

Occupational Safety and Health (OSH) Risk Management Analysis of Hazardous Waste Treatment Using the HIRARC and Bowtie Analysis Methods

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Abstract

The management of hazardous medical waste is an important aspect in maintaining occupational safety and the environment in healthcare facilities. Medical waste collection activities have high potential hazards, such as the risk of needle stick injuries, chemical exposure, and biological contamination. This study aims to analyze the potential hazards and risks in the process of collecting hazardous medical waste using the Hirarc (Hazard Identification, Risk Assessment, and Risk Control) and Bowtie Analysis methods. The Hirarc method is used to identify hazards, assess risk levels, and determine appropriate control measures, while the Bowtie method is used to map the relationship between causes, top events, consequences, and controls. The results of the analysis show that hazards with high risk levels originate from direct contact with sharp objects and infectious materials. Recommended control measures include the use of complete personal protective equipment (PPE), routine training on waste handling, and the implementation of strict standard operating procedures. The integration of the HIRARC and Bowtie methods proved effective in providing a comprehensive overview of potential hazards and risk control strategies in the collection of hazardous medical waste, thus improving work safety and preventing environmental pollution.

Keywords: Waste, HIRARC, Bowtie Analysis, Occupational Safety, Risk Control.

Abstrak

Pengelolaan limbah medis B3 merupakan aspek penting dalam menjaga keselamatan kerja dan lingkungan di fasilitas pelayanan kesehatan. Aktivitas pengambilan limbah medis memiliki potensi bahaya tinggi, seperti risiko tertusuk jarum, paparan bahan kimia, dan kontaminasi biologis. Penelitian ini bertujuan untuk menganalisis potensi bahaya dan risiko dalam proses pengambilan limbah medis B3 menggunakan metode Hirarc (Hazard Identification, Risk Assessment, and

Risk Control) serta Bowtie Analysis. Metode Hirarc digunakan untuk mengidentifikasi bahaya, menilai tingkat risiko, dan menentukan langkah pengendalian yang tepat, sedangkan metode Bowtie digunakan untuk memetakan hubungan antara penyebab, kejadian puncak (top event), serta konsekuensi dan pengendaliannya. Hasil analisis menunjukkan bahwa bahaya dengan tingkat risiko tinggi berasal dari kontak langsung dengan benda tajam dan bahan infeksius. Upaya pengendalian yang direkomendasikan meliputi penggunaan alat pelindung diri (APD) lengkap, pelatihan rutin tentang penanganan limbah, serta penerapan prosedur kerja standar yang ketat. Integrasi metode Hirarc dan Bowtie terbukti efektif dalam memberikan gambaran menyeluruh mengenai potensi bahaya serta strategi pengendalian risiko pada kegiatan pengambilan limbah medis B3, sehingga dapat meningkatkan keselamatan kerja dan mencegah pencemaran lingkungan.

Keywords: *Limbah, HIRARC, Analisis Bowtie, Keselamatan Kerja, Pengendalian Risiko.*

1. Introduction

Hospitals are one type of health care facility that provides health services by offering various facilities such as inpatient care, outpatient care, emergency care, laboratories, and other medical support facilities aimed at improving public health. In carrying out these activities, hospitals generate waste that is categorized into non-medical waste (domestic waste) and medical waste, which is also categorized as Hazardous and Toxic Waste (B3) [1].

Hospitals produce medical waste every day, consisting of liquid waste, solid waste, and hazardous waste [2]. To prevent contamination of the area surrounding hospitals, medical waste must be managed properly. Occupational Safety and Health (OSH) in hospital waste management is crucial because solid medical waste contains hazardous and toxic materials, such as pathogenic microorganisms, toxic chemicals, and sharp objects that have the potential to cause infection and injury to staff and the surrounding community. This waste must not be disposed of directly into the environment without being processed according to standards due to the serious risk of disease spread and environmental pollution [3].

