Third-party Logistics in Bio-medical Waste System: a Path Towards a Risk-free Sector

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Abstract
After the sudden advent of COVID-19, the amount of medical waste has escalated to a great extent. The incremented medical waste amidst the pandemic exposes the improper waste management system of various developing countries. India, being one of the prominent developing countries, produces the largest waste in the world. Nonetheless, the Indian waste management system is not able to manage the massive amount of waste generated. Henceforth, this research study approaches to reveal the prominent factors which are causing failure in the system of medical waste management in India. This manuscript mainly focuses on two aspects. Firstly, this paper illuminates the factors which are hindering medical waste management by third-party logistics (3PL). Secondly, this study discusses a unique interval-value intuitionistic fuzzy set (IVIFS) based on Decision Making Trial and Evaluation Laboratory (DEMATEL) to depict graphical causal interrelationships among the factors. In addition, the analytic network process (ANP) is utilized to estimate the influence ranking of each factor. The results of this research anticipate that the transportation and disposal-related constraining factors require more attention from 3PL managers. The current study is unique as it enriches the various hindering factors on 3PL BMW management by discussing the ranking and relationship among factors.

Keywords Bio-medical waste (BMW) · Third-party Logistics · IVIFS · DEMATEL · ANP

Introduction
At its core, the issue of a clean environment is a matter of public health.

After the impact of COVID-19, this quote by Gina McCarthy is more relevant than ever. A tremendous amount of bio-medical waste (BMW) has been generated worldwide, posing a severe threat to humanity (Rume and Islam 2020). This medical waste contains various harmful substances such as radioactive burns, micro-organisms, and different cytotoxic drugs (Padmanabhan and Barik 2019). Due to health and environmental concerns, every country’s government attempts to manage the produced BMW with proper treatment (Varmani 2020). However, many developing countries do not possess systematic executable plans and provisions to tackle this situation, causing improper medical waste disposal in their countryside (Rahman et al. 2020). Along with this, on-site treatment by hospitals and medical corporations is prohibitively expensive since disposal equipment are costly to purchase, maintain, and operate. To deal with such uneconomical and inconvenient BMW disposal difficulties, many developing Asian countries, such as China and Korea, came up with a solution, which is to hire third-party vendors to dispose off their medical waste in an efficient manner (He et al. 2016). Contracting third-party vendor helps government administration and health care centers to mitigate the severity of medical waste by facilitating storage, transportation, proper treatment, and disposal services (Mahya 2020). However, there are certain challenges that 3PL faces during the treatment of BMW; for instance, less investment by government and...
healthcare administration is one of the predominant issues due to which many third-party professionals are not able to treat medical waste properly (Hossain et al. 2011). Many hospitals corresponding in rural areas give less attention to the medical waste segregation practices (Capoor and Bhowmik 2017). Furthermore, most of the 3PL waste-collecting personnel do not possess sufficient knowledge about legislation regarding medical waste but are still employed by their respective 3PL companies (Sarfo-Mensah et al. 2019). All of the preceding instances demonstrate that 3PL services are failing to develop cost-effective and efficient disposal networks; thus, it is worthwhile to study barriers for vendors. Henceforth, there is a dire need to study 3PL’s perspective in BMW management since it forms a crucial player in the BMW supply chain, responsible for logistics activities management. By studying the hurdles faced during BMW management from 3PL’s perspective, the associated 3PL policymakers and managers will be able to recognize and analyze the major barriers in BMW management process. This paper takes a comprehensive approach by describing the factors hindering effective BMW management from the perspective of third-party logistics.

India is one of the prominent Asian countries generating a large volume of medical waste. Nevertheless, only a small part of it gets properly disposed of. Although in 2016, after acknowledging the severity of generated medical waste, the Indian government made many changes in their policies regarding medical waste management, separation, storage transportation, and disposal of BMW (Datta et al. 2018). Besides the above-mentioned endeavors, the amount of medical waste is continuously escalating. According to Jaganmohan (2020), in 2018, 550 metric tons of medical waste were generated per day, out of which 20 metric tons remain in the environment without any proper treatment. This data depicts that there exist certain hidden issues which have not been identified after hiring 3PL services. Many researchers (Awodele et al. 2016; Eren and Tuzkaya 2019; Tirkolaee et al. 2021) have introspected the problem of rapidly increasing medical waste worldwide along with the hindering factors in the BMW disposal process. Nonetheless, hardly any of them have emphasized factors hindering 3PL during the disposal process. Henceforth, this study tends to discover certain hindering factors in third-party medical waste management and their impact on BMW.

The purpose of this research is to perform an exhaustive assessment of the BMW disposal system from the standpoint of third-party operators. The emergence of COVID-19 necessitates an immediate consideration of this aspect. This manuscript conducts a thorough discussion of certain hindering factors with a hierarchical structure. And since these factors have a causal relationship, it is worthwhile to describe such factors whose impact can affect others as well. Hence, identifying those criteria will be extremely beneficial to third-party operators. Therefore, this study evaluates medical waste disposal by setting the following objective as a benchmark:

i. To determine the role of third-party logistics in BMW management amidst the COVID-19 situation.

ii. To identify the hindering factors associated with third-party logistics in bio-medical waste management.

iii. To explore the influence of constraining factors, priority weightage, and their causal relationships on BMW management services.

iv. To highlight the research implications of this study and how 3PL managers can utilize this study.

This study emphasizes on structural analysis of medical waste disposal services by merging the IVIFS-DEMATEL technique with ANP, intimated as IVIFS-DANP, to calculate the causal relationships and weight preference of all the factors constraining BMW management. It is evident from the earlier studies that the integration of different MCDM techniques enhances the overall accuracy of the analysis (Govindan et al. 2018; Shanker et al. 2021a; Supeekit et al. 2016). Moreover, recent studies endorse theories based on IVIFS-DEMATEL with the ANP technique. In IVIFS-DANP, IVIFS-DEMATEL facilitates obtaining the causal relationships among the constraining factors (Abdullah et al. 2019). Furthermore, ANP is utilized to compute the weightage of all the hindering factors and ultimately to rank them based on their global weights. Considering this study as a benchmark, policymakers and hospital administration can analyze concerns and devise strategies to reduce them.

This research paper is organized in the following manner. The “Introduction” section consists brief introduction of this topic and methodology. In the “Literature review” section, this study discusses previous literature work and contains a comprehensive review of the applied research methodology. The “Factors Hindering 3PL in BMW Management” section exposes the constraining factors and their impact on management services by splitting the overall management process into four zones. The “Application of the Integrated IVIFS-DANP Methodology” section enlightens the application of the proposed methodology with case studies. The “Result and Discussion” section explains the result and discussion, and the “Implication for Practice and Research Work” section consists of the implication of results in BMW management services. The “Conclusion” section concludes this research study.

**Literature Review**

This section will review the earlier studies and research models that have been discovered in the past few years. This section consists of two parts:
(i) Firstly, the paper discusses the various perspectives of different authors and their conclusive remarks based on constraining factors in medical waste management services (“Research Work in BMW Management Sector” section).

(ii) Then, this research paper will analyze the facts regarding the proposed research methodology (“A Literature Review for the Integration of IVIFS-DEMATEL with ANP” section).

Research Work in BMW Management Sector

After the advent of COVID-19, the use of medicines and medical equipment has increased, causing an increment in the amount of medical waste generation. To reduce the amount of medical waste and its proper disposal, many hospital administrations and governments hire third-party professionals. Wilujeng (2019) and Rahman et al. (2020) have also mentioned that many countries, such as China and Bangladesh, are hiring third-party for transportation and disposal of medical waste. In previous years, many researchers have identified different factors that are impendent medical waste management, which is also contributed to the current predicament. According to Shareefdeen (2012) and Qasim et al. (2020), only a few hospitals segregate and store their medical waste properly, which causes an increment in the toxicity of overall waste. Lack of precautionary measures while handling hazardous wastes contributes to the rapid spreading of SARS-Cov2 in any country. Niyompanitpatana and Bonollo (2012) also deduce that one of the biggest reasons for mixed medical waste is unskilled workers, as improper communication between them and their insufficient knowledge about medical waste indirectly creates difficulties in BMW management. Abdullah and Al-Mukhtar (2013) and Akum (2014) suggested that medical waste should be stored for a maximum of up to 48 h. However, in this pandemic situation, in several storage sites, medical waste remains untreated, which emphasizes reckless behavior of management. In case medical waste remains in the environment for a long time, then as Xin (2015) discussed, its toxicity increases, which ultimately pollutes the environment as well as increases the risk factor for 3PL waste-collecting workers. After the BMW collection, its transportation from the storage facility to the disposal factory within a specified time limit is necessary. Kwikiriza et al. (2019) and He et al. (2016) found that many vehicle drivers do not follow the legislation regarding medical waste because of the lack of monitoring practice, which enhances the propagation of COVID-19 in outside areas through medical waste. Once medical wastes reach the factory, the disinfection and disposal process begins. Qi et al. (2018) found that many factories usually use incinerators for disposing of medical waste, which is sufficiently effective in the treatment of COVID-19 waste. While Li et al. (2019) enlightens the fact that some factories do not use gas cleaners in their incinerators due to which many gasses such as dioxin get produced which causes human cancer, deformation in newborns, and also disturbs flora and fauna of environment. Apart from this, the medical waste also contains a recyclable portion; it is necessary to focus on recycling by chemical disinfection or sterilization processes. Sharma et al. (2020) discussed that due to the low recyclability demand of plastic, it gets accumulated, directly escalating the quantity of non-biodegradable waste present in the environment.

The above-mentioned studies reveal that abundant research work has been done on medical waste management, but challenges from a third-party perspective have not been addressed thoroughly. Henceforth, this manuscript attempts to fill this research gap by identifying the various hindering factors related to third-party logistics in the sector of medical waste management.

