

**DEVELOPING A DECISION SUPPORT SYSTEM FOR
EFFECTIVE MATERIAL MANAGEMENT IN
CONSTRUCTION**

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CONSTRUCTION**

by

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Submitted

In fulfilment of the requirements of the degree of Doctor of Philosophy

to the



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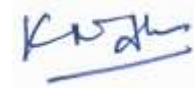
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*Dedicated to My Parents, Wife, and
Son...*

CERTIFICATE

This is to certify that the thesis entitled “**Developing a decision support system for effective material management in construction**”, being submitted by **Mr. Santu Kar** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a bonafide record of the research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard, fulfilling the requirements for the degree of Doctor of Philosophy.

The contents of this thesis, in full or in parts, have not been submitted to any other University or Institute for the award of any degree or diploma.



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A handwritten signature in cursive script that reads "Santu Kar". The signature is written in dark ink on a light background.

SANTU KAR

ABSTRACT

An effective material management can improve productivity, reduce cost, and help the timely completion of a construction project, and thus, plays a key role in the project's success. However, the material management process in construction suffers from several issues and the process is not so effective. To improve the material management effectiveness, this study aims to develop a decision support system that can address the critical issues. However, the questions raise: which issues are critical and should be addressed in the decision support system; and how to develop such a system. Identification of the critical issues enables to define the specific aspects that need to be emphasized in the material management decision support system.

To answer the research questions, it is required to identify the real facts and figures to understand the current state of practice in material management as well as to develop and test hypotheses for determining the critical issues. Thus, pragmatism research philosophy, which suggests the use of both the positivism and interpretivism philosophies, is found suitable in this study. Moreover, both the quantitative and qualitative data are required to address these questions, which shows the requirement of a combination of deductive and inductive approaches. Besides, primary data in the form of interviews and surveys, and secondary data in the form of the literature review are the need of this study to answer the questions.

To address the research questions, this study focuses to identify the critical issues pertaining to the Indian construction industry. An extensive literature review identifies that limited studies are conducted focusing on the existing practices and critical issues in material management in the context of the Indian construction industry. Therefore, this study explores the material management state-of-practice in India based

on interviews with material management experts as well as two questionnaire surveys—Part I and Part II. The descriptive statistical analysis of Part I and Part II survey data identifies that level of implementation of traditional and sustainable material management practices is unsatisfactory and needs improvement. Moreover, analysis of Part I survey data, using exploratory factor analysis and structural equation modelling, determines that improper delivery of materials is the most critical issue disrupting projects' schedule and cost performances, followed by inadequate planning of materials, lack of information and communication, financial issues in procurement, changes in scope of materials, and difficulty in transportation. Thus, this study focuses to address the two most critical issues—improper delivery and inadequate planning of materials—in the development of the decision support system to improve material management. By examining the influence of material management issues on the disruption of projects' schedule and cost performances and determining the critical issues, this study contributes to the relevant body of knowledge relating to material management in the construction industry.

Identification of these two most critical issues reveals the further need to emphasize the assessment of lead time, prioritization of procurement of materials based on their criticality values, and development of an optimum material procurement schedule, which are the key aspects of material management relating to material planning and delivery. It also determines that these key aspects should be incorporated into the decision support system.

An appropriate material management system requires estimation of, and classification based on, the lead time of construction materials. To estimate the lead time precisely, the identification of the factors that influence it is essential. Previous studies in material management have not comprehensively examined the factors that

influence lead time and have not emphasized the classification of materials based on the lead time. To address this, the present study has collected a large sample of procurement data from 16 building construction projects in India. A two-step cluster analysis has resulted in three clusters, namely long lead (L), moderate lead (M), and short lead (S), referred to here as LMS based on the average lead time of the materials. Combining the LMS classification with the existing ABC classifications, where materials are classified in A, B, and C types based on their usage values can facilitate more reliable control over the inventory of materials. Furthermore, the regression analysis of the procurement data determines that the lead time of construction materials is positively correlated with the unit price and order value but negatively correlated with the project value. Besides, the capacity of a supplier has a negative influence on the lead time of bulk materials. The findings of this study would enable construction practitioners to precisely estimate the lead time of materials, thereby enhancing the availability of materials for the project.

