

**INTEGRATED INFORMATION AND DECISION
SYNERGY MODELS FOR PERFORMANCE
IMPROVEMENT OF PRODUCT RECOVERY SYSTEM**

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INTEGRATED INFORMATION AND DECISION SYNERGY MODELS FOR PERFORMANCE IMPROVEMENT OF PRODUCT RECOVERY SYSTEM

by

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CERTIFICATE

This is to certify that the thesis titled “**Integrated Information and Decision Synergy Models for Performance Improvement of Product Recovery System**”, being submitted by **Mr. ASHISH DWIVEDI** to the Indian Institute of Technology Delhi, for the award of the degree of **DOCTOR OF PHILOSOPHY** 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

Product Recovery System (PRS) subsist of reducing bulk of waste directed towards the landfill by retrieving materials and parts of obsolete products through remanufacturing and recycling. Due to environmental concerns, product recovery has become a substantial strategy for developing customer satisfaction. Product recovery decisions are perplexing due to scarcity of information linked with the returned products. Product data is required for adequate handling of returns and it is difficult to fetch this critical data and investigate the necessary information for effective return management. Considering the fact that some products are always returned, it becomes challenging to analyze whether to process the new product or to rework on the returned product at every step of the product recovery chain. Information and decision sharing when linked with PRS result in performance improvement of the system. Information Facilitated Product Recovery System (IFPRS) has captivated industry attention and has developed into matter of consideration among the researchers because of enhanced climate concerns, jurisdictive logics and societal liabilities. Although, IFPRS implementation has become an essential aspect in manufacturing industries functional in the developed nations, still limited consideration has been given in the literature to analyze the issues to IFPRS implementation in context of emerging and developing nations. Therefore, requirement for decision models to appraise the product recovery performance has been realized among the practitioners and academicians. The present research is an attempt to analyze the Key Performance Indicators (KPIs) for improving the performance of Information Facilitated Product Recovery System (IFPRS). This study has been conducted in five phases, which has been designed into nine chapters in the thesis.

In the first phase, a comprehensive framework among Key Performance Indicators (KPIs) of the Information Facilitated Product Recovery System (IFPRS) has been proposed on the basis of feedback captured from the industry experts' and the researchers'. Total Interpretive Structural Modeling (TISM) methodology interspersed with fuzzy MICMAC is employed to extract the interrelationships and develop a hierarchical structure among the identified KPIs. This study has identified fifteen KPIs of IFPRS and developed an integrated model using TISM and the fuzzy MICMAC approach, which is helpful to describe and organize the important KPIs and reveal the direct and indirect effects of each KPI on the IFPRS implementation. The results from the study indicate that 'Information sharing', 'technology capacity' and 'technology standards such as EDI, RFID' are the KPIs that have attained

highest driving power. The proposed modelling could empower various governmental and non-governmental regulatory bodies in formulation of policies to effectively tackle the problem related to PRSs. It is expected that the results originated will assist the experts' to relevantly identify the significant and drop the insignificant KPI for successful product recovery implementation and performance improvement of IFPRS.

In the second phase, an extensive assessment tool and decision model among KPIs of IFPRS is proposed. Structural Equation Modeling (SEM) technique is adopted to generate measurement and structural models. The segregation of fifteen KPIs into three perspectives namely (regulatory, technological and operational) is performed on the basis of results obtained from Exploratory Factor Analysis (EFA). The EFA results recognize that all the KPIs that were examined in this study are important for successful implementation of IFPRS. Further, Confirmatory Factor Analysis (CFA) is performed by scanning a vast range of experts' working in the domain of IFPRS. CFA was adopted to test the model fit with the empirical data by employing SEM analysis. The measurement model was tested and the proposed model was found to be compatible with the empirical data. SEM analysis is performed to calculate the model fit, three hypotheses are tested and all are accepted. It can be concluded that the regulatory factors are positively related to both the operational and technological factors. Also, the operational factors are positively related to technological factors. The results deduced from the study can assist companies in electing the important KPIs to execute IFPRS practices in manufacturing industries based on varying prospects. This study can benefit practitioners to measure the performance of the IFPRS and mentor them in decision making for future enhancements.

