A FRAMEWORK FOR IDENTIFICATION OF CRITICAL MATERIAL WASTE CAUSES DURING CONSTRUCTION USING DEMATEL AND SOCIAL NETWORK ANALYSIS

Prashanth Kumar Sreram[1] and Albert Thomas[2]

[1&2] Department of Civil Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, Maharashtra 400076, India

[1] School of Construction Management, National Institute of Construction Management and Research, Jagganguda(V), Hyderabad, Telangana 500101, India

The construction sector is the second major contributor to India's gross domestic product with the consumption of natural resources such as sand, aggregate, and lime. Along with the consumption of these resources, material waste also occurs during a construction project with its knock-on effect on cost and other detrimental effects on the environment. Understanding various factors causing material waste and the inter relationships would help the construction industry to alleviate the detrimental effects of such causes on sustainable construction. While the literature review has provided the reasons for the material waste, limited research is available on investigating the interrelations between the contributing factors. Therefore, an integrated framework consisting of construction site specific questionnaire survey, decision-making trial and evaluation laboratory (DEMATEL) and social network analysis (SNA) is proposed to identify the critical causes of material waste and its inter relationships. The results have indicated that 55 out of 110 interrelations are important. Further, tendering errors and design errors are the critical causes of material waste, and human errors are central within the network of critical interrelations.

Keywords: material management; material waste; network analysis; sustainability

INTRODUCTION

Responsible Consumption and Production (RCP) is one of the 17 Sustainable Development Goals (SDG) towards achieving sustainable development, as per agenda 2030 of United Nations (UN). In an increasingly resource-constrained world, India, a signatory to the UN, is therefore focused to balance the economic aspirations as a developing economy and environmental responsibilities towards SDG. Construction sector being the second-largest contributor to the nation’s economy has a bigger role to play in this movement by contributing to the RCP targets by producing more with fewer resources. However, waste generation during new construction in India is at 8% - 10%, and with increased construction activity due to the government's infrastructure and housing schemes, waste generation is poised to increase in the years to come (CPCB 2017). Since construction material component form 40-50% of the

[1] 194048001@iitb.ac.in

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project cost (Oko and Emmanuel 2013), significant efforts are therefore required to reduce the material wastage while executing projects to positively contribute towards SDGs.

One of the obstacles in material waste management is identifying the critical causes of waste generation at construction sites. Existing literature has explored the ranking of such causes using qualitative research with mainly a list of causes as the research outcome (Al-Hajj and Hamani 2011; Adewuyi and Odesola 2015). Owing to the uncertain environment in construction project sites such as unpredictable environment, resource unavailability, interdependent activities, and inefficiency of operations (Dubois and Gadde 2002), identifying the right causes and finding the remedies are suggested as the key to better waste management (Liu *et al.,* 2020). In material management, the causes of material waste typically occur in isolation, and as an outcome of each other (Ofori and Ekanayake 2000). For instance, Polat and Ballard (2004) reported material wastes due to procurement errors, which has occurred due to both the wrong choice of material while planning (planning error) and providing incorrect purchase order information (procurement error). Construction sites have several such instances of material waste generation instances, and there is a need for understanding the interrelation of each factor with other causes for better material management and avoiding unnecessary wastages (Formoso *et al.,* 2002; Nagapan *et al.,* 2013). This study proposes an integrated approach of questionnaire survey-based data collection and analysing the data through decision-making trial and evaluation laboratory (DEMATEL) and social network analysis (SNA) to quantify the inter relationships and the weightages existing between material wastage causes.

RESEARCH BACKGROUND

Material Waste Causes

Conceptually, sources of material waste are organized into six categories such as design, procurement, handling of materials, operation, residual related, and others (Gavilan and Bernold 1994). As was previously mentioned, the existing literature (Kaliannan (2018)) has identified several such causes, and a comprehensive list of material waste causes is presented in Table 1. The associated literature is referred in Table 2.

Network Analysis Methods

The graph theory forms the basis of network analysis methods (NAM), and the major NAM includes structural equation modelling (SEM), SNA, analytical hierarchical process (AHP), interpretive structural modelling (ISM), and DEMATEL. SEM is typically used where the sample size is more than 100 (Xiong *et al.,* 2015). AHP does not help analyse relationship influence, whereas ISM can only be used to analyse direct relations (Ristono *et al.,* 2018). DEMATEL and SNA are more suitable methods quantitatively analysing inter relationships and the weightage of those relations between the nodes (Bastian *et al.,* 2009; Ristono *et al.,* 2018; Liu *et al.,* 2020).

