Analysing the Challenges to Sustainable Food Grain Storage Management: A Path to Food Security in Emerging Nations

Abstract: Food security is a critical concern for emerging nations, where agriculture is a vital source of livelihood for a significant proportion of the population. However, ineffective food grain storage management (FGSM) poses a substantial threat to food security, resulting in significant post-harvest loss (PHL). This research aims to identify and analyse the challenges of sustainable FGSM in emerging nations, with a specific focus on India using Total Interpretive Structural Modelling (TISM) and Matrice d'Impacts Croisés Multiplication Appliquée á un Classement (MICMAC) analysis. The study identifies 15 critical challenges after doing a thorough literature review, consulting with industry experts, and a dedicated questionnaire survey. The study finds that inadequate government policies and a lack of commitment from the top management are the major challenges to sustainable FGSM. The combination of the qualitative and quantitative model provides a comprehensive understanding of the identified factors and their interrelationships, offering a logical framework to support decision-making and encourage sustainability. This paper contributes to the broader debate on sustainable food production and consumption by highlighting the importance of sustainable FGSM in emerging nations.

Keywords: Food Security; Sustainability; Food Grain Storage Management; Post-harvest Loss (PHL); TISM-MICMAC

1. Introduction

The FGSM is a crucial aspect of food security, especially in emerging nations where a large proportion of the population depends on agriculture for their livelihoods. India, in particular, faces several challenges in sustainable FGSM, leading to significant losses and food insecurity. These challenges also lead to financial losses for farmers and traders, exacerbating the issue of food security further. The average annual loss is estimated at 11-15% of total output, or roughly 27.5-37.5 MT grain (FAO, 2021). The efficient storage of food grains is essential to ensure that they remain edible and nutritious for an extended period.

The majority of grain storage in many industrialized nations is conducted by private firms and farmers that utilize their own storage facilities or rent storage space from commercial storage providers. Unfortunately, sustainable FGSM may be difficult in many developing nations because of low resources (Bhattacharya & Fayezi, 2021), insufficient infrastructure (Gunasekera et al., 2017), and other considerations. For example, India does not have modern storage facilities, such as grain silos but it has an extensive network of government-owned storage facilities, and warehouses, which are used to store grains for distribution via the Public Distribution System (PDS). This is a significant distinction from other affluent nations. The grain stock often retains in outdoor depots spread throughout the region which results in substantial grain losses. It makes grain prone to moisture and rodents, birds, pests, and microorganisms (Kasso & Bekele, 2018; Manandhar et al., 2018). The instability of climate and rainstorm makes the circumstance exceedingly terrible. A few significant issues related to the FGSM, for example, inefficient procurement and distribution process (Das et al., 2021; Mahapatra & Mahanty, 2021), shortages of store-rooms, inappropriate planning and coordination, spillages, and wrong aeration strategy, are explored by different researchers in their investigations (Balaji & Arshinder, 2016; Gunasekera et al., 2017; Spiess et al., 2013). Several studies have also reported carelessness to safe and scientific rehearses brought about

excessive damage to food (Bohtan et al., 2017; Mangla et al., 2021). There have been numerous efforts by researchers and organizations to deal with existing issues of FGSM in developing countries. These efforts have focused on a range of approaches, including the development of new technologies and techniques (Mangla et al., 2021), the implementation of better management practices (Mogale et al., 2017), and the establishment of partnerships and collaborations with local communities and governments (Ambekar & Kapoor, 2019).

However, there has been no systematic effort to educate decision-makers on how to prioritize these concerns to reduce wastage and establish sustainable FGSM. No studies have yet been undertaken to create a theory and identify the interdependencies among these challenges and how addressing one challenge may impact others. Previous research has only illuminated these problems and tested particular ideas using quantitative methodologies but lacks providing strategic practices that aim to preserve the quality and nutritional value of stored grains while minimizing negative impacts on the environment and the community (Devi et al., 2021; Gunasekera et al., 2017; Jha et al., 2016).