A Literature Review for the Integration of IVIFS-DEMATEL with ANP

Evaluating the elements that adversely affect BMW management during the pandemic outbreak is a very critical verdict since many hindering factors include a qualitative and subjective appraisal. Multiple criteria decision-making (MCDM) techniques are eminent for such a situation, as those are great techniques to deal with perplexing issues that comprise opposing objectives, hierarchical structure, and affiliation of numerous partners (Demirel et al. 2010). Nevertheless, every methodology has its limitations, which can be overcome using a blend of quantitative and qualitative approaches (Shahsavari and Khamehchi 2018). Thus, professionals recommend using a blend of MCDM techniques (Li and He 2021); these strategies allow to discover the character of interdependent factors and prioritize those factors according to their weight, which will be extremely prominent in the pandemic situation (Kumar and Anbanandam 2020). The affiliated model of several MCDM techniques facilitates in better research analysis of impendent factors at this outbreak (Beheshtinia and Omidi 2017). This research work focuses on defining interrelationships and prioritizing constraint factors in the BMW management process with the hybrid MCDM approach.

Fuzziness in decision-making for real-life problems and ambiguous data cannot be inferred with crisp values; thus, to deal with all these realistic situations, the interval-valued intuitionistic fuzzy set (IVIFS) technique is utilized. IVIFS determines the degree of membership, non-membership, and hesitancy in decision-making in interval values which is a subsidiary of real-life problems. To define the causal relationships of different factors in terms of their relative dependency, Decision-Making Trials and Evaluation
Laboratory (DEMATEL) approach is harnessed (Gölcük and Baykasoğlu 2016). This technique facilitates the decision-making process by offering interrelated dependency of variables and providing their efficacious compatible graphs (Nilashi et al. 2019). With the use of the DEMATEL strategy, the priority weight of the variable cannot be predicted; thus, the ANP technique helps BMW managers take prudent decisions regarding the priority of complex variables (Aung et al. 2019). ANP technique needs pairwise relationships of various standards and inspection of consistency associated with all the decision matrices, which causes an increase in the uncertainty of the decision outcomes (Govindan et al. 2018). On the contrary, pairwise matrices are not necessary for DEMATEL, which reduces the uncertainty in decision outcomes (Tadić et al. 2014). Thus, the incorporation of DEMATEL with ANP (DANP) has become more effective in the estimation of decision issues. The utilization of relation matrices obtained from DEMATEL in ANP is used for enhancing the processing of relative weight (Abikova 2020).

In DANP, DEMATEL is applied to collect statistical facts, apprehend interrelationships and degrees of interdependencies, while the ANP is utilized to drive the unweighted super-matrix, weighted super-matrix, and limiting matrix for processing the influential weights of the elements (Abikova 2020). Nevertheless, many policymakers are suffering from MCDM problems that fail in the determination of accurate choices. K. Atanassov and Gargov (1989) introduced an interval-valued intuitionistic fuzzy set (IVIFS) as an upgraded version of the intuitionistic fuzzy set (IFS), wherein functions are classified in interval form in place of the crisp value form. The reason behind choosing interval form is the inconvenience of crisp values with human minds. In this regard, DMs’ inputs were collected considering fuzzy membership degrees for accurate decision-making (Zadeh 1965). However, fuzzy sets do not count the degree of human hesitancy in the decision. For this issue, Atanassov (1986) proposed an intuitionistic fuzzy set (IFS) to show the degree of membership, non-membership, and human hesitancy function. IFS assists DMs in determining accurate choices. Afterward, IVIFS was established as an extended form of IFS. IVIFS has been broadly preferred by researchers since its inception for decision-making (Abdullah and Najib 2016). This study combines IVIFS with DANP to analyze the impact of hindering factors encountered by 3PL in BMW management. The prominent reason behind choosing this integrated methodology was the power of IVIFS to deal with ambiguity, the ability of DEMATEL to obtain a cause-and-effect diagram of the identified factors, and ultimately, the potentiality of ANP in ranking the identified factors. Combined together, the integrated IVIFS-DANP technique forms a powerful tool for analyzing the identified factors in the study.

Factors Hindering 3PL in BMW Management

Third-party logistics performs a crucial role in managing the BMW supply chain. 3PL’s major operations include collecting waste from the source, transporting the waste to various storage locations, segregating it into different categories, and then choosing the right disposal method for the waste. This figure illustrates operations performed by 3PL when it is hired by a private/government enterprise. When it comes to government hospitals, the entire waste disposal supply chain is given on contract and outsourced to any eligible third-party enterprise, and then onwards, the chosen 3PL is responsible for their hospital-related BMW management. Figure 1 throws light on how exactly the waste is managed by 3PL.

BMW is an infectious waste that can pollute the environment by forming hazardous compounds and affect human health adversely. Since medicines are largely used in health care centers, testing centers, and vaccination centers, it gives rise to the amount of this infectious waste. BMW contains chemicals, syringes, and non-biodegradable compounds, and the accumulation of this waste may form different health-hazardous compounds, and hence, treatment and disposal of this waste are essential. After the impact of SARS-Cov2, medical waste exponentially increased all over the world. Many countries’ governments and hospitals’ administrations generally hire professionals or third-party for proper treatment of their medicinal waste. However, there are various risks involved for the 3PL in managing the BMW. These risks incorporate workers’ exposure to toxic waste, waste-processing-related machinery malfunctioning, improper waste collection and segregation strategies, and poor selection of waste disposal methods. These risks are caused by numerous factors that hinder the seamless functioning of the BMW management supply chain at different stages. This study throws light on the identification of these hindering factors according to their area of impact in the BMW management supply chain. Henceforth, the manuscript categorizes the hindering factors into four zones of the BMW management system, which are described in the subsequent sections and have also been briefly mentioned in Table 1:

Zone 1 (Z₁): Issues Associated with Hospitals/Healthcare Center

Nowadays, many healthcare centers and medical institutes are contracting 3PL services to execute their massive amount of generated medical waste. However, communication between both hospitals and the 3PL party is essential to make a sustainable disposal facility. This section consists of detailed discussion of the problems which 3PL services are facing due to less cooperation by the hospitals and healthcare firms.
Dearth of Waste Segregation Practices (Z₁-1)

There are various kinds of waste present in health care centers, which need to be segregated as per their hazardous nature and treatment processes (Azmal et al. 2014). According to the World Health Organization (WHO 2018), only 10–15 % of medical waste is hazardous. Especially amid the COVID-19 epidemic, distinguishing hazardous and non-hazardous medical waste is critical for efficient and safe disposal. Nevertheless, a lack of knowledge related to the isolation of waste has been found in many hospitals (Datta et al. 2018). Subsequently, less segregation of hazardous and non-hazardous waste raises the hazardousness of total waste. Henceforth, the amount of hazardous waste which needs special treatment before disposal escalates drastically (Pant 2012). This negligent behavior by hospital staff nurtures potential threats for workers involved in the treatment of medical waste. Additionally, less segregation prevents service managers from utilizing better and more cost-effective disposal (Oroei et al. 2014). Therefore, the result of improper isolation becomes unnecessarily cumbersome for the 3PL (Birpınar et al. 2009).

Communication Gap Between 3PL and the Hospital (Z₁-2)

When a healthcare administration or government appoints a third party, it is significant to build proper communication (Chauhan and Singh 2018). In case there is a communication failure between the 3PL and the hiring firm, it will result in information distortion (Shanker et al. 2021b). Communication facilitates 3PL to manage the waste management according to the specific demand of the respective hospital, for instance, sending transporting vehicles with different containing capacities according to the amount of waste generated by a particular hospital (Yong et al. 2009). In case the communication gap will be there, all the hospitals get treated likewise by 3PL, resulting in wastage of large and expensive transportation resources, which will disrupt the entire working of 3PL (Wisdom et al. 2012).
| Serial no. | Factor | Description | Impact on 3PL’s disposal service | References |
|-----------|--------|-------------|----------------------------------|------------|
| Zone 1 (Z₁): issues associated with hospitals/healthcare Center | 1. Dearth of waste segregation practices | Segregation of medical waste is the most crucial phenomenon in the overall disposal process of hospital waste. However, less attention by hospital staff to waste segregation is prevalent in most healthcare centers. | • Increases the risk of spreading infection among personnel.  
• Poor separation reduces the efficiency of chosen procedures while also causing machinery damage. | Datta et al. (2018), Oroei et al. (2014) |
| | 2. Communication gap between 3PL and the hospital | Communication facilitates 3PL to manage the waste management according to the specific demand of the respective hospital. Nevertheless, this results in poor information divulgence. | • Lack of communication creates time management issues for the collection and transportation of waste. | Shanker et al. (2021a, b), Wisdom et al. (2012) |
| | 3. Insufficient efforts towards waste minimization | Healthcare organizations should make every effort to reduce waste generated. Instead of any other disposal method, this is the most acceptable and environmentally friendly option. However, most of the hospitals amid this epidemic are inattentive towards their contribution to a massive amount of waste produced in India. | • A large amount of medical waste creates potential threats for 3PL workers during handling.  
• A massive amount of medical waste production raises the cost of management, storage, transport and disposal. | Alam et al. (2019), Chauhan and Singh (2018) |
| | 4. Higher dependencies on off-site disposal | Hospitals should approach to dispose or recycle their non-infectious waste. Considering recycling as an on-site option will significantly relieve the expenses of storage, transportation, and disposal. Nonetheless, after appointing a third party for disposing of their medical waste, healthcare centers rely solely on off-site disposal. | • The high reliance on outside disposal resulted in an overabundance of medical waste, subsequently increasing the cost of the overall management of BMW. | Ruoyan et al. (2010), Taghipour et al. (2014) |
| | 5. Complications in execution of rules | Under Indian government laws of 2016, hospitals are required to use chlorinated bags for medical waste and offer an appropriate bar code. Due to the lack of investment, many small hospitals and government hospitals usually do not prefer bag packaging or use polyvinyl chloride (PVC) bags for packaging and do not use barcodes in their packaging. | • Different forms of waste have different disposal methods which are hampered by improper packaging.  
• Medical waste management and tracking concerns arise as a result of a lack of focus on the bar-coding of various shipments. | Datta et al. (2018), Kulkarni and Yeravdekar (2020) |

