A Comprehensive framework on Supplier Selection based on Sustainability Scores -A study of RMC Supply Chain in HMA

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Abstract

Choosing suppliers only on price and quality will never yield the best outcomes, so look for an ethical and transparent supplier. Being a mindful consumer makes sense as sustainability becomes one of the most pressing challenges of our time. In industries such as construction, where each stage from raw material mining to end product finishing has a significant impact on the environment and the socio-economic position of the industry's dependents, it makes more sense for construction supply chains to be sustainable. Choosing a source for a product has always been a difficult undertaking. Participants in the construction sector are seeking for suppliers who are willing to work with them in the long run and supply high-quality products, not just the cheapest. In this article, Ready Mix Concrete suppliers in the Hyderabad Metropolitan Area will be evaluated using three sustainability indicators: environmental management, social responsibility, and economic performance. A machine learning optimization based on Python will be utilised to identify an optimum supplier based on the sustainability score and transportation distance.

Keywords: Sustainability, Supply Chains, RMC, Supplier Selection

Introduction

It is commonly recognised that the term "sustainable development" or "sustainability" is gaining traction in all countries in order to address the better quality of life of their populations. To some extent, it is becoming obvious that achieving global sustainability requires significant positive contributions from industry. As a result, policies encouraging sustainable development are currently focusing on industrial growth by improving resource efficiency and productivity in manufacturing and consumption throughout the lifecycle of a product.

As a result, supply chain management has become a main priority in the building sector in order to achieve sustainability. At each stage of the building lifespan, collaborative agreements, as well as the involvement of all construction stakeholders throughout supply chains, are essential. Choosing suppliers only on price and quality will never yield the best outcomes, so look for an ethical and transparent supplier. Being a mindful consumer makes sense as sustainability becomes one of the most pressing challenges of our time.

Sustainability has grown into a development policy that helps economies to raise their sustainable growth rate while decreasing their reliance on resources. As shown in Figure 1, such a pace of increase can be achieved by raising living standards while balancing environmental sustainability, social development, and economic expansion.

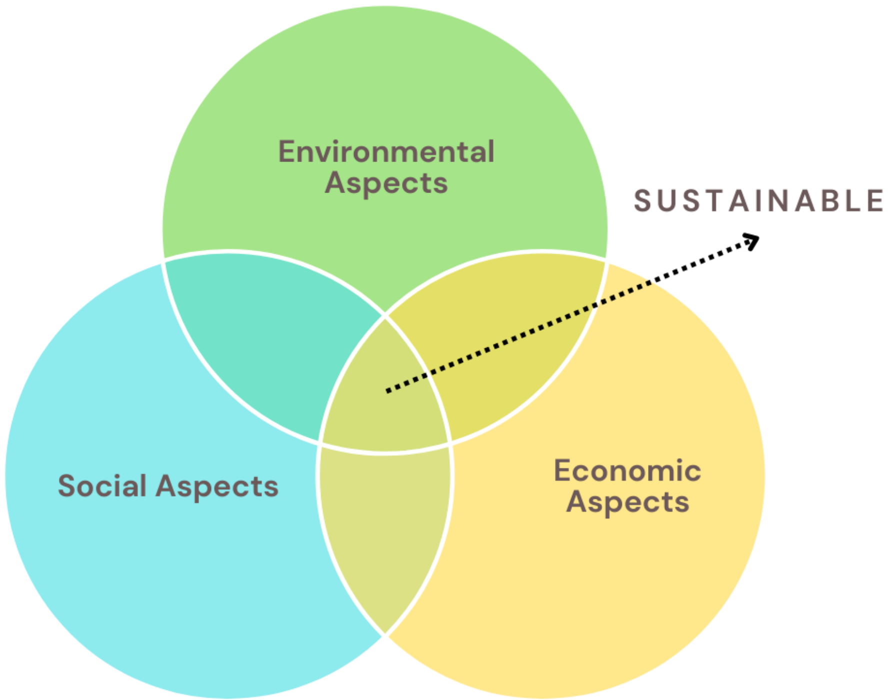

Figure 1 Sustainable Development Triple Wins Outcome

Construction Sector and Supply Chains

The construction business is highly fragmented, with thousands of contractors working at different levels of the supply chain. Contractors at each level frequently subcontract portions of their work to lower-level contractors or subcontractors. As a result, no clear roles or duties exist at any point of the supply chain. Construction supply chains in the Hyderabad metropolitan area have grown dramatically over the years, particularly following the region's real estate boom. Many variables, including technology and globalisation, drive the evolution of these supply chains.