Decision Making Trial and Evaluation Laboratory (DEMATEL)

In order to identify the core causes in a complex network of relationships and establish the cause-and-effect relationship, DEMATEL is adopted in management research (Chang *et al.,* 2011; Zhou *et al.,* 2011). Input for DEMATEL analysis is a direct relation matrix (DRM). It is prepared based on the opinions obtained, usually through questionnaire surveys or interviews.

Table 1: Compilation of material waste causes

Cause	Explanation
Tendering Errors (TE)	Errors in contract specifications and documents; misinterpretation of contractual terms
Design Errors (DE)	Constant design changes; design errors, bad design quality, inexperienced designer, poor coordination during design
Material Requirement Planning Errors (MRPE)	Errors in quantity take off; over allowances; inappropriate site layout planning, lack of waste management plan; construction method selection; delayed information flow between teams; last minute changes
Material Procurement Errors (MPE)	Ordering errors, supplier errors, poor supply chain management
Material Receipt and Storage Errors (MRSE)	Storage mistakes; damages during transportation;
Material Use Errors (MUE)	Poor supervision, inefficient material usage, wastage due to equipment/resource problems; excess offcuts; interference by other trades, rework
Project Site Specific Errors (PSSE)	Congested site, difficult to access site, untidy construction site, unforeseen ground conditions
Human Related Errors (HRE)	Poor workmanship, lack of skill, damage, negligence, no interest, overtime, poor coordination and communication
Lack of Supporting Culture Within Organization (LSCO)	Lack of support from senior management; lack of training about the work and material management; lack of awareness about environmental protection by waste reduction
Lack of Contractual Incentives (LCI)	No contractual provisions to prevent material wastage; No incentive for reducing waste
Lack of Regulation/ Policy Implementation (LRPI)	No policy by government to prevent waste; lack of policy enforcement; no government action for waste generation

Table 2: Material waste causes- literature meta-analysis

Years Range	Sources	Factors identified
<2000	Skoyles (1974) ; Gavilan and Bernold (1994); Bossink and Brouwers (1996); Faniran and Caban (1998);	TE,DE,MPE,MRSE,MUE
2000-2010	Ofori and Ekanayake (2000); Lingard et al., (2000); Poon and Jaillon (2002); Alwi et al., (2002); Poon et al., (2004); Polat and Ballard (2004);	TE,DE,MPE,MRSE,MUE,PSSE,LRPI,LSCO,LCI
>2010	Al-Hajji and Hamani (2011); Mokhtar et al., (2011); Nagapan et al., (2013); Adewuyi and Odesola (2015); Llatas and Osmani (2016); Ikau et al., (2016); Kaliannan et al., (2018)	TE,DE,MRPE, MPE,MRSE,MUE,PSSE,LRPI,HRE,LSCO

DRM indicates factors in rows and columns, indicating the relationships and the associated weightages. After DRM is developed, a normalized relation matrix (NRM) is prepared by dividing each cell with a maximum of the sum of each row's value in DRM. Further NRM and identity matrix are used to derive the total relation matrix (TRM). The summation of each row value and column values of the TRM is computed to determine the causes and effects between the factors. From the TRM, the relations which are above the threshold value (above the average of the total elements in TRM) are considered as critical relations. Overall, the output of DEMATEL provides a network of important relations from the total relation matrix as a network graph. More details regarding the procedure and formulae for conducting DEMATEL analysis can be referred from Tsai *et al. (*2015) and Chang *et al. (*2011).

Social Network Analysis (SNA)

SNA is defined by Wasserman and Faust (1994) as "a finite set of actors and the relation or relations [between them]." The application of SNA in construction management is growing prominence, as construction projects are predominantly visualized in the form of networks (Zheng *et al.,* 2016). SNA is generally used for studying people aspects, i.e., teams, performance, and interactions (Lin 2015; Pryke 2004; Chinowsky *et al.,* 2008), and process aspects of construction management, i.e., logistics, accidents, and defects (Li *et al.,* 2016; Eteifa and El-Adaway 2018; Lee *et al.,* 2019). SNA provides network visualization, and the network characteristics are computed with software tools such as UCINET, Gephi, NodeXL, Pajek, and NetMiner.