Hence, this paper aims to analyse 15 identified challenges to the sustainable FGSM with a specific focus on India using a contextual relationship-based TISM and MICMAC approach. The main objectives of the research are as follows:

RO1. To find out the critical challenges for the sustainable FGSM in India.

RO2. To establish the contextual relationship between the identified factors

RO3. To propose a hierarchical framework for the identified challenges and,

RO4. To illustrate how this framework can assist policymakers and supply chain managers.

The framework uses a word-and-graph-based structural model and proposes a hierarchical framework of the identified targets, which helps policymakers and supply chain managers reduce the PHL during storage. Overall, this research paper will contribute to the broader

debate on sustainable food production and consumption by highlighting the importance of sustainable food grain storage management in emerging nations.

The remainder of this paper is written the way that follows. Section 2 points out the different challenges for the sustainable FGSM. Section 3 presents the research methodology. Section 4 outlines the TISM and MICMAC analysis. The findings of the analysis and their consequences are addressed in Section 5. Finally, Section 6 offers a few concluding remarks, recommendations, and scope for future research

2. Challenges for the Sustainable FGSM:

Storage management has a significant task to meet the national supply and demand requirement by procuring food grains and distributing them for consumption. However, there are several problems associated with grain storage management. Figure 1 shows the detrimental effect on the quality of food grains due to inefficient storage management.

<Insert Figure 1>

Literature surveys and discussions with professionals have identified 15 challenges that can affect the efficiency of the FGSM, which have been identified and analysed using the TISM-MICMAC approach. These are discussed in Table 1.

<Insert Table 1>

3. Research Methodology:

To identify the challenges to sustainable FGSM, a model was developed to categorize the identified factors according to their relevance in a hierarchy. An extensive literature review revealed the implementation of the Interpretive Structural Modeling (ISM) technique in similar circumstances, but it has certain limitations. Therefore, the present study adopted the TISM technique to construct an interpretive matrix and understand the relationship between the identified factors. TISM examines effective transitive links and utilizes expert opinion to

identify the real cause of transitivity. This methodology helps to overcome the limitations of ISM and provides a more accurate understanding of the hierarchy of factors affecting sustainable FGSM (Bohtan et al., 2017; Singh & Sushil, 2013).

Next, MICMAC analysis categorizes obstacles and identifies essential aspects that drive the structural model based on power (dominance) and mutual reliance. The different steps of the research are discussed below (see Figure 2).

<Insert Figure 2>

4. TISM-based model development for the FGSM challenges:

4.1 Identification of the factors:

The initial step of the TISM technique is to distinguish different relevant factors relating to the issue under scrutiny (see Table 1). A questionnaire survey (see Appendix A, Table A1) was conducted among the chosen experts and 15 factors were finalized for the analysis.

4.2 Contextual relationship interpretation:

This phase is used to comprehend and identify the model's logic. Table A2 shows the expert's profile. Table A3 shows the interpretive knowledge base.

4.3 Pairwise comparison:

Table A4 displays the consensus of experts on the nature of the relationships between each pair of indicators.

4.4 Reachability matrix and transitivity check:

In Table A5, the first reachability matrix for the variables is generated. To create the final reachability matrix in Table A6, the original reachability matrix is further examined and evaluated following the concept of transitivity.

4.5 Level partitioning:

Similar to ISM, level partitioning is performed to determine where in the hierarchy certain challenges should be placed (Singh & Sushil, 2013) from the FRM. Table A7 represents the level portioning of the identified challenges.

4.6 Developing the digraph:

Figure A1 shows a simple digraph that shows transitive relationships and whose significance is important.

4.7 Development of interaction matrix and interpretive matrix:

The final digraph is then converted into a form that depicts all of the interactions using a binary interaction matrix with 1 entry. Table A8 and Table A9 present the interaction matrix interpretive matrix, respectively.

4.8 TISM Model:

The TISM model was constructed by combining the data in the interpretive matrix and the digraph, which provide relevant and interpretive information (see Figure 3). Link interpretations from the TISM model have been included next to the relevant nodes.