Hospital waste management must include sorting at source, safe containment, transportation by personnel wearing full personal protective equipment (PPE), temporary storage in a location that meets occupational health and safety requirements, and final disposal using appropriate methods, such as incineration or autoclaving [4]. Training and awareness among waste management personnel are crucial for effective implementation of occupational health and safety measures, including the appropriate use of PPE and the appropriate storage of used PPE to ensure it remains sterile for future use [5]. Challenges still arise in many hospitals, such as the lack of dedicated waste disposal channels, minimal awareness of occupational health

and safety among staff, and limited licensed waste treatment facilities, resulting in frequent reliance on third parties at high costs [6].

Only 3,421 of the total 12,831 health facilities (hospitals and community health centers) managed medical waste according to standards in 2021. According to [7], the main danger is the risk of infection from microorganisms present in the waste. Generally, infection occurs as a result of punctures from sharp objects, especially syringes. Serious threats from the risk of exposure to infectious medical waste include hepatitis B, hepatitis C, and even HIV/AIDS. According to [8], there are several groups that are potentially at risk of contracting diseases due to waste or discharge in hospitals. First are doctors, nurses, healthcare workers, and hospital maintenance staff. Second are patients undergoing medical treatment, third are patient visitors or hospital visitors, fourth are support service workers employed by healthcare institutions, and fifth are workers employed at medical waste disposal facilities. The result is a decline in environmental quality due to a decline in the level of health in that environment.

Hospital medical waste consists of infectious waste (such as used syringes, bandages, used medical equipment), toxic chemical and pharmaceutical waste, and non-medical waste such as plastic and paper [9]. These characteristics determine the appropriate management methods in accordance with regulations such as Government Regulation No. 101 of 2014 and Minister of Environment and Forestry Regulation No. 56 of 2015, which regulates the procedures for managing hazardous waste from hospitals. Infectious waste must be treated at high temperatures using incinerators or autoclaves, while other waste must be treated and stored using strict procedures to avoid contamination and the risk of nosocomial infection [2].

To ensure the safety of personnel, occupational health and safety is implemented in every stage of medical waste management [10]. Starting from sorting waste by labeling and color coding to distinguish different types of waste, using appropriate PPE such as gloves and masks when managing and transporting waste, to temporary storage in a shaded, waterproof, and well-ventilated place. This procedure serves to prevent exposure to toxic waste and minimize work accidents caused by sharp objects. However, observations in several hospitals still show gaps in implementation, such as PPE that is not stored properly and inconsistent use of PPE during waste transport.

Against this backdrop, strengthening the implementation of occupational safety and health in hospital medical waste management is a must so that the process of collecting, sorting, transporting, storing, and disposing of waste can be carried out safely, healthily, and in an environmentally friendly manner, while reducing management costs and minimizing the risk of accidents and disease transmission in hospitals and surrounding communities.

The purpose of this study is to identify potential hazards in the management of hazardous waste in hospitals and to map risks and provide practical control recommendations to support the prevention of workplace accidents and the sustainability of hospital waste management. This study is novel in its integration of two methods, namely Hirarc and Bowtie analysis, whereas most risk analyses to date have only used the Hirarc method.

2. Method

This study was conducted at Hospital X Banyuwangi in East Java Province from September to October 2025. In this study, the author used a method involving systematic steps based on several standards to ensure that all risks were identified and controlled effectively. The first step was to identify risks through direct observation and data collection through interviews with B3 medical waste clean-up personnel. This process was expected to provide a clear understanding of the risks that may occur to B3 waste clean-up personnel and to determine the impact on their occupational safety.

Data collection was carried out through observation and interviews with the personnel concerned. The informants in this study were people who were considered knowledgeable and relevant to the research objectives, such as the head of environmental health and personnel directly involved in the management of hazardous waste at Hospital X. The study population consisted of all 55 cleaning service staff members. From this number, 15 people were selected as samples using purposive sampling based on specific criteria. The criteria selected were staff members who worked in areas with high activity levels or significant potential exposure to waste, such as the emergency room, medical laboratory, and treatment rooms.

Meanwhile, the method used for data management and analysis to obtain risk categories and risk control measures is carried out using the Hazard Identification, Risk Assessment, and Risk Control (Hirarc) method by conducting field observations to observe unsafe behaviors and unsafe conditions [11]. In addition, researchers also used the Bowtie Analysis (BTA) method to map causes, consequences, and control measures to prevent or reduce risks [12].