The vital structural characteristics computed for a network are nodal degree, closeness centrality, betweenness centrality, and eigenvector centrality. A nodal degree is a weighted sum of relations that are leading-in and leading-out of a given node. Meanwhile, closeness centrality indicates how far each node is from other nodes. If the value of closeness centrality is high, then the time taken to reach the node by other nodes would be less, implying that the node can create an immediate effect on other connected nodes. Likewise, betweenness centrality measures how a node is situated between other pairs of nodes. A higher value of betweenness centrality indicates the power to control the interrelations. Further, eigenvector centrality considers the leading-in and leading-out relations of the given node as well as its neighbour node. If the eigenvector centrality for a given node is high, then it means that the node is central in the network of relations (Wasserman and Faust 1994).

Research Motivation

As was previously mentioned, several studies have explored in detail about the causes of material waste causes during construction through questionnaire surveys, interviews, and case studies (Kaliannan *et al.,* 2018; Wu *et al.,* 2019). However, research on identifying the interrelations between the material waste causes during construction and quantifying the criticality of such interrelations is limited. A network-based approach is necessary to identify such relationships and understand the most critical factors that have the maximum knock-on effects on other factors. Such a result would be appropriate for a project manager to control the waste generation in construction projects, considering the triple constraints of cost, time, and scope in construction projects (Silvius *et al.,* 2017; Liu *et al.,* 2020). As the DEMATEL method provides criticality of each factor and SNA provides the centrality of each factor, DEMATEL and SNA are selected in this study as combined quantitative and network approaches, for analysing the data collected from construction professionals.

RESEARCH METHODOLOGY

Fig 1 summarizes the proposed framework of the study. The research work involves four main steps. The first step involves identifying the causes of material waste from literature. A survey approach is adopted for identifying the interrelationships. The second step involves conducting a survey to obtain responses from the construction professionals. The respondents chosen are site engineers, site managers, and project managers from the construction industry in India. Purposive sampling is used to select respondents whose work experience and primary location is mainly at construction sites (Amoatey *et al.,* 2015). As a third step, the inputs from the respondents are analysed to create the matrix of relations. The fourth step identifies the most critical cause and effect relation matrix using the DEMATEL method. The final step is creating a network map, using UCINET version 6.716 of the matrix derived from DEMATEL and performing SNA to identify the vital metrics of the network (Borgatti *et al.,* 2002).

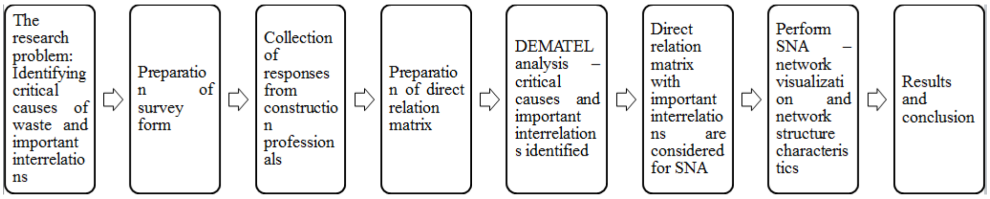

Fig 1: Framework for identifying critical causes and interrelations of material waste

The data required for the research is the connection(s) between the 11 factors identified in Table 1. The number of connections possible in an 11 x 11 matrix is 11 * (11-1) = 110, excluding the self-relation. Survey form with an entire network is prepared both in Microsoft excel and, in a web,-based platform and floated through e-mail to the construction professionals so that the respondents use the form of their convenience. The survey form comprised of collecting following inputs:

- General information (experience and role) ………………………… (A)
- Rating each factor towards its potential to cause material waste …… (B)
- Rating each link /interrelation as the frequency of occurrence ...…… (C)

A five-point Likert scale is used for both questions (B) and (C) with textual and numerical score values as: never (0) / rarely (1) / sometimes (2) / usually (3) / always (4)) (Chang *et al.,* 2011). The responses are collected as text inputs, and the same is converted to corresponding numbers while performing quantitative analysis.

DATA COLLECTION

A total of 114 construction professionals were approached through e-mail during 17-31 March 2021, of which a total of 35 responses were received. Thirty-one (31) fully completed survey responses were considered for analysis, indicating a response rate of 27%. Respondent's characteristics such as role, experience, and representing organization are provided in Table 3 below. The responses were collected using the full-network method and yielded maximum information as each respondent provided answers for a total of 110 questions. Moreover, the response rate is in the range of 25 - 40%, as commonly observed in web-based surveys in construction management research (David and Carol 2002; Carter and Fortune 2004). Further analysis is carried out using DEMATEL and SNA, as explained in the next section below.