Prioritization of procurement of materials based on their criticality values is an important aspect of material management relating to material planning and delivery. In this context, total criticality (TC) values of materials are determined by combining their material criticality (MC) and activity criticality (AC) values. Based on the data collected from Part III and Part IV surveys and using an integrated analytic network process (ANP) and technique for order preference by similarity to an ideal solution (TOPSIS) method, the MC values of materials are determined. The AC values are determined using float available in associated activities. Among the nine building materials considered in this study, the TC value of structural steel is found to be the highest followed by reinforcement bar, cement, autoclave aerated concrete block, coarse aggregate, tiles, sand, plywood, and binding wire. The results are validated

further based on Part V questionnaire survey and using the Spearman's rank correlation (R) test. Therefore, this study provides a novel approach for assessing the criticality values of construction materials which adds value to the existing body of knowledge. Moreover, the TC values would help practitioners to prioritize the materials for procurement. The criticality values of materials are further used as a measure of shortage impact in the optimum material procurement schedule, as discussed below.

The development of an optimum material procurement schedule is another critical aspect relating to material planning and delivery. The procurement schedule would help in procuring the correct materials at the right time and for the lowest cost in construction projects. However, few studies examine the development of a material procurement schedule by integrating construction schedule and optimizing material costs as well as any material shortage impact. In addition, budget constraints and maximum storage capacity are rarely captured in the existing models for material procurement optimization. The present study has addressed these shortcomings and developed an optimization model incorporating all these aspects and using the nondominated sorting genetic algorithm II (NSGA II), which is executed in MATLAB R2017a. Implementation of this model in a building project results in a significant saving in procurement costs and shortage impact of materials.

Finally, this study develops a material management decision support system (DSS) integrated with lead time, criticality values of materials, and optimum material procurement schedule. For this, a framework for the DSS is developed first. Next, a user interface is developed for the DSS using visual basic for application (VBA) and MATLAB program. Following this, the effectiveness of the DSS is measured based on responses collected from Part VI and Part VII surveys. An ANP method and a scoring model method were deployed for the analysis of data. Furthermore, a t-test is performed

that determines significantly improved effectiveness of the DSS compared to the existing material management systems used by the construction organizations. Therefore, the developed DSS can be used in construction to improve the material management effectiveness, particularly the material planning and delivery. Since very few previous studies have emphasized these critical aspects and developed a decision support system incorporating them to improve the material planning and delivery in construction, this study significantly contributes to the existing body of knowledge.

सार

प्रभावी सामग्री प्रबंधन, उत्पादकता में सुधार कर सकता है, लागत को कम कर सकता है और एक निर्माण परियोजना को समय पर पूरा करने में मदद कर सकता है, इसीलिए, परियोजना की सफलता में महत्वपूर्ण भूमिका निभाता है। तब भी, निर्माण में सामग्री प्रबंधन प्रक्रिया कई मुद्दों से ग्रस्त है और प्रभावी भी नहीं है। सामग्री प्रबंधन प्रभावशीलता में सुधार करने के लिए, इस अध्ययन का उद्देश्य एक डिसिज़न् सपोर्ट सिस्टम् विकसित करना है जो महत्वपूर्ण मुद्दों को संबोधित करेगा। सवाल है की : कौन से मुद्दे महत्वपूर्ण हैं और डिसिज़न् सपोर्ट सिस्टम् में संबोधित किए जाने चाहिए; तथा इस तरह की प्रणाली को कैसे विकसित किया जाए। महत्वपूर्ण मुद्दों की पहचान उन विशिष्ट पहलुओं को परिभाषित करने में सक्षम बनाती है जिन पर डिसिज़न् सपोर्ट सिस्टम् में जोर देने की आवश्यकता है।