<Insert Figure 3>

4.9 MICMAC analysis:

The objective of the MICMAC analysis is to discover and break down the factors as per driving power and dependency (Sharma et al., 2022). The identified factors are categorized into four clusters depending on the driving power and dependency (see Table 2) based on the final reachability matrix, shown in Figure 4.

<Insert Table 2>

<Insert Figure 4>

The first cluster is of independent factors, which have less driving power and less dependency and are moderately disengaged from the framework. There are no factors under this group. The second cluster is dependent on factors that have high dependency yet less driving power. The third cluster has a place with the factors with high driving power, just as dependency power. These elements are insecure, and any activity on these factors would impact others. The fourth cluster is autonomous factors, with high driving power and less dependency power. For instance, it is observed from Figure 3 that factor C7 has a driver power of 9 and a dependency of 3. It is then located at a spot relating to the driver power of 9 and dependency of 3.

5. Discussion:

The findings of this research provide a meaningful understanding of the challenges faced by growing countries, particularly India, in managing sustainable food grain storage (FGSM. The research used a TISM-based methodology to develop a seven-level hierarchy of factors affecting FGSM.

The TISM model shows that wastages of food grains (C9) are placed at the top level of the hierarchy, while inadequate government policies (C1) and lack of commitment from the top management (C14) are at the bottom. This indicates that factors C1 and C14 are the most crucial factors driving the system. There is still a significant gap between the production and distribution of food grains. This gap is often attributed to inadequate government policies and a lack of commitment from the top management. Policymakers and top management must take a more proactive approach to ensure an effective and efficient food distribution system, investing in infrastructure and technology to improve storage, transportation, and distribution. Our study results are consistent with the claims of other researchers who have previously reported similar findings that policies should be created to incentivize farmers and other

stakeholders in the food supply chain to reduce food waste. (Das et al., 2021; Mogale et al., 2016).

Level 2 consists of two challenges C2 (Inadequate implementation of advanced technology) and C7 (Lack of coordination between stakeholders). Previous literature shows that negligence and unfamiliarity with technology can impact sustainability in FGSM. Top management must focus on adopting new technology for efficient storage and data management which can provide real-time data related to grain quality and storing period. Additionally, the government should focus on policies that incentivize 3rd party storage warehouses to work within a value chain. Our study results are in line with (Rathore et al., 2020). Further, the impact of inadequate government policies (C1) on the inadequate implementation of advanced technology (C2) is exacerbated by poor storage infrastructure (C4), inadequate storage capacity (C6), and excessive procurement (C8), which are placed at the third level in the hierarchy. These factors ultimately result in poor inventory control management (C3) at the fourth level. The government needs to allocate funds efficiently and take initiatives for developing advanced storage structures, as reported by previous researchers (Devi et al., 2021).

Factor C4 directly impacts four other factors: poor packaging system (C5), unscientific way of storing grains (C10), non-utilization of existing capacity (C11), and theft and pilferage (C13). These two factors (C5 and C10) have been placed at the fifth level of the digraph. To address these issues, policymakers and top management must focus on adopting an integrated approach that includes implementing a FIFO system, improving packaging, and utilizing existing storage capacity efficiently (Gunasekera et al., 2017). Additionally, they should promote awareness campaigns and training programs to educate stakeholders on the importance of proper storage and inventory control management.

These three factors (C11, C12, and C13) are at the sixth level in the hierarchy. The use of low-quality jute bags and the unscientific way of storing grains lead to insect infestation (C12), which causes a significant amount of wastage. Moreover, lack of supervision from the management side leads to corruption and swapping of high-quality food grains with low quality to sell in the retail market and that hinders the sustainability of the FGSM.