The results of the probability assessment will be used to determine the risk level of each risk. The method used is likely to be as stated in Table 3 of the qualitative risk matrix. The matrix criteria for determining the risk level are as follows: (1) Extreme Risk indicates a condition where activities should not be carried out or continued until the risk is reduced (symbolized by the letter E). (2) High Risk is indicated in the orange block with the letter T or risks that are unacceptable. (3) Medium Risk is indicated in the yellow block with the letter S or risks that are tolerable. (4) Low Risk is indicated in the green block with the letter R. These risks are acceptable risks.

3. Results and Discussion

Hazard identification and risk assessment were carried out based on direct observation by researchers in the field and interviews with the heads of environmental health and hazardous waste management officers. The results of hazard identification carried out at Hospital.

After identifying the hazards, the potential hazards must then be analyzed to determine their risk level, whether they fall into the low, medium, high, or extreme category [11]. The following is a risk assessment of each source of danger and potential risk

Table 1. Risk Assessment in the Management of Hazardous Medical Waste

No	Activity Description	Hazard Identification		Risk Assessment				
		Hazard Source	Potential Hazard	Risk Incurred	L	S	RR	Level
1	Collection of hazardous medical waste from generating rooms to transport trolleys	Safety box Sharp Objects	Punctured by a needle	Infected with Disease	1	3	3	S
		Infectious, Pathological, Cytotoxic Waste	Exposure to Patient Blood	Contagious Diseases Hepatitis B/C, TB infection, environmental contamination.	1	2	2	R
		Patients with infectious diseases	Punctured by syringes, infusion needles, or other sharp objects used to support treatment/examination Exposed to the patient's bodily fluids	Infected with infectious diseases from patients	1	5	5	T
		Laboratory waste such as bacterial cultures, viruses, or test media	Inhalation of odors from laboratory waste	Unpleasant odors, irritating to the respiratory system	4	1	4	S
			spill into the environment.	Pathogenic bacterial/viral infections, nosocomial outbreaks	3	3	9	T
		Tying plastic bags of hazardous medical waste B3	Hunching over	Back pain, lower back pain	1	1	1	R
			Inhaling infectious waste	Dizziness, nausea, respiratory problems	1	2	2	R
		Slippery floor conditions	Slipping, tripping	Bruises, falling on waste, sprains	1	2	2	R
		Closing the trolley	Caught in the trolley cover	Bruised	4	2	8	T
		Torn B3 Medical Waste plastic bags	Spilled and scattered Medical Waste	Exposed to viruses/bacteria from B3 Medical Waste disposal residues	2	3	4	S
2	Weighing waste from rooms	Plastic bag for medical waste B3	Hit by waste	Bruises, hit by waste	1	1	1	R
		Closing the trolley	Caught in the trash can	Bruised	1	2	2	R
		Safety box Sharp Objects	Exposure to sharp objects (needles/glass)	Contagious Diseases	1	3	3	S

Hazard Identification				Risk Assessment				
No	Activity Description	Hazard Source	Potential Hazard	Risk Incurred	L	S	RR	Level
		Leaking B3 Medical Waste plastic bags	Exposure to liquid waste from leaking bags	Exposure to splashes of viruses/bacteria from B3 Medical Waste disposal residues	1	3	3	S
		Strong-smelling waste	Exposure to the smell of weighed waste	Dizziness, nausea, respiratory problems	1	2	2	R
		Transferring waste from the trolley to the scales	Heavy medical waste	Muscle pain, joint pain	1	1	1	R
3	Cleaning of hazardous medical waste containers B3	Use of chemicals (disinfectants)	Exposure to chemical disinfectants on the body	Respiratory problems, skin irritation	1	2	2	R
4	Internal Transportation of Hazardous Medical Waste	The route taken was crowded with people	hit by people	Bruises, scratches	1	2	2	R
		Hasty (careless) movements, lack of concentration			1	2	2	R
		Slippery floor conditions	Slipping	Bruises, falling on waste, sprains	1	2	2	R
		Steep road conditions	Slipping, falling	Bruises, being hit by waste, sprains, material damage	1	2	2	R
		Pushing a trolley of solid B3 medical waste	Hazardous medical waste that is too heavy	Joint pain, muscle pain	1	1	1	R
5	Transfer of B3medical waste from transport trolleys to B3waste storage areas	Road/stair conditions from the road surface to the waste collection point are quite high (steep)	Tripping, falling	Bruises, scratches, abrasions, being hit by waste	1	2	2	R
		Rushing (careless) movements	Falling, bumping into surrounding objects	Bruises, scratches, abrasions, being hit by waste	1	2	2	R
6	Performing work inside and around the B3 waste storage area	Cramped area/limited space and poor layout	Colliding with surrounding objects and bumping into them	Bruises, scratches, material damage	2	1	2	R
		Hasty (careless) movements	Friction against hard objects, bumping into surrounding objects, falling	Bruises, scrapes, abrasions	1	1	1	R
		Irregular cleaning of waste collection points	Dusty	Respiratory problems, eye irritation	1	2	2	R