Table 3: Respondent's profile

Organization	**Years of experience**				**Total**	**Role**	**No. of respondents**	**%**
	<=5	**6-10**	**11-15**	**16-20**				
Contractor	7	9	8	4	**28**	Site engineers	8	26%
Client				1	**1**	Site Managers	10	32%
Consultant	1			1	**2**	Project managers	13	42%
Total	**8**	**9**	**8**	**6**	**31**	**Total**	**31**	**100%**

RESULTS AND DISCUSSION

Referring to the question seeking the degree of importance of each factor in material waste generation (MWG), the mean of response scores is calculated. Ranking based on the mean of response scores, the top three factors are material usage errors, human-related errors, and material requirement and planning errors, indicating the degree of importance of execution, people, and planning in a construction site. Regarding the network of interrelations, one significant contribution here is the responses sought by using the Likert scale (as explained in research methodology) provided the weights that indicate the strength of each relation. The average scores were computed from the responses received, and a direct relation matrix is prepared as presented in Table 4 below. As can be inferred from Table 4, every factor is leading to other factors, indicating that material waste generation is a complex issue (Adewuyi and Odesola 2015). A total of 110 weighed connections were determined, taken as an input to the DEMATEL method for identifying the cause-and-effect pattern within the factors.

Table 4: Direct relation matrix of all the 11 causes ad their weighed interrelations

Adjacency Matrix	TE	DE	MRPE	MPE	MRSE	MUE	PSSE	HRE	LSCWO	LCI	LRPI
TE		2.10	1.48	1.42	0.74	0.87	1.19	1.39	1.10	1.32	1.16
DE	1.39		2.19	1.71	1.06	1.52	1.61	1.71	1.10	1.10	1.23
MRPE	1.00	1.16		2.03	1.97	1.81	1.61	2.03	1.26	1.13	1.03
MPE	0.87	1.06	1.39		1.68	1.81	1.65	1.81	1.45	1.42	1.06
MRSE	0.84	0.90	1.52	1.68		1.84	1.45	1.90	1.29	1.26	0.94
MUE	0.74	0.97	1.61	1.84	1.42		1.68	1.87	1.48	1.29	0.97
PSSE	0.90	1.29	1.87	1.87	1.45	1.68		1.77	1.29	1.39	0.97
HRE	1.58	1.71	2.32	2.26	2.19	2.29	1.77		1.68	1.48	1.06
LSCWO	0.87	0.94	1.39	1.52	1.32	1.42	1.42	1.90		1.23	1.06
LCI	1.23	1.26	1.39	1.52	1.19	1.29	1.39	1.87	1.35		1.26
LRPI	1.42	1.39	1.06	1.23	1.06	1.10	1.16	1.29	1.19	1.13	

The threshold value is calculated as a mean of each weighed relation in the total relation matrix, and the relations having the value below the threshold are eliminated. Fig 2 indicates from the DEMATEL analysis that critical causes of material waste in construction sites are DE, TE, LRPI, LCI, HRE, and remaining factors (LSCWO, PSSE, MRSE, MRPE, MUE, and MPE) are corresponding effects.

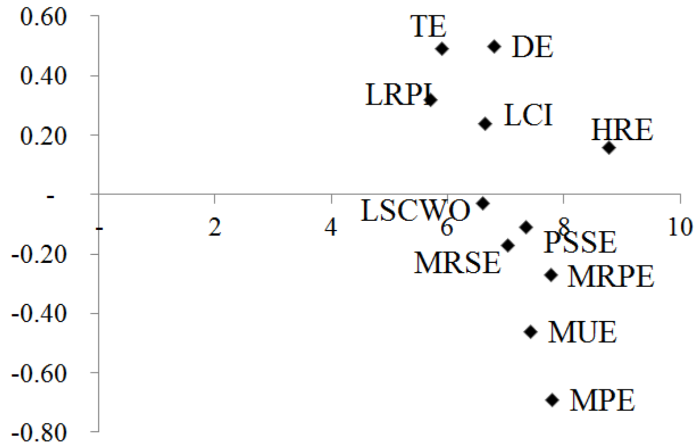

Fig 2: output of DEMATEL method – cause-and-effect graph

The total relation matrix with only the relations above the threshold value of 0.32 has eliminated 55 interrelations as unimportant, leaving the balance interrelations as input for SNA. The network of 55 interrelations is imported to Gephi software, and essential network characteristics are calculated (Bastian *et al.,* 2009). Table 5 indicates the summary of the SNA structural characteristics. The node-level parameters studied are weighed degree and closeness centrality. HRE has the maximum weighed degree with 34.82, followed by MPE and MRPE. HRE has maximum closeness centrality.