Zone 2 (Z₂): third-party storage problems
| Serial no. | Factor                                                                 | Description                                                                                                                                  | Impact on 3PL’s disposal service                                                                                                           | References                                      |
|-----------|------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|
| 1.        | 3PL’s delusions on isolating radioactive waste                        | Professionals propose storing different isotopes of radioactive waste in distinct storage rooms and bins for 1/2–1 month under the observation of radiation safety inspectors to limit exposure to different isotopes of radioactive waste. But due to the unprofessional behavior and fewer segregation practices among the 3PL personnel, unknowingly, they store different isotopes with each other. | • The mixing of radioactive waste causes an increase in the half-life of the waste. Subsequently, it leads towards an increase in the time of warehousing, delay in disposal, a threat to the workforce, etc. Ultimately, this will lead to a considerable increase in the overall maintenance cost for 3PL. | Kasperson (1983), Khan et al. (2010), Menon and Kumar (2019) |
| 2.        | Inadequate facilities in 3PL’s storage area                           | Since medical waste contains other infectious wastes, temperature control, biohazard packaging, sharp containers for sharp trash, and other facilities are beneficial from a managerial standpoint. However, many storage centers owned by the 3PL do not possess these above facilities, which adversely affects the management of BMW. | • Inadequate storage facilities elevate the risk during the handling and treatment of infectious medical waste. | Babanyara et al. (2013), Marinković et al. (2008), Olaniyi et al. (2021) |
| 3.        | Overfilling of storage containers by 3PL                             | During storage of sharp medical waste, it is recommended that containers should not be filled with more than 75% of their original capacity. This mitigates the risk of injuries and facilitates in management of waste. Nonetheless, in many storage facilities, employees overfill these containers, which increases the risk and lessens work efficiency. | • Injuries from sharp metallic waste can result in the transmission of the COVID-19 virus among workers. | Malsparo (2021), Nelson (2020) |
| 4.        | Improper packaging practices opted by 3PL                            | The use of different colored bag packing for different types of waste promotes effective storage and collection. Moreover, it helps to identify the toxicity of waste during the handling procedure of medical waste | • Identical packaging leads to the same handling and treatment for different kinds of medical waste, enhancing the risk for infections and contamination | Mugabi et al. (2018), Sarfo-Mensah et al. (2019) |

Zone 3 \( (Z_3) \): collection and transportation-related difficulties
| Serial no. | Factor | Description | Impact on 3PL's disposal service | References |
|-----------|--------|-------------|---------------------------------|------------|
| 1.        | Inappropriate utilization of 3PL transporting vehicles | Many 3PL factories use big and uncovered vehicles for the transportation of waste. Due to uncovered vehicles, contaminated waste can interact with the outer environment particles and also can spread in an area. However, many 3PL factories are using big uncovered vehicles which cause inefficient waste transportation. | • Transportation with large vehicles causes problems during collecting since driving from limited routes is difficult. In addition, the cost of transportation of medical waste rises with the size of the vehicle. • Uncovered vehicles let the waste escape from the container and interact with the surroundings. This promulgates the inefficiency of 3PL regarding waste disposal. | Mantzaras and Voudrias (2017) |
| 2.        | Unspecified route map for 3PL transporters | To transport medical waste more safely and easily, operators must create new road-maps that take public safety, accidental probabilities and financial considerations into account. Nonetheless, many third-party managers do not facilitate proper route maps for waste-collecting personnel. | • Unspecified road maps create difficulties for waste collection workers to select an optimal route. Ultimately, it leads towards an increase in time and cost of transportation. | Bucătaru et al. (2021), Gur et al. (2015) |
| 3.        | Unskilled 3PL's personnel | Medical waste contains several contagious particles; hence, skilled and qualified staff are crucial for safe collection and transportation activities. Nevertheless, 3PL managers do not offer essential training to staff which increases the possibility of an accident and mishandling due to the inattentiveness of workers. | • Untrained workers mitigate the efficiency of 3PL’s transportation services, resulting in a delay in the disposal of BW. • Due to insufficient knowledge and training workers recklessly mix medical waste which raises disposal processes. | Bari et al. (2019), Ismail et al. (2013) |
| 4.        | Paucity of activity monitoring | Management of BW waste consolidated with modern monitoring technologies facilitates managers to track records. Furthermore, personnel monitoring improves their performance and makes them more attentive while working. However, proper monitoring is absent in the context of the transportation operations which also affects the employees’ performance. | • The absence of monitoring performance of workers greatly lessens. Additionally, a lack of monitoring also causes an increase in illegal recycling and dumping of medical waste. | Chaniago and Al (2021), Letho et al. (2021) |

**Zone 4 (Z₄): troubles associated with disposal**

| 1.        | Inattentiveness towards new methodologies | Many other low-cost and better techniques have been developed over the years such as autoclaving and microwaving. Instead of choosing these methods, many healthcare centers and 3PL companies are using former incinerators for medical waste disposal. | • Incineration generates a lot of residuals and gasses which again need to be handled. • Instead of opting for multiple methodologies for different waste, factories are only relying on incineration which elevates the cost of disposal. | Narayananmooorthy et al. (2020), Wisniewski et al. (2020) |
Insufficient Efforts Towards Waste Minimization (Z₁-3)

Hospitals ought to introduce audits and proper training programs for their employees regarding waste minimization (Alam et al. 2019). This is the most appropriate and environmentally friendly method instead of any other disposal (Moreira and Günther 2013). However, most of the hospitals amid this epidemic are inattentive towards the massive amount of waste produced in India. According to Mordani (2021), the production of BMW by healthcare facilities has grown 46% between April and May of 2021. Subsequently, fewer efforts to reduce waste, causing a large amount of waste production (Javadi et al. 2013). This escalates the overall storage, transportation, as well as disposal costs incurred by the 3PL (Chauhan and Singh 2018; Taghipour and Mosaferi 2009).

Higher Dependencies on Off-site Disposal (Z₁-4)

Hospitals should attempt to dispose off their non-infectious waste on-site and transport their infectious waste for off-site disposal, that is, by taking the help of 3PL (Ruoyan et al. 2010). Furthermore, considering recycling as an on-site option will significantly relieve the expenses of storage, transportation, and disposal (Lee et al. 2004). Hospitals should approach for recycling of metallic and reusable waste by sterilization and chemical disinfection process. Nonetheless, after appointing a third party for disposing of their medical waste, healthcare centers rely solely on off-site disposal, causing the overproduction of BMW (Taghipour et al. 2014). This will directly escalate the costs associated with various management and disposal processes used by waste management operators.

Complications in Execution of Rules (Z₁-5)

Under Indian government laws of 2016 on organic waste management, hospitals are required to use chlorinated bags for medical waste and offer an appropriate bar code that does not fade for 48 h (Datta et al. 2018; Khan and Raj 2020). Due to the lack of investment, many small hospitals and government hospitals usually prefer polyvinyl chloride (PVC) bags for packaging and do not use barcodes in their packaging (Capoor and Bhowmik 2017). Proper bar-coding facilitates 3PL managers in tracking and also helps in record maintenance regarding medical waste (Kulkarni and Yeravdekar 2020), but due to fewer efforts by some hospitals in this regard, 3PL managers face the consequences during the management of BMW.

Zone 2 (Z₂): Third-party Storage Problems

Since medical waste contains various contagious and harmful substances, it must be stored under the supervision of a qualified 3PL manager with proper instructions. However, to
reduce the cost, 3PL managers do not confer treatment directives to the workers regarding storage, and workers overlook taking certain precautions in their storage facilities which becomes deleterious for 3PL workers. This section reveals the problems faced by 3PL personnel during storage and disposal due to improper storage.

3PL’s Delusions on Isolating Radioactive Waste (Z₂-1)

To restrain the exposure of different isotopes of radioactive waste, professionals recommend storing these wastes in the different storage areas and different bins for 1/2–1 month under the supervision of radioactivity safety officers (RSO) to decrease the concentration of radioactive nuclei (Khan et al. 2010). But due to the lack of knowledge and fewer segregation practices among the 3PL personnel, unknowingly, they store different isotopes with each other, which cause an increase in the half-life of the radioactive waste (Kasperson 1983; Menon and Kumar 2019). This causes to increase in the time of warehousing, delay in disposal, the threat to the workforce, etc. Ultimately, this will lead to a considerable increase in the overall maintenance cost for 3PL.

Inadequate Facilities in 3PL’s Storage Area (Z₂-2)

Since medical waste contains other infectious waste, thus, professionals recommend taking certain circumspections during storage (Babanyara et al. 2013). Temperature control, biohazard packaging, sharp containers for sharp trash, and other facilities are beneficial from a managerial standpoint at a storage facility (Mohamed et al. 2009; Olaniyi et al. 2021). But many storage centers owned by the 3PL do not possess these above facilities, which adversely affects the management of BMW (Marinković et al. 2008). Furthermore, improper storage of medical waste creates difficulty during the collection process by 3PL personnel.

