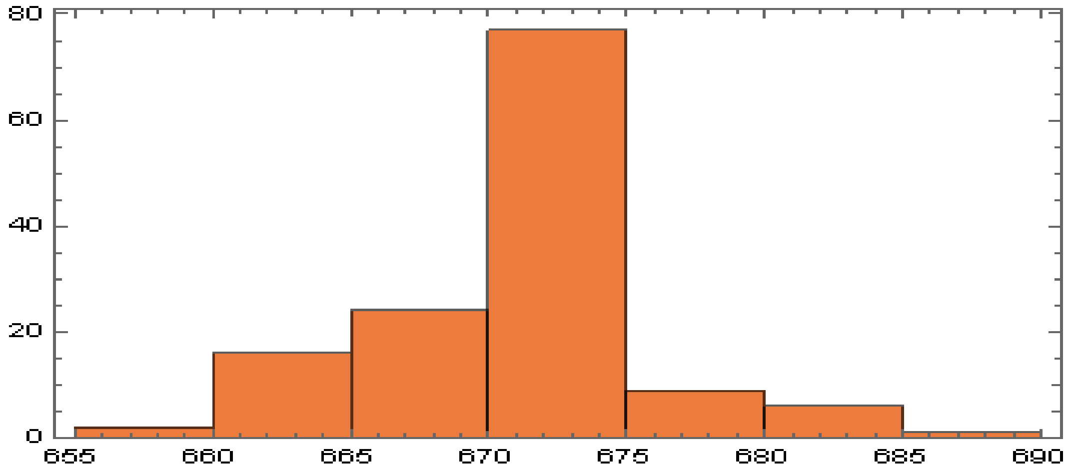

Figure 14 Histogram for all Inventory values in all scenarios

Figure 14 shows Histogram of all possibilities against all possible scenarios.

Another view is shown in Figure 16, 17 and 18 with sorted data for each 5%, 10% and 15% fluctuation respectively.

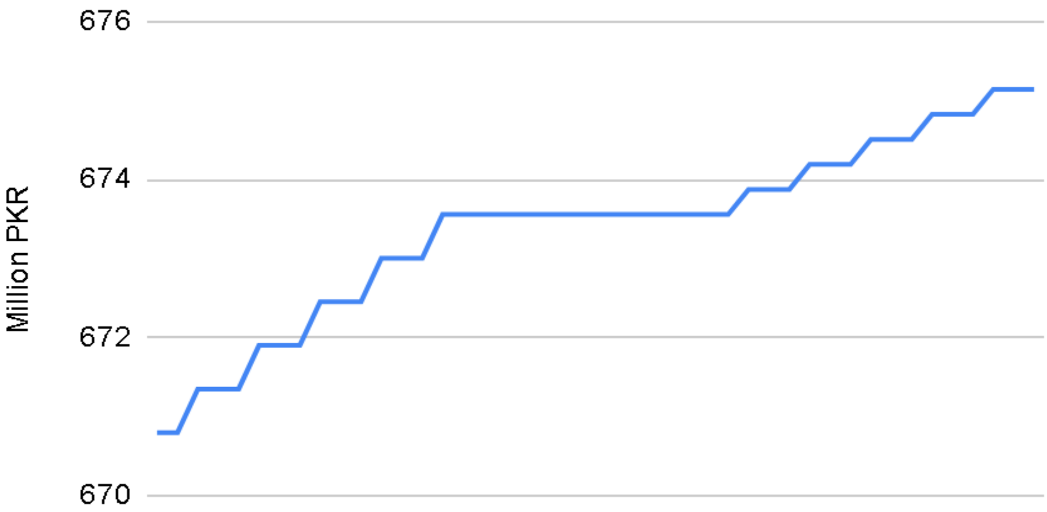

Figure 15 5% fluctuations in both currencies

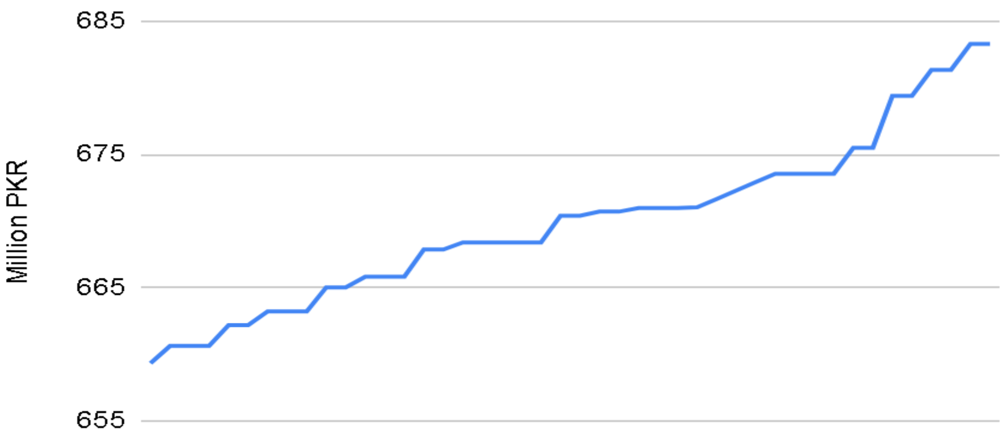

Figure 16 10% fluctuations in both currencies

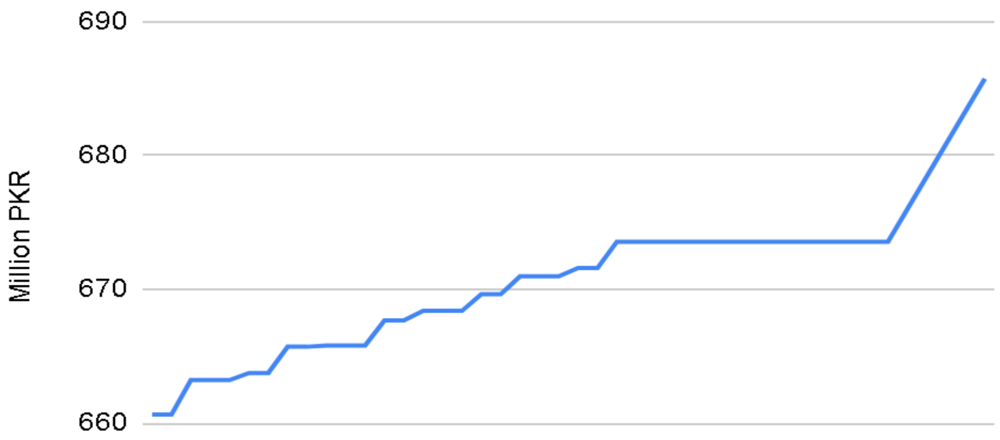

Figure 17 15% fluctuations in both currencies

The study concludes that forecasting approach using the Grey-Markov process for Inventory values produces satisfactory results with high accuracy. Both short term and long-term inventory values can be estimated through this method, however, short term forecasts are preferred over long term forecasts as they can be faulty due to considerable change in various variables with time. Both quantity and value were forecasted with satisfactory results.

For currency fluctuation, use of random variation with defined percentage change is better than using fixed values or complex models as it yields probabilistic values that can be utilized in the scenario list. We can also use forecast from other reliable sources as well like banks or other financial institutions. We conclude that around 16% cost is incurred when considering complete inventory value. Considering inventory value as 4109 million PKR, cost of around 670 million PKR is incurred each passing year.

For local/import mix we used 10% steps. This has led to the conclusion that significant impact is observed by change in imported inventory percentage.

4.2. Supplier Selection

Supplier selection was carried out as per above mentioned procedure in methodology section 3.3.2.1.

Input from experts is obtained via questionnaires. The input are used to construct below QFDs as shown in Table 13

Table 13 HOQ 1a: Stakeholder with green sub factor

Stakeholder	Importance of Stake holder	Compliance with Industrial Policies	Compliance with Environmental Policies	Quality Control System	Waste Disposal Program	Pollution Control	Reliability of Order Fulfilment	Reverse Logistics
Finance	1	3	3	3	3	3	6	3
HSE	1	6	6	6	9	9	3	6
Maintenance	1	9	3	9	3	3	6	3
Planning	1	9	6	9	6	6	9	9
Production	1	9	3	6	3	3	9	3
Procurement	1	3	6	9	3	3	9	9
Importance of sub factor		39	27	42	27	27	42	33
Rating		0.165	0.114	0.177	0.114	0.114	0.177	0.139

QFD1a: This HOQ links stakeholder with the requirements of sub green factors
HOQ linking stakeholder with the requirements of sub green factors as shown in Table 14

Table 14 HOQ 1b: green factor with green sub factor

Stakeholder Requirements	Importance of Stake holder	Green Design	Green Logistics	Environment Management System
Compliance with Industrial Policies	0.165	9	6	3
Compliance with Environmental Policies	0.114	9	9	9
Quality Control System	0.177	6	3	9
Waste Disposal Program	0.114	6	6	9
Pollution Control	0.114	9	9	6
Reliability of Order Fulfilment	0.177	3	3	3
Reverse Logistics	0.139	6	6	6
Importance of sub factor	18.459	6.648	5.622	6.189
Rating		0.36	0.30	0.34

QFD2a: This HOQ links stakeholder with the requirements of resilient factors/sub dimensions as shown in Table 15.