Hazard Identification				Risk Assessment				
No	Activity Description	Hazard Source	Potential Hazard	Risk Incurred	L	S	RR	Level
7	External Transportation of B3 Waste	Cramped areas/limited space and poor layout	Colliding with surrounding objects and bumping into things	Bruises, scrapes, abrasions, being hit by waste	1	1	1	R
		Rushing movements (carelessness)	Friction against hard objects, colliding with surrounding objects	Bruises, scrapes, abrasions	1	1	1	R
		Process of transferring B3 medical waste from the B3 waste storage site to a third-party transport vehicle	Exposure to sunlight	Dehydration, fatigue	2	2	4	R
			Working position and duration	Fatigue, back pain, and lower back pain, lack of concentration	1	1	1	R

Source: Analysis Results, 2025.

Based on the results of hazard analysis and risk assessment using the Hirarc method, the table above shows the risk level for each risk identified. From this analysis, 30 risks were identified, consisting of 23 low-level risks, 5 moderate-level risks, 3 high-level risks, and 0 very high-level risks. The results of the risk analysis indicate that the risks associated with the management of hazardous medical waste are still acceptable because the resulting impacts are still within acceptable/tolerable limits. However, the hospital must continue to take precautions to avoid occupational accidents.

The final stage of the Hirarc method is to determine the risk control measures for the risks identified. Risk control is carried out to reduce the likelihood and severity/consequences of risks. The following are the risk control measures based on each source of danger and potential risk.

Table 2. Risk Control in the Management of Hazardous Medical Waste

Hazard Identification					Risk Control
No	Description of Activities	Sources of Danger	Potential Dangers	Risks Involved	
1	Collection of B3 Medical Waste from the generating rooms to the transport trolleys	Sharp Object Safety Box	Needle prick inject	Infected with Disease	Substitution, Engineering Controls, Administrative Controls, Personal Protective Equipment 1. Use 2 layer gloves 2. Work according to SOP 3. Do not fill the Sharps Safety Box beyond the capacity ($\frac{3}{4}$ volume) of the volume of the Safety Box being used. 4. Providing training/socialization on PPE and management of B3 Medical Waste. 5. Using complete PPE