Overfilling of Storage Containers by 3PL (Z₂-3)

According to Malsparo (2021), containers used during the storage of sharp waste should be filled up to 3/4 of its original size. This eliminates risk considerations for workers and made easy to deal with waste during storage (Perry et al. 2012). But in many storage facilities, workers completely fill these containers and managers do not take any action about overfilled containers, which increases the probability of causing risk of injuries to 3PL workers (Saaded et al. 2020). Recent studies about COVID-19 promulgate that the coronavirus can sustain on metallic surfaces for up to 24 h, which varies for different metals (Nelson 2020). Injuries from sharp metallic waste can result in the transmission of the COVID-19 virus among workers (Derso et al. 2018). Moreover, overfilling lessens the efficiency of workers and may result in vexatious accidents with workers (Manyele and Mujuni 2010). Subsequently, it reduces the work efficiency of the 3PL disposal process.

Improper Packaging Practices Opted by 3PL (Z₂-4)

Different colored bag packaging for distinct categorized waste facilitates proper storage and collection (Datta et al. 2018). Moreover, it helps to identify the toxicity of waste during the handling procedure of medical waste. Nevertheless, the 3PL organization does not provide knowledge regarding packaging guidelines to their workers (Mugabi et al. 2018). Thus, 3PL workers often end up with the same packaging for all sorts of medical waste (Sarfo-Mensah et al. 2019). Identical packaging leads to the same handling and treatment for different kinds of medical waste, enhancing the risk for infections and contamination (He et al. 2016).

Zone 3 (Z₃): Collection and Transportation-related Difficulties

In this section, transportation and collection are classified into two categories: healthcare centers to the 3PL storage area and 3PL storage to the disposal facility. Due to improper transportation of the BMW, it may pollute the environment. Henceforth, safety measures are important to prevent BMW from being mixed with other wastes. Although, in both categories, 3PL transportation workers are dealing with similar circumstances in BMW transportation. This section gives a detailed analysis of the factors that are causing issues during transportation and the collection of medical waste.

Inappropriate Utilization of 3PL Transporting Vehicles (Z₃-1)

Many factories use only big and uncovered vehicles for the transportation of medical waste. On the one hand, many hospitals do not even require big vehicles, due to which there is a wastage of extra free space left (Alagöz and Kocasoy 2008). On the other hand, uncovered vehicles let the waste escape from the container and interact with the surroundings, ultimately leading to pollution (Mantzaras and Voudrias 2017). Henceforth, vehicles of different sizes according to the respective demand, which is fully covered to ensure the isolation of waste, should be opted for by the 3PL.

Unspecified Route Map for 3PL Transporters (Z₃-2)

After the advent of COVID-19, cautious transportation of medical waste from storage to disposal area is crucial (Bucătaru et al. 2021; Liu et al. 2017). To transport medical waste more safely and easily, operators must create new roadmaps that take public safety, accidental
probabilities, and financial considerations into account (Taslimi et al. 2020). Furthermore, these roadmaps should be integrated into the garbage collection truck system (Gur et al. 2015). This facilitates workers on path optimization during transportation (Ahlaqqach et al. 2019). However, many third-party managers do not facilitate proper route maps for waste-collecting personnel, which increases the transportation cost and overall time elapsed by the respective 3PL.

**Unskilled 3PL’s Personnel (Z3-3)**

Medical waste contains several contagious particles; hence, skilled and qualified staff are crucial for safe collection and transportation activities (Bari et al. 2019). Nevertheless, many 3PL facilities do not conduct audits for their staff and employ untrained workers for medical waste collection (Rahman et al. 2020). Due to their lack of expertise and insufficient training in the relevant field, they end up mixing the medical waste with the ordinary waste, ultimately causing problems during the disposal process (Ismail et al. 2020). An untrained worker reduces the efficiency of 3PL’s transportation services, resulting in a delay in the disposal of BMW (Gunawardana 2018). In addition, unaware personnel increases the risk of injuries during the garbage disposal process.

**Paucity in Activity Monitoring (Z3-4)**

After the onset of COVID-19, there has been a substantial increase in the need to integrate modern technologies with third-party BMW management systems (Letho et al. 2021). The incorporation of modern technologies also helps managers in monitoring and keeping track of records of logistic operations (Ilyas et al. 2020). Radio-frequency identification (RFID) technology has been suggested by professionals for proper monitoring in the transportation process (Chaniago and Al 2021). However, proper monitoring is absent in the context of the transportation operations in many disposal companies (Kumar and Rahman 2014). It may result in loss of BMW or illegally recycling, which adversely affects the efficiency and performance of 3PL regarding the disposal of medical waste.

**Zone 4 (Z4): Troubles Associated with Disposal**

Treatment and disposal are the most crucial operations in any waste management supply chain. Henceforth, to dispose of this waste properly, the segregated medical wastes must be treated under suitable techniques of disposal. Nevertheless, 3PL vendors do not classify medical waste based on their appropriate methods that lead to improper disposal. In addition, 3PL managers ignore the benefits of recycling, causing economic losses as well as increasing demand for plastics in hospitals. All these problems are classified in this section with their detailed discussion.

**Inattentiveness Towards New Methodologies (Z4-1)**

Many other low-cost and better techniques have been developed over the years, such as autoclaving, microwaving, and chemical disinfection. Instead of choosing these methods, many healthcare centers and 3PL companies are using former incinerators for medical waste disposal (Wisniewski et al. 2020). These techniques are far better than incineration; the use of other methods such as autoclaving is economically more favorable in comparison to incineration for BMW management (Ferdowsi et al. 2013). Similar methodology for all sorts of waste in 3PL factories causes improper disposal of a different kind of waste. 3PL companies should not just rely on a single disposal technique and try to prefer multiple methodologies based on their requirements (Narayanamoorthy et al. 2020). Incineration not only increases the cost but also releases many pollutant gasses causing severe air pollution and releasing ash after final disposal leading to soil quality deterioration (Gautam et al. 2010).

**Inappropriate System Upgrades (Z4-2)**

Many waste disposal sites are available where incineration is prevalent for disposing of chemicals and other medical waste. Since incineration releases many harmful gasses, that is why gas cleaning systems are recommended by experts (Quina et al. 2018). Nonetheless, very few healthcare centers and factories are using it in their incinerators; thus, a system upgrade is essential. Due to the lack of gas cleaning systems, many flue gasses are released during the disposal process in the incinerators (Ilyas et al. 2020). Dioxin and furans are few gasses produced due to the incineration of medical waste. These gasses have many adverse effects on humans, such as cancer, deformation in newborns, and other neurological problems (Thind et al. 2021). Henceforth, these gasses can cause health issues among 3PL workers (Jang et al. 2006).

**Deprivation of Recycling Practices (Z4-3)**

COVID-19’s outrageous influence has resulted in a potentially hazardous situation due to the massive generation of medical waste. Recycling is a crucial factor which cannot be overlooked in this scenario (Subramanian et al. 2021). Autoclaving is one of the prominent methodologies which has been suggested for recycling BMW management (Vortexrealm 2021). Since medical waste consists huge amount of plastic and solid recyclable waste; thus, recycling is significant. Similarly, the ash produced by incineration
can also be recycled in the construction of buildings (Ducoli et al. 2021). Recycling often leads to the enhancement of the overall profit (Goldberg et al. 1996). Nevertheless, there is no such effort for recycling among healthcare centers as well as in 3PL disposal factories (Sharma et al. 2021). Many 3PL disposal factories dump these wastes in the soil which causes soil pollution as well as the release of different pollutants into the environment (Olaniyan et al. 2021). In addition, due to fewer traits of recycling, treatment and disposal expense of 3PL increases.

Application of the Integrated IVIFS-DANP Methodology

The advent of COVID-19 causes an outrageous impact on bio-medical waste management services. Furthermore, it increases the cumbersome medical waste management process. To tackle this issue, factors hindering BMW management in the context of 3PL were recognized, utilizing the available literature. A total of 23 factors were identified, and then these factors were reviewed by the experts. A total of 4 academicians and 3 industrialists were contacted for the same purpose, and finally, 16 factors were framed. To analyze the factors which are constraining in the BMW management process, IVIFS-DANP is utilized; the steps and framework of this methodology are shown in the below sub-sections and appendix. Individual ratings were collected from the experts and then aggregated into a single rating table, on which the following computations were done. The ratings have been taken in a fuzzy environment to deal with the ambiguity present in the human judgments of the experts. Fuzzy is better than crisp number scale because of the characteristic of human judgments being lying in an interval instead of a rigid number. Henceforth, the fuzzy environment produces more accurate results as compared to a non-fuzzy or crisp environment (Fig. 2).

Steps of Methodologies

**Step-1:** Acquire linguistic statistics to define the priority scales.

The group of decision-makers is requested to provide the linguistic evaluation by prioritizing the elements by using linguistic scales in tabulated form.

**Step-2:** Aggregation of different element priority data from decision-makers.

The linguistic terms used in Tables 2 and 3 are utilized to define the weightage of decision-makers.

**Step-3:** Compute the priorities of decision-makers.

Priorities of decision-makers are computed by utilizing Eq. (6), through which the normalized initial direct relation matrix (C) has been derived.

**Step-4:** Utilizing the IVIF entropy scale to obtain the crisp values from the normalized initial direct relation matrix. IVF entropy scale present in Eq. (7) is applied to get crisp values from the normalized initial direct relation matrix.

**Step-5:** Generalize the normalized initial direct relation matrix.

The normalized initial direct relation matrix is generalized by utilizing Eqs. (8), (9), and (10). The matrix is tabulated in Table 4.

**Step-6:** Compute the total relation matrix.

The total impact matrix (N) can be attained by using Eq. (11).

The matrix total relation matrix for zones and factors are tabulated in Tables 4 and 5. And compute the sum of the row \( X_i \) up to \( ith \) element and the sum of column \( Y_j \) up to \( jth \) element in \( N \) and the values of \( X_i \) and \( Y_j \) has been calculated by utilizing Eq. (12). The impact among sub-elements is tabulated in Table 6. Furthermore, the tabulated values are depicted in an influential network relationship map (INRM).

**Weighting the Zones and Sub-elements by IVIFS-DANP**

After defining the causal relationships by utilizing IVIFS-DEMATEL, ANP is used for prioritizing based on the weightage of each factor.