अनुसंधान प्रश्नों का उत्तर देने के लिए, महत्वपूर्ण मुद्दों को निर्धारित करने के लिए सामग्री प्रबंधन में अभ्यास की वर्तमान स्थिति को समझने के साथ-साथ परिकल्पनाओं को विकसित करने और परीक्षण करने के लिए वास्तविक तथ्यों और आंकड़ों की पहचान करना आवश्यक है। इस प्रकार, प्रैग्मटिज़म् अनुसंधान दर्शन, जो पॉज़िटिविजम् और इनटरप्रिटिविजम् दर्शन दोनों के उपयोग का सुझाव देता है, इस अध्ययन के लिए उपयुक्त है। इसके अलावा, इन प्रश्नों को संबोधित करने के लिए क्वॉन्टिटटिव् और क्वॉलिटटिव् दोनों आंकड़ों की आवश्यकता होती है, जो कि डिडक्टिव् और इन्डक्टिव् दृष्टिकोण के संयोजन की आवश्यकता को दर्शाता है। इसके अलावा, साक्षात्कार और सर्वेक्षण के रूप में प्राथमिक आंकड़ों, और साहित्य समीक्षा के रूप में माध्यमिक आंकड़ों प्रश्नों का उत्तर देने के लिए इस अध्ययन में आवश्यक है।

अनुसंधान प्रश्नों को संबोधित करने के लिए, यह अध्ययन भारतीय निर्माण उद्योग से संबंधित महत्वपूर्ण मुद्दों की पहचान करने पर केंद्रित है। एक व्यापक साहित्य समीक्षा से पता

चलता है कि भारतीय निर्माण उद्योग के संदर्भ में सामग्री प्रबंधन में मौजूदा प्रथाओं और महत्वपूर्ण मुद्दों पर केंद्रित अध्ययन सीमित है। इसलिए, यह अध्ययन सामग्री प्रबंधन विशेषज्ञों के साक्षात्कारों के आधार पर तथा दो प्रश्नावली सर्वेक्षणों- भाग I और भाग II के आधार पर भारत में सामग्री प्रबंधन की स्थिति का पता लगाता है। भाग I और भाग II सर्वेक्षण आंकड़ों के डिस्क्रिप्टिव् स्टैटिस्टिक्ल् अनालसिस से पता चलता है कि पारंपरिक और स्थायी सामग्री प्रबंधन प्रथाओं के कार्यान्वयन का स्तर असंतोषजनक है और इसमें सुधार की आवश्यकता है। इसके अलावा, भाग I सर्वेक्षण आंकड़ों का विश्लेषण, इक्स्प्लॉरटरी फैक्टर अनालसिस और स्ट्रक्चरल् इक्वेशन् मॉडलिङ् का उपयोग करके, यह निर्धारित करता है कि सामग्रियों की अनुचित वितरण परियोजनाओं के कार्यक्रम और लागत प्रदर्शन को बाधित करने वाला सबसे महत्वपूर्ण मुद्दा है, इसके बाद सामग्री की अपर्याप्त योजना, जानकारी और संचार की कमी, खरीद में वित्तीय मुद्दे, सामग्री के दायरे में बदलाव और परिवहन में कठिनाई। इस प्रकार, यह अध्ययन सामग्री प्रबंधन में सुधार के लिए निर्णय समर्थन प्रणाली के विकास में दो सबसे महत्वपूर्ण मुद्दों-अनुचित वितरण और सामग्रियों की अपर्याप्त योजना को संबोधित करने पर केंद्रित है। परियोजनाओं के कार्यक्रम और लागत प्रदर्शन के विघटन पर सामग्री प्रबंधन के मुद्दों के प्रभाव की जांच और महत्वपूर्ण मुद्दों का निर्धारण करके, यह अध्ययन निर्माण उद्योग में सामग्री प्रबंधन से संबंधित ज्ञान के प्रासंगिक संस्था में योगदान देता है।