Additionally, the MICMAC analysis was conducted to determine the driving and dependence power among the identified factors for sustainable FGSM. The analysis revealed that no autonomous factor was identified in cluster I. The non-appearance of autonomous factors demonstrates that none of them is separated from the system (Singh & Sushil, 2013). Further, factors C3, C5, C9, C10, C11, C12, and, C13 in cluster II were found to have high dependence but less driving power. These factors cannot independently cause significant change (Singh & Sushil, 2013). However, in line with the literature, this study confirms that these factors collectively have the strength to disrupt the sustainability in FGSM and increase the wastage of food grains, thus requiring specific measures to tackle them (Kumar & Kalita, 2017; Mogale et al., 2017). The analysis further revealed that no factors were present in cluster III, indicating that the identified factors are not unstable (Singh & Sushil, 2013). Factors C1, C2, C4, C6, C7, C8, C14, and C15 were situated in cluster IV, which had high driving power and less dependence. These factors were identified as decisive factors and formed the primary level of the TISM hierarchy. Policymakers and experts must prioritize these factors while addressing FGSM challenges to achieve sustainability.

5.1 Research implications:

The research presented in this paper has significant theoretical and managerial implications for the sustainable FGSM. The use of TISM-MICMAC methodology enables us to identify the contextual linkages between the various factors involved in the FGSM and to classify them as autonomous, independent, dependent, or linkage variables. It also evaluates the driving and

dependence power of the identified factors to gain a better understanding of their impact on the system.

From a managerial perspective, this research demonstrates that inadequate government policies and top management indifference are the biggest issues in the FGSM, which have a direct impact on food waste and food security. Top management must commit to the vision and policies set by the government, bringing more accountability and responsibility to the top management. The results of this research are comparable to (Mangla et al., 2021). The research also emphasised that urgent consideration should be given to the factors driving the driving category of poor storage structures, inadequate implementation of advanced technology, inadequate storage capacity, poor information sharing, lack of coordination between stakeholders, and excessive procurement. To address these issues, managers should develop advanced storage structures with special training and awareness to experts about new methods, tools, and technology. This study provides managers with a clear understanding of the outcomes and inputs required when formulating policies and helps them prioritize their resources to address the challenges facing the FGSM. Overall, this research provides valuable insights that will help decision-makers formulate effective policies and strategies for implementing sustainable FGSM in India.

6. Conclusion and directions for future research:

This research attempted to improve food security and reduce food waste by providing a deeper understanding of the challenges to sustainable FGSM and developed a framework to prioritize them. The study's initial goal was to identify the challenges faced by the Indian FGSM. Fourteen of the originally indicated challenges have been deemed significant, and one has been designated as a result of other challenges.

In the second part of our research, we sought to connect the issues in Indian FGSM to each other. We have created an interpretive logic-knowledgebase matrix to show how paired

problems are linked together, as well as reveal hidden links between difficulties, i.e., the rationale behind how one challenge affects the other. Hence, this TISM-based model reduces the uncertainty around the sustainability of FGSM.

Another of the study's goals was to develop a system for categorizing and analysing challenges. As a result, the TISM technique has been used to explain the underlying connections between chosen challenges.

The study's final goal was to provide suggestions for management. Figure 3 shows how the different obstacles are rationally linked together. There is urgent need to tackle challenges at the bottom level of the TISM hierarchy. By adopting sustainable practices, FGSM can help to ensure that grains are available and accessible to meet the needs of consumers while also supporting the long-term sustainability of the community and the environment.

However, this research has certain limitations. This problem under consideration may have several components and might change depending on the study field. While the present study focused specifically on India, the findings have potential implications for other emerging nations facing similar challenges with FGSM. The identification of the key challenges and strategies for improvement can provide insights and guidance for policymakers and stakeholders in other countries seeking to enhance food security and reduce food grain losses. Thus, the study result contributes to knowledge beyond the Indian context and can serve as a basis for future cross-country comparisons and analyses. However, the TISM approach can't analyse each factor's influence on the system. Future research can use other MCDM methods like SEM to statistically validate this model.

Conflict of interest:

The authors declare no conflict of interest.

Ethical approval:

Ethics approval was not required for this research.

Data availability:

The authors affirm that the data supporting the study's conclusions are included in the article and its supplementary materials.