**Step-7:** Calculation for the unweighted super-matrix (W).

The unweighted super-matrix \( W (i.e., W = (N^w)^t) \) are attained from the total relation matrix \( N \) by utilizing Eqs. (14) and (17). Subsequently, the generalization of the total relation matrix of dimensions is completed by using Eqs. (19) and (20).

**Step-8:** Computation of weighted super-matrix \( (W^w) \).

The weighted super-matrix (i.e., \( W^w = N^wD \times W \)) is computed by utilizing Eq. (21) which is shown in Table 7.

**Step-9:** Limiting weighted super-matrix.

The absolute weights of mentioned criteria are calculated by limiting the power of the weighted super-matrix \( \lim_{p \rightarrow \infty} (W^w)^p \), where \( p \) is limiting towards infinity. The stable matrix of IVIFS-DANP is shown in Table 8. Here, every row indicates a different factor. The IVIFS with DANP provides the overall importance of factors and precise them with priority in Table 9.
**Result and Discussion**

The evaluation of the dimensions and their sub-elements for the results is depicted based on combined and individual dimension levels.

**Estimation of Cause and Effect**

The cause-and-effect diagram aids the understandability of the policymakers regarding the recognized factors hindering BMW management. The cause-and-effect diagram aids the understandability of the policymakers regarding the recognized factors hindering BMW management.
illustrated the relationships among the hindering factors by categorizing them into cause-and-effect groups. Moreover, the factors falling into the cause group require critical attention for their mitigation, as they are the root cause of the entire problem.

The overall impact evaluation of main elements (zones) is depicted in Tables 5 and 6 which deduced that issues associated with hospitals/healthcare centers (Z1) and troubles associated with disposal (Z4) fall under the cause group. Besides this, collection and transportation-related difficulties (Z3) and third-party storage problems (Z2) come under the category of effect factors. Hence, this indicates that Z1 and Z4 are the predominantly influencing factors; in contrast, Z2 and Z3 more likely act as influenced dimensions. Graphical interrelation between influencing and influenced zones are mentioned in Fig. 3.

The relation \((X_i - Y_j)\) values from Table 6 deduced that there are eight sub-factors grouped in the cause group and eight factors are considered as in the effect group. Ranking of sub-factors classified in cause group are in the following manner:

Z3 – 3 > Z1 – 1 > Z1 – 2 > Z1 – 3 >
Z4 – 1 > Z4 – 2 > Z1 – 5 > Z2 – 1

The above ranking shows that “Dearth of Waste Segregation Practices (Z1-1)” is the prominent causal factor that hinders BMW management. Similarly, prominence \((X_i + Y_j)\) values concluded that “Troubles Associated with Disposal (Z4)” having a prominence value (1.011) has a higher impact on BMW management in comparison to the other zones. Similarly, by using the value of \((X_i + Y_j)\), Unskilled 3PL’s Personnel (Z3-3), Inattentiveness Towards New Methodologies (Z4-1), Dearth of Waste Segregation Practices (Z1-1), Insufficient Efforts Towards Waste Minimization (Z1-3), and Paucity in Activity Monitoring (Z3-4) are the most important factors having prominence degree of 4.504, 4.461, 4.395, 4.098, and 4.056 respectively. The overall influence of all

### Table 3 Scale for weightage of DMs

| Linguistic priority scale | IVIFS                     |
|---------------------------|---------------------------|
| Very important            | ([0.875, 0.925], [0.025, 0.075], [0.000, 0.100]) |
| Important                 | ([0.725, 0.775], [0.175, 0.225], [0.000, 0.100]) |
| Medium                    | ([0.450, 0.550], [0.350, 0.450], [0.000, 0.200]) |
| Unimportant               | ([0.175, 0.325], [0.525, 0.675], [0.000, 0.300]) |
| Very unimportant          | ([0.050, 0.150], [0.750, 0.850], [0.000, 0.200]) |

### Table 4 Total relation matrix for sub-factor

|     | Z1  | Z2  | Z3  | Z4  |
|-----|-----|-----|-----|-----|
| Z1  | 0.114 | 0.103 | 0.19 | 0.239 | 0.15 | 0.174 | 0.157 | 0.193 | 0.188 | 0.15 | 0.102 | 0.142 | 0.125 | 0.172 | 0.151 | 0.143 |
| Z2  | 0.125 | 0.071 | 0.109 | 0.129 | 0.103 | 0.09 | 0.122 | 0.135 | 0.091 | 0.192 | 0.116 | 0.097 | 0.136 | 0.132 | 0.091 | 0.104 |
| Z3  | 0.174 | 0.094 | 0.103 | 0.198 | 0.099 | 0.144 | 0.124 | 0.172 | 0.138 | 0.192 | 0.107 | 0.106 | 0.117 | 0.16 | 0.134 | 0.132 |
| Z4  | 0.105 | 0.112 | 0.151 | 0.09 | 0.09 | 0.118 | 0.103 | 0.139 | 0.108 | 0.179 | 0.087 | 0.088 | 0.131 | 0.121 | 0.101 | 0.106 |
| Z5  | 0.118 | 0.089 | 0.118 | 0.12 | 0.09 | 0.102 | 0.1 | 0.127 | 0.09 | 0.14 | 0.078 | 0.079 | 0.109 | 0.121 | 0.101 | 0.104 |
| Z6  | 0.135 | 0.086 | 0.129 | 0.132 | 0.087 | 0.092 | 0.118 | 0.121 | 0.147 | 0.154 | 0.124 | 0.144 | 0.171 | 0.123 | 0.114 |
| Z7  | 0.1 | 0.071 | 0.099 | 0.09 | 0.078 | 0.137 | 0.083 | 0.174 | 0.142 | 0.11 | 0.088 | 0.113 | 0.133 | 0.125 | 0.132 | 0.108 |
| Z8  | 0.087 | 0.062 | 0.082 | 0.083 | 0.064 | 0.111 | 0.087 | 0.081 | 0.126 | 0.104 | 0.094 | 0.098 | 0.105 | 0.1 | 0.09 | 0.087 |
| Z9  | 0.091 | 0.07 | 0.093 | 0.092 | 0.102 | 0.127 | 0.127 | 0.108 | 0.075 | 0.124 | 0.082 | 0.086 | 0.095 | 0.114 | 0.086 | 0.084 |
| Z10 | 0.072 | 0.096 | 0.08 | 0.077 | 0.074 | 0.066 | 0.064 | 0.087 | 0.071 | 0.084 | 0.118 | 0.082 | 0.123 | 0.083 | 0.076 | 0.071 |
| Z11 | 0.084 | 0.073 | 0.104 | 0.096 | 0.064 | 0.072 | 0.073 | 0.097 | 0.067 | 0.2 | 0.071 | 0.064 | 0.151 | 0.087 | 0.076 | 0.073 |
| Z12 | 0.167 | 0.206 | 0.154 | 0.185 | 0.121 | 0.201 | 0.176 | 0.266 | 0.2 | 0.181 | 0.142 | 0.113 | 0.17 | 0.178 | 0.155 | 0.208 |
| Z13 | 0.104 | 0.102 | 0.105 | 0.109 | 0.084 | 0.114 | 0.126 | 0.162 | 0.106 | 0.193 | 0.204 | 0.117 | 0.103 | 0.131 | 0.11 | 0.127 |
| Z14 | 0.162 | 0.122 | 0.143 | 0.141 | 0.092 | 0.132 | 0.162 | 0.174 | 0.144 | 0.17 | 0.121 | 0.143 | 0.168 | 0.117 | 0.15 | 0.23 |
| Z15 | 0.14 | 0.092 | 0.12 | 0.137 | 0.083 | 0.131 | 0.15 | 0.141 | 0.133 | 0.122 | 0.096 | 0.127 | 0.154 | 0.148 | 0.093 | 0.197 |
| Z16 | 0.124 | 0.076 | 0.124 | 0.131 | 0.068 | 0.093 | 0.106 | 0.141 | 0.094 | 0.102 | 0.077 | 0.108 | 0.105 | 0.13 | 0.132 | 0.087 |
the factors and their cause-and-effect relationship is shown in Fig. 3.

**Evaluation of Every Zones Based on their Causal Relationships**

**Issues Associated with Hospitals/Healthcare Centers (Z1)**

The resulting data from Table 6 indicate that there are four factors present in (Z1) that comes under the cause group and the mere one comes under the effect group. The elements which are present in the cause group are Dearth of Waste Segregation Practices (Z1-1), Communication Gap Between 3PL and the Hospital (Z1-2), Insufficient Efforts Towards Waste Minimization (Z1-3), and Complications in Execution of Rules (Z1-5) having (X_i - Y_j) values of 0.591, 0.318, 0.29, and 0.237 respectively. The presence of these factors in the causal group is comprehensible since poor waste segregation, unhealthy communication, large waste production, and disobedience of safety rules may have a significant impact on subsequent processes. Similarly, Higher Dependencies on Off-Site Disposal (Z1-4) falls under the

| Table 6 | Influence between zones and sub-elements |
|----------|------------------------------------------|
| Z1       | 0.502 0.439 0.941 0.063 **Cause** Z1-1 2.493 1.902 4.395 0.591 **Cause** |
| Z1-2     | 1.843 1.525 3.368 0.318 **Cause** |
| Z1-3     | 2.194 1.904 4.098 0.29 **Cause** |
| Z1-4     | 1.829 2.049 3.878 -0.22 **Effect** |
| Z1-5     | 1.656 1.419 3.075 0.237 **Cause** |