इन दो सबसे महत्वपूर्ण मुद्दों की पहचान से पता चलता है कि अगुवाई समय के आकलन पर जोर देने की आवश्यकता है, उनके महत्वपूर्ण मूल्यों के आधार पर सामग्रियों की खरीद का प्राथमिकताकरण और एक अनुकूलतम सामग्री खरीद अनुसूची का विकास, जो की योजना और वितरण से संबंधित सामग्री प्रबंधन के प्रमुख पहलू हैं। यह भी निर्धारित करता है कि इन प्रमुख पहलुओं को डिसिज़न् सपॉर्ट सिस्टम् में शामिल किया जाना चाहिए।

एक उपयुक्त सामग्री प्रबंधन प्रणाली को निर्माण सामग्री के अगुवाई समय के आधार पर अनुमान और वर्गीकरण की आवश्यकता होती है। अगुवाई समय का सटीक अनुमान लगाने के लिए, इसे प्रभावित करने वाले कारकों की पहचान आवश्यक है। सामग्री प्रबंधन में पिछले अध्ययनों ने बड़े पैमाने पर उन कारकों की जांच नहीं की है जो अगुवाई समय को प्रभावित करते हैं और अगुवाई समय के आधार पर सामग्रियों के वर्गीकरण पर जोर नहीं दिया है। इसे संबोधित करने के लिए, वर्तमान अध्ययन ने भारत में 16 भवन निर्माण परियोजनाओं के खरीद आंकड़ों का एक बड़ा नमूना एकत्र किया है। टू-स्टेज क्लस्टर अनालसिस के परिणामस्वरूप तीन समूहों में परिणाम प्राप्त हुए, जैसे कि लंबी अगुवाई (एल), मध्यम अगुवाई (एम), और छोटी अगुवाई (एस), सामग्री के औसत अगुवाई समय के आधार पर यहां एलएमएस के रूप में अल्लेखित हैं। एलएमएस वर्गीकरण का संयोजन मौजूदा एबीसी वर्गीकरणों के साथ, जहां सामग्री को ए, बी और सी प्रकार में वर्गीकृत किया गया है उनके उपयोग मूल्यों के आधार पर, सामग्रियों की सूची पर अधिक विश्वसनीय नियंत्रण की सुविधा प्रदान कर सकता है। इसके अलावा, खरीद आंकड़ों के रिग्रेशन अनालसिस से निर्धारित होता है कि निर्माण सामग्री का प्रमुख समय इकाई मूल्य और ऑर्डर का मूल्य के साथ सकारात्मक रूप से सहसंबद्ध है लेकिन परियोजना मूल्य के साथ नकारात्मक रूप से सहसंबद्ध है। इसके अलावा, थोक सामग्रियों के प्रमुख समय पर आपूर्तिकर्ता की क्षमता पर नकारात्मक प्रभाव पड़ता है। इस अध्ययन के निष्कर्षों से निर्माण वृत्तिक को सामग्री के प्रमुख समय का सटीक अनुमान लगाने में मदद मिलेगी, जिससे परियोजना के लिए सामग्री की उपलब्धता बढ़ेगी।

सामग्री की खरीद को प्राथमिकता देना उनके क्रिटिक्ल्टि के आधार पर सामग्री योजना और वितरण से संबंधित सामग्री प्रबंधन का एक महत्वपूर्ण पहलू है। इस संदर्भ में, सामग्री की टोटल क्रिटिक्ल्टि (टीसी) मूल्यों को उनकी मटेरियल क्रिटिक्ल्टि (एमसी) और एक्टिविटी क्रिटिक्ल्टि (एसी) मूल्यों के संयोजन से निर्धारित किया जाता है। भाग III और भाग IV सर्वेक्षणों