The fundamental difficulty with building supply chains in the Hyderabad Metropolitan Area is that they are very fragmented, making it difficult for enterprises to efficiently bring their products and services to market. Poor infrastructure also causes problems, such as bad roads and traffic jams at toll booths on routes going into the city. This may increase the cost of deliveries for business owners who rely on trucks or other delivery vehicles to transport items into their warehouse or project location. In addition to the economic cost, these supply chain challenges have an indirect environmental impact.

Construction has a lot more space for improvement in terms of supply chain management than other industries. In comparison to other industries such as retail or manufacturing, the industry has historically been relatively fragmented and inefficient. This is due in part to the industry's reliance on small firms and contractors rather than huge corporations; many smaller enterprises lack the scale or finances to invest in new technologies such as automation or AI-powered solutions that would assist streamline their supply chains.

When establishing a supply chain for the construction sector in Hyderabad, there are various factors to keep in mind. The first requirement is that the supply chain be able to manage the large volume of commodities required. The second requirement is that it be able to handle the quick turnaround times demanded by the building sector.

Aim and Objectives

The aim of the research is to identify the circumstances that allow building supply chain management to become sustainable, assess suppliers on sustainability, and design a mechanism for selecting suppliers based on sustainability scores.

- Calculate the suppliers' environmental, economic, and social sustainability scores using data analytics.
- Calculate and rank suppliers based on sustainability scores.
- Select suppliers by optimising sustainability scores and transportation distance.

Literature Review

The building sector began to understand its environmental impact in the 1990s. It faced numerous hurdles in transitioning from the specified green building standards to a sustainable construction. Environment assessment approaches are required for sustainable construction. These methodologies range from extensive life cycle assessments (LCAs) to high-level impact assessments.

The widely accepted definition of sustainable development is as follows: "The ability of humanity to make development sustainable in order to ensure that it meets the needs of the present without jeopardising future generations' ability to meet their own needs" ("WCED Definition | Law Insider" 1987, 2013).

According to Rodrguez López et al. (2011), sustainability standards are becoming a need in project management. Various strategies have been developed in order to achieve an integrated sustainability value. Sensitivity ranges for the various indicators must be defined while geographical variations are taken into account. Sustainable construction has arisen as a major worry for the future of the construction sector. A gap exists between social integration and the societal costs of civil engineering projects.

While the phrase "supply chain" was coined by the "The Independent" in 1905, the concept of a network of suppliers, producers/manufacturers, and customers has been around for a long time. Because the term "supply chain management" was not coined until the 1980s, it is still relatively young when compared to related professions like as procurement, logistics, and manufacturing, all of which play a role in supply chain management.

Xiangyu Wang et al. addressed supply chain management in megaprojects (2017). They provide information for decision making and managing project complexity. It has been discovered that a proper decision-making algorithm will aid in the selection of appropriate contract procedures depending on supplier or vendor behaviour, maximising cooperation and minimising opportunism throughout the entire mega project supply chain. Based on their research, they developed an outline of the present requirement and research trend for supply chain management (SCM) in megaprojects. SCM must be examined beyond its organisational and technological challenges in order to evaluate expanding project requirements and new business conditions. A poor vendor selection procedure is one of the leading causes of cost and time overruns.

Patil and Desai (2018) investigated the role of supply chain management in Maharashtra infrastructure projects. The SPSS approach was used to identify the primary construction supply chain management standards. The statistical tool was used to test hypotheses and determine the significance of key success factors, as well as the goals and purposes of the SCM implementation choice. Potential suppliers, manufacturers, vendors, retailers, clients, and so on are all part of a chain. The selection of suppliers appears to be a barrier for selecting an effective mix of vendors, enterprises, and services. According to the authors, the substantially stronger influence of supply chain management on organisational choices is related not only to the strategy's lower adoption by corporate decision makers, but also to the conventional supply chain management's lower usage.