| Table 7 | Unweighted super-matrix (W_α) |
|----------|--------------------------------|
| Z1-1     | 0.035 0.057 0.063 0.047 0.057 0.051 0.049 0.049 0.044 0.041 0.045 0.045 0.047 0.056 0.055 0.055 0.054 |
| Z1-2     | 0.031 0.032 0.034 0.05 0.043 0.032 0.035 0.035 0.033 0.054 0.039 0.056 0.046 0.042 0.036 0.033 |
| Z1-3     | 0.058 0.049 0.038 0.067 0.057 0.048 0.048 0.046 0.044 0.045 0.056 0.042 0.047 0.049 0.047 0.053 |
| Z1-4     | 0.073 0.059 0.072 0.04 0.058 0.05 0.044 0.047 0.044 0.044 0.051 0.05 0.049 0.048 0.054 0.057 |
| Z1-5     | 0.046 0.047 0.036 0.04 0.029 0.033 0.038 0.036 0.049 0.042 0.034 0.033 0.038 0.032 0.033 0.029 |
| Z2-1     | 0.064 0.054 0.065 0.066 0.063 0.052 0.069 0.074 0.078 0.059 0.06 0.061 0.057 0.056 0.061 0.055 |
| Z2-2     | 0.057 0.072 0.056 0.057 0.062 0.067 0.042 0.058 0.078 0.056 0.061 0.053 0.063 0.068 0.07 0.063 |
| Z2-3     | 0.071 0.08 0.078 0.077 0.079 0.076 0.068 0.088 0.054 0.067 0.077 0.08 0.081 0.081 0.073 0.066 0.083 |
| Z2-4     | 0.069 0.054 0.062 0.06 0.056 0.083 0.071 0.084 0.046 0.063 0.055 0.06 0.054 0.061 0.062 0.056 |
| Z3-1     | 0.071 0.088 0.091 0.091 0.085 0.073 0.064 0.068 0.082 0.057 0.114 0.083 0.087 0.068 0.059 0.062 |
| Z3-2     | 0.049 0.053 0.051 0.044 0.047 0.059 0.051 0.062 0.054 0.081 0.041 0.065 0.092 0.048 0.046 0.047 |
| Z3-3     | 0.068 0.044 0.05 0.045 0.048 0.056 0.066 0.064 0.057 0.056 0.037 0.052 0.052 0.057 0.061 0.066 |
| Z3-4     | 0.059 0.062 0.055 0.066 0.066 0.069 0.077 0.063 0.063 0.084 0.086 0.078 0.047 0.067 0.074 0.064 |
| Z4-1     | 0.092 0.101 0.094 0.092 0.109 0.089 0.093 0.104 0.087 0.089 0.079 0.086 0.065 0.093 0.103 0.013 |
| Z4-2     | 0.08 0.069 0.078 0.076 0.077 0.078 0.094 0.084 0.079 0.079 0.077 0.069 0.072 0.083 0.059 0.104 |
| Z4-3     | 0.077 0.079 0.077 0.081 0.08 0.073 0.077 0.081 0.077 0.074 0.075 0.093 0.083 0.127 0.124 0.069 |
effect group having \((X_i - Y_j)\) values of \(-0.29\). Likewise, prominence \((X_i + Y_j)\) values for \(Z_{1-1}\), \(Z_{1-2}\), \(Z_{1-3}\), \(Z_{1-4}\), and \(Z_{1-5}\) are 4.395, 3.368, 4.098, 3.878, and 3.075 which implicates the influence of respective factors in overall BMW management. By the above evaluations, it is mandatory for healthcare facilities and government administration to build proper communication with third-party vendors. In addition, all government-funded or private healthcare centers must have a source of investment for the proper implementation of rules.

### Third-party Storage Problems (Z2)

In Zone-2 (Z2), 3PL’s delusions on isolating radioactive waste \((Z_{2-1})\) are categorized as a cause group. In contrast, inadequate facilities in 3PL’s storage area \((Z_{2-2})\), overfilling

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#### Table 8 Limiting weighted super-matrix (Wa0)

| \(Z_{1-1}\) | \(Z_{1-2}\) | \(Z_{1-3}\) | \(Z_{1-4}\) | \(Z_{1-5}\) | \(Z_{2-1}\) | \(Z_{2-2}\) | \(Z_{2-3}\) | \(Z_{3-1}\) | \(Z_{3-2}\) | \(Z_{3-3}\) | \(Z_{3-4}\) | \(Z_{4-1}\) | \(Z_{4-2}\) | \(Z_{4-3}\) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |

#### Table 9 Importance of weight computation of factors through IVIFS-DANP

| Dimensions/sub-factors | Local weight | Global weight | Rank |
|------------------------|--------------|---------------|------|
| Issues associated with hospitals/healthcare centers (Z1) | 0.228 | 3 |
| \(Z_{1-1}\) | 0.219298246 | 0.05 | 13 |
| \(Z_{1-2}\) | 0.175438596 | 0.04 | 15 |
| \(Z_{1-3}\) | 0.214912281 | 0.049 | 14 |
| \(Z_{1-4}\) | 0.228070175 | 0.052 | 12 |
| \(Z_{1-5}\) | 0.162280702 | 0.037 | 16 |
| Third-party storage problems (Z2) | 0.262 | 1 |
| \(Z_{2-1}\) | 0.236641221 | 0.062 | 8 |
| \(Z_{2-2}\) | 0.25784127 | 0.062 | 8 |
| \(Z_{2-3}\) | 0.286259542 | 0.075 | 5 |
| \(Z_{2-4}\) | 0.240458015 | 0.063 | 7 |
| Collection and transportation-related difficulties (Z3) | 0.256 | 2 |
| \(Z_{3-1}\) | 0.296875 | 0.076 | 4 |
| \(Z_{3-2}\) | 0.21875 | 0.056 | 10 |
| \(Z_{3-3}\) | 0.21875 | 0.056 | 10 |
| \(Z_{3-4}\) | 0.265625 | 0.068 | 6 |
| Troubles associated with disposal (Z4) | 0.256 | 2 |
| \(Z_{4-1}\) | 0.35546875 | 0.091 | 1 |
| \(Z_{4-2}\) | 0.30859375 | 0.079 | 3 |
| \(Z_{4-3}\) | 0.3359375 | 0.086 | 2 |
of storage containers by 3PL (Z3-3), and improper packaging practices opted by 3PL (Z3-4) are counted under the effect group. Improper segregation of radioactive waste can enhance the toxicity of non-hazardous waste, making the overall waste elimination process more time-consuming. This explains why (Z2-1) is in the cause group. Furthermore, by the prominence analysis (X_i + Y_j) of all elements of Z2, it is estimated that all the elements of 3PL’s Delusions on Isolating Radioactive Waste (Z2-1), inadequate facilities in 3PL’s storage area (Z2-2), overfilling of storage containers by 3PL (Z2-3), and improper packaging practices opted by 3PL (Z2-4) having prominence value of 3.899, 3.661, 3.721, and 3.476, respectively, have considerable influence in overall BMW management. By this study, it is recommended for 3PL vendors to arrange proper training for their employees regarding waste segregation and packaging. Moreover, more investment in storage facilities is significant to build an efficient and safer way to dispose of medical waste.

Collection and Transportation-related Difficulties (Z3)

The “Z3” zone consists of four factors, and by referring to Table 6, inappropriate utilization of 3PL transporting vehicles (Z3-1), unspecified route map for 3PL transporters (Z3-2), and paucity in activity monitoring (Z3-4) defined as effect group and unskilled 3PL’s personnel (Z3-3) fall under cause group. Unskilled personnel’s irresponsible behavior exacerbates problems in the waste management process as a whole. In contrast, Z3-1, Z3-2, and Z3-4 affect BMW management from an individual standpoint rather than in a wide sense. Hence, from their mathematical calculations of causal relationships, Z3-1, Z3-2, and Z3-4 fall under the effect group, whereas Z3-3 comes under the cause group. The prominence (X_i + Y_j) evaluation of the above elements depicts that unskilled 3PL’s personnel (Z3-3) and paucity in activity monitoring (Z3-4) possess the highest prominence value in this zone of 4.506 and 4.056, respectively. These results depict that 3PL service providers should organize a
proper awareness program regarding legislation about medical waste and should monitor their personnel activities.

**Troubles Associated with Disposal (Z₄)**

In this zone (refers to Table 6), inattentiveness towards new methodologies (Z₄-1) and inappropriate system upgrades (Z₄-2) are defined as causal factors, whereas deprivation of recycling practices (Z₄-3) refers to the effect group. Appropriate methodology and waste disposal system can aid in easy disposal, whereas the other process has not been significantly affected by recycling. This explains why (Z₄-3) belongs to the effect group, whereas (Z₄-2) and (Z₄-1) belong to the cause group. Moreover, the order prominence value of inattentiveness towards new methodologies (Z₄-1), inappropriate system upgrades (Z₄-2), and deprivation of recycling practices (Z₄-3) are 4.461, 3.865, and 3.673, respectively. This data depicts that Z₄-1 has the highest importance among all factors of zone 4 (Z₄) on BMW management. These results conclude that 3PL service providers ought to adopt new, economically more remunerative and environmentally friendly methodologies of disposal and should try to recycle plastic and metallic waste.