In the third phase, a framework based on TOPSIS approach is proposed to provide a coherent and systematic process for evaluating and prioritizing the KPIs of IFPRS under a fuzzy environment. The analysis reflects that 'technology capacity' is ranked as the highest and is the most efficient KPI for successful fulfillment of IFPRS practices. The 'environmental concern' and 'waste management system' are ranked at second and third position respectively. The results would automatically enhance the perception of product recovery professionals regarding the nature of relations among the KPIs of IFPRS. Consequently, the results of this study provide a vivid picture that would facilitate the organization to reveal the importance of KPIs relevant to IFPRS.

In the fourth phase, a mathematical problem is formulated to enhance the overall productivity of the product recovery chain. The problem is developed as a Mixed Integer Linear Programming (MILP) model. Genetic Algorithm (GA) and Particle Swarm Optimization

(PSO) are the two meta-heuristic algorithms which are proposed for solving the MILP problem. A recovery scenario is modelled subject to time and type of product to be processed. A case study is represented for a Fast Moving Consumer Goods (FMCG) industry to demonstrate the approach. The proposed model demonstrates a reduction in overall cost of the product recovery chain.

In the fifth and the last phase, a study is proposed to recognize the issues to implementation of IFPRS for a Circular Economy (CE) in Indian manufacturing industries. In this study, twenty-four potential issues are established from the literature and suggestion from the experts. The issues are clubbed under five different perspectives of technical, government, organization, policy and knowledge. Further, the identified issues are prioritized through fuzzy VIKOR technique. Sensitivity analysis has been carried out to check the robustness of the framework. The results form the study reflect that lack of skills and expertise in IFPRS implementation for a CE, requirement of capital to implement CE in IFPRS, inadequate in adopting recent Information Technology (IT), feasibility of IFPRS employment for a CE and no efficient training and program to CE adoption are the top five potential issues in implementation of IFPRS practices for a CE in Indian manufacturing industries.

The present study includes a detailed investigation of the KPIs relevant to IFPRS. Also, the issues pertaining to implementation of IFPRS for a CE are addressed in this study. This study has resulted in methodological and practical methods for transacting with the various aspects of PRSs. The study carried out is an effort to fill the gaps established from the literature and also attempts to address the concerns that are most relevant to the industry. In rundown, the study made contributions to the frame of knowledge and management as displayed in different phases of research.

सार

उत्पाद रिकवरी सिस्टम (पीआरएस) सामग्री को हटाने और पुनर्चक्रण के माध्यम से अप्रचलित उत्पादों के कुछ हिस्सों को प्राप्त करके लैंडफिल के लिए निर्देशित कचरे के थोक को कम करने का निर्वाह करता है। पर्यावरणीय चिंताओं के कारण, उत्पाद की वसूली ग्राहक संतुष्टि को विकसित करने के लिए एक महत्वपूर्ण रणनीति बन गई है। लौटाए गए उत्पादों के साथ जुड़ी जानकारी की कमी के कारण उत्पाद रिकवरी के फैसले हैरान करने वाले हैं। रिटर्न के पर्याप्त संचालन के लिए उत्पाद डेटा की आवश्यकता होती है और इस महत्वपूर्ण डेटा को लाने और प्रभावी रिटर्न प्रबंधन के लिए आवश्यक जानकारी की जांच करना मुश्किल है। इस तथ्य को ध्यान में रखते हुए कि कुछ उत्पाद हमेशा लौटाए जाते हैं, यह विश्लेषण करना चुनौतीपूर्ण हो जाता है कि नए उत्पाद को संसाधित करना है या उत्पाद पुनर्प्राप्ति श्रृंखला के प्रत्येक चरण पर लौटे उत्पाद पर फिर से काम करना है या नहीं। सूचना और निर्णय साझा जब पीआरएस के साथ जुड़ा हुआ है, तो सिस्टम के प्रदर्शन में सुधार होता है। सूचना सुविधा उत्पाद रिकवरी सिस्टम (आईएफपीआरएस) ने उद्योग का ध्यान आकर्षित किया है और शोधकर्ताओं के बीच जलवायु परिवर्तन, क्षेत्राधिकार संबंधी लॉजिक और सामाजिक दायित्व के कारण अनुसंधानकर्ताओं के बीच विचार के मामले में विकसित हुआ है। हालांकि, विकसित देशों में कार्यात्मक उद्योगों के निर्माण में (आईएफपीआरएस) कार्यान्वयन एक अनिवार्य पहलू बन गया है, फिर भी उभरते और विकासशील राष्ट्रों के संदर्भ में (आईएफपीआरएस) कार्यान्वयन के मुद्दों का विश्लेषण करने के लिए साहित्य में सीमित विचार दिया गया है। इसलिए, चिकित्सकों और शिक्षाविदों के बीच उत्पाद वसूली के प्रदर्शन का मूल्यांकन करने के लिए निर्णय मॉडल की आवश्यकता महसूस की गई है। वर्तमान अनुसंधान सूचना सुविधा उत्पाद रिकवरी सिस्टम (आईएफपीआरएस) के प्रदर्शन में सुधार के लिए प्रमुख प्रदर्शन संकेतक (केपीआई) का विश्लेषण करने का एक प्रयास है। यह अध्ययन पांच चरणों में आयोजित किया गया है, जिसे थीसिस में नौ अध्यायों में डिजाइन किया गया है।

