

**SELECT STUDIES FOR PERFORMANCE IMPROVEMENT
OF FLEXIBILITY FOCUSED FREIGHT TRANSPORTATION**

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OF FLEXIBILITY FOCUSED FREIGHT TRANSPORTATION**

by

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CERTIFICATE

This is to certify that the thesis titled “**Select Studies for Performance Improvement of Flexibility focused Freight Transportation**”, being submitted by **Mr. Vipulesh Shardeo** to the Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy (Ph.D.)**, is a record of bonafide research work carried out by him. He has worked under my supervision and has fulfilled the requirements for the submission of this thesis, which is in accordance with the standards required for a Ph.D. degree of the institute. The results contained in it have not been submitted in part or full to any other university or Institute for award of any degree/diploma.

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ABSTRACT

Unpredicted disruptions force organizations to ensure flexibility for fulfilling customer demand. Enabling flexibility along the transportation system is the most suitable solution for unpredictable disruptions. Freight transportation involves the movement of freight, service, value, and cost within the supply chain system. Flexibility, being a potential element, requires more attention to gain competitive advantages. This study investigates the freight transportation issues to improve its performance from flexibility perspective. The research is conducted in different phases.

In first phase of study, an effort has been made to investigate different Transport Flexibility Measures (TFMs) related to freight transportation. Initially, an extensive literature survey is performed to identify different TFMs linked with the supply chain and logistics domain. Further, an integrated Fuzzy Best Worst Method (FBWM) have been adopted to rank the identified TFMs. Lastly to ensure robustness of the model, sensitivity analysis is performed. The findings of the study reflect mode, fleet, vehicle, and speed flexibility as the significant flexibility measures for freight transportation. The information systems flexibility also plays an important part to build flexible systems by strengthening coordination among the actors. This study will help practitioners, managers and decision-makers associated with freight transportation to make better decisions to ensure flexibility in the freight transportation system.

The demand uncertainty costs a significant loss to the organization which is needed to be rectified. An efficient forecasting would be significant solution to these problems. The second study proposes variants of grey forecasting models to forecast the container demand at various major ports of India. The data of past 20 years of container traffic of Indian major ports have been considered for this study. Further, three variants of grey forecasting models: Grey Model (GM (1,1)), Rolling Grey Model (RGM (1,1)) and Rolling Grey Model with error adjustment (e-RGM (1,1)) have been developed. To test the accuracy of the model, Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) is used. The results of the study found that the grey model provides significant forecasting results and can be used for container forecasting with shorter past data. Addition to this, the Rolling Grey Model with error adjustment (e-RGM (1,1)) outperforms other two variants of grey forecasting model. The study would provide a pathway to practitioners to forecast the container demand to strategize the operations accordingly.

The COVID-19 pandemic has affected the whole world and forced countries to impose lockdown and restrict travel and transportation. However, the transportation of essential services was functional during the peak of COVID-19 pandemic spread. Later, different countries formulated different policies, and transportation resumed with some restrictions. Such strategies forced transporters to rethink mode choice decision making for freight transportation. The third study attempts to help in formulation of new strategies for mode choice decisions considering the pandemic such as the COVID-19 pandemic outbreak. Initially, the factors affecting the mode choice decisions for freight transportation amid the Coronavirus outbreak have been extracted from literature survey and group discussion with experts. Further, this paper employs the integration of Grey-Decision Making Trial and Evaluation Laboratory (G-DEMATEL) with Fuzzy Best Worst Method (FBWM) to analyze the identified factors and their categories. The results indicated that the "Disaster Characteristics" and "Social Factors" as a most significant factor which affect the mode choice decisions. Precisely, "Panic", "Travel restrictions", and "Border restrictions" are the top three ranked sub-factors. The findings of the study would guide the practitioners, planners, and policymakers to strategize the mode choice decision-making issues considering the COVID-19 pandemic outbreak.

In the subsequent study, different strategic measures to minimize disease infection has been analyzed. The study utilized simulation modelling for effect analysis of disease outbreak on Intermodal freight transport operations. Initially, Discrete Event Simulation (DES) modelling approach is used to model the intermodal freight transport operations. The developed intermodal freight transportation network includes three modes of transportation: road, rail, and inland waterways. The lead time and infected cases are taken as performance metrics. Further, the DES model is integrated with SEIR model to identify the impact of preventive measures in terms of human infection cases. Five different preventive measures have been analyzed and compared. The results of the study highlighted a trade-off between the risk of COVID-19 pandemic exposure and lead time.