Lining stake holder requirement with sub-dimensions of resilience that make up the primary dimensions

Table 15: HOQ links stakeholder with the requirements of resilient factors/sub dimensions

Table 15 HOQ 2a: Stakeholder with resilient sub factor

Stakeholder	Importance of Stake holder	Complexity of Suppliers Supply Chain	Multiple Transportation options	Operation at Multiple Locations	Optimized operations	New Product Development	Order Flexibility	Financial Stability	Risk assessment and Mitigation planning	Crisis Teams	Reference of previous good performance of
Finance	1	3	6	3	3	3	6	9	3	3	3
HSE	1	3	3	3	6	3	3	3	9	6	3
Maintenance	1	3	6	3	6	6	6	3	3	3	9
Planning	1	6	9	6	6	9	6	3	6	6	6
Production	1	3	3	3	3	6	3	3	3	3	6
Procurement	1	6	9	6	9	9	9	6	6	3	9
Importance of sub factor		24	36	24	33	36	33	27	30	24	36
Rating		0.079	0.119	0.079	0.109	0.119	0.109	0.089	0.099	0.079	0.119

QFD2b: This HOQ links resilient factors/sub dimension with resilient parameter/primary dimension

Table 16 HOQ 2b: Resilient factor with resilient sub factor

Stakeholder Requirements	Importance of Stake holder	Proactive Capacity	Supply Chain Design Quality	Reactive Capacity
Complexity of Suppliers Supply Chain	0.079	3	9	3
Multiple Transportation options	0.119	3	6	3
Operation at Multiple Locations	0.079	3	6	3
Optimized operations	0.109	6	9	3
New Product Development	0.119	9	3	3

Order Flexibility	0.109	3	6	3
Financial Stability	0.089	6	3	9
Risk assessment and Mitigation planning	0.099	9	6	9
Crisis Teams	0.079	3	3	9
Reference of previous good performance of supplied parts	0.119	3	9	3
Importance of sub factor		4.901	6.059	4.604
Rating		0.315	0.389	0.296

The three primary main criterions/dimensions are “proactive capability, reactive capability and supply chain design quality” as per previous papers and discussion by.

5. **Implementation Phase**

Considering the procedure defined above we can carry out a comparison of 5 registered supplier (S1, S2, S3, S4, and S5) that provided fabricated spares for Cement Plant A.

Rating each green sub factors out of 10 for each supplier

Table 17 Supplier assigned relative scores on Green

Supplier	**Compliance with Industrial Policies**	**Compliance with Environmental Policies**	**Quality Control System**	**Waste Disposal Program**	**Pollution Control**	**Reliability of Order Fulfilment**	**Reverse Logistics**
S1	8	5	6	3	3	8	3
S2	8	6	8	4	4	9	5
S3	6	4	4	3	3	6	3
S4	8	3	8	3	3	9	6
S5	8	4	6	4	4	9	4

Table 18 Green Factor Multipliers

	Compliance with Industrial Policies	Compliance with Environmental Policies	Quality Control System	Waste Disposal Program	Pollution Control	Reliability of Order Fulfilment	Reverse Logistics
Green Design	1.485	1.026	1.062	0.684	1.026	0.531	0.834
Green Logistics	0.99	1.026	0.531	0.684	1.026	0.531	0.834
Environment Management System	0.495	1.026	1.593	1.026	0.684	0.531	0.834

Table 19 Suppliers relative Green Scores

Supplier	Green Design	Green Logistics	Environment Management System	$\sum W_{gf} G_{gf}$
S1	35.262	28.116	30.528	93.906
S2	42.321	34.113	38.649	115.083
S3	28.08	22.986	24.264	75.33
S4	38.367	30.159	34.695	103.221
S5	37.311	30.165	32.577	100.053

Table 20 Suppliers obtained relative scores on resilience

Supplier	Complexity of Suppliers Supply Chain	Multiple Transportation options	Operation at Multiple Locations	Optimized operations	New Product Development	Order Flexibility	Financial Stability	Risk assessment and Mitigation planning	Crisis Teams	Reference of previous good performance of supplied parts
S1	3	6	3	3	3	6	9	3	3	3
S2	3	3	3	6	3	3	3	9	6	3
S3	3	6	3	6	6	6	3	3	3	9
S4	6	9	6	6	9	6	3	6	6	6
S5	3	3	3	3	6	3	3	3	3	6

Table 21 Resilience factor multipliers

	Complexity of Suppliers Supply Chain	Multiple Transportation options	Operation at Multiple Locations	Optimized operation	New Product Development	Order Flexibility	Financial Stability	Risk assessment and Mitigation planning	Crisis Teams	Reference of previous good performance of
Proactive Capacity	0.238	0.356	0.238	0.653	1.069	0.327	0.535	0.891	0.238	0.356
Supply Chain Design Quality	0.713	0.713	0.475	0.980	0.356	0.653	0.267	0.594	0.238	1.069
Reactive Capacity	0.238	0.356	0.238	0.327	0.356	0.327	0.802	0.891	0.713	0.356

Table 22 Supplier relative Resilience Scores

Supplier	Proactive Capacity	Supply Chain Design Quality	Reactive Capacity	$\sum W_{rf} R_{rf}$
S1	25.960	32.673	22.040	80.673
S2	32.287	41.970	28.455	102.713
S3	18.000	24.178	16.396	58.574
S4	25.129	30.921	19.693	75.743
S5	30.891	40.782	26.525	98.198

Table 23 Supplier main parameters

Supplier	**Production Capacity in Kilograms**	**Production Time in Hours**	**Batch Size**	**Price of product in USD**	**Quality complaints last year**	**Units Sold last year**	**AQL of Supplier**	**Distance from Plant (in km)**
Supplier 1	20.77x50~1040	160	50	58.3	8	150	3.2	261
Supplier 2	1040	240	50	66.6	10	150	2.9	262
Supplier 3	1040	144	50	54.3	7	200	3.3	260
Supplier 4	1040	120	50	60.0	10	50	1.5	257
Supplier 5	1040	144	50	55.0	2	50	3.3	266

Table 24 Supplier other parameters

Parameter	**Values**	**Units**
Demand of specific spare	1000	Kgs
Standard AQL	3.5	-
Inspection time	3	Hrs.
Inspection cost	20	USD
Energy cost	1	USD
Labor cost	5	USD
CR Subscript [CR, tr] during handling	0.5	USD
CE Subscript [CE, h] tax during transport	0.2	USD
Transport cost	2	USD
Average Speed	100	km/hr
Inventory holding	1	USD
Order management cost	2	USD
Rework cost	5	USD

Table 25 Individual Solutions

Function	Result	Supplier
F(Green)	115.083	Supplier 2
F(Resilient)	102.713	Supplier 2
F(Cost)	3787	Supplier 3
F(Time)	125.6	Supplier 4
F(Quality)	35000	Supplier 3

Payoff data to find the constraints of single objective function.

Table 26 Payoff Table

	F(Green)	F(Resilient)	F(Cost)	F(Time)	F(Quality)	
F(Green)	115.083	102.713	4,402	245.62	66,666.7	Supplier 2
F(Resilient)	115.083	102.713	4,402	245.62	66,666.7	Supplier 2
F(Cost)	75.330	58.574	3,787	149.6	35,000	Supplier 3
F(Time)	103.221	75.743	4,072	125.6	200,000	Supplier 4
F(Quality)	75.330	58.574	3,787	149.6	35,000	Supplier 3

Fuzzy membership functions

The fuzzy membership functions for all objectives are:

$Ø_{green}$ = (115.083-F (Green)/115.083-75.330) = 115.083-F (Green)/39.753

$Ø_{resilient}$ = (102.713-F (Resilient)/102.713-58.574) = 102.713-F (Resilient)/44.139

$Ø_{cost}$ = (4402-F (Cost)/4402-3787) = 4402-F (Cost)/615

$Ø_{time}$ = (245.62-F (Time)/245.62-125.6) = 245.62-F (Time)/120.02

$Ø_{quality}$ = (200,000-F (Quality)/200,000-35,000) = 200,000-F (Quality)/165,000

NFW_{green} =0.07

$NFW_{resilient}$=0.06

NFW_{cost} =0.23

NFW_{time} =0.12

$NFW_{quality}$=0.51

Single Objective Function Minimization

f=0.07*(F (Green) -115.083/39.753) + 0.06* (F (Resilient)-102.713/44.139) + 0.23*(4402-F (Cost)/615) + 0.12*(245.62-F (Time)/120.02) + 0.51*(200,000-F (Quality)/165,000)

Below graph as Figure 18 shows behaviour of function when we plot 10,000 points.

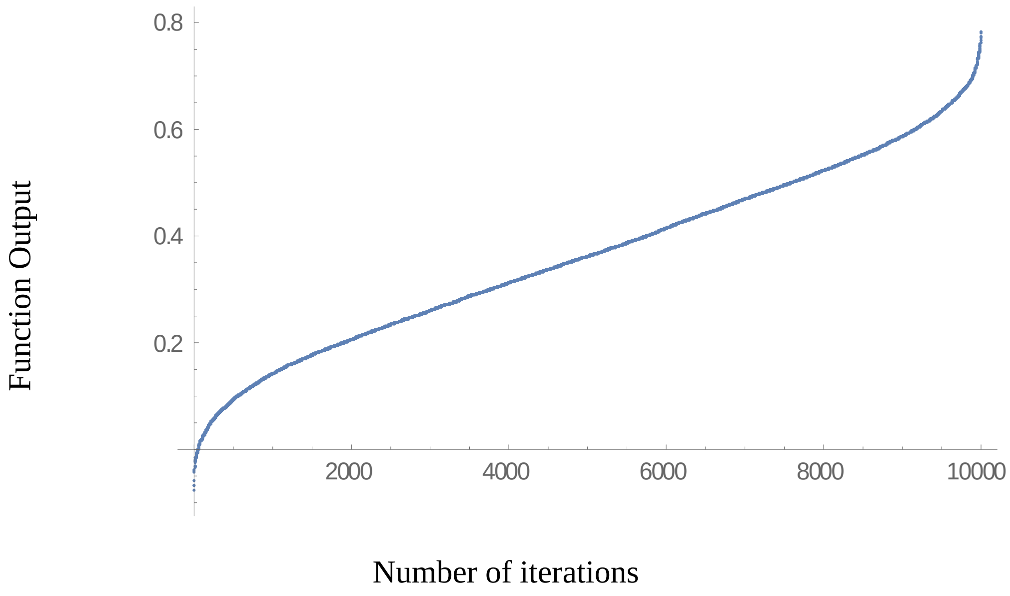

Figure 18 Results of Single Objective Function

When we find the maxima and minima of the above function, we get the values such as "0.86" and "-0.13" respectively.