Supply chain sustainability (SCS) is a broad view of supply chain operations, logistics, and technology as they affect a company's environmental, social, economic, and legal aspects. The management of material, information, and capital flows along the supply chain while keeping all three factors of sustainable development in mind, namely economic, environmental, and social, is characterised as sustainable supply chain management.

The construction industry is one of the world's largest emitters of CO2. Yuqi Su et al. (2021) presented a report on the connections between China's building sector expansion, carbon emissions, and economic growth. The construction sector is a significant contributor to economic development since it provides the necessary shelters for society. The A-effect matrix of the SPLD approach suggests that the non-metallic mineral products sector (s14) is principally responsible for the increase in carbon emissions. Improving the life cycle of buildings and infrastructure, as well as reducing China's participation of new development, may minimise intermediate input. The non-metallic business is related to other industries important to the construction sector, resulting in an increase in carbon emissions in the construction sector. A cleaner power generation system, according to the organisation, will dramatically reduce emissions in the building sector.

Jihui Wu et al. (2018) released empirical research on the factors influencing sustainable supply chain management. This study has important theoretical and practical implications for accelerating the adoption of sustainable supply chain management by Chinese enterprises. The four contributing elements on the measure were internal management cognition, government participation, consumer pressure, and industry pressure. It was revealed that the impact of government engagement aspects on internal management cognitive variables was negligible. Economic growth and social progress have paved the way for the theory of sustainable development to emerge. Long-term response to this change is sustainable supply chain management.

Ahi and Searcy described how to measure social concerns in sustainable supply chains (2015). The literature on measuring corporate performance is well-established. A total of 53 unique metrics were discovered after a thorough analysis of the scientific literature. Only three metrics addressed both environmental and social concerns. Social dimensions are usually overlooked in research focusing on performance measurement in sustainable supply chains. There was no context-based statistic discovered that addressed any of the issues of safety, welfare, or community. The researchers point out that, while the study focused on a somewhat narrow meaning of the term "social problems in supply chains," it restricted its search for relevant metrics to the Scopus database.

Multi-criteria decision-making approaches and sustainable supply chain management were described by Ananna Paul et al. (2021). The decision-making trial and evaluation laboratory was also used to examine criteria and alternatives in sustainable supply chains. This research does a literature review on Multi-criteria decision-making processes utilised in various dimensions of SSCM. DEMATEL has been used in various studies to study and assess barriers to sustainable development. To select a sustainable supplier and management practises, the AHP-VIKOR integrated technique was predominantly employed in green supply chain management. To evaluate and analyse sustainable suppliers and other alternatives in SSCM, integrated MCDM approaches were applied.

According to Sharfuddin et al. (2018), corporations have begun to integrate sustainable business practises into their internal operations as a result of increased global pressures for sectors to become more sustainable. To construct sustainable supplier performance evaluation criteria, three fuzzy sets membership functions are applied. According to the study's findings, the most important criteria for economic, environmental, and social sustainability are quality, cleaner technology implementation, and information disclosure. M. Bevilacqua et al. (2006) noticed that renowned business management publications emphasise the need of understanding production decisions and procedures in order to improve a company's competitive position. They suggest and show a supplier selection decision-making model based on TQM approaches such as quality function deployment. The role of suppliers and supply chain management is becoming increasingly crucial as more manufacturing organisations implement TQM and JIT ideas.

Many managers, according to Constantine Katsikeas et al. (2004), see the purchasing function as a vital strategic weapon in the firm's attempt to obtain a competitive positioning advantage. The vast majority of research in this area focuses on identifying the various supply source selection variables. Little empirical study has been conducted on how well suppliers are considered to perform. Many executives now see purchasing as a vital strategic instrument. This survey contributes to the body of existing knowledge on supply source selection criteria by investigating the topic of supplier performance in purchasing decision areas.

Suppliers, according to Sarkar and Mohapatra (2006), contribute to a supply chain's overall success. They draw attention to the important distinctions between supply base rationalisation and supply base reduction. The team uses a fuzzy set technique to address the problem of measurement imprecision. Poor supplier performance has repercussions throughout the supply chain. Creating a strong buyer–supplier relationship is an effective approach to improve supplier performance. The authors propose a supply-base reduction strategy based on long-term capability aspects as well as a set of short-term performance variables.