से एकत्र किए गए आंकड़ों के आधार पर और एक एकीकृत ऐनलिटिक नेटवर्क प्रोसेस (एएनपी) और एक टेक्नीक् फ़ॉर ऑर्डर प्रीफ़ेरेंस बाइ सिमलैरिटी टू ऐन आइडीअल सलूशन (टीओपीएसआईएस) का उपयोग करके, सामग्री के एमसी मान निर्धारित किए जाते हैं। एसी मान संबंधित कार्यकलाप में उपलब्ध अतिरिक्त समय का उपयोग करके निर्धारित किया जाता है। इस अध्ययन में, जिस नौ निर्माण सामग्रियों पर विचार किया गया है, उनमें स्ट्रक्चरल स्टील की टीसी मूल्यों सबसे ज्यादा पाया गया है, इसके बाद रिइन्फ़ोरस्मन्ट बार, सीमेंट, आटोक्लेव एअरेटेड कंक्रीट ब्लॉक, मोटा एग्रीगेट, टाइल्स, बालू, प्लाईवुड और बाईन्डिंग तार हैं। आगे परिणाम, भाग V प्रश्नावली सर्वेक्षण और स्पीयरमैन रैंक कॉरलेशन् (आर) परीक्षण का उपयोग करके मान्य किए हैं। इसलिए, यह अध्ययन निर्माण सामग्री के क्रिटिकल्टी मूल्यों का आकलन करने के लिए एक नया दृष्टिकोण प्रदान करता है जो ज्ञान के प्रासंगिक संस्था में मूल्य जोड़ता है। इसके अलावा, टीसी मान वृत्तिक को खरीद के लिए सामग्रियों को प्राथमिकता देने में मदद करेगा। आगे की चर्चा के अनुसार, सामग्री की क्रिटिकल्टी मूल्यों को अनुकूलतम सामग्री खरीद अनुसूची में कमी के प्रभाव के उपाय के रूप में आगे उपयोग किया है।

एक अनुकूलतम सामग्री खरीद अनुसूची का विकास सामग्री योजना और वितरण से संबंधित एक महत्वपूर्ण पहलू है। खरीद अनुसूची सही सामग्री को सही समय पर खरीदने और निर्माण परियोजनाओं में सबसे कम लागत लगाने में मदद करेगा। हालांकि, कुछ अध्ययन निर्माण अनुसूची को एकीकृत करके और सामग्री लागत के साथ-साथ किसी भी सामग्री की कमी के प्रभाव से सामग्री खरीद अनुसूची के विकास की जांच करते हैं। इसके अलावा, सामग्री की खरीद के अनुकूलन के लिए मौजूदा प्रतिरूप में बजट की कमी और अधिकतम भंडारण क्षमता शायद ही कभी समन्वेषण की है। वर्तमान अध्ययन ने इन कमियों को संबोधित किया है और इन सभी पहलुओं को शामिल करते हुए एक अनुकूलन प्रतिरूप विकसित किया है और ननडॉमिनेटेड सॉर्टिंग जेनेटिक एल्गोरिदम II (एनएसजीए II) का उपयोग कर एमएटीएलएबी २०१७ए में

निष्पादित किया गया है। एक इमारत की परियोजना में इस प्रतिरूप के कार्यान्वयन से खरीद लागत और सामग्रियों की कमी के प्रभाव में महत्वपूर्ण बचत दिखायी ।

अंत में, यह अध्ययन एक सामग्री प्रबंधन डिसिश्न् सपोर्ट सिस्टम् (डीएसएस) विकसित करता है जिसमें अगुवाई समय, सामग्री के क्रिटिकल्टि मूल्यों और अनुकूलतम सामग्री खरीद अनुसूची के साथ एकीकृत किया जाता है। इसके लिए, सबसे पहले डीएसएस के लिए एक रूपरेखा विकसित की है। अगला, डीएसएस के लिए विजुअल बेसिक् फ़ॉर ऐप्लिकेशन (वीबीए) और एमएटीएलएबी प्रोग्राम का उपयोग करके एक यूजर इंटरफ़ेस विकसित किया गया है। इसके बाद, भाग VI और भाग VII सर्वेक्षणों से प्राप्त प्रतिक्रियाओं के आधार पर डीएसएस की प्रभावशीलता को मापा जाता है। आंकड़ों के विश्लेषण के लिए एक एएनपी प्रणाली और एक स्कोरिंग मॉडल् प्रणाली तैनात की गई थी। इसके अलावा, एक टी-टेस्ट किया जाता है जो निर्माण संगठनों द्वारा उपयोग की जाने वाली मौजूदा सामग्री प्रबंधन प्रणालियों की तुलना में डीएसएस की बेहतर सुधार क्षमता को निर्धारित करता है। इसलिए, विकसित डीएसएस का उपयोग निर्माण में किया जा सकता है ताकि सामग्री प्रबंधन प्रभावशीलता, विशेष रूप से सामग्री नियोजन और वितरण में सुधार हो सके। चूंकि पिछले कुछ अध्ययनों ने इन महत्वपूर्ण पहलुओं पर जोर दिया है और निर्माण में सामग्री नियोजन और वितरण को बेहतर बनाने के लिए एक डिसिश्न् सपोर्ट सिस्टम् विकसित की है, इसलिए यह अध्ययन ज्ञान के मौजूदा निकाय में महत्वपूर्ण योगदान देता है।