पहले चरण में, उद्योग के विशेषज्ञों और शोधकर्ताओं के 'फीडबैक' के आधार पर सूचना सुविधा उत्पाद रिकवरी प्रणाली (आईएफपीआरएस) के प्रमुख प्रदर्शन संकेतक (केपीआई) के बीच एक व्यापक रूपरेखा प्रस्तावित की गई है। फजी मिकमैक के साथ अंतरित कुल इंटरप्रिटिव स्ट्रक्चरल मॉडलिंग (टीआईएसएम) कार्यप्रणाली अंतःसंबंधों को निकालने और पहचाने गए (केपीआई) के बीच एक पदानुक्रमित संरचना विकसित करने के लिए नियोजित है। इस अध्ययन ने (आईएफपीआरएस) के पंद्रह (केपीआई) की पहचान की है और (टीआईएसएम) और फजी मिकमैक दृष्टिकोण का उपयोग करके एक एकीकृत मॉडल विकसित किया है, जो महत्वपूर्ण (केपीआई) का वर्णन और व्यवस्थित करने में सहायक है और (आईएफपीआरएस) कार्यान्वयन पर प्रत्येक (केपीआई) के प्रत्यक्ष और अप्रत्यक्ष प्रभावों को प्रकट करता है। अध्ययन के नतीजों से पता चलता है कि से सूचना साझा करना, प्रौद्योगिकी क्षमता 'और उसी प्रकार का ईडीआई, आरएफआईडी' जैसे प्रौद्योगिकी मानक केपीआई हैं जो उच्चतम ड्राइविंग शक्ति प्राप्त कर चुके हैं। प्रस्तावित मॉडलिंग पीआरएस से संबंधित समस्या से प्रभावी ढंग से निपटने के लिए नीतियों के निर्माण में विभिन्न सरकारी और गैर-सरकारी नियामक संस्थाओं को सशक्त बना सकता है। यह उम्मीद की जाती है कि परिणाम उत्पन्न होने से विशेषज्ञों को प्रासंगिक रूप से महत्वपूर्ण की पहचान करने और सफल उत्पाद वसूली कार्यान्वयन और (आईएफपीआरएस) के प्रदर्शन में सुधार के लिए महत्वहीन (केपीआई) छोड़ने में सहायता मिलेगी।

दूसरे चरण में, (आईएफपीआरएस) के (केपीआई) के बीच एक व्यापक मूल्यांकन उपकरण और निर्णय मॉडल प्रस्तावित है। माप और संरचनात्मक मॉडल उत्पन्न करने के लिए संरचनात्मक समीकरण मॉडलिंग (सेम) तकनीक को अपनाया जाता है। एक्सप्लोरेटरी फैक्टर एनालिसिस (ईएफए) से प्राप्त परिणामों के आधार पर पंद्रह केपीआई का पृथक्करण तीन दृष्टियों (नियामक, तकनीकी और परिचालन) में किया जाता है। ईएफए परिणाम