**Prioritizing Factors Based on IVIFS-DEMATEL**

The advent of COVID-19 caused a sudden increment in BMW; thus, policymakers are facing many different practical problems in decision-making based on the current situation regarding BMW disposal. These real-life hindering factors cannot be analyzed by just using the DEMATEL technique. Considering failing to deal with real-life problems by DEMATEL, fuzziness in multi-decision-making, priority, and weightage of all the factors have been calculated by utilizing IVIFS-DEMATEL. Furthermore, ANP facilitates the final ranking of the hindering factors based on their influence on BMW management. The rankings obtained by ANP provided the policymakers with a priority order of hindering factors depending upon their impact on the BMW supply chain. The factors having ranks ranging from one to five are highly vicious and impose a high value of disruption in BMW’s supply chain. Thus, they need to be mitigated urgently with a proper strategy by the associated policymakers. Henceforth, this study utilizes the IVIFS-DANP methodology to analyze the various identified hindering factors associated with 3PL in the sector of BMW management. Table 9 analyzes the local and global weightage of all the factors that have been calculated by using IVIFS-DANP. In Table 9, the local weight of each factor is calculated by dividing their global weights by the global weights of their respective zones. Table 9 shows that inattentiveness towards new methodologies (Z₄-1), deprivation of recycling practices (Z₄-3), inappropriate system upgrades (Z₄-2), inappropriate utilization of 3PL transporting vehicles (Z₄-1), and overfilling of storage containers by 3PL (Z₄-3) are the top five factors having highest global weightage. This data can be set as a benchmark for policymakers and help them to take precise decisions. In this aspect, Table 10 can be found as more helpful. For instance, unskilled 3PL personnel (Z₄-3) is the factor that falls under the “cause group” having higher influence over BMW management in this pandemic situation. This data depicts that 3PL service providers ought to introduce awareness programs regarding legislation on medical waste for their waste-collecting personnel, particularly essential at this COVID outbreak. Likewise, inappropriate utilization of 3PL transporting vehicles (Z₄-1) and (Z₄-3) overfilling of storage containers by 3PL is the hindering factor that falls under the “effect group” having high weightage in BMW management concerning the other factors. All the above statements enlighten the fact that certain improvements are urgently needed to mitigate the current hindering factors in the sector of sustainable waste management.

**Implication for Practice and Research Work**

To develop a proper strategy for handling problems due to the pandemic situation, the model of integration of IVIFS-DEMATEL with ANP is more convenient to define the causal relationship and for comparison of weights among all the hindering. From a managerial aspect, the contributions of this study are as follows.

(i) This research paper analyzes BMW management based on four different aspects (zones) which organizes this study in a more detailed manner. These zones represent the different areas of impact of the hindering factors in a BMW supply chain. The policymakers can thus find the exact problem along with the precise supply chain stage getting affected.

(ii) This manuscript incorporates the repercussions of poor interactions between third-party and healthcare management. Consideration of these factors by hospitals and operators will aid in the delivery of long-term services.

(iii) This study incorporates the need for innovative waste elimination strategies, as well as the demand for sound, transportation, and storage facilities in the COVID-19 situation. Discussions on these issues with third-party operators can provide beneficial results for management.

(iv) IVIFS technique used in this manuscript defines membership, non-membership, and hesitancy degree in interval values, which helps in dealing with the real-life ambiguities. In addition, IVIFS is more accurate to deal with practical problems in decision-
making with vague data. Hence, 3PL managers can correlate these factors with their real-life situations and take reference to approach for a solution.

(v) Furthermore, the DEMATEL technique defines causal relationships between factors, also illustrating the graphical representation of cause-and-effect factors. Thus, it facilitates policymakers to understand the relationships among the recognized hindering factors, eventually enhancing the comprehensiveness of the problem. Moreover, the factors falling under the cause category need special attention for mitigation as they are the root cause of the entire problem.

(vi) The ANP technique is utilized to obtain the rank of recognized hindering factors by determining the global and local weightage of each factor. By utilizing the rankings obtained, the concerned policymakers can understand the intensity of a particular factor in disrupting BMW’s supply chain management. The factors having five rankings have to be mitigated first.

(vii) Many 3PL managers attempt to reduce the impact of the “effect group” from their BMW management services, which can only be done more effectively by paying more attention to “cause group” factors and their relative impact on individual factors. For example, assessment by the above-declared model concludes that unskilled 3PL personnel ($Z_{3-3}$) are the influential factor in the management of medical waste. Hence, 3PL management can solve this problem by employing skillful personnel or by organizing proper training programs for their workers.

(viii) This is the manuscript that consolidates IVIFS with the DANP technique, which has not been utilized by any study yet. Moreover, the results and conclusion of this study can be set as a benchmark during the decision-making process.

(ix) Nowadays, where 3PL is mostly present in all the work sectors, contracting 3PL is a very difficult job for any hiring firm. This manuscript defines constraining factors for 3PL in the BMW management sector that can be more helpful in the future for medicinal firms and administrations to make certain contracts regarding services by 3PL.

(x) This study concludes a priority list of different factors by analyzing BMW management services in every possible aspect. Policymakers use these outcomes as a benchmark to reduce the problems in their management services.

(xi) Weights estimated for factors included in this study facilitate policymakers in dealing with several policies in their respective regions. The weightage of the prominent hindering elements helps them to identify the problems and rank the problems in their specific BMW management service.

### Conclusion

Healthcare services are the fundamental requirements for any country, and after the impact of COVID-19, the necessity of medical equipment and various medicines for treatment services in the healthcare sector escalated exponentially. India’s dense population is causing rapid augmentation of COVID cases which triggered the requirements for medical services. Such a large volume of medical waste needs to be disposed of properly; although many hospitals hire 3PL services for their generated waste, still, some extent of the medical waste gets left behind without getting proper
attention. With the sudden increment in volume of BMW, policymakers need to take certain actions for the proper treatment of this waste. Assessment of factors that are hindering managers in BMW management service based on the interrelationship among them is more crucial than ever in the event of an epidemic. This manuscript seeks to address such impediments to medical waste management from the standpoint of third-party operators. Policymakers can identify flaws in their management system and make better judgments and take proactive measures by studying the findings of this research.

This paper analyzes the barriers faced by 3PL managers by integrating three different MCDM techniques which are IVIFS, DEMATEL, and ANP. Analysis of the factors has been done in a hierarchical structure by splitting all the factors into four zones. The results of this model can be further classified into two categories; the first is interrelated dependencies between each factor, and the second is the calculation of preference order by defining the influence of each factor among the other. IVIFS-DEMATEL establishes the interrelationships between the defined zone and factors, and then by using the IVIFS-DEMATEL technique, priority weightage is obtained. The influence relation matrix (IRM) depicts the cause-and-effect relationship between the factors, as shown in Fig. 3. The priority area, where improvements in policies are more necessary, can only be identified by determining impact factors so that policymakers can enumerate their constraints in management services and improve their approaches to deal with various on-vision problems. To enhance the accuracy of these results, data is considered in interval values which define the degree of membership, non-membership, and hesitancy. The conglomeration of IVIFS-DEMATEL with ANP improves the results of the ANP technique, which helps policymakers accomplish better strategies.

After the mortal impact of COVID-19, many countries are required to improve their condition regarding escalating medical waste disposal. This study approaches to describe what are the actual difficulties to achieve a sustainable BMW management service by addressing certain objectives in the “Introduction” section. “To determine the role of third-party logistics in BMW management amidst the COVID-19 situation.” This objective has been thoroughly discussed in the “Factors Hindering 3PL in BMW Management” section by defining the importance of medical waste management. “To identify the hindering factors associated with third-party logistics in bio-medical waste management.” This paper analyzes all the constraining factors consolidated with medical waste management by splitting all the factors into four zones in the “Factors Hindering 3PL in BMW Management section. “To explore the influence of constraining factors, priority weightage and their causal relationships on BMW management services.” The “Result and Discussion” section comprises ranking, causal relationships, and weightage of all the factors by utilizing IVIFS-DEMATEL consolidated with the ANP technique. “To highlight the research implications of this study, and how 3PL managers can utilize this study.” The implication portion of this research has been thoroughly discussed in the “Implication for Practice and Research Work” section. Operators can use factors from this article in real-world disposal situations and devise improved solutions.

The limitations of this research paper are based on human (professional) judgments. Thus, managers and policymakers can further extend the study and enhance the results of this topic by aggregating different methodologies such as spherical fuzzy with integrated maximizing deviation. Hence, by conglomerating new methodologies, this topic could be explored more for future research.

Appendix 1. IVIFS-DANP Methodology

IVIFS-DANP technique has subsequent steps.

- **Step-1:** Obtaining direct relation matrix using IVIFS and conversion to crisp number.

  **Theory-1:** (Atanassov 1986). Consider $F$ being a finite non-empty set. An IFS $E$ in $F$ is expressed as

  $$E = \{ (f, \Phi_E(f), u_E(f)) | f \in F \}$$

  Here, $\Phi_E(f) : F \rightarrow [0, 1]$ and $u_E(f) : F \rightarrow [0, 1]$ are defined as $0 \leq \Phi_E(f) + u_E(f) \leq 1$, $f \in F$. The symbol $\Phi_E(f)$ shows the degree of membership, and $u_E(f)$ shows the degree of non-membership of component $f \in F$ in set A. If $\rho_E(f)$ represents the level of the hesitance of $f \in F$ in set E and $0 \leq \rho_E(f) \leq 1$, $f \in F$, then $\rho_E(f)$ can be described as

  $$\rho_E(f) = 1 - \Phi_E(f) - u_E(f), f \in F$$

  **Theory-2:** (Atanassov and Gargov 1989). Consider $F$ being a finite non-empty set. An IVIFS $E$ in $F$ is given through

  $$E = \{ (f, \Phi_E^+(f), \Phi_E^-(f), u_E^+(f), u_E^-(f)) | f \in F \},$$

  where $\Phi_E^+(f) \in [0, 1], \Phi_E^-(f) \in [0, 1], u_E^+(f) \in [0, 1], \rho_E(f) \in [0, 1]$ are intervals, representing the degree of membership, non-membership, and hesitation of component $f$ in set A, correspondingly $\rho_E^+(f) = 1 - \Phi_E^+(f) - u_E^+(f), \rho_E^-(f) = 1 - \Phi_E^-(f) - u_E^-(f)$ for every value of $f \in F$.