Table 27 Centre point analysis

Data	Results	Green	Resilient	Cost	Time	Quality
Data point 1	0.365	115	79	3,869	224	142,899
Data point 2	0.365	87	77	3,922	203	126,413
Data point 3	0.365	78	90	3,958	190	126,834
Data point 4	0.365	106	84	4,350	149	105,935
Data point 5	0.365	100	99	4,304	192	100,747
Data point 6	0.365	92	81	3,796	227	138,378
Data point 7	0.365	100	78	4,282	179	98,335
Data point 8	0.365	97	98	4,361	176	96,793
Data point 9	0.365	98	98	3,883	139	167,134
Data point 10	0.365	111	80	4,250	187	106,712
	Min	**78**	**69**	**3,796**	**134**	**96,793**
	Max	**115**	**102**	**4,361**	**227**	**167,134**
	Average	**97**	**85**	**4,084**	**177**	**124,755**

When we consider the maximum value of the function that comes to 0.86 we will notice that each criterion is satisfied 100 %. All the variable reach their desired min or max values. In real life this will not be the case, for all practical purposes we may consider the half-way point our criterion to determine the impact of supplier on business operations. Any supplier whose rating falls above the Average value as given in above table may be considered as contributing positively to green and resilient objective while ensuring traditional econometric and quality objectives. Given this a good green score is 97 while a good resilience score is 85 and not below. This is followed by cost 4084, time 177 and quality being 124,755 and not above.

Table 28 Individual Solution for each supplier

Supplier	Green	Resilience	Cost	Time	Quality	MCDM
Supplier 1	93.906	80.673	3987	165.61	53,333.33	0.62
Supplier 2	115.083	102.713	4402	245.61	66,666.67	0.41
Supplier 3	75.33	58.574	3787	149.61	35,000.00	0.71
Supplier 4	103.221	75.743	4072	125.61	200,000.00	0.19
Supplier 5	100.053	98.198	3822	149.61	40,000.00	0.77

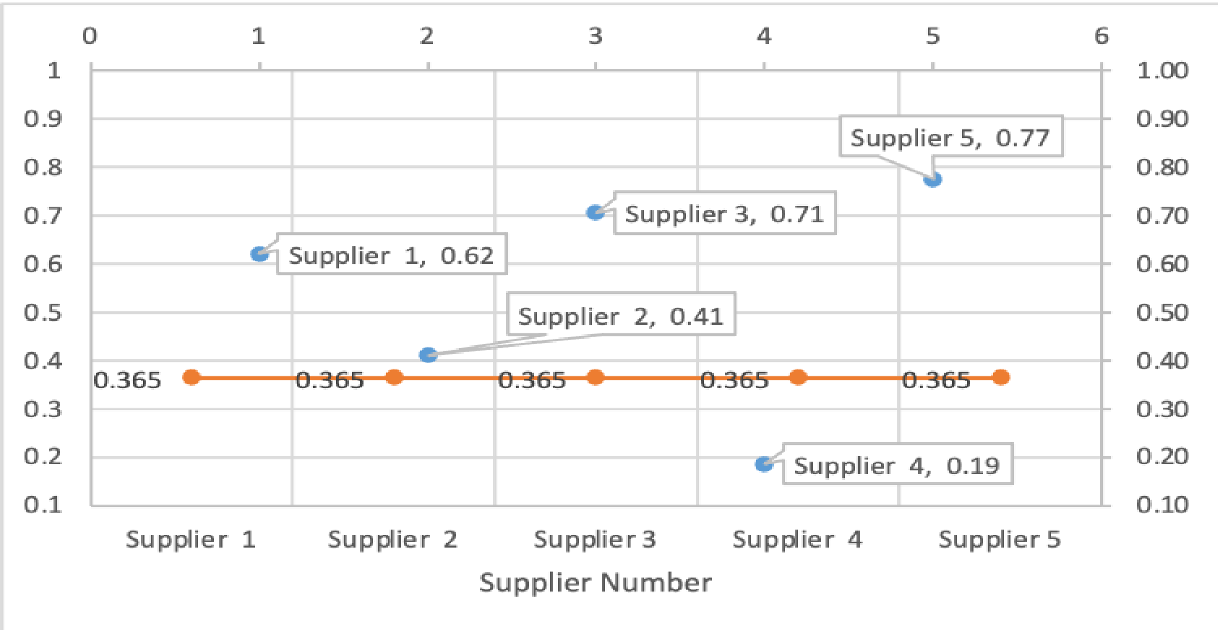

Figure 19 all supplier results combined

The above graph shows that four of selected suppliers are above the selected scale of selection. These will have positive impact on business operation. When we select supplier 4 we may face the consequences of bad quality even though cost and lead time is less. The best supplier is supplier 5 which is apparent based on very less quality observations.

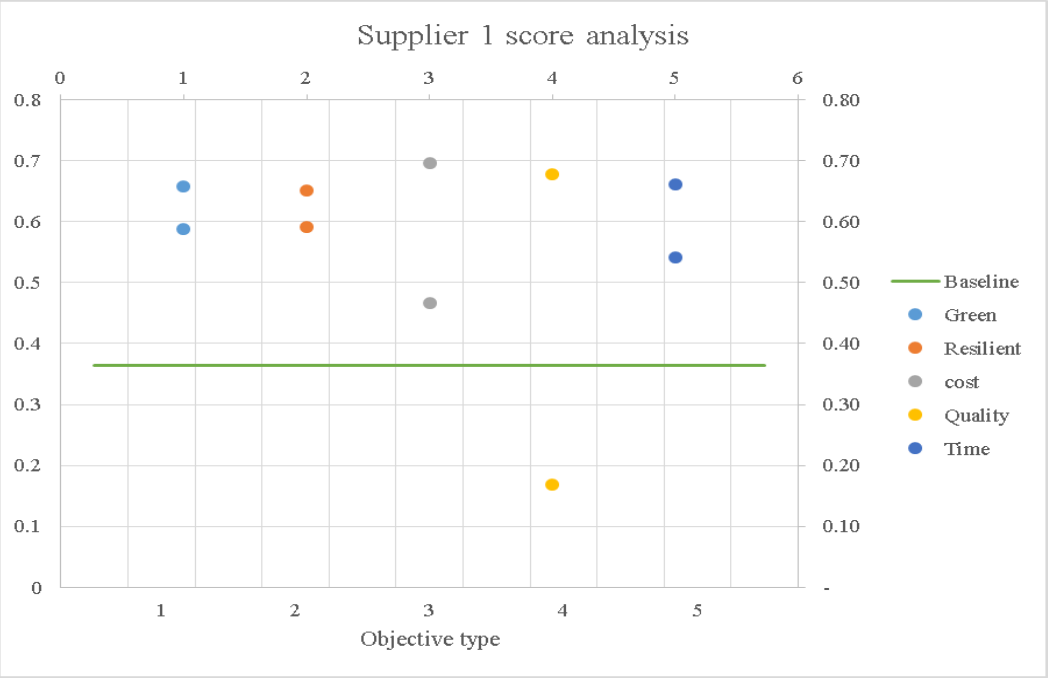

Figure 20 Supplier 1 analysis

We may also analyze the impact of variation of each objective. In the above graph supplier 1 rating is discussed with respect to variation of each objective.