Methodology

Based on the extensive literature review, the following parameters are identified as to be contributing towards the sustainability of a supply chain.

- Environmental Parameters: Carbon Footprint, Chemical Emissions, Dust Emissions
- Economic Parameters: Cost, Reliability of the Supplier, Reputation of the supplier, Quality of the product, Flexibility of the supplier to adapt to changes in the requirements
- Social Parameters: Employment potential, WASH facilities, Information disclosure, CSR

With the collected data having different units of measurement and representing diverse aspects, a composite index or indicator must be developed to depict the sustainability of a provider as a single relative score or rank. In policy analysis and public communication, composite indicators (CIs) that compare performance are becoming increasingly common. According to Saltelli (2007), composite indicators appear to be easier for the general public to interpret than discovering common trends across multiple individual measures, and they have also proven useful in assessing country performance.

When the numerous parameters suggested as influencing supply chain sustainability were examined, the following procedures were discovered in order to generate a composite score and ranking based on it.

The development of composite indicators is built on a sound theoretical framework. The framework should fully identify the phenomenon to be measured as well as its sub-components, selecting individual indicators and weights that indicate their relative importance as well as the overall composite dimensions. ("Handbook for Developing Composite Indicators") The following steps are involved in establishing the theoretical framework:

- Defining the concept
- Identifying the concept's sub-groups
- Choosing the criteria

The carbon footprint in the specified supply chain is calculated as the sum of direct and indirect CO_2 emissions based on site electricity and fuel usage, as well as transit vehicle emissions. The carbon dioxide emission parameters for the fuel used and the energy spent must be identified based on the local market and production conditions. Once the various direct and indirect fuel and electricity consumptions have been calculated, they must be translated into equivalent CO_2 units.

CO_2 from External Power = Electricity Purchased X Grid CO_2 Factor

CO_2 from fuel consumption = Quantity X Density X Heating Value X Fuel CO_2 factor

Thus, when estimated values to the proper units are converted, the total CO_2 emissions of that supplier are provided.

Any supply chain's total cost is the sum of the material and delivery costs. The material cost is determined by the provider based on the exact costs of the obtained raw materials, location influence, demand, and market reputation. The transportation expenses for the selected supply chain are as follows:

Transit Cost = No of Trips x Fuel Efficiency x Distance of supply network (in km) x Price of Fuel

Data standardisation is the process of turning data to a uniform format so that users can analyse and evaluate it. Because the indicators in a data set frequently have different measurement units, standardisation is required before data aggregation. Data standardisation is a type of data normalisation. Standardisation often means rescaling data to have a mean of 0 and a standard deviation of 1.

The standard score or z-score of any dataset can be calculated using the formula

$$z = \frac{x - \mu}{\sigma}$$

Where, z is the standard score, x is the data, μ is the mean of the data, σ is the standard deviation of the data. Once the data has been normalised, it should be aggregated to determine the overall influence of the various criteria.

Even after a weighted aggregate of the standardised data, it is possible to see that the final data varies from the most negative value, which is the furthest away from the mean to the most positive value, which is the most above the mean. It is suggested that the data be standardised in order to be understood.

To facilitate understanding, it is proposed in the current approach to normalise the weighted aggregate of data to a scale of 1 to 10. Using the formula, the data can be standardised to any scale of choice.

new value= (max'-min')/(max-min) * (value-max) + max'

(or)

new value= (max'-min')/(max-min) * (value-min) + min'

where, max' and min' are the maximum and minimum values of a scale, max and min are the maximum and minimum values of the selected data.

Any type of commodity or service requires raw materials and equipment to be manufactured. Supply chain operations refer to the method through which businesses purchase all of the supplies they need to run their businesses. However, supply chain operations require far more than simply acquiring raw materials. It is proposed in this study to choose the best supplier based on distance from the project site and sustainability score. In this regard, a Python-based optimization algorithm is developed that is based on the Gaussian mixture and the Sequential Least SQuares Programming (SLSQP) optimizer. The sample SLSQP program follows the following protocol.