Hazard Identification					Risk Control
No	Description of Activities	Sources of Danger	Potential Dangers	Risks Involved	
		Infectious, Pathological, Cytotoxic Waste	Exposed to Blood Patient	Infected with Infectious Diseases Hepatitis B/C, TB infection, environmental contamination.	Administrative Control, Personal Protective Equipment
					1. Work according to SOP 2. Providing training on B3 Medical Waste management 3. Provide regular Medical Check-Ups (MCU) 4. Using complete PPE
		Patients suffering from HIV/AIDS	Punctured by a syringe, infusion needle/other sharp object used to support treatment/examination	Infected with HIV/AIDS	Administrative Control, Personal Protective Equipment
			Exposure to patient's body fluids		1. Using complete PPE 2. Provide regular Medical Check-Ups (MCU)
	Laboratory waste such as bacterial cultures, viruses, or test media	Inhaling the smell of laboratory waste	Bad smell, interferes with breathing	Personal protective equipment	Using complete PPE
		spill into the environment.	Pathogenic bacterial/viral infections, nosocomial outbreaks	Administrative Control, Personal Protective Equipment	1. Using PPE 2. Immediately clean the area affected by the virus
	Binding of B3 Medical Waste plastic bags	Hunched posture	Back pain, lower back pain	Administrative control	Provision of first aid boxes
		Inhalation of Infectious Waste	Dizziness, nausea, respiratory problems	Personal protective equipment	Using complete PPE
	Slippery floor conditions	Slip, slip	Bruises, crushed by waste, sprains	Administrative Control, Personal Protective Equipment	1. Establish special routes/lanes for the transportation of B3 waste 2. Provide warning signs if the floor is slippery 3. Provision of first aid boxes
	Close the cart	Stuck in the trolley cover	bruises	Personal protective equipment	1. Using PPE 2. Be careful when working

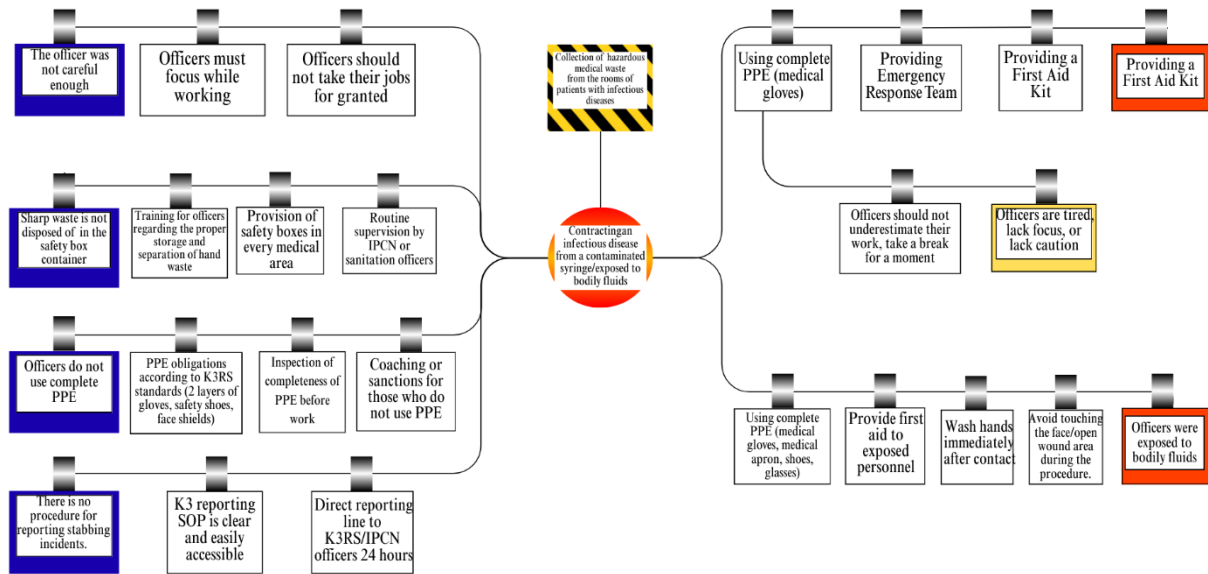
Hazard Identification					Risk Control
No	Description of Activities	Sources of Danger	Potential Dangers	Risks Involved	
2	Weighing waste from the room	Torn B3 Medical Waste plastic bag	Medical waste poured out and scattered	Infected with viruses/bacteria from the remaining hazardous medical waste	Engineering controls, administrative controls, personal protective equipment
					1. Providing training/socialization on B3 waste management 2. Implementation of K3 procedures regarding B3 waste 3. Using complete PPE 4. Avoid compaction or compression of waste 5. Do not fill the waste container with more than $\frac{3}{4}$ of the waste volume capacity. 6. Using double plastic bags
		B3 Medical Waste Plastic Bags	Hit by waste	Bruises, hit by waste	Personal protective equipment
		Close the cart	Stuck in the dumpster	bruises	Personal protective equipment
		Sharp Object Safety Box	Exposed to sharp objects (injections/glass)	Infected with Disease	Substitution, Engineering Controls, Administrative Controls, Personal Protective Equipment
					1. Use 2 layer gloves 2. Work according to SOP 3. Do not fill the Sharps Safety Box beyond the capacity ($\frac{3}{4}$ volume) of the volume of the Safety Box used. 4. Providing training/socialization on PPE and management of B3 Medical Waste 5. Using complete PPE
		Leaking B3 Medical Waste plastic bag	Exposed to liquid waste from a leaking bag	Exposure to splashes of viruses/bacteria from the remaining hazardous medical waste disposal	Administrative Control, Personal Protective Equipment
		Waste that smells bad	Exposed to odors from weighed waste	Dizziness, nausea, respiratory problems	using PPE
		Transferring waste from the trolley to the scales	Heavy Medical Waste	Muscle pain, joint pain	administrative control
					1. Provision of first aid boxes 2. do not pile up waste at the disposal point