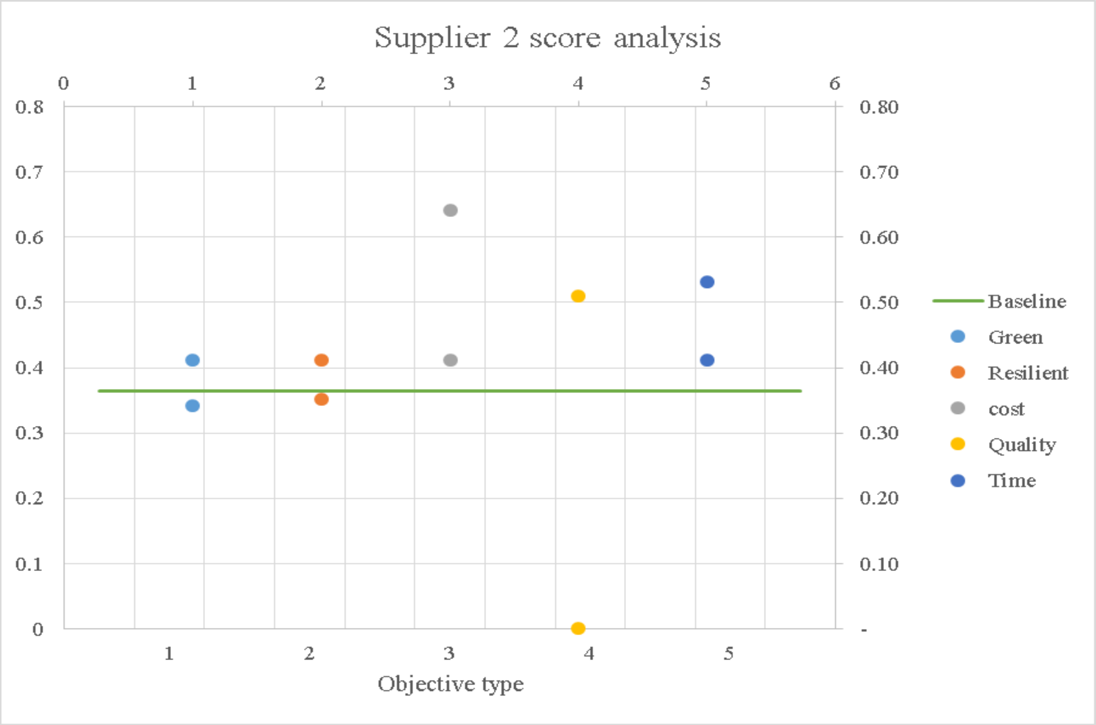

Figure 21 Supplier 2 analysis

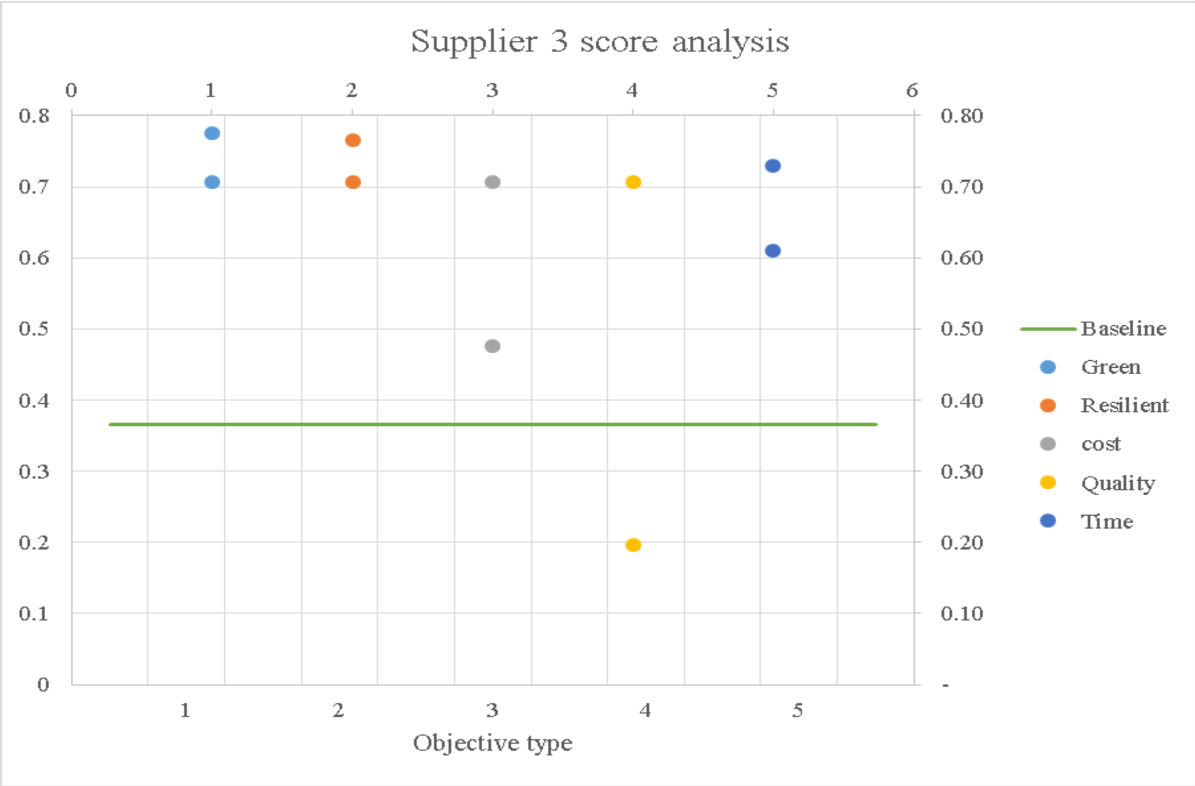

Figure 22 Supplier 3 analysis

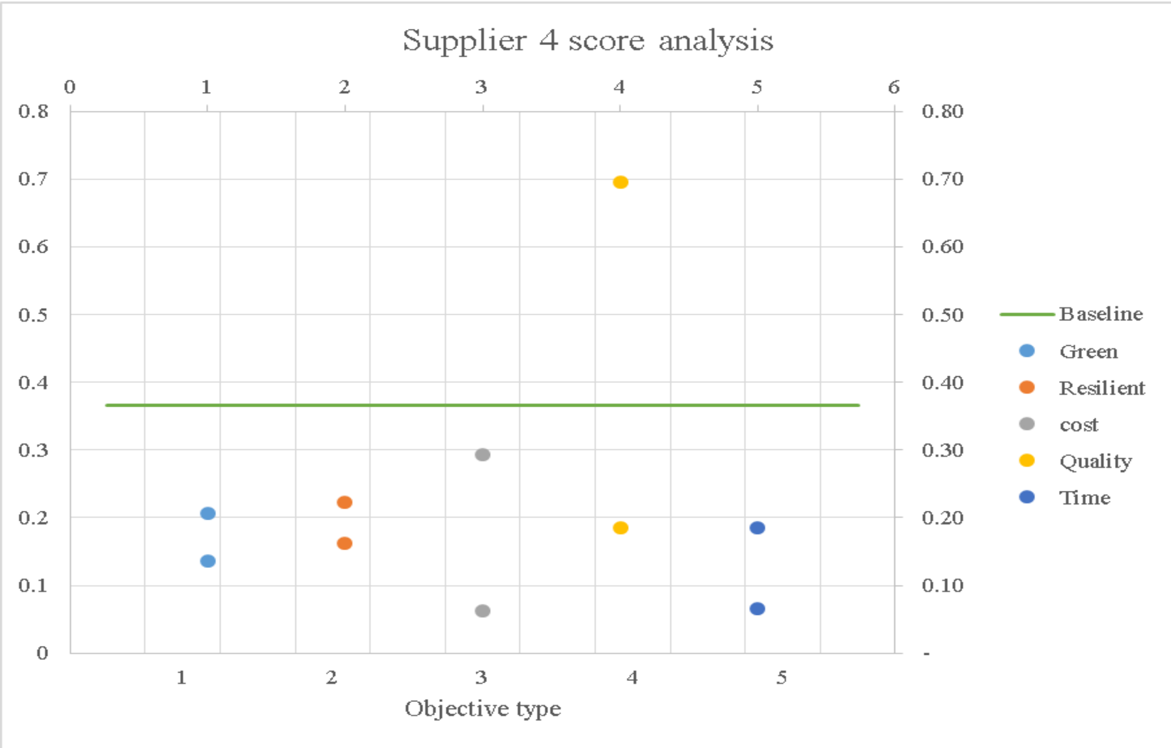

Figure 23 Supplier 4 analysis

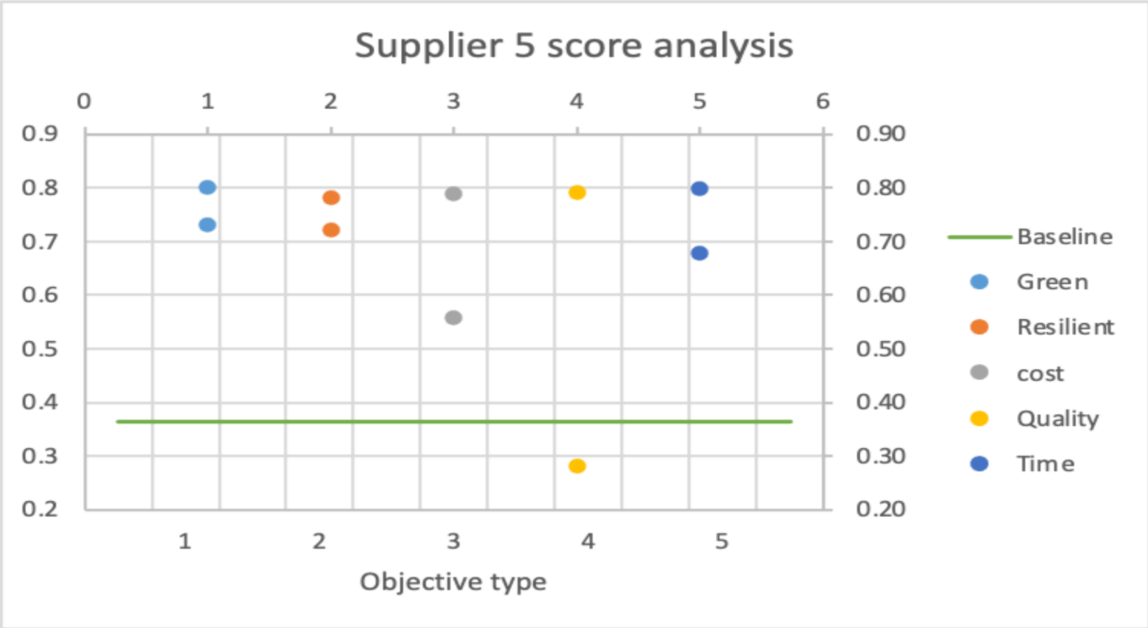

Figure 24 Supplier 5 analysis

CHAPTER 5 CONCLUSIONS AND FUTURE RESEARCH

In order to effectively manage the inventory and purchase component of cement plant supply chains, it is important to consider exchange rate fluctuations and supplier's resilience and impact on the environment. Being vigilant in monitoring the exchange rate change and placing orders where the prices are lower may yield saving of around 5% in case considered here as highest inventory cost is 685 million PKR vs lowest being 660 million PKR. The percentage saving may change as different or additional scenarios are considered. It is worth noting that purchase department must take upon the task of keeping track of forecasts and estimate beforehand the changes in prices for upcoming budget year. The model provides a guideline and further factors may be added specific to experience of certain Cement Plants. Specifically Cement Industry in Pakistan was studied therefore all considerations including target currencies were selected accordingly. The model can be further improved by incorporating inflation for local inventory items.

As Cement plants are major contributors of greenhouse gas emissions, the subject selection procedure is suitable in gauging on going purchase processes and aligning those for future targets of being green. The purchase process is also sensitive to disruption so resilience is built into the purchase process when using proposed model in study. The method was tested on locally manufactures steel items which successfully graded suppliers based on their overall performance not just the price. The supplier may also be communicated this data in order to build long term relations with them. The model helps in quantifying current and future state and can be utilized from supplier performance management as well. The model can be further improved by incorporating other new factors or additional sub factors.

5.1.Academic contribution

- Application of Grey Markov to forecast complete inventory
- Application of Grey Markov to forecast individual spare or raw material for input in supplier selection
- Combining exchange rate fluctuations, import purchase percentages and capacity utilization for scenario analysis in inventory cost function
- Combining resilient and green factors for supplier selection for Cement Plants

5.2.Practical contribution

- Improved forecast of spares and Inventory
- Minimization of Inventory cost
- Inclusion of green and resilient factors in purchase process
- Nurturing suppliers' relationships to improve ranking and scores on factors

5.3. Research Limitations

This research on supplier selection and inventory forecasting has certain limitations that should be acknowledged. Firstly, the study's reliability and generalizability may be influenced by the limited availability and varying quality of historical data on supplier performance and inventory levels. Additionally, the industry specificity of the research might restrict the transferability of findings to other sectors due to differences in supply chain dynamics, product characteristics, and demand patterns. The rapid pace of technological advancements poses a challenge, as the proposed strategies and models may become outdated in the face of emerging technologies. External environmental factors such as geopolitical events, economic downturns, or natural disasters may not be fully considered, impacting supplier performance and disrupting inventory forecasting models. Variability in organizational structures and strategies among companies may limit the general applicability of the research, and the study may not comprehensively account for human factors, including individual expertise and biases. The dynamic nature of market conditions, including changing demand, customer preferences, and competitive pressures, may not be fully addressed. The complexity of proposed models and resource requirements may hinder their practicality for small or resource-constrained organizations. Limited stakeholder perspectives, excluding insights from suppliers, customers, and logistics partners, may overlook critical considerations in the supply chain. Finally, the research's time frame may constrain the observation of long-term trends or cyclic patterns, affecting the assessment of proposed strategies over an extended period. Recognizing these limitations is essential for a nuanced interpretation of findings and future research enhancements.