“ scipy.optimize.minimize(*fun*, *x0*, *args=()*, *method='SLSQP'*, *jac=None*, *bounds=None*, *constraints=()*, *tol=None*, *callback=None*, *options={'func': None, 'maxiter': 100, 'ftol': 1e-06, 'iprint': 1, 'disp': False, 'eps': 1.4901161193847656e-08, 'finite_diff_rel_step': None}*) ”

The nonlinearly constrained gradient-based optimization algorithm Sequential Least SQuares Programming (SLSQP) is proposed because the optimization function is nonlinear, and the study has a limitation. SLSQP was chosen over random optimization techniques in Python because of its ability to find optimal solutions almost immediately for a small number of input features and its effectiveness in better optimising the objective function.

Data Collection and Analysis

An industrial study is undertaken based on the findings of the literature review and text analysis to attempt to analyse the various aspects involved in supply chain selection and to assess the sustainability of the selected Ready Mix Concrete supply chain in the Hyderabad Metropolitan region. As supplier sites for this inquiry, 96 RMC plants have been identified.

For a proper understanding and further analysis of the supply chain, as well as developing a protocol for the optimum selection of the supplier based on a required quantity and location, it has been decided that this project will analyse and develop the optimization model using data from a total of 40 project sites, 30 of which are completed projects and the remaining ten of which are ongoing projects.

Because the research involves the evaluation and combination of a total of 13 parameters, each parameter must be researched and comprehended independently in order to determine the optimum data collection process. While testing agencies assess the NOx, SOx, and TPM emission details empirically, the carbon footprint, or total carbon dioxide production of the plant, can be derived using the following equations, which are based on the approach described above.

The plants provide the concrete cost per m^3. The challenge is acquiring information about the supplier's quality, reputation, dependability, and adaptability. The reputation of the supplier can be established using reviews gathered from rating sites such as Google, and the found values are scored on a scale of 1 to 10. End users of the supply chain, architects, and engineers were asked to rate the suppliers on a scale of 10 to determine the supplier's quality and flexibility and reliability as yes (1) or no (1).

The social dimensions in this study cover employment, WASH facilities, information disclosure, and CSR policy. The employment data was taken from the site's sources. The research team evaluated WASH facilities using a field visit and a ten-point scale. The websites and social media portals of the company were analysed to determine the company's openness to information and stated CSR policy. Despite the fact that the Government of India requires a CSR policy, companies were only assessed in this study if the CSR policy was reported on any of the firm's official platforms.

Because the collected data is separated into three categories, the category-specific scores must be examined in order to calculate the overall sustainability ratings. The scoring procedure varies according on the criteria. The parameters must first be harmonised before being mixed based on relative weights. As a result, in order for the findings to be easily comprehended, combined data must be normalised on a scale of 1 to 10.

The most difficult component of environmental scoring is identifying the specific weights of CO2, NOx, SOx, and TPM effect. While the statistical study suggests equal weightage, the literature suggests that industry-based expert judgement is important in deciding weights. The weights listed in table 1 are determined based on the opinions of 31 experts in the subject.

Table 1 Weights of Environmental Parameters

Parameter	**Weight**
TPM	0.36129
CO2	0.32581
Nox	0.14516
Sox	0.16774

A weighted aggregation of the standardised values can be used to get the environmental ratings. While the normalised scores show a lower value for the lowest environmental emissions, the data has been recoded to display the highest environmental score as the lowest emission for the sake of subsequent calculation. The lowest cost value is optimal for economic metrics, whereas the maximum value is optimal for other parameters such as reputation, reliability, and flexibility. As a result, in this study, the cost parameter is first standardised and reverse scored, whereas the rest parameters are scored normally. The social elements of WASH, employee potential, CSR, and information disclosure are integrated and scored using the identified approach.

Given that the fundamental assumption is that sustainability is an equal and balanced grasp of the environmental, economic, and social factors, the individual category scores can be blended with equal weightage to obtain the final sustainability scores. Table 2 presents the suppliers' sustainability scores as well as their ranking based on the overall sustainability score.