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LIST OF ABBREVIATIONS

AAC	Autoclaved aerated concrete
AC	Activity criticality
ANP	Analytic network process
BD	Buyer's dependence on suppliers
BOM	Bill of materials
CFI	Comparative fit index
CI	Consistency index
CII	Construction industry institute
CLP	Construction logistics planning
CPWD	Central public works department
CR	Consistency ratio
CS	Customers' specificity
CSM	Changes in scope of materials
CSR	Corporate social responsibility
DCP	Disruption in cost performance
DSP	Disruption in schedule performance
DSS	Decision support system
DTM	Difficulty in transportation of materials
ECVI	Expected cross-validation index
EFA	Exploratory factor analysis
EFT	Earliest finish time
EI	Environmental implication
EIP	Enterprise information portal
EOQ	Economic order quantity
ERP	Enterprise resource planning
EST	Earliest start time
FE	Flexibility
FIP	Financial issues in procurement
FS	Finish-start
FSN	Fast-moving, slow-moving, and non-moving
GA	Genetic algorithm
GFR	General financial rules

GIN	Goods inward number
GOF	Goodness-of-fit
GP	Government procurement
HML	High, medium, and low unit price
HSE	Health, safety, and environment
ICMM	Integrated construction material management model
ICT	Information and communication technology
ID	Identification
IDM	Improper delivery of materials
IFI	Incremental fit index
IMM	Ineffective material management
IPM	Inadequate planning of materials
IT	Information technology
JIC	Just-in-case
JIT	Just-in-time
KMO	Kaiser-Meyer-Olkin
LEED	Leadership in energy and environmental design
LFT	Latest finish time
LIC	Lack of information and communication
LMS	Long lead, moderate lead, and short lead
LST	Latest start time
LT	Lead time
MC	Material criticality
MLE	Maximum likelihood estimation
MOSPI	Ministry of Statistics and Programme Implementation
MPS	Material procurement schedule
MR	Material requisition
MRN	Material receipt notes
MRP	Material requirement planning
MTMIS	Material tracking management information system
MWBE	Minority/women-owned business enterprise
NSGA	Nondominated sorting genetic algorithm
OECD	Organization for economic co-operation and development
PC	Percentage contribution

PCA	Principal component analysis
PLS	Partial least squares
PO	Purchase order
PSR	Purchasing social responsibility
QA	Quality assurance
QC	Quality control
RCC	Reinforced cement concrete
RFID	Radio frequency identification
RFP	Request for proposal
RFQ	Request for quotation
RI	Random index
RMSEA	Root mean square error of approximation
SAP	Systems applications and products
SD	Super Decisions
SEM	Structural equation modelling
SMM	Sustainable material management
TC	Total criticality
TF	Total float
TLI	Tucker-Lewis index
TMT	Thermomechanical treated
TOPSIS	Technique for order preference by similarity to an ideal solution
VBA	Visual basic for application
VED	Vital, essential, and desirable
VIF	Variance inflation factor
VP	Volatility in price of materials
WBS	Work-breakdown structure