5.4. Future Directions

Future research in supplier selection and inventory forecasting holds significant potential for advancing both theoretical understanding and practical applications. One promising avenue involves the integration of advanced artificial intelligence (AI) and machine learning (ML) techniques to improve the accuracy of supplier selection and enhance inventory forecasting. Another area of exploration is the application of block chain technology in supply chain management, aiming to enhance transparency, traceability, and efficiency, particularly in ethical and sustainable supplier selection processes. Researchers may also focus on developing dynamic risk management models capable of adapting to evolving external factors such as geopolitical events and economic fluctuations. Additionally, investigating the integration of demand sensing techniques and predictive analytics could lead to more responsive supply chain strategies and improved inventory forecasting accuracy. Cross-functional collaboration and communication within organizations, as well as the exploration of digital twins for simulating and optimizing supply chain processes, present opportunities for enhancing overall efficiency. Robotic process automation (RPA) is another area of interest, with potential applications in automating routine tasks related to supplier selection and inventory forecasting. Exploring innovative supplier relationship management (SRM) strategies and identifying best practices through benchmarking studies can further contribute to the improvement of supply chain performance. Overall, these future research directions aim to address emerging challenges and leverage technological advancements to advance the field of supplier selection and inventory forecasting.

Social factors such as providing for safe and healthy working conditions and Fight for fair-trading and against corruption in the model to make it more accurate. Further investigation can be done using Raw material or Fuels related to Cement Plants. The supplier relation with the plants can also if these results are shared for improving the supplier performance of each criterion. Long term plans can be set for procurement team based on all suppliers in system or based on next year forecasted procurement. The proposed model can be applied to other industries as well such as fertilizer, sugar etc. for inventory forecasting and cost estimation. This model is more suitable for plants with well-defined capacities. In future, in case of demand dependency only on market factors, certain growth rate metrics such as per capita consumptions and population growth may be incorporated to strengthen the analysis. The current model can be specifically applied to capital nature spares and depreciation value can be considered for better financial impact calculations. Comparison with other Grey Models may be carried out to further improve the accuracy of the forecast. Other factors such as change in import duties by Government or International sanctions may be added to scenario list to study the impact and improve the model. Further research can also be done by incorporating local currency inflation and discounting rates. Expert opinion may also be added further as a multiplicative factor (for example 0.95 or 0.97 etc.) for the forecast.

For practitioners, plant capacity utilization can be incorporated fully (historical data addition) in the model to better gauge the impact of prevailing market demand into the forecast. Another focused effort can be applied by specific selection of import local ratio by incorporating equipment inspection-based spares requirement into the model. For a business that has multiple plants, the analysis can be carried out on one cement line as well as all cement lines to estimate the specific or overall cost impact. Finding the impact of imported spares may help in deciding whether it is feasible to invest in developing local partner for manufacturing of some critical spares.

References

1. Addabo, T., Fort, A., Mugnaini, M., Vignoli, V., Simoni, E., Mancini, M., (2016). Availability and reliability modeling of multicore controlled UPS for datacenter applications. *Reliability Engineering & System Safety, 149*, 56-62.
2. Aggarwal, A., Kumar, S., Singh, V., (2015). Performance modeling of the skim milk powder production system of a dairy plant using RAMD.
3. Akbar, M., Ahmad, E., (2021). Repercussions of exchange rate depreciation on the economy of Pakistan: Simulation analysis using macro econometric model. *Journal of Policy Modeling*, *43*(3), 574-600. https://doi.org/10.1016/j.jpolmod.2020.06.007.
4. Ali, M., Boylan, J. E., Syntetos, A. A., (2011). On the relationship between forecast errors and inventory performance. *International Journal of Forecasting.* Advance online publication. http://doi:10.1016/j.ijforecast.2010.08.003
5. APCMA. (2020). Historical Analysis of Cement Production Capacity & Despatches (Operational Units Data). Retrieved from https://www.apcma.com/data_history.html.
6. Bestway Cement. (2022). Bestway Group Annual Report & Accounts 2022. Bestway Group. Retrieved from https://www.bestwaygroup.co.uk/files/annual-report-2022_dfalf.pdf.
7. Box, G. E. P., Jenkins, G. M., Reinsel, G. C., (1994). Time Series Analysis: Forecasting and Control (3rd ed.). Prentice-Hall, Englewood Cliffs, NJ.
8. Brown, R. G. (1959). Statistical Forecasting for Inventory Control. McGraw-Hill, New York.
9. Chen, C. H., Shen, Y., Ren, Y., (2021). Economic Decision-Making Algorithm for Cross-Border Industrial E-Commerce Material Purchase Quantity Based on Markov Chain. *Security and Communication Networks, 1939-0114,* 1439692. https://doi.org/10.1155/2021/1439692.
10. Chen, Z., Wang, X., (2012). Applying the Grey Forecasting Model to the Energy Supply Management Engineering. *Systems Engineering Procedia, 5,* 179-184. https://doi.org/10.1016/j.sepro.2012.04.029.
11. Choudhary, D., Tripathi, M., Shankar, R., (2019). Reliability, availability, and maintainability analysis of a cement plant: a case study. *International Journal of Quality & Reliability Management*, *36*(3), 298-313. https://doi.org/10.1108/IJQRM-10-2017-0215.

12. Chouhan, V., Goswami, S., Sharma, R. B., (2021). Use of proactive spare parts inventory management (PSPIM) techniques for material handling vis-à-vis cement industry. *Materials Today: Proceedings, 45*(6), 4383-4389. https://doi.org/10.1016/j.matpr.2020.11.757.
13. Darvishi, F., Ghasemy Yaghin, R., Sadeghi, A., (2020). Integrated fabric procurement and multi-site apparel production planning with cross-docking: A hybrid fuzzy-robust stochastic programming approach. *Applied Soft Computing, 92,* 106267. https://doi.org/10.1016/j.asoc.2020.106267.
14. Ding, Y., Ceglarek, D., Shi, J., (2002). Fault Diagnosis of Multistage Manufacturing Processes by Using State Space Approach. *Journal of Manufacturing Science and Engineering, 124*(2), 313-322. https://doi:10.1115/1.1445155 .
15. Dunkel, J., Fernández, A., Ortiz, R., Ossowski, S., (2011). Event-driven architecture for decision support in traffic management systems. *Expert Syst. Appl., 38*(6), 6530-6539.
16. Ebrahimi, S., Ghaderi, O., Saeed, B., (2021). Differences in Exchange Rate Effects on Production Growth: the Case of Iranian Industries. *Studies in Business and Economics, 15,* 16-35. https://doi.org/10.2478/sbe-2020-0042.
17. Ene, S., Öztürk, N., (2017). Grey modelling based forecasting system for return flow of end-of-life vehicles. *Technological Forecasting and Social Change, 115,* 155-166. https://doi.org/10.1016/j.techfore.2016.09.030.
18. Fan, Y. Y., (2022). DEMAND PREDICTION OF PRODUCTION MATERIALS AND SIMULATION OF PRODUCTION MANAGEMENT. *International Journal of Simulation Modelling (IJSIMM), 21*(4).
19. Goltsos, T. E., Syntetos, A. A., Glock, C. H., Ioannou, G., (2022). Inventory – forecasting: Mind the gap. *European Journal of Operational Research, 299*(2), 397-419. https://doi.org/10.1016/j.ejor.2021.07.040.
20. Hammami, R., Frein, Y., Hadj-Alouane, A. B., (2012). An international supplier selection model with inventory and transportation management decisions. *Flex Serv Manuf J, 24*(1), 4–27.
21. Holt, C. C., (1957). Forecasting Seasonals and Trends by Exponentially Weighted Moving Averages. O.N.R. Memorandum no. 52. Carnegie Institute of Technology, Pittsburgh, Pennsylvania.
22. Hu, X., Motwani, J., (2014). Minimizing downside risks for global sourcing under price-sensitive stochastic demand, exchange rate uncertainties, and supplier capacity

constraints. *International Journal of Production Economics, 147,* 398-409. https://doi:10.1016/j.ijpe.2013.04.045 .

23. Jia, Z. Q., Zhou, Z. F., Zhang, H. J., Li, B., Zhang, Y. (2020). Forecast of coal consumption in Gansu Province based on Grey-Markov chain model. *Energy, 199,* 117444. https://doi.org/10.1016/j.energy.2020.117444.
24. Khakbaz, A., Mensi, W., Tirkolaee, E. B., Hammoudeh, S., Simic, V., (2023). The combined effects of interest and inflation rates on inventory systems: A comparative analysis across countries. *International Journal of Production Economics, 266,* 109035. https://doi.org/10.1016/j.ijpe.2023.109035.
25. Li, O., Liu, B., Li, C., & Gao, D. (2020). Demand Forecast of Weapon Equipment Spare Parts Based on Improved Gray-Markov Model. *International Journal of Advanced Network, Monitoring and Controls, 5*(3), 47-56. https://doi.org/10.21307/ijanmc-2020-027.
26. Liu, X., & Shen, D. Y. (2022). Application of Grey Markov Prediction Model in Airline EDP Maintenance Requirement Decision. In 2022 5th World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM) (pp. 349-354). IEEE.
27. MAO Zhan-li, SUN Jin-hua (2011). Application of Grey-Markov Model in Forecasting Fire Accidents. *Procedia Engineering, 11,* 314-318. https://doi.org/10.1016/j.proeng.2011.04.663.
28. Mishra, R. S., Kumar, R., Dhingra, S., Sengupta, S., Sharma, T., Gautam, G. D., (2022). Adaptive grey model (AGM) approach for judgmental forecasting in short-term manufacturing demand. *Materials Today: Proceedings, 56*(6), 3740-3746. https://doi.org/10.1016/j.matpr.2021.12.531.
29. Mohaddes, K., Raissi, M., (2020). Compilation, Revision and Updating of the Global VAR (GVAR) Database, 1979Q2-2019Q4. University of Cambridge: Judge Business School (mimeo).
30. Nia, A. R., Awasthi, A., Bhuiyan, N., (2021). Industry 4.0 and demand forecasting of the energy supply chain: A literature review. *Computers & Industrial Engineering, 154,* 107128.
31. Ogunranti, G. A., Ceryan, O., Banerjee, A., (2021). Buyer-supplier currency exchange rate flexibility contracts in global supply chains. *European Journal of Operational Research, 288*(2), 420-435. https://doi.org/10.1016/j.ejor.2020.05.053.