Table 2 Sustainability Scores and Ranks of Suppliers

Site	Environmental Score	Economic Score	Social Score	Sustainability Score	Rank
RMC 54	9.231894749	7.75	8.60947662	8.530457122	1
RMC 47	8.692077205	7.8625	8.30400207	8.286193091	2
RMC 26	8.689264392	7.6825	8.42358186	8.265115416	3
RMC 29	9.160677606	6.783771418	8.75440725	8.232952092	4
RMC 21	8.573168558	6.921874745	9.09918963	8.198077645	5
RMC 46	8.677054444	7.3	8.42358186	8.133545434	6
RMC 27	10	6.626271418	7.73401709	8.120096171	7
RMC 20	8.633670867	6.558771418	9.09918963	8.097210639	8
RMC 40	9.923750896	7.008880692	6.95278652	7.961806035	9
RMC 48	7.726686615	8.065	8.07879948	7.956828697	10
RMC 24	7.958867228	7.233880692	8.64878445	7.947177456	11
RMC 56	6.796512648	6.851271418	10	7.882594689	12
RMC 28	7.468627693	7.571380692	8.30400207	7.781336817	13
RMC 55	7.237633329	7.008880692	9.01974582	7.755419948	14
RMC 19	9.229987379	5.93015211	8.06484249	7.741660659	15
RMC 41	8.787657839	5.88515211	8.54316165	7.738657198	16
RMC 39	8.528339169	7.008880692	7.4031917	7.646803854	17
RMC 45	7.688165509	7.214265471	7.85359688	7.585342621	18

Site	Environmental Score	Economic Score	Social Score	Sustainability Score	Rank
RMC 11	8.4983082	5.696963111	8.52920466	7.574825324	19
RMC 49	7.741958613	6.626271418	8.15907143	7.509100488	20
RMC 30	5.953750643	6.896380692	9.54959482	7.466575384	21
RMC 42	7.863091957	6.626271418	7.82824604	7.439203138	22
RMC 57	8.953224313	6.783771418	6.49660671	7.411200814	23
RMC 18	6.446317234	6.288771418	9.09918963	7.278092762	24
RMC 23	8.273698991	5.767457164	7.74797408	7.263043412	25
RMC 22	9.250009611	7.6825	4.63115544	7.187888352	26
RMC 43	8.311968777	7.211380692	5.86030677	7.127885412	27
RMC 44	9.341452123	6.738771418	5.03407043	7.038097991	28
RMC 51	8.645294023	5.823640215	6.30335773	6.924097324	29
RMC 92	7.776039683	7.6825	5.29775271	6.91876413	30
RMC 9	6.160022413	5.730646163	8.6234336	6.83803406	31
RMC 25	6.623025509	4.938771418	8.87398704	6.811927989	32
RMC 82	8.199571253	4.913837856	6.95361466	6.689007924	33
RMC 8	9.207736644	6.539265471	4.16917662	6.638726245	34
RMC 95	7.776033834	7.146874745	4.99310631	6.638671628	35
RMC 7	8.885599049	5.138837856	5.83899556	6.621144155	36

Site	Environmental Score	Economic Score	Social Score	Sustainability Score	Rank
RMC 31	8.958996856	5.70515211	5.06594735	6.576698771	37
RMC 52	7.495366098	5.910646163	6.23787091	6.547961056	38
RMC 77	8.344394599	4.455296412	6.80868403	6.536125013	39
RMC 93	8.783837372	4.770405686	5.99871133	6.517651462	40
RMC 78	7.923348753	7.121380692	4.19470725	6.413145564	41
RMC 84	7.198493278	5.955646163	5.94800964	6.367383026	42
RMC 38	8.375493292	4.587411633	6.11829112	6.360398681	43
RMC 86	9.464697889	5.466524994	4.08908445	6.340102443	44
RMC 62	8.093834616	4.981337856	5.93322451	6.336132326	45
RMC 16	8.423182125	6.941380692	3.4911855	6.285249438	46
RMC 10	6.14862901	5.235536889	7.42937069	6.271178863	47
RMC 72	8.407456408	3.5875	6.76854805	6.254501486	48
RMC 53	7.464004525	5.70515211	5.46886233	6.21267299	49
RMC 94	7.907195299	6.539265471	4.18075026	6.209070343	50
RMC 74	8.89362102	5.654957164	4.07512746	6.207901881	51
RMC 65	8.649579156	6.854374745	2.98842233	6.16412541	52
RMC 12	8.200220001	5.730646163	4.49679052	6.142552228	53
RMC 90	7.960710957	6.446271418	4.00881249	6.138598288	54