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Annotated references:

These references are included in the study as they provide valuable insights into the complex issues surrounding food security and post-harvest loss, and underscore the need for continued efforts to address these challenges.

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Table 1 FGSM challenges in India

Sl. No.	Challenges in FGSM	How it influences the FGSM	Relevant literature
1	Inadequate government. policies (C1)	It fails to provide necessary guidelines and regulations to address the storage issues. This results in inefficient storage practices leading to wastage.	(Ambekar & Kapoor, 2019; González, 2010; Mahapatra & Mahanty, 2021).
2	Inadequate Implementation of advanced technology (C2)	Limited use of sensors, blockchain technology, and the Internet of Things (IoT) results in substantial storage loss.	(Mangla et al., 2021; Zhang et al., 2019).

3	Poor inventory management (C3)	Not following the First-In-First-Out (FIFO) principle can lead to overstocking, understocking, spoilage, and expiration of old stocks, impacting food security and economic stability.	(Bhattacharya & Fayezi, 2021; Bohtan et al., 2017).
4	Poor storage infrastructures (C4)	It increases the risk of spoilage, pest infestation, and physical damage to the grains, resulting in significant economic losses and food insecurity.	(Bhardwaj & Sharma, 2020; Devi et al., 2021)
5	Poor packaging system (C5)	It can lead to spoilage, contamination, and infestation, posing a significant challenge to sustainable food grains storage management.	(Balaji & Arshinder, 2016; Gunasekera et al., 2017; Raut et al., 2018)
6	Inadequate storage capacity (C6)	It causes spoilage and wastage, which leads to food insecurity and financial losses both for farmers and the government.	(Bhardwaj & Sharma, 2020; Mahapatra & Mahanty, 2021)
7	Lack of coordination between the government and other agencies (C7)	It leads to duplication of efforts, inefficiencies, and delays in decision-making, hindering sustainable FGSM.	(Balaji & Arshinder, 2016; Mogale et al., 2016)
8	Excessive procurement (C8)	Excessive procurement by FCI can lead to a surplus of food grains, storing problems and wastage.	(Mahapatra & Mahanty, 2021; Zhang et al., 2019)
9	Wastage of food grains (C9)	It results in significant economic losses and hampers efforts towards achieving food security.	(Ambekar & Kapoor, 2019; Bhattacharya & Fayezi, 2021)
10	Unscientific way of storing grains (C10)	Unscientific way of storing grains does not provide staple crop security, causing grain loss due to post-harvest pest irritation.	(Gunasekera et al., 2017; Jha et al., 2016; Raut et al., 2018)
11	Non-utilization of existing storage capacity (C11)	The use of existing storage limits in different states decreased by 75% in most cases between 2006-07-2012.	(Balaji & Arshinder, 2016; Hiremath & Netravathi, 2018)

12	Insect infestation (C12)	Storage conditions are poor for food grains, leading to increased risk of insect infestations of up to 80-90%.	(Balaji & Arshinder, 2016; Manandhar et al., 2018)
13	Theft and pilferage (C13)	it results in significant losses of food grains, leading to financial and operational inefficiencies.	(Hiremath & Netravathi, 2018; Rathore et al., 2020)
14	Lack of commitment from the top management (C14)	The lack of commitment hinders the implementation of effective policies and strategies.	(Balaji & Arshinder, 2016; Das et al., 2021)
15	Poor information sharing (C15)	It hinders the effective coordination and communication among stakeholders.	(Bhattacharya & Fayezi, 2021; Chimatiro, 1998; Das et al., 2021)

Table 2 Driving power and dependence power of the identified challenges

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**	**C15**
Driving Power	15	9	7	8	3	8	9	8	1	3	2	2	2	15	8
Dependence power	2	3	9	3	10	3	3	3	15	10	10	12	10	2	5