Hazard Identification						
No	Description of Activities	Sources of Danger	Potential Dangers	Risks Involved	Risk Control	
3	Cleaning of B3 Medical Waste Containers	Use of chemicals (disinfectants)	Exposed to chemical disinfectant liquid on the body	Respiratory disorders, skin irritation	Personal protective equipment	Using complete PPE
4	Internal Transportation of B3 Medical Waste	There are lots of people on the route Hasty (careless) movements, lack of concentration	hit by someone	Bruises, scratches	Administrative control	1. Establish special routes/lanes for the transportation of B3 waste 2. Provide K3 warning signs if the floor is slippery 3. Provision of First Aid Boxes
		Slippery floor conditions	Slipped	Bruises, crushed by waste, sprains		
		Steep road conditions	Slipped, fell	Bruises, crushed by waste, sprains, material damage	Administrative control	1. Providing K3 Fall warning signs 2. Provision of First Aid Boxes 3. Work according to SOP 4. Using complete PPE
		Pushing a Solid B3 Medical Waste Trolley	B3 Medical Waste that is too heavy	Joint pain, muscle pain	administrative control	1. Provision of First Aid Boxes 2. Do not pile up Medical Waste on the transport trolley
5	Transfer of B3 Medical Waste from the transport trolley to the B3 Waste TPS	The condition of the road/stairs from the road surface to the TPS is quite high (steep)	Stumbled, fell	Bruises, scratches, abrasions, crushed by waste	Engineering Controls, Administrative Controls, Personal Protective Equipment	1. Installing stair railings 2. Providing K3 Fall warning signs 3. Provision of First Aid Boxes 4. Using Complete PPE
		Hasty (careless) movements	Falling, hitting objects around	Bruises, scratches, abrasions, crushed by waste	administrative control	Provision of First Aid Boxes
6	Carrying out work indoors & around the B3 Waste TPS	Narrow area/Limited space and poor layout	Hitting objects around and getting hit	Bruises, scratches, material damage	Engineering Controls, Administrative Controls, Personal Protective Equipment	1. Do not place any objects anywhere that will obstruct movement around the room. 2. Arranging the room 3. Provision of First Aid Boxes

Hazard Identification					Risk Control	
No	Description of Activities	Sources of Danger	Potential Dangers	Risks Involved		
7	External Transportation of B3 Waste	Hasty (careless) movements	Friction on hard objects, hitting surrounding objects, falling	Bruises, scratches, abrasions		
		Irregular cleaning of TPS	Dusty	Respiratory disorders, eye irritation	Administrative Control, Personal Protective Equipment	1. Routine cleaning maintenance by officers 2. Conducting routine K3 inspections includes checking all conditions. 3. Using complete PPE
		Narrow area/Limited space and poor layout	Hitting objects around and getting hit	Bruises, scratches, abrasions, crushed by waste	Engineering Controls, Administrative Controls, Personal Protective Equipment	1. Do not place any objects anywhere that will obstruct movement around the room. 2. Arranging the room 3. Provision of first aid boxes 4. Providing K3 warning signs 5. Conducting routine K3 