The dynamic and uncertain demand forces organizations to provide flexible services to fulfil customer demands. Freight transportation, being the key component of the businesses, require adoption of efficient Information and Communication technologies which can induce transparent and flexible services. Blockchain Technology (BT) is an emerging technology which has great potential to cater solutions to freight transportation issues. This study identifies different critical success factors of BT adoption in freight transportation. An integrated Fuzzy

Analytic Network Process (FANP) is applied to prioritize identified success factors. Further, modified Total Interpretive Structural Modelling (mTISM) is used to represent the interrelationship among different sub-factors. The findings of the study revealed that the Development Aspects, Customer Services and Technological Aspects, Data Transparency, Reliability and Organizational Culture as most significant factors and sub-factors, respectively. The proposed model will guide freight transport managers to formulate their strategies regarding BT adoption.

The study presents a detailed investigation of freight transportation issues aligning towards the flexibility perspective. The studies carried out is an attempt to answer the research question derived from the research gaps. The study contributed to the body of knowledge and management through different phases of research work.

सार

अप्रत्याशित व्यवधान संगठनों को ग्राहकों की मांग को पूरा करने के लिए लचीलापन सुनिश्चित करने के लिए मजबूर करते हैं। परिवहन प्रणाली के साथ लचीलेपन को सक्षम करना अप्रत्याशित व्यवधानों के लिए सबसे उपयुक्त समाधान है। माल ढुलाई में आपूर्ति श्रृंखला प्रणाली के भीतर माल ढुलाई, सेवा, मूल्य और लागत की आवाजाही शामिल है। लचीलापन, एक संभावित तत्व होने के नाते, प्रतिस्पर्धी लाभ प्राप्त करने के लिए अधिक ध्यान देने की आवश्यकता होती है। यह अध्ययन लचीलेपन के परिप्रेक्ष्य से अपने प्रदर्शन में सुधार करने के लिए माल ढुलाई के मुद्दों की जांच करता है। यह शोध विभिन्न चरणों में किया गया है।

अध्ययन के पहले चरण में, माल ढुलाई से संबंधित विभिन्न परिवहन लचीलेपन उपायों (टीएफएम) की जांच करने का प्रयास किया गया है। प्रारंभ में, आपूर्ति श्रृंखला और रसद डोमेन से जुड़े विभिन्न टीएफएम की पहचान करने के लिए एक व्यापक साहित्य सर्वेक्षण किया गया। इसके अलावा, पहचाने गए टीएफएम को रैंक करने के लिए एक एकीकृत फजी बेस्ट वर्स्ट मेथड (FBWM) को अपनाया गया है। अंत में मॉडल की मजबूती सुनिश्चित करने के लिए, संवेदनशीलता विश्लेषण किया गया। अध्ययन के निष्कर्ष माल ढुलाई के लिए महत्वपूर्ण लचीलेपन उपायों के रूप में मोड, बेड़े, वाहन और गति लचीलेपन को दर्शाते हैं। सूचना प्रणाली लचीलापन भी अभिनेताओं के बीच समन्वय को मजबूत करके लचीली प्रणालियों के निर्माण के लिए एक महत्वपूर्ण भूमिका निभाता है। यह अध्ययन माल ढुलाई से जुड़े चिकित्सकों, प्रबंधकों और निर्णय निर्माताओं को माल ढुलाई प्रणाली में लचीलापन सुनिश्चित करने के लिए बेहतर निर्णय लेने में मदद करेगा।

मांग अनिश्चितता संगठन के लिए एक महत्वपूर्ण नुकसान है जिसे ठीक करने की आवश्यकता है। एक कुशल पूर्वानुमान इन समस्याओं के लिए महत्वपूर्ण समाधान होगा। दूसरे अध्ययन में भारत के विभिन्न प्रमुख बंदरगाहों पर कंटेनर की मांग का पूर्वानुमान लगाने के लिए ग्रे पूर्वानुमान मॉडल के वेरिएंट का

प्रस्ताव किया गया है। इस अध्ययन के लिए भारतीय प्रमुख बंदरगाहों के कंटेनर यातायात के पिछले 20 वर्षों के आंकड़ों पर विचार किया गया है। इसके अलावा, ग्रे पूर्वानुमान मॉडल के तीन संस्करण: ग्रे मॉडल (जीएम (1,1)), रोलिंग ग्रे मॉडल (आरजीएम (1,1)) और त्रुटि समायोजन (ई-आरजीएम (1,1)) के साथ रोलिंग ग्रे मॉडल विकसित किए गए हैं। मॉडल की सटीकता का परीक्षण करने के लिए, रूट मीन स्क्वायर त्रुटि (RMSE) और माध्य निरपेक्ष प्रतिशत त्रुटि (MAPE) का उपयोग किया जाता है। अध्ययन के परिणामों में पाया गया कि ग्रे मॉडल महत्वपूर्ण पूर्वानुमान परिणाम प्रदान करता है और इसका उपयोग छोटे पिछले डेटा के साथ कंटेनर पूर्वानुमान के लिए किया जा सकता है। इसके अलावा, त्रुटि समायोजन (ई-आरजीएम (1,1)) के साथ रोलिंग ग्रे मॉडल ग्रे पूर्वानुमान मॉडल के अन्य दो संस्करणों को मात देता है। यह अध्ययन चिकित्सकों को तदनुसार संचालन की रणनीति बनाने के लिए कंटेनर की मांग का अनुमान लगाने के लिए एक मार्ग प्रदान करेगा।