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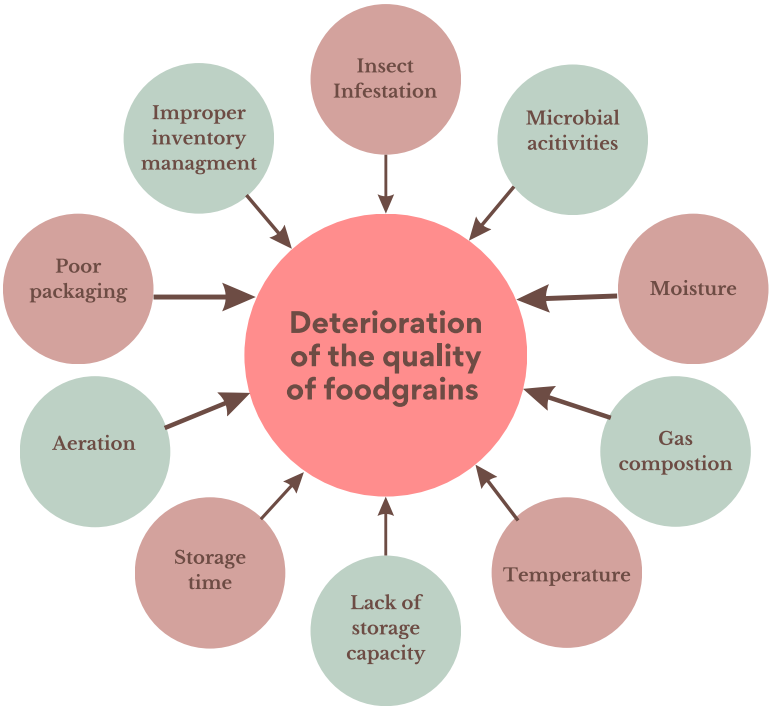

Figure 1 Deterioration of the quality of food grains due to inefficient grain storage management