यह मानते हैं कि इस अध्ययन में जिन सभी केपीआई की जांच की गई, वे (आईएफपीआरएस) के सफल कार्यान्वयन के लिए महत्वपूर्ण हैं। इसके अलावा, (आईएफपीआरएस) के डोमेन में काम करने वाले विशेषज्ञों की एक विशाल श्रृंखला को स्कैन करके कन्फर्मेटरी फैक्टर एनालिसिस (ईएफए) किया जाता है। सीएफए को एसईएम विश्लेषण को लागू करके अनुभवजन्य डेटा के साथ मॉडल फिट का परीक्षण करने के लिए अपनाया गया था। माप मॉडल का परीक्षण किया गया था और प्रस्तावित मॉडल को अनुभवजन्य डेटा के साथ संगत पाया गया था। मॉडल के फिट की गणना के लिए (सेम) विश्लेषण किया जाता है, तीन परिकल्पनाओं का परीक्षण किया जाता है और सभी को स्वीकार किया जाता है। यह निष्कर्ष निकाला जा सकता है कि नियामक कारक परिचालन और तकनीकी दोनों कारकों से सकारात्मक रूप से संबंधित हैं। इसके अलावा, परिचालन कारक सकारात्मक रूप से तकनीकी कारकों से संबंधित हैं। अलग-अलग संभावनाओं के आधार पर विनिर्माण उद्योगों में (आईएफपीआरएस) प्रथाओं को निष्पादित करने के लिए महत्वपूर्ण (केपीआई) के चुनाव में कंपनियों की सहायता कर सकते हैं अध्ययन के परिणाम स्वरूप तैयार परिणाम कंपनियों की सहायता कर सकते हैं। यह अध्ययन चिकित्सकों को (आईएफपीआरएस) के प्रदर्शन को मापने और भविष्य में वृद्धि के लिए निर्णय लेने में उन्हें सलाह देने के लिए लाभान्वित कर सकता है।

तीसरे चरण में, एक अस्पष्ट वातावरण के तहत (आईएफपीआरएस) के (केपीआई) का मूल्यांकन और प्राथमिकता देने के लिए टॉपसीस दृष्टिकोण पर आधारित एक रूपरेखा एक सुसंगत और व्यवस्थित प्रक्रिया प्रदान करने का प्रस्ताव है। विश्लेषण दर्शाता है कि 'प्रौद्योगिकी क्षमता' को उच्चतम स्थान दिया गया है और यह (आईएफपीआरएस) प्रथाओं की सफल पूर्ति के लिए सबसे कुशल (केपीआई) है। 'पर्यावरण संबंधी चिंता' और 'अपशिष्ट प्रबंधन प्रणाली' क्रमशः दूसरे और तीसरे स्थान पर हैं। परिणाम स्वचालित रूप से (आईएफपीआरएस) के (केपीआई) के बीच संबंधों की प्रकृति के बारे में उत्पाद वसूली पेशवरों की धारणा को बढ़ाएगा। नतीजतन, इस अध्ययन के परिणाम एक ज्वलंत तस्वीर प्रदान करते हैं जो संगठन को (आईएफपीआरएस) के लिए प्रासंगिक (केपीआई) के महत्व को प्रकट करने की सुविधा प्रदान करेगा।

चौथे चरण में, उत्पाद की पुनर्प्राप्ति श्रृंखला की समग्र उत्पादकता को बढ़ाने के लिए एक गणितीय समस्या तैयार की जाती है। समस्या को एक मिश्रित पूर्णांक रैखिक प्रोग्रामिंग (एमआईएलपी) मॉडल के रूप में विकसित किया गया है। जेनेटिक एलगोरिदम (जीए) और पार्टिकल स्वार्म ऑप्टिमाइजेशन (पीएसओ) दो मेटा-हेयूरिस्टिक एल्गोरिदम हैं जो एमआईएलपी समस्या को हल करने के लिए प्रस्तावित हैं। पुनर्प्राप्ति परिदृश्य संसाधित होने के लिए समय और उत्पाद के प्रकार के अधीन है। दृष्टिकोण का प्रदर्शन करने के लिए फास्ट मूविंग कंज्यूमर गुड्स (एफएमसीजी) उद्योग के लिए एक केस स्टडी का प्रतिनिधित्व किया जाता है। प्रस्तावित मॉडल उत्पाद पुनर्प्राप्ति श्रृंखला की समग्र लागत में कमी दर्शाता है।