Site	Environmental Score	Economic Score	Social Score	Sustainability Score	Rank
RMC 32	9.013655548	6.810646163	2.59037513	6.138225614	55
RMC 87	7.461357165	4.789911633	6.14703324	6.132767346	56
RMC 17	6.831229871	4.770405686	6.72758392	6.109739827	57
RMC 59	7.988485857	5.466524994	4.75073523	6.068582028	58
RMC 2	7.998827007	5.823640215	4.31428704	6.045584753	59
RMC 33	7.025627506	4.254078333	6.72758392	6.002429921	60
RMC 64	8.038591315	5.798146163	4.0882563	5.974997925	61
RMC 5	6.565401371	5.986469059	5.09872911	5.88353318	62
RMC 88	7.930309776	7.021469059	2.59037513	5.847384655	63
RMC 15	7.530138545	5.119331909	4.87269837	5.840722941	64
RMC 68	8.238903122	7.008880692	2.13996995	5.79591792	65
RMC 50	9.362484225	4.929078333	2.93515751	5.742240023	66
RMC 35	8.622120151	7.46015211	1	5.694090754	67
RMC 69	8.290386049	5.603969059	3.14557497	5.679976693	68
RMC 3	8.300239431	6.037457164	2.59037513	5.642690575	69
RMC 34	8.876513553	5.546380692	2.47079534	5.631229862	70
RMC 66	9.504370819	5.809463111	1.56998497	5.627939635	71
RMC 83	7.39836762	6.809265471	2.47079534	5.559476144	72

Site	Environmental Score	Economic Score	Social Score	Sustainability Score	Rank
RMC 67	8.641525371	6.192072385	1.80914455	5.54758077	73
RMC 91	8.820849832	5.643640215	2.02039016	5.494960068	74
RMC 13	8.489730046	4.936228582	3.04078031	5.488912981	75
RMC 58	6.914347948	5.068343803	4.42651261	5.469734786	76
RMC 60	8.730536177	4.314759523	3.27993989	5.441745198	77
RMC 81	8.845149633	4.775734529	2.59037513	5.403753097	78
RMC 63	8.606603851	6.513771418	1	5.373458423	79
RMC 75	8.790452814	3.658103327	3.50514248	5.317899542	80
RMC 76	7.159825361	5.328530941	3.27993989	5.256098732	81
RMC 36	8.620476347	4.486228582	2.60837176	5.238358895	82
RMC 85	8.011380476	5.696963111	1.91476735	5.207703647	83
RMC 96	7.995940965	6.471765471	1.11957979	5.195762075	84
RMC 1	9.286031726	3.796097379	2.48475233	5.188960478	85
RMC 73	8.613399659	4.573234529	2.12601296	5.104215716	86
RMC 70	7.602131858	4.796963111	2.82953471	5.076209893	87
RMC 4	7.828812762	4.15	2.70995492	4.896255894	88
RMC 61	7.889924695	4.117796412	2.59037513	4.866032079	89
RMC 6	5.835531899	6.342302359	2.13996995	4.772601402	90

Site	Environmental Score	Economic Score	Social Score	Sustainability Score	Rank
RMC 79	5.852626753	3.275494053	5.00046052	4.70952711	91
RMC 71	5.547945129	5.669024994	2.24559275	4.487520957	92
RMC 14	5.060243065	5.180843803	2.93432937	4.391805411	93
RMC 80	4.870877956	3.883103327	4.05381625	4.269265845	94
RMC 37	6.585279647	3.883103327	1.56998497	4.012789316	95
RMC 89	1	5.864265471	3.27258567	3.378950382	96

Discussion

In this study, the following processes were tested to select an RMC supplier for the construction sites under consideration: Selection based on least carbon footprint; Selection based on least dust emissions; Selection based on least material cost; and Selection based on least distance from supplier site.

- It has been observed that choosing a plant with the lowest carbon footprint costs clients 21% more than choosing the cheapest plant.
- Similarly, selecting the plant with the lowest dust emissions costs 21% more than selecting the plant with the highest cost.
- If RMC 6, the lowest-cost plant, is chosen for the procurement, the carbon footprint is 6.88 percent higher, the Sox emission is 27.43 percent higher, the NOx emission is 47.04 percent higher, and the dust emission is 87.8 percent higher, compared to individual plants with the lowest carbon footprint, Sox emission, NOx emission, and dust emission, respectively.
- In comparison, choosing plants closest to project locations results in an average economic impact of 19.99 percent.