  **Theory-3:** (Abdullah and Najib 2016). The IVIFN is evolved by relying upon IFS with the condition $\gamma + \delta \in [0, 1]$ here $\gamma = 0.5$ and $\delta = 0.5$ are utilized for fuzzification. Then interval can be shown as
\[
\begin{align*}
\Phi_{E}^{L}(f), \Phi_{E}^{U}(f) &= \left[\Phi_{E}(f) - \gamma f_{E}(f), \Phi_{E}(f) + \gamma f_{E}(f)\right] \\
\Phi_{E}(f) &= \left[\left|\Phi_{E}(f) - \rho_{E}(f)\right|, \left|\Phi_{E}(f) + \rho_{E}(f)\right|\right] \\
\left[\begin{array}{l}
u_{E}^{L}(f), \nu_{E}^{U}(f) \end{array}\right] &= \left[\left|\nu_{E}(f) - \Phi_{E}(f)\right|, \left|\nu_{E}(f) + \Phi_{E}(f)\right|\right] \\
\nu_{E}(f) &= \left[\left|\nu_{E}(f) - \Phi_{E}(f)\right|, \left|\nu_{E}(f) + \Phi_{E}(f)\right|\right] \\
\left[\begin{array}{l}v_{E}^{L}(f), v_{E}^{U}(f) \end{array}\right] &= \left[\left|v_{E}(f) - \nu_{E}(f)\right|, \left|v_{E}(f) + \nu_{E}(f)\right|\right] \\
\left[\begin{array}{l}w_{E}^{L}(f), w_{E}^{U}(f) \end{array}\right] &= \left[\left|w_{E}(f) - \nu_{E}(f)\right|, \left|w_{E}(f) + \nu_{E}(f)\right|\right] \\
\left[\begin{array}{l}w_{E}^{L}(f), w_{E}^{U}(f) \end{array}\right] &= \left[\left|w_{E}(f) - \nu_{E}(f)\right|, \left|w_{E}(f) + \nu_{E}(f)\right|\right]
\end{align*}
\]

\[
X = \max_{1 \leq i \leq n} \sum_{j=1}^{n} M_{ij}^{*}
\]

- **Step-4:** Calculate the net (total) relation matrix

In this step, a net relation matrix \((N)\) is calculated with the following equation:

\[
N = (n_{ij}) = C \times (I - C)^{-1}
\]

Here, \(n_{ij}\) symbolizes related values of \(N\) and \(I\) represents the identity matrix.

- **Step-5:** Identify the connection and importance of each factor

\[
\begin{align*}
X_{i} &= \sum_{1 \leq j \leq m} n_{ij} \\
Y_{j} &= \sum_{1 \leq i \leq m} n_{ij}
\end{align*}
\]

Here, \(X_{i}\) symbolizes addition of row elements up to \(i\)th element and \(Y_{j}\) shows the sum of \(j\)th column elements in \(N\). If \(i = j\), then \((X_{i} + Y_{j})\) represents the “importance” that factor \(i\) plays in the overall discussion. Likewise, \((X_{i} - Y_{j})\) represents “connection.”

This shows the entire contribution, which element \(i\) plays in the overall discussion.

- **Step-6:** Devise a cause-effect graph and compute the threshold net relationship matrix (NRM)

The addition of average with one standard deviation of NRM represents the threshold value. In this graph, the relationship is shown by using a dataset obtained from \([X_{i} + Y_{j}, (X_{i} - Y_{j})]\) \(\forall i = j\).

### Integration of IVIFS-DEMATEL with ANP

- **Step 1:** Computation for unweighted super-matrix (W).

\(N_{c}\) and \(N_{d}\) indicate the sub-elements (factors) and main elements (zones) in the total influence matrix, respectively, obtained from the IVIFS DEMATEL methodology.
Consider \( N_c \) is formulated as Eq. (13).

\[
\begin{bmatrix}
\mathbf{D}_1 & \cdots & \mathbf{D}_j & \cdots & \mathbf{D}_n
\end{bmatrix}
\begin{bmatrix}
\begin{bmatrix}
\mathbf{c}_{11} & \cdots & \mathbf{c}_{1m_1} & \cdots & \mathbf{c}_{ij} & \cdots & \mathbf{c}_{jm_j} & \cdots & \mathbf{c}_{n1} & \cdots & \mathbf{c}_{nm_m}
\end{bmatrix}
\begin{bmatrix}
\mathbf{N}_c^{11} & \cdots & \mathbf{N}_c^{1j} & \cdots & \mathbf{N}_c^{in}
\end{bmatrix}
\end{bmatrix}
\]

(13)

For the factor, the normalized relationship matrix represents by \( \mathbf{N}_c^a \), which is attained by generalizing the total influence matrix for factors \( \mathbf{N}_c \) which is represented in Eq. (14):

\[
\begin{bmatrix}
\mathbf{D}_1 & \cdots & \mathbf{D}_j & \cdots & \mathbf{D}_n
\end{bmatrix}
\begin{bmatrix}
\begin{bmatrix}
\mathbf{c}_{11} & \cdots & \mathbf{c}_{1m_1} & \cdots & \mathbf{c}_{ij} & \cdots & \mathbf{c}_{jm_j} & \cdots & \mathbf{c}_{n1} & \cdots & \mathbf{c}_{nm_m}
\end{bmatrix}
\begin{bmatrix}
\mathbf{N}_c^{a11} & \cdots & \mathbf{N}_c^{aj1} & \cdots & \mathbf{T}_c^{a1n}
\end{bmatrix}
\end{bmatrix}
\]

(14)

Normalized element \( \mathbf{N}_c^{a11} \) is analyzed and developed in Eqs. (15) and (16):

\[
d_{ci}^{11} = \sum_{j=1}^{m_1} \frac{n_{ci}^{11} \cdot i = 1, 2, \ldots, m_1}{n_{cj}^{11} \cdot j = 1, 2, \ldots, m_m}
\]

\[
\mathbf{N}_c^{a11} = \begin{bmatrix}
n_{c11}^{11} / d_{c11}^{11} & \cdots & n_{c1j}^{11} / d_{c1j}^{11} & \cdots & n_{c1m_1}^{11} / d_{c1m_1}^{11} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
n_{cj1}^{11} / d_{cj1}^{11} & \cdots & n_{cij}^{11} / d_{cij}^{11} & \cdots & n_{cjm_1}^{11} / d_{cjm_1}^{11} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
n_{cm_11}^{11} / d_{cm_11}^{11} & \cdots & n_{cmj_1}^{11} / d_{cmj_1}^{11} & \cdots & n_{cm_1m_1}^{11} / d_{cm_1m_1}^{11}
\end{bmatrix}
\]

(15)
To calculate the unweighted super-matrix, the transpose of the normalized total normalized matrix for factors are present in Eq. (17).

\[
D_1 \quad \ldots \quad D_i \quad \ldots \quad D_n
\]

\[
\begin{bmatrix}
C_{11} & \ldots & C_{1m_1} & \ldots & C_{i1} & \ldots & C_{im_i} & \ldots & C_{n1} & \ldots & C_{nm_n}
\end{bmatrix}
\]

Here,

\[
W^{11} = \begin{bmatrix}
W_{c_{11}}^{11} & \ldots & W_{c_{1j}}^{11} & \ldots & W_{c_{im_i}}^{11}
\end{bmatrix}
\]  

(18)

- **Step 2:** Computation of weighted super-matrix.

To compute the weighted super-matrix, the TRM for main factors (zones) was considered, as shown in Eq. (19).

\[
N_D = \begin{bmatrix}
N_{D1}^{11} & \ldots & N_{Dj}^{1j} & \ldots & N_{Dm}^{1n}
\end{bmatrix}
\]  

(19)
The weighted super-matrix (\(W^n\)) is acquired by using Eq. (21).

\[
N_D^n = \begin{bmatrix}
\frac{n^1_D}{d_1} & \ldots & \frac{n^j_D}{d_1} & \ldots & \frac{n^n_D}{d_1} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
\frac{n^1_D}{d_n} & \ldots & \frac{n^j_D}{d_n} & \ldots & \frac{n^n_D}{d_n}
\end{bmatrix} = \begin{bmatrix}
\frac{n^{a1}_D}{d_1} & \ldots & \frac{n^{aj}_D}{d_1} & \ldots & \frac{n^{an}_D}{d_1} \\
\vdots & \ddots & \vdots & \ddots & \vdots \\
\frac{n^{a1}_D}{d_n} & \ldots & \frac{n^{aj}_D}{d_n} & \ldots & \frac{n^{an}_D}{d_n}
\end{bmatrix} \tag{20}
\]

- **Step 3:** Limiting the weighted super-matrix.

To obtain a stable and converged matrix, the weighted super-matrix which we derived in the previous step is to be limited by raising the unweighted super-matrix to a satisfactorily large power \(p\), i.e., \(\lim_{p \to \infty} \left(\frac{N}{D}\right)^p\). The final matrix will show the overall priority scores, which are known as IVIFS-DANP influential weights (Govindan et al. 2018).

### Appendix 2

#### Detailed information about specialists

| Specialist's domain | Serial number | Year of experience | Qualification | Designation and job description |
|---------------------|---------------|--------------------|---------------|--------------------------------|
| Academicians        | 1             | 16                 | PhD           | Professor                     |
|                     | 2             | 14                 | PhD           | Associate Professor           |
|                     | 3             | 13                 | PhD           | Associate Professor           |
| Waste management    | 4             | 13                 | Master's degree in Engineering | Warehouse Manager |
| companies specialists| 5             | 11                 | MBA           | Operation Manager             |
|                     | 6             | 10                 | MBA           | 3PL manager                   |
|                     | 7             | 14                 | Master of Technology | Transportation Network Planning |

Academics associated with logistics and supply chain

Waste management companies specialists

Operations management

Logistics service management

Route optimization
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Data Availability Data sharing does not apply to this article as no datasets were generated or analyzed during the current study.

Declarations

Conflict of Interest The authors declare no competing interests.

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