पांचवें और अंतिम चरण में, भारतीय विनिर्माण उद्योगों में एक परिपत्र अर्थव्यवस्था (सीई) के लिए (आईएफपीआरएस) के कार्यान्वयन के मुद्दों को पहचानने के लिए एक अध्ययन प्रस्तावित है। इस अध्ययन में, विशेषज्ञों से साहित्य और सुझाव से चौबीस संभावित मुद्दे स्थापित किए गए हैं। मुद्दों को तकनीकी, सरकार, संगठन, नीति और ज्ञान के पांच अलग-अलग दृष्टिकोणों के तहत रखा गया है। इसके अलावा, फजी विकोर तकनीक के माध्यम से पहचाने गए मुद्दों को प्राथमिकता दी जाती है। ढांचे की मजबूती की जांच के लिए संवेदनशीलता विश्लेषण किया गया है। परिणाम इस अध्ययन को दर्शाते हैं कि एक (सीई) के लिए (आईएफपीआरएस) कार्यान्वयन में कौशल और विशेषज्ञता की कमी, (आईएफपीआरएस) में (सीई) को लागू करने के लिए पूंजी की आवश्यकता, हाल ही में सूचना प्रौद्योगिकी (आईटी) को अपनाने में अपर्याप्त, एक (सीई) के लिए (आईएफपीआरएस) रोजगार की व्यवहार्यता और कोई कुशल प्रशिक्षण और नहीं (सीई) के लिए कार्यक्रम

भारतीय विनिर्माण उद्योगों में (सीई) के लिए (आईएफपीआरएस) प्रथाओं के कार्यान्वयन में शीर्ष पांच संभावित मुद्दे हैं।

वर्तमान अध्ययन में (आईएफपीआरएस) के लिए प्रासंगिक (केपीआई) की विस्तृत जांच शामिल है। इसके अलावा, इस अध्ययन में एक (सीई) के लिए (आईएफपीआरएस) के कार्यान्वयन से संबंधित मुद्दों पर ध्यान दिया जाएगा। इस अध्ययन से पीआरएस के विभिन्न पहलुओं के साथ व्यवहार करने के लिए पद्धतिगत और व्यावहारिक तरीके सामने आए हैं। किया गया अध्ययन साहित्य से स्थापित अंतराल को भरने का प्रयास है और उन चिंताओं को दूर करने का भी प्रयास है जो उद्योग के लिए सबसे अधिक प्रासंगिक हैं। शोध में, अध्ययन ने ज्ञान और प्रबंधन के फ्रेम में योगदान दिया जैसा कि अनुसंधान के विभिन्न चरणों में प्रदर्शित किया गया है।

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List of Abbreviations

PRS	Product Recovery System	ISM	Interpretive Structural Modelling
RES	Reverse Enterprise System	GIS	Graphic Interface System
MOL	Middle of Life	KPIs	Key performance indicators
EOL	End of Life	SEM	Structural Equation Modelling
IFPRS	Information Facilitated Product Recovery System	BDRM	Binary Direct Relationship Matrix
PEID	Product Embedded Information Devices	FDRM	Fuzzy Direct Relationship Matrix
RFID	Radio-frequency Identification Devices	FST	Fuzzy Set Theory
IT	Information Technology	FMSM	Fuzzy MICMAC Stabilized Matrix
ICTs	Information Communications Technologies	PCA	Principal Component Analysis
ISC	IT in Supply Chain	INS	Ideal Negative Solution
PM	Performance Measurement	IPS	Ideal Positive Solution
CE	Circular Economy	MCDM	Multi Criteria Decision Making
SPSS	Statistical Package for Social Science	EDI	Electronic Data Interchange
MSMEs	Micro, Small and Medium Enterprises	DMs	Decision Makers'
TISM	Total Interpretive Structure Modeling	KMO	Kaiser-Meyer-Oklin
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution	CITC	Corrected Item Total Correlation
EFA	Exploratory Factor Analysis	AMOS	Analysis of Moment Structures
CFA	Confirmatory Factor Analysis	SE	Standard Error
MILP	Mixed Integer Linear Programming	CC	Closeness Coefficient
GA	Genetic Algorithm	CLSC	Closed Loop Supply Chain
PSO	Particle Swarm Optimization	MINLP	Mixed Integer Non Linear Programming
FMCG	Fast Moving Consumer Goods	DSS	Decision Support System
IoT	Internet of Things	VIKOR	Multi Criteria Optimization and Compromise Solution
SCM	Supply Chain Management	OEM	Original Equipment Manufacturer

LIST OF ANNEXURE

Annexure I	Detail of industry type and respondents
Annexure II	Brief profile of the Decision Makers (DMs) and their organization
Annexure III	Introduction of DMs with their organization
Annexure IV	Questionnaire for conducting survey