When the 'Sustainability Score' is 'Maximum' and the 'Distance' is 'Minimum,' the ideal supplier sites for each project site can be calculated utilising the identified approach of Gaussian Mixture and Sequential Least SQuares Programming (SLSQP). Before arriving at the ideal solution, the model was built to go through 10000 iterations of data testing and analysis. Figure 2 shows the part of the code in python environment.

```
n_customers=40
n_sites=96
optimum_custom_supplier=dict()
warehouse_sus_score = data.values[2:,1]
for n in range(0,n_customers):
    cost_matrix=data[2:].values[:,2+n]
    cost_m=return_appended_matrix(cost_matrix,warehouse_sus_score)
    #print(cost_m)
    result = optimize.minimize(gaussian_mixture,x0=list(cost_m),method='SLSQP',options={'maxiter':10000})

    array_1=result.x[:n_sites]
    array_2=result.x[n_sites:]
    #print(np.argmax(array_1))
    #print(max(array_1))
    optim_ind=np.argmax(array_2)
    optimum_custom_supplier[customer_columns[n]]=supplier_names[optim_ind]
print(optimum_custom_supplier)
```

Figure 2 SLSQP Optimization in Python

The optimal supplier location for each of the selected projects is shown in table 3.

Table 3 Optimal Solution for Supplier Selection

Project Site	Optimized_Supplier
C 1	RMC 85
C 2	RMC 85
C 3	RMC 83
C 4	RMC 85
C 5	RMC 29
C 6	RMC 63
C 7	RMC 77
C 8	RMC 77
C 9	RMC 77
C 10	RMC 77
C 11	RMC 85
C 12	RMC 85
C 13	RMC 85
C 14	RMC 77
C 15	RMC 77
C 16	RMC 87
C 17	RMC 85
C 18	RMC 85

Project Site	Optimized_Supplier
C 19	RMC 85
C 20	RMC 85
C 21	RMC 77
C 22	RMC 77
C 23	RMC 85
C 24	RMC 77
C 25	RMC 77
C 26	RMC 77
C 27	RMC 77
C 28	RMC 77
C 29	RMC 15
C 30	RMC 15
O 1	RMC 71
O 2	RMC 37
O 3	RMC 85
O 4	RMC 85
O 5	RMC 85
O 6	RMC 85
O 7	RMC 85
O 8	RMC 85
O 9	RMC 21
O 10	RMC 69

The following observations were made based on the optimization model outputs:

- The technique prioritised providers based on the highest sustainability score and the shortest distance.
- A balance of environmental, economic, and social effect has been maintained since the model was run at the supplier location with the sustainability score as the key metric.
- It is observed that the output does not include any single characteristic in a substantial way, decreasing the overall environmental and economic load on end users.
- The project site's location was also significant in locating supplier sites.

- It should be highlighted that, even though a few alternative supply sites are closer to the project site, the model excluded them to maintain a balanced sustainability-based supplier selection.

Conclusions

According to our research, businesses can benefit by analysing their suppliers' carbon footprints in addition to their overall sustainability score. When you buy or encourage the purchase of products from suppliers at the bottom of the sustainability index, as well as those with a poor record on labour rights and environmental norms, you have ethical and environmental implications. We were able to effectively show the promise of machine learning when applied to industry-specific business problems using this approach.

Choosing a provider based solely on lowest emission levels or shortest travel distance can have an economic impact. Likewise, selecting a supplier based on the lowest potential product cost may have a large environmental impact if a sufficient amount of material is created. According to the study, a company's social sustainability scores reflect its positive market impact and will help the company's long-term existence. The comparison of sustainability scores shows that, even if a supplier is not the best performer in terms of environmental, economic, and social sustainability on its own, taking a balanced approach can enhance the organization's overall sustainability score.

Disclosure

To retain the autonomy of the RMC plants and project sites in the study, the RMC plants have been designated as RMC 1, RMC 2, and so on; and the project sites have been designated as C1, C2, and so on for completed projects; and O1, O2, and so on for ongoing projects.

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