The network-level characteristics computed were betweenness centrality and eigenvector centrality. In terms of betweenness centrality, HRE remains at the top, indicating that construction project's material management is dependent on the interests, attitudes, and behaviours of the people involved in the process. This result agrees with Wu *et al. (*2019), indicating that exploring human factors involved in material waste management as a research direction is growing prominence. The network visualisation of the 55 important interrelations is represented in Fig 3. The material waste causes are represented as nodes, and the relations are depicted as arrows. The arrow width is in proportion to the weightage as provided by the construction professionals. The node size reflects the betweenness centrality of each cause.

Table 5: Output of SNA using Gephi- Key structure characteristics

Id	Indegree	Outdegree	Degree	Weighted indegree	Weighted outdegree	Weighted Degree	Closness centrality	Betweeness centrality	Eigen centrality
HRE	10.00	9.00	19.00	17.54	17.28	34.82	1.00	39.40	1.00
MPE	10.00	5.00	15.00	17.08	8.34	25.42	0.69	3.40	1.00
MRPE	9.00	5.00	14.00	15.16	9.45	24.61	0.69	1.40	1.00
MUE	8.00	5.00	13.00	13.66	8.42	22.08	0.69	0.40	0.97
PSSE	8.00	5.00	13.00	12.58	8.64	21.22	0.69	0.40	0.97
MRSE	6.00	5.00	11.00	9.77	8.39	18.16	0.69	-	0.92
DE	1.00	6.00	7.00	1.71	9.80	11.51	0.75	-	0.18
LSCWO	1.00	5.00	6.00	1.68	7.65	9.33	0.69	-	0.18
LCI	1.00	5.00	6.00	1.48	7.46	8.94	0.69	-	0.18
TE	1.00	3.00	4.00	1.58	4.29	5.87	0.60	-	0.18
LRPI	-	2.00	2.00	-	2.52	2.52	0.56	-	-

In terms of eigenvector centrality, HRE, MPE, MRPE are having the highest score indicating that human factors, material procurement, and material planning are major root causes than the other eight causes. Therefore, for reducing the waste generation, the construction project managers in India should focus on these three factors for reducing their knock-on effect on other causes.

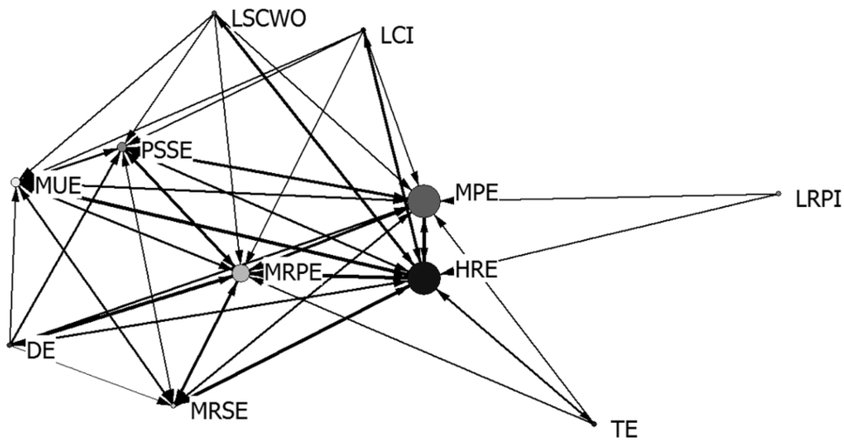

Fig 3: Output of SNA- Node size is representative of betweenness

CONCLUSIONS AND A WAY FORWARD

The study is aimed to identify the most critical causes and the causes more central in the network of interrelations between causes of material waste. The study proposes a novel approach to use DEMATEL and SNA as combined network methods to assess the interrelations between the material waste causes and quantify the weightage of those relations. The results from the DEMATEL method indicate that TE, DE, LRPI, LCI, and HRE are critical causes to be addressed for material waste reduction. Further, SNA results identified that HRE, MPE, MRPE are to be managed efficiently as these causes are central to the network of important interrelations. As the human-related errors were critical and central, the study can be a theoretical basis for further studies on human factors in construction waste reduction.

From a practical perspective, for efficient and effective results in material waste reduction, human resources are to be managed and trained by the project managers apart from process improvements.

The study focuses on the interrelations between material waste causes rather than material waste in general, specifically to the construction industry in India. However, similar studies can be carried out in other developing countries based on the framework proposed. Further, the study analysed the total relations from a macro perspective, whereas further studies can focus on specific relationships. Overall, the study and the novel framework proposed can be considered a significant step to imbibe sustainability in materials management of construction projects in developing countries.

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