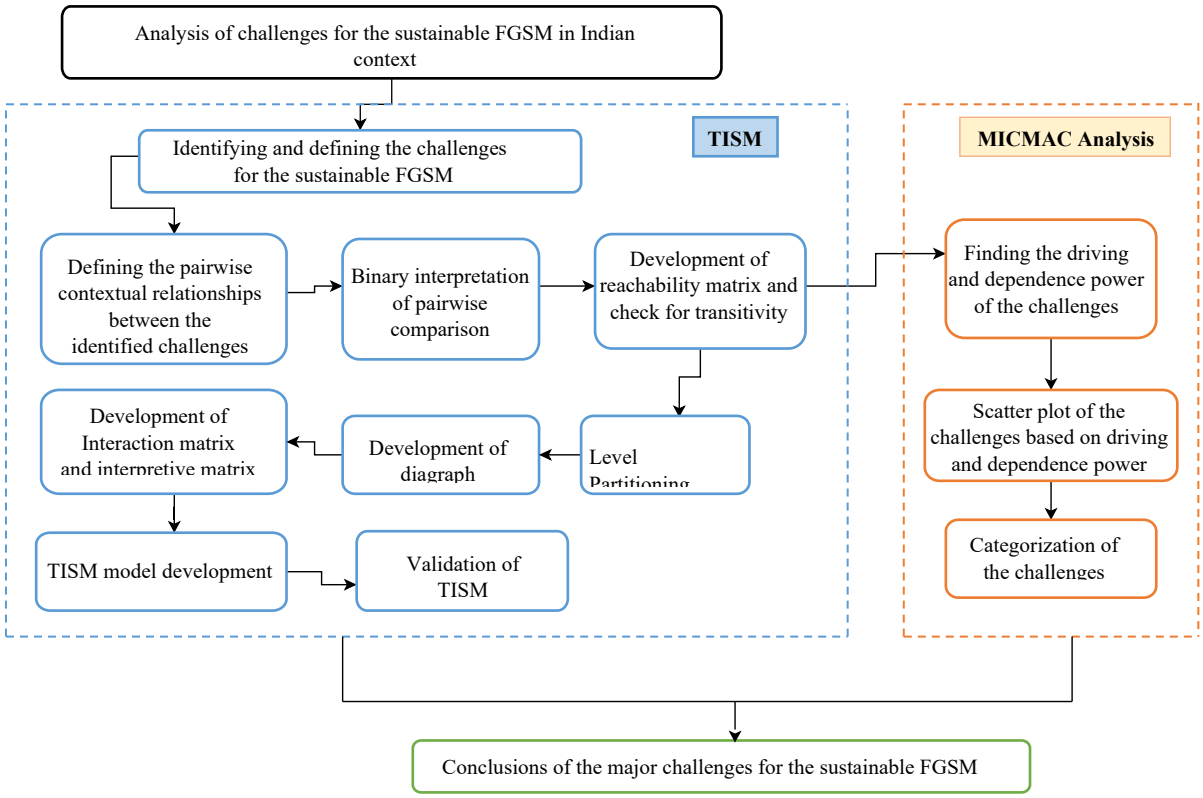

Figure 2 Proposed research methodology

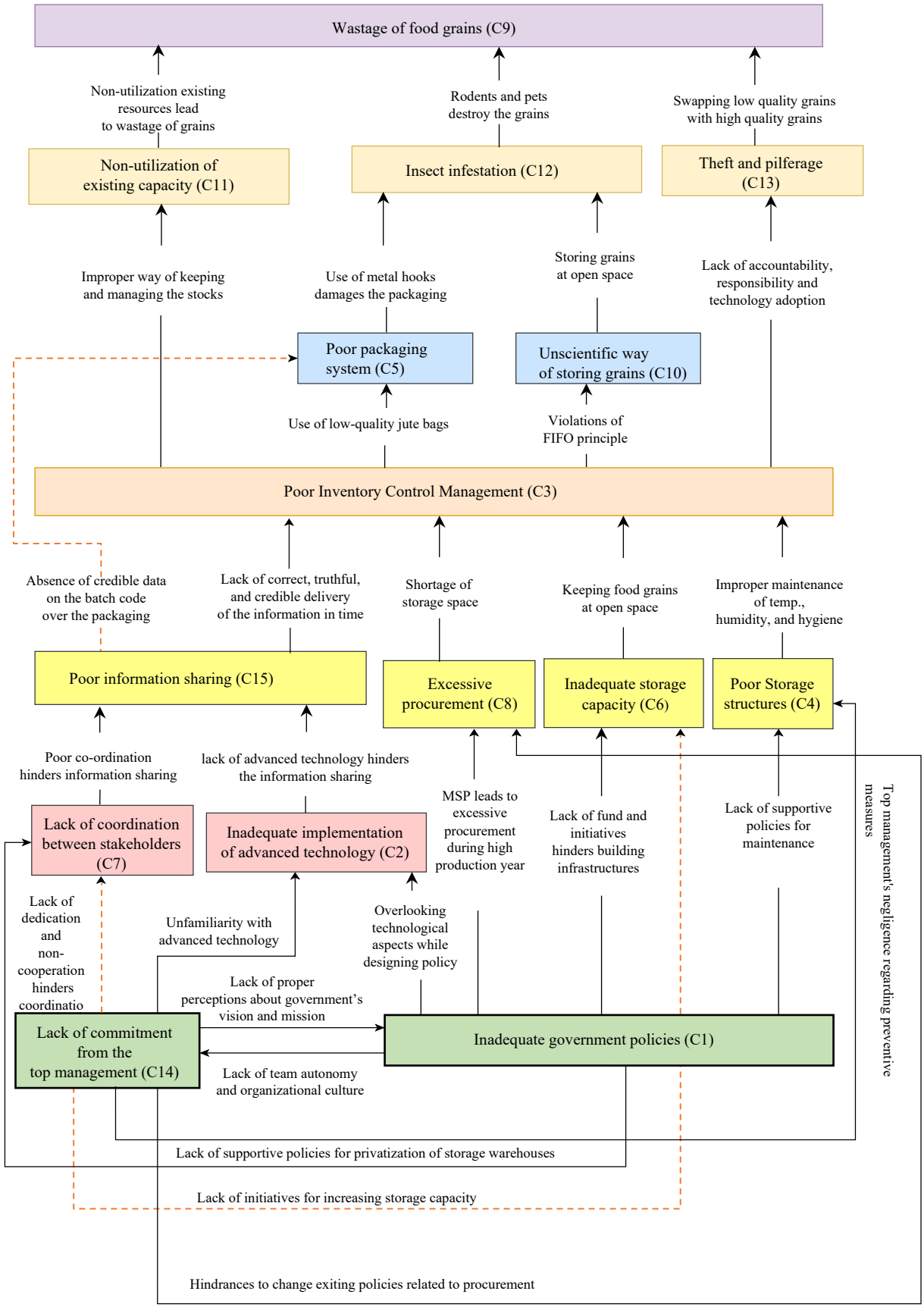