कोविड-19 महामारी ने पूरी दुनिया को प्रभावित किया है और देशों को लॉकडाउन लगाने और यात्रा और परिवहन को प्रतिबंधित करने के लिए मजबूर किया है। हालांकि, आवश्यक सेवाओं का परिवहन कोविड-19 महामारी के प्रसार के चरम के दौरान कार्यात्मक था। बाद में, विभिन्न देशों ने अलग-अलग नीतियां तैयार कीं, और कुछ प्रतिबंधों के साथ परिवहन फिर से शुरू हुआ। इस तरह की रणनीतियों ने ट्रांसपोर्टर्स को माल ढुलाई के लिए मोड विकल्प निर्णय लेने पर पुनर्विचार करने के लिए मजबूर किया। तीसरा अध्ययन कोविड-19 महामारी के प्रकोप जैसी महामारी को ध्यान में रखते हुए मोड विकल्प निर्णयों के लिए नई रणनीतियों को तैयार करने में मदद करने का प्रयास करता है। प्रारंभ में, कोरोनोवायरस प्रकोप के बीच माल ढुलाई के लिए मोड विकल्प निर्णयों को प्रभावित करने वाले कारकों को साहित्य सर्वेक्षण और विशेषज्ञों के साथ समूह चर्चा से निकाला गया है। इसके अलावा, यह पेपर पहचाने गए कारकों और उनकी श्रेणियों का विश्लेषण करने के लिए फजी बेस्ट वर्स्ट मेथड (एफबीडब्ल्यूएम) के साथ ग्रे-डिसीजन मेकिंग ट्रायल एंड इवैल्यूएशन लेबोरेटरी (जी-डीईएमटीएल) के

एकीकरण को नियोजित करता है। परिणामों ने संकेत दिया कि "आपदा विशेषताएं" और "सामाजिक कारक" एक सबसे महत्वपूर्ण कारक के रूप में जो मोड विकल्प निर्णयों को प्रभावित करते हैं। ठीक है, "आतंक", "यात्रा प्रतिबंध", और "सीमा प्रतिबंध" शीर्ष तीन रैंक वाले उप-कारक हैं। अध्ययन के निष्कर्ष चिकित्सकों, योजनाकारों और नीति निर्माताओं को कोविड-19 महामारी प्रकोप पर विचार करने वाले मोड विकल्प निर्णय लेने के मुद्दों की रणनीति बनाने के लिए मार्गदर्शन करेंगे।

बाद के अध्ययन में, रोग संक्रमण को कम करने के लिए विभिन्न रणनीतिक उपायों का विश्लेषण किया गया है। अध्ययन ने इंटरमोडल माल ढुलाई संचालन पर बीमारी के प्रकोप के प्रभाव विश्लेषण के लिए सिमुलेशन मॉडलिंग का उपयोग किया। प्रारंभ में, असतत घटना सिमुलेशन (डीईएस) मॉडलिंग दृष्टिकोण का उपयोग इंटरमोडल माल ढुलाई संचालन को मॉडल करने के लिए किया जाता है। विकसित इंटरमॉडल फ्रेट ट्रांसपोर्टेशन नेटवर्क में परिवहन के तीन तरीके शामिल हैं: सड़क, रेल और अंतर्देशीय जलमार्ग। लीड समय और संक्रमित मामलों को प्रदर्शन मीट्रिक के रूप में लिया जाता है। इसके अलावा, डीईएस मॉडल को मानव संक्रमण के मामलों के संदर्भ में निवारक उपायों के प्रभाव की पहचान करने के लिए एसईआईआर मॉडल के साथ एकीकृत किया गया है। पांच अलग-अलग निवारक उपायों का विश्लेषण और तुलना की गई है। अध्ययन के परिणामों ने कोविड-19 महामारी के जोखिम और लीड टाइम के जोखिम के बीच एक व्यापार-बंद पर प्रकाश डाला।