32. Rostami-Tabar, B., Hasni, M., Babai, M. Z., (2022). On the inventory performance of demand forecasting methods of medical items in humanitarian operations. *IFAC-PapersOnLine*, *55*(10), 2737-2742. https://doi.org/10.1016/j.ifacol.2022.10.132.
33. Rushton, R., Lorraine, O., Tiong, J., Karim, M., Dixon, R., Greenshields, W., Marotti, R., Bretaña, N. A., (2023). Forecasting inventory for the state-wide pharmaceutical service of South Australia. *Procedia Computer Science, 219,* 1257-1264. https://doi.org/10.1016/j.procs.2023.01.409.
34. Virtanen, P., et al. (2020). SciPy 1.0: fundamental algorithms for scientific computing in Python. *Nature methods*, *17*(3), 261-272.
35. Winters, P. (1960). Forecasting sales by exponentially weighted moving averages. *Management Science*, *6,* 324-342.
36. Xie, X., Liu, X., Blanco, C., (2023). Evaluating and forecasting the niche fitness of regional innovation ecosystems: A comparative evaluation of different optimized grey models. *Technological Forecasting and Social Change, 191,* 122473. https://doi.org/10.1016/j.techfore.2023.122473.
37. Yao, Y. M., Wang, J., Zhou, Z. C., et al. (2023). Grey Markov prediction-based hierarchical model predictive control energy management for fuel cell/battery hybrid unmanned aerial vehicles. *Energy, 262,* 125405. https://doi:10.1016/j.energy.2022.125405 .
38. Zarindast, A., Hosseini, S. M. S., Pishvaee, M. S., (2017). A robust multi-objective global supplier selection model under currency fluctuation and price discount. *Journal of Industrial Engineering International, 13,* 161-169. https://doi.org/10.1007/s40092-016-0177-3.
39. Zhao, H., Guo, S., (2016). An optimized grey model for annual power load forecasting. *Energy, 107,* 272-286. https://doi.org/10.1016/j.energy.2016.04.009.
40. Zhao, L. T., Zheng, Z. Y., Wei, Y. M., (2023). Forecasting oil inventory changes with Google trends: A hybrid wavelet decomposer and ARDL-SVR ensemble model. *Energy Economics*, *120,* 106603. https://doi.org/10.1016/j.eneco.2023.106603.
41. Zhu, S., van Jaarsveld, W., Dekker, R., (2020). Spare parts inventory control based on maintenance planning. *Reliability Engineering & System Safety, 193,* 106600. https://doi.org/10.1016/j.ress.2019.106600
42. Bartosz Paradowski, Zdzisław Szyjewski, Comparative analyses of multi-criteria methods in supplier selection problem, Procedia Computer Science, Volume 207, 2022, Pages 4593-4602, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2022.09.523 .

43. Cao, Qingwei, Wu, Jian, and Liang, Changyong. ‘An Intuitionsitic Fuzzy Judgement Matrix and TOPSIS Integrated Multi-criteria Decision Making Method for Green Supplier Selection’. 1 Jan. 2015 : 117 – 126.
44. Demir, L., Akpınar, M. E., Araz, C., & Ilgın, M. A. (2018). A green supplier evaluation system based on a new multi-criteria sorting method: VIKORSORT. Expert Systems with Applications, 114, 479-487.
45. Fang Zhou, Ting-Yu Chen, A hybrid group decision-making approach involving Pythagorean fuzzy uncertainty for green supplier selection, International Journal of Production Economics, Volume 261, 2023, 108875, ISSN 0925-5273, https://doi.org/10.1016/j.ijpe.2023.108875.
46. Fariba Goodarzi, Vahid Abdollahzadeh, Masoomeh Zeinalnezhad, An integrated multi-criteria decision-making and multi-objective optimization framework for green supplier evaluation and optimal order allocation under uncertainty, Decision Analytics Journal, Volume 4, 2022, 100087, ISSN 2772-6622, https://doi.org/10.1016/j.dajour.2022.100087 .
47. G.W. Dickson, An analysis of vendor selection systems and decisions, J. Purchasing, 2 (1) (1966), pp. 5-17, 10.1111/j.1745-493X.1966.tb00818.x
48. Ghodsypour, S. H., & O’brien, C. (2001). The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint. International journal of production economics, 73(1), 15-27.
49. Harshad Sonar, Angappa Gunasekaran, Swati Agrawal, Matthew Roy, Role of lean, agile, resilient, green, and sustainable paradigm in supplier selection, Cleaner Logistics and Supply Chain, Volume 4, 2022, 100059, ISSN 2772-3909, https://doi.org/10.1016/j.clscn.2022.100059.
50. Hossein Mirzaee, Hamed Samarghandi, Keith Willoughby, A robust optimization model for green supplier selection and order allocation in a closed-loop supply chain considering cap-and-trade mechanism, Expert Systems with Applications, Volume 228, 2023, 120423, ISSN 0957-4174, https://doi.org/10.1016/j.eswa.2023.120423.
51. Qin, J., Liu, X., & Pedrycz, W. (2017). An extended TODIM multi-criteria group decision making method for green supplier selection in interval type-2 fuzzy environment. European Journal of Operational Research, 258(2), 626-638.
52. Jing et al, 2019 present their work on Maintenance, Repair, and Operations Parts Inventory Management in the Era of Industry 4.0,

53. Jing Li, Hong Fang, Wenyan Song, Sustainable supplier selection based on SSCM practices: A rough cloud TOPSIS approach, Journal of Cleaner Production, Volume 222, 2019, Pages 606-621, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2019.03.070 .
54. Jothi Basu R, Muhammad D. Abdulrahman, M. Yuvaraj, Improving agility and resilience of automotive spares supply chain: The additive manufacturing enabled truck model, Socio-Economic Planning Sciences, Volume 85, 2023, 101401, ISSN 0038-0121, https://doi.org/10.1016/j.seps.2022.101401.
55. Khattak et. al, 2022 have incorporated management opinion in Green Supplier selection model using QFD and interactive fuzzy programming
56. Wei, G., Wei, C., & Guo, Y. (2021). EDAS method for probabilistic linguistic multiple attribute group decision making and their application to green supplier selection. Soft Computing, 25(14), 9045-9053.
57. Lu, J., Zhang, S., Wu, J., & Wei, Y. (2021). COPRAS method for multiple attribute group decision making under picture fuzzy environment and their application to green supplier selection. Technological and economic development of economy, 27(2), 369-385.
58. Malika-Sofi Akhmatova, Antonina Deniskina, Dzhennet-Mari Akhmatova, Anna Kapustkina, Green SCM and TQM for reducing environmental impacts and enhancing performance in the aviation spares supply chain, Transportation Research Procedia, Volume 63, 2022, Pages 1505-1511, ISSN 2352-1465, https://doi.org/10.1016/j.trpro.2022.06.162.
59. Mario Angos Mediavilla, Fabian Dietrich, Daniel Palm, Review and analysis of artificial intelligence methods for demand forecasting in supply chain management, Procedia CIRP, Volume 107, 2022, Pages 1126-1131, ISSN 2212-8271, https://doi.org/10.1016/j.procir.2022.05.119 .
60. Mostafa Hajiaghaei-Keshteli, Zeynep Cenk, Babek Erdebilli, Yavuz Selim Özdemir, Fatemeh Gholian-Jouybari, Pythagorean Fuzzy TOPSIS Method for Green Supplier Selection in the Food Industry, Expert Systems with Applications, Volume 224, 2023, 120036, ISSN 0957-4174, https://doi.org/10.1016/j.eswa.2023.120036.
61. Muhammad Imran, Changwook Kang, Muhammad Babar Ramzan, Medicine supply chain model for an integrated healthcare system with uncertain product complaints, Journal of Manufacturing Systems, Volume 46, 2018, Pages 13-28, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2017.10.006.

62. Bari, A. M., Siraj, M. T., Paul, S. K., & Khan, S. A. (2022). A Hybrid Multi-Criteria Decision-Making approach for analysing operational hazards in heavy fuel oil-based power plants. Decision Analytics Journal, 3, 100069.
63. Muhammad Imran, Changwook Kang, Muhammad Babar Ramzan, Medicine supply chain model for an integrated healthcare system with uncertain product complaints, Journal of Manufacturing Systems, Volume 46, 2018, Pages 13-28, ISSN 0278-6125, https://doi.org/10.1016/j.jmsy.2017.10.006.
64. Ozlem et al.,,2015 have mentioned Determinants of the Green Supplier Selection.
65. P. Cash, O. Isaksson, A. Maier, J. Summers, Sampling in design research: Eight key considerations, Des. Stud. 78 (2022) 101077.
66. R. Rajesh, Technological capabilities and supply chain resilience of firms: A relational analysis using Total Interpretive Structural Modeling (TISM), Technol. Forecast. Soc. Chang., 118 (2017), pp. 161-169
67. Ramzi Hammami, Cecilia Temponi, Yannick Frein, A scenario-based stochastic model for supplier selection in global context with multiple buyers, currency fluctuation uncertainties, and price discounts, European Journal of Operational Research, Volume 233, Issue 1, 2014, Pages 159-170, ISSN 0377-2217,
68. S. Belay, J. Goedert, A. Woldesenbet, S. Rokooei, AHP based multi criteria decision analysis of success factors to enhance decision making in infrastructure construction projects, Cogent Eng. 9 (1) (2022) 2043996.
69. S.Y. Ponomarov, M.C. Holcomb, Understanding the concept of supply chain resilience, Int J Logist Manag (2009)
70. Sajad et al, 2021 propose a fuzzy Delphi analytic hierarchy model to rank factors influencing public transit mode choice which may be useful for fuzzy parameters in our study
71. Salman Nazari-Shirkouhi, Mahdokht Tavakoli, Kannan Govindan, Saeed Mousakhani, A hybrid approach using Z-number DEA model and Artificial Neural Network for Resilient supplier selection, Expert Systems with Applications, Volume 222, 2023, 119746, ISSN 0957-4174, https://doi.org/10.1016/j.eswa.2023.119746.
72. V. Sharma, R.D. Raut, S.K. Mangla, B.E. Narkhede, S. Luthra, R. Gokhale, A systematic literature review to integrate lean, agile, resilient, green and sustainable paradigms in the supply chain management, Business Strat. Environ. (2020), pp. 1-22.