Figure 3 TISM model

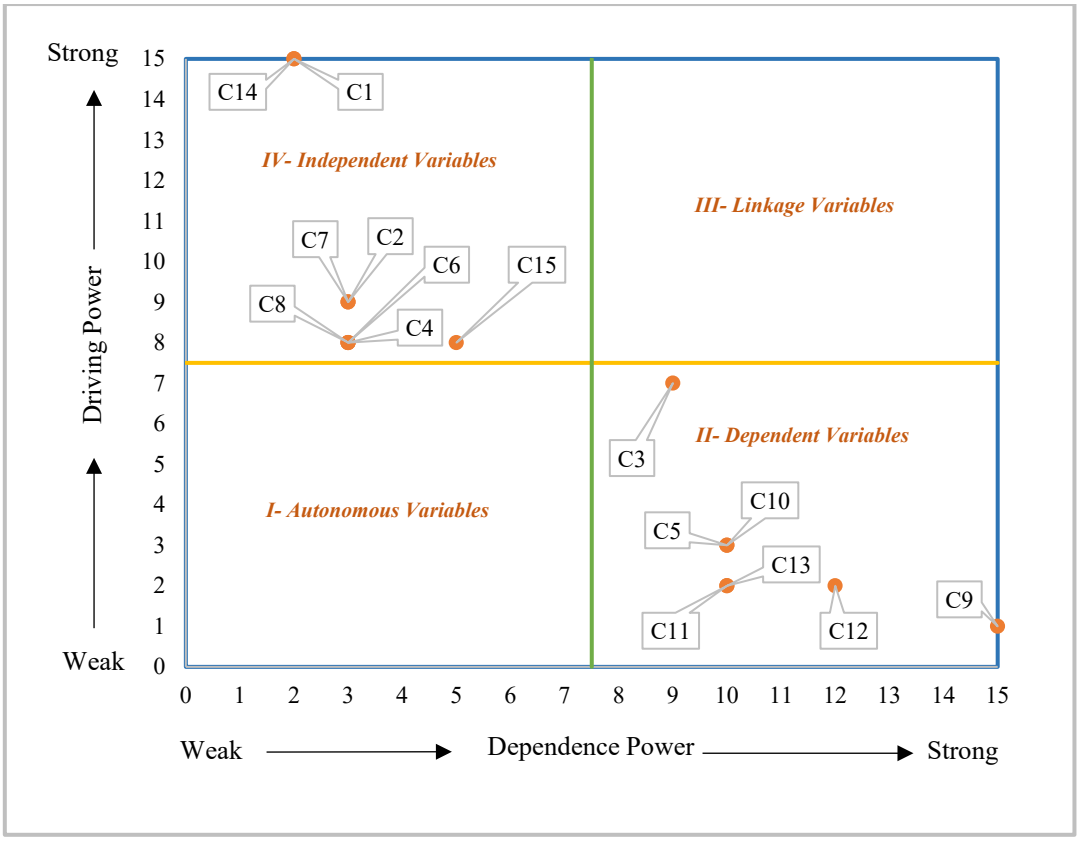

Figure 4 Driving power vs dependence power