गतिशील और अनिश्चित मांग संगठनों को ग्राहकों की मांगों को पूरा करने के लिए लचीली सेवाएं प्रदान करने के लिए मजबूर करती है। माल ढुलाई, व्यवसायों का प्रमुख घटक होने के नाते, कुशल सूचना और संचार प्रौद्योगिकियों को अपनाने की आवश्यकता होती है जो पारदर्शी और लचीली सेवाओं को प्रेरित कर सकती हैं। ब्लॉकचेन प्रौद्योगिकी (बीटी) एक उभरती हुई तकनीक है जिसमें माल ढुलाई के मुद्दों के समाधान को पूरा करने की बड़ी क्षमता है। यह अध्ययन माल ढुलाई में बीटी उपयोगों के विभिन्न महत्वपूर्ण सफलता कारकों की पहचान करता है। एक एकीकृत फजी एनालिटिक नेटवर्क प्रक्रिया (FANP) पहचाने

गए सफलता कारकों को प्राथमिकता देने के लिए लागू किया गया। इसके अलावा, संशोधित कुल व्याख्यात्मक संरचनात्मक मॉडलिंग (एमटीआईएसएम) का उपयोग विभिन्न उप-कारकों के बीच अंतर-संबंध का प्रतिनिधित्व करने के लिए किया गया। अध्ययन के निष्कर्षों से पता चला है कि विकास पहलू, ग्राहक सेवाएं और तकनीकी पहलू, डेटा पारदर्शिता, विश्वसनीयता और संगठनात्मक संस्कृति क्रमशः सबसे महत्वपूर्ण कारकों और उप-कारकों के रूप में। प्रस्तावित मॉडल बीटी उपयोगों के बारे में अपनी रणनीतियों को तैयार करने के लिए माल दुलाई प्रबंधकों का मार्गदर्शन करेगा।

अध्ययन लचीलेपन परिप्रेक्ष्य की ओर संरचित माल दुलाई के मुद्दों की एक विस्तृत जांच प्रस्तुत करता है। किए गए अध्ययन अनुसंधान अंतराल से प्राप्त शोध प्रश्न का उत्तर देने का एक प्रयास है। अध्ययन ने अनुसंधान कार्य के विभिन्न चरणों के माध्यम से ज्ञान और प्रबंधन के क्षेत्र में योगदान दिया।

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LIST OF ANNEXURES

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Annexure II	Experts' Details

LIST OF ABBREVIATIONS

ARIMA	Auto Regressive Integrated Moving Average
BT	Blockchain Technology
CFS	Container Freight Station
CR	Consistency Ratio
CI	Consistency Index
CoG	Centre of Gravity
CONCOR	Container Corporation of India
DEMATEL	Decision Making Trial and Evaluation Laboratory
DES	Discrete Event Simulation
DIS	Decision Information Synchronization
e-RGM	Rolling Grey Model with error correction
EDI	Electronic Device Interface
ELM	Extreme Learning Machine
EtI	Exposed to Infected
FANP	Fuzzy Analytic Network Process
FBWM	Fuzzy Best Worst Method
FI	Financial Impact
FMCG	Fast Moving Consumer Goods
FT	Freight Transportation
FTWZ	Free Trade Warehousing Zones
GDP	Gross Domestic Product
GRA	Grey Relational Analysis
GST	Goods and Service Tax
HSC	Humanitarian Supply Chain
ICD	Inland Container Depot
ILP	Integer Linear Programming
ISM	Interpretive Structural Modelling
ITS	Intelligent Transport System
ICT	Information and Communication Technology
IFT	Intermodal Freight Transportation

ItR	Infected to Recovered
INR	Indian Rupee
LCL	Less than Container Load
LP	Linear Programming
LPI	Logistics Performance Index
MABAC	Multi-attributive Border Approximation Area Comparison
MAD	Mean Absolute Deviation
MAPE	Mean Absolute Percentage Error
MCDA	Multi-Criteria Decision Analysis
MIP	Mixed Integer Programming
mTISM	modified Total Interpretive Structural Modelling
OMS	Order Management System
RFID	Radio Frequency Identification
RGM	Rolling Grey Model
RMSE	Root Mean Square Error
SC	Supply Chain
SCLM	Supply Chain and Logistics Management
SCM	Supply Chain Management
SEIR	Suspected Exposed Infected Recovered
StE	Susceptible to Exposed
TEU	20 ft. Equivalent Unit
TFM	Transport Flexibility Measures
TMC	Transport Mode Choice
TMS	Transportation Management System
TTR	Time to Recovery
VMD	Variational Mode Decomposition
WMS	Warehouse Management System
WoS	Web of Science
3PL	Third-party Logistics
4PL	Fourth-party Logistics
5PL	Fifth-party Logistics