73. Sharma, D. G., & Rawani, A. M. (2016). Green supplier selection for Indian cement industry: AHP based approach. International Research Journal of Engineering and Technology, 3(4), 2368-2373.
74. Singh, R. K., & Modgil, S. (2020). Supplier selection using SWARA and WASPAS–a case study of Indian cement industry. Measuring Business Excellence, 24(2), 243-265.
75. Mabrouk, N. (2021). Green supplier selection using fuzzy Delphi method for developing sustainable supply chain. Decision Science Letters, 10(1), 63-70.
76. Kumar, M., Vrat, P., & Shankar, R. (2004). A fuzzy goal programming approach for vendor selection problem in a supply chain. Computers & industrial engineering, 46(1), 69-85.
77. Negar Karimi, Mohammad Reza Feylizadeh, Kannan Govindan, Morteza Bagherpour, Fuzzy multi-objective programming: A systematic literature review, Expert Systems with Applications, Volume 196, 2022, 116663, ISSN 0957-4174, https://doi.org/10.1016/j.eswa.2022.116663 .
78. Ku, C. Y., Chang, C. T., & Ho, H. P. (2010). Global supplier selection using fuzzy analytic hierarchy process and fuzzy goal programming. Quality & Quantity, 44, 623-640.
79. Siguaw JA, Simpson PM. Toward assessing supplier value: usage and importance of supplier selection, retention, and value-added criteria. Journal of Marketing Channels. 2004 Mar 15;11(2-3):3-1. https://doi.org/10.1300/J049v11n02_02.
80. Sushil Punia, Sonali Shankar, Predictive analytics for demand forecasting: A deep learning-based decision support system, Knowledge-Based Systems, 2022, 109956, ISSN 0950-7051, https://doi.org/10.1016/j.knosys.2022.109956.
81. Tijo M Joy, K.S. Aneesh, V. Sreekumar, Analysis of a decision support system for supplier selection in glove industry, Materials Today: Proceedings, Volume 72, Part 6, 2023, Pages 3186-3192, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2022.11.344
82. Youpeng etal, 2021 have developed a modified Teunter-Syntetos-Babai method for intermittent demand forecasting, which may be useful in estimating demand of MRO spare parts
83. Yunna et al.,, 2019 propose an integrated decision-making model for sustainable photovoltaic module supplier selection based on combined weight and cumulative prospect theory

84. Tang, J., Zhang, Y. E., Tu, Y., Chen, Y., & Dong, Y. (2005). Synthesis, evaluation, and selection of parts design scheme in supplier involved product development. Concurrent Engineering, 13(4), 277-289. https://doi.org/10.1177/1063293X05059806
85. Siddiquee, M., Shaha, P., & Hasin, A. (2024). Greening the pillars of pharmaceuticals: Sustainable supplier selection in emerging economies. Journal of Future Sustainability, 4(3), 159-168.
86. Talon, A., & Curt, C. (2017). Selection of appropriate defuzzification methods: Application to the assessment of dam performance. Expert Systems with Applications, 70, 160-174.
87. Mery Ellen Brandt de Oliveira, Francisco Rodrigues Lima-Junior, Nadya Regina Galo, A comparison of hesitant fuzzy VIKOR methods for supplier selection, Applied Soft Computing, Volume 149, Part A, 2023, 110920, ISSN 1568-4946, https://doi.org/10.1016/j.asoc.2023.110920.
88. Ahmad Abdulla, George Baryannis, Ibrahim Badi, An integrated machine learning and MARCOS method for supplier evaluation and selection, Decision Analytics Journal, Volume 9, 2023, 100342, ISSN 2772-6622, https://doi.org/10.1016/j.dajour.2023.100342. (https://www.sciencedirect.com/science/article/pii/S2772662223001820)
89. Vanessa Batista Schramm, Luciana Priscila Barros Cabral, Fernando Schramm, Approaches for supporting sustainable supplier selection - A literature review, Journal of Cleaner Production, Volume 273, 2020, 123089, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.123089. (https://www.sciencedirect.com/science/article/pii/S0959652620331346)
90. Tian, X., Niu, M., Zhang, W., Li, L., & Herrera Viedma, E. (2020). A novel TODIM based on prospect theory to select green supplier with q-rung orthopair fuzzy set.
91. Sharafi, H., Soltanifar, M., & Lotfi, F. H. (2022). Selecting a green supplier utilizing the new fuzzy voting model and the fuzzy combinative distance-based assessment method. EURO Journal on Decision Processes, 10, 100010.
92. Abdullah, S., Qiyas, M., Naeem, M., & Liu, Y. (2022). Pythagorean Cubic fuzzy Hamacher aggregation operators and their application in green supply selection problem. AIMS Mathematics, 7(3), 4735-4766.
93. Murry, J.W. and Hammons, J.O. (1995) Delphi: A Versatile Methodology for Conducting Qualitative Research. The Review of Higher Education, 18, 426-436. https://doi.org/10.1353/rhe.1995.0008

94. Hallowell, J.A. Gambatese Qualitative research: application of the Delphi method to CEM research, J. Constr. Eng. Manag., 136 (1) (2010), pp. 99-107
95. Md. Ramjan Ali, Shah Md. Ashiquzzaman Nipu, Sharfuddin Ahmed Khan, A decision support system for classifying supplier selection criteria using machine learning and random forest approach, Decision Analytics Journal, Volume 7, 2023, 100238, ISSN 2772-6622, https://doi.org/10.1016/j.dajour.2023.100238.
96. Tushar, Z. N., Bari, A. M., & Khan, M. A. (2022). Circular supplier selection in the construction industry: A sustainability perspective for the emerging economies. Sustainable Manufacturing and Service Economics, 1, 100005.
97. Shyur, H. J., & Shih, H. S. (2006). A hybrid MCDM model for strategic vendor selection. Mathematical and computer modelling, 44(7-8), 749-761.
98. Sawik, B. (2013). Survey of multi-objective portfolio optimization by linear and mixed integer programming. In Applications of management science (pp. 55-79). Emerald Group Publishing Limited.
99. Pramanik, D., Haldar, A., Mondal, S. C., Naskar, S. K., & Ray, A. (2017). Resilient supplier selection using AHP-TOPSIS-QFD under a fuzzy environment. International journal of management science and engineering management, 12(1), 45-54.
100. Haldar, A., Ray, A., Banerjee, D., & Ghosh, S. (2014). Resilient supplier selection under a fuzzy environment. International Journal of Management Science and Engineering Management, 9(2), 147-156.
101. Ghosh, T., Chakraborty, T., & Dan, P. K. (2012). An effective AHP-based metaheuristic approach to solve supplier selection problem. International Journal of Procurement Management, 5(2), 140-159.
102. Torabi, S. A., Baghersad, M., & Mansouri, S. A. (2015). Resilient supplier selection and order allocation under operational and disruption risks. Transportation research part e: logistics and transportation review, 79, 22-48.
103. Prasad, K. D., Prasad, M., Rao, S. B., & Patro, C. S. (2016). Supplier selection through AHP-VIKOR integrated methodology. SSRG International Journal of Industrial Engineering, 3(5), 1-6.
104. Rajesh, R., & Ravi, V. (2015). Supplier selection in resilient supply chains: a grey relational analysis approach. Journal of cleaner production, 86, 343-359.
105. Mühlbacher, A. C., & Kaczynski, A. (2016). Making good decisions in healthcare with multi-criteria decision analysis: the use, current research and future development of MCDA. Applied health economics and health policy, 14, 29-40.

106. Foroozesh, N., Jolai, F., Mousavi, S. M., & Karimi, B. (2021). A new fuzzy-stochastic compromise ratio approach for green supplier selection problem with interval-valued possibilistic statistical information. Neural Computing and Applications, 33, 7893-7911.

107. Parkouhi, S. V., Ghadikolaei, A. S., & Lajimi, H. F. (2019). Resilient supplier selection and segmentation in grey environment. Journal of cleaner production, 207, 1123-1137.

108. Davoudabadi, R., Mousavi, S. M., & Sharifi, E. (2020). An integrated weighting and ranking model based on entropy, DEA and PCA considering two aggregation approaches for resilient supplier selection problem. Journal of Computational Science, 40, 101074.

109. Zarei, E., Ramavandi, B., Darabi, A. H., & Omidvar, M. (2021). A framework for resilience assessment in process systems using a fuzzy hybrid MCDM model. Journal of Loss Prevention in the Process Industries, 69, 104375.

110. Tsai, C. M., Lee, H. S., & Gan, G. Y. (2021). A new fuzzy DEA model for solving the MCDM problems in supplier selection. Journal of Marine Science and Technology, 29(1), 7.

111. S. Pazhani, J. A. Ventura, A. Mendoza, A serial inventory system with supplier selection and order quantity allocation considering transportation costs, Appl. Math. Model., 40 (2016), 612–634.

112. R. M. Monczka, R. Trent, R. B. Handfield, Purchasing & Supply Chain Management, Cengage Learning, 2015

A. Mendoza, J. A. Ventura, Modeling actual transportation costs in supplier selection and order quantity allocation decisions, Oper. Res., 13 (2013), 5–25

113. Panigrahi, C. M. A. (2013). Relationship between inventory management and profitability: An empirical analysis of Indian cement companies. Asia Pacific Journal of Marketing & Management Review, 2(7).

114. Koumanakos, D. P. (2008). The effect of inventory management on firm performance. International journal of productivity and performance management, 57(5),

115. Janjua, A. R., Asghar, A., Munir, U., Raza, A., Akhtar, N., & Shahzad, K. (2016). Influence of Liquidity on Profitability of Cement Sector: Indication from Firms Listed in Pakistan Stock Exchange. Business Management Dynamics, 6(5). 355-369.

116. Ghodsypour, S.H., and O‟Brien, C., "A Decision Support System for Supplier Selection Using an Integrated Analytic Hierarchy Process and Linear Programming", International Journal of Production Economics, vol. 56-57, pp. 199-212, 1998.
117. Onut, S., Kara, S.S., and Işık, E, "Long Term Supplier Selection Using a Combined Fuzzy MCDM Approach: A Case Study for a Telecommunication Company", Expert Systems with Applications, vol. 36, pp. 3887-3895, 2009.
118. Liao, C.N., and Kao, H.P., "An Integrated Fuzzy TOPSIS and MCGP Approach to Supplier Selection in Supply Chain Management", Expert Systems with Application, vol. 38, pp. 803-1081, 2011.
119. Warren Liao, T., & Chang, P. C. (2010). Impacts of forecast, inventory policy, and lead time on supply chain inventory—A numerical study. International Journal of Production Economics, 128(2), 527–537. https://doi.org/10.1016/j.ijpe.2010.07.002
120. Kaufmann & Gupta (1988), Fuzzy mathematical models in engineering and management science, Elsevier Science, New York (1988)
121. Chen, S.-M. (1996). Evaluating weapon systems using fuzzy arithmetic operations. *Fuzzy Sets and Systems*, *77*(3), 265–276. https://doi.org/10.1016/0165-0114(95)00096-8
122. Cheng, C.-B. (2004). Group opinion aggregationbased on a grading process: A method for constructing triangular fuzzy numbers. *Computers & Mathematics with Applications*, *48*(10–11), 1619–1632. https://doi.org/10.1016/j.camwa.2004.03.008
123. Huang, Y.-S., & Chang, C.-C. (2004). A study of defuzzification with experts' knowledge for deteriorating repairable systems. *European Journal of Operational Research*, *157*(3), 658–670. https://doi.org/10.1016/S0377-2217(03)00270-4
124. Khemiri, R., Naija, M., & Exposito, E. (2023). Dispatching and rebalancing for ride-sharing autonomous mobility-on-demand systems based on a fuzzy multi-criteria approach.*Soft Computing*, *27*(4), 2041–2069.https://doi.org/10.1007/s00500-022-07377-1
125. Zhao, R., & Govind, R. (1991). Algebraic characteristics of extended fuzzy numbers. *Information Sciences*, *54*(1–2), 103–130. https://doi.org/10.1016/0020-0255(91)90047-X

APPENDICES

1. Questionnaire for Green Parameters

Marked by experts on Likert scale

I. All packaging is non-recyclable, in your opinion is this necessary to consider when evaluating Green Supplier

II. All Primary Packaging is recyclable, in your opinion is this necessary to consider when evaluating Green Supplier

III. Both Primary and Secondary Packaging is recyclable, in your opinion is this necessary to consider when evaluating Green Supplier

IV. "Primary and Secondary packaging is recyclable along and tertiary packaging is returnable, in your opinion is this necessary to consider when evaluating Green Supplier"

V. No Energy Monitoring is in place, in your opinion is this necessary to consider when evaluating Green Supplier

VI. Energy Monitoring in place with, Analysis and Saving Policies, in your opinion is this necessary to consider when evaluating Green Supplier

VII. Energy friendly resources being used in manufacturing processes, in your opinion is this necessary to consider when evaluating Green Supplier

VIII. ISO 50001 Energy Management System Certified, in your opinion is this necessary to consider when evaluating Green Supplier

IX. Non-recyclable Raw materials are being used, in your opinion is this necessary to consider when evaluating Green Supplier

X. Non-recyclable Raw materials are being used, in your opinion is this necessary to consider when evaluating Green Supplier

XI. Primary Raw materials are recyclable, in your opinion is this necessary to consider when evaluating Green Supplier

XII. Primary Raw materials are Compostable or biodegradable materials, in your opinion is this necessary to consider when evaluating Green Supplier

XIII. Recyclable primary raw materials using as Secondary Raw materials, in your opinion is this necessary to consider when evaluating Green Supplier

XIV. No Green House Gas emissions monitoring and control in place, in your opinion is this necessary to consider when evaluating Green Supplier

XV. Green House Gas emissions control policies in place without reduction, in your opinion is this necessary to consider when evaluating Green Supplier

XVI. Green House Gas emissions reduction policies in place like carbon cap and trade, carbon tax, in your opinion is this necessary to consider when evaluating Green Supplier

XVII. ISO 14064 Environmental Management or other related certifications acquired, in your opinion is this necessary to consider when evaluating Green Supplier

XVIII. Air Pollution Control during transportation, in your opinion what level is necessary to consider when evaluating Green Supplier

XIX. Passing ISO 14000 Environmental Management or other environmental Certifications, in your opinion what level is necessary to consider when evaluating Green Supplier

XX. Degree of having environmentally friendly plans & policies, in your opinion what level is necessary to consider when evaluating Green Supplier

XXI. No Water Conservation, No Waste Water Generation Monitoring, and Record, in your opinion is this necessary to consider when evaluating Green Supplier

XXII. Water Conservation Objectives and Policies in place, in your opinion is this necessary to consider when evaluating Green Supplier

XXIII. Recycling and Reuse of Natural Water e.g. rainwater harvesting technologies being used, in your opinion is this necessary to consider when evaluating Green Supplier

XXIV. Wastewater Treatment Plant in use, in your opinion is this necessary to consider when evaluating Green Supplier

XXV. Solid waste treatment, in your opinion what’s the most suitable from below options to consider when evaluating Green Supplier

2. Questionnaire for Resilient Parameters

Marked by experts on Likert scale

I. Dealing directly with their buyers and suppliers to reduce complexity in supply chain, in your opinion is this necessary to consider when evaluating Resilient Supplier

II. keeping multiple suppliers to avoid the risk of supply, in your opinion is this necessary to consider when evaluating Resilient Supplier

III. keeping multiple buyers to avoid the buyers’ disruptions, in your opinion is this necessary to consider when evaluating Resilient Supplier

IV. Being critically dependent on specific supplier, in your opinion is this necessary to consider when evaluating Resilient Supplier

V. Critical distribution center which is responsible to distribute many other distributions center, in your opinion is this necessary to consider when evaluating Resilient Supplier

VI. Considering alternative transportation options, in your opinion is this necessary to consider when evaluating Resilient Supplier

VII. Buyers are not concentrated to specific geographic region, in your opinion is this necessary to consider when evaluating Resilient Supplier

VIII. "Selection of suppliers from diversified region (alternative supplier) to avoid the risk of supply in specific area, in your opinion is this necessary to consider when evaluating Resilient Supplier"

IX. "Production facility in different area (alternative production facility) to avoid risk of operational disruption in specific area, in your opinion is this necessary to consider when evaluating Resilient Supplier"

X. Idle capacity and waste, in your opinion is this necessary to consider when evaluating Resilient Supplier

XI. Efficient employees, in your opinion is this necessary to consider when evaluating Resilient Supplier

XII. Strong quality control process, in your opinion is this necessary to consider when evaluating Resilient Supplier

XIII. Flexibility in production in terms of volume of order and production schedule, in your opinion is this necessary to consider when evaluating Resilient Supplier

XIV. Different types of products being dealt to meet customer requirements, in your opinion is this necessary to consider when evaluating Resilient Supplier

XV. Multi-skilled workforce is available to continue production, in your opinion is this necessary to consider when evaluating Resilient Supplier

XVI. Contract flexibility such as partial order, partial payment, partial shipment etc., in your opinion is this necessary to consider when evaluating Resilient Supplier

XVII. Capability of introducing new product, in your opinion is this necessary to consider when evaluating Resilient Supplier

XVIII. Enough fund available to mitigate disruptions, in your opinion is this necessary to consider when evaluating Resilient Supplier

XIX. Consistent Profit over the last couple of years, in your opinion is this necessary to consider when evaluating Resilient Supplier

XX. Insurance against potential damage and destruction, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXI. Back up capacity for machinery, parts and logistical supports, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXII. Availability of Buffer stock for raw material, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXIII. Backup energy/utility source, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXIV. Able to recover in short time, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXV. Reduction in impact of loss by our ability to handle crisis, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXVI. Able to Recover from crisis at less cost, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXVII. Ability to detect Supply Chain disruptions quickly, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXVIII. Readiness training for overcoming crisis, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXIX. Resources to get ready during crisis, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXX. Forecasting for meeting demand disruptions, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXXI. Strong security system to protect man-made crisis, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXXII. Quick response to disruptions, in your opinion is this necessary to consider when evaluating Resilient Supplier

XXXIII. Response team available for mitigating crisis, in your opinion is this necessary to consider when evaluating Resilient Supplier

3. Questionnaire for weightage for each Criterion

Marked by experts on Likert Scale

I. In your opinion, what is the relative importance of Cost in supplier selection process
II. In your opinion, what is the relative importance of Quality in supplier selection process
III. In your opinion, what is the relative importance of Lead Time in supplier selection process
IV. In your opinion, what is the relative importance of Green Factors in supplier selection process
V. In your opinion, what is the relative importance of Resilience in supplier selection process

4. **Scoring suppliers on Green Parameters**

Marked by practitioners on scale of 0-10, 10 being best practice

I. Compliance with Industrial Policies
II. Compliance with Environmental Policies
III. Quality Control System
IV. Waste Disposal Program
V. Pollution Control System
VI. Reliability of Order Fulfilment
VII. Reverse Logistics System

5. **Scoring suppliers on Resilient Parameters**

Marked by practitioners on scale of 0-10, 10 being best practice

I. Complexity of Suppliers Supply Chain
II. Multiple Transportation options
III. Operation at Multiple Locations
IV. Optimized operations
V. New Product Development
VI. Order Flexibility
VII. Financial Stability
VIII. Risk assessment and Mitigation planning
IX. Crisis Teams
X. Reference of previous good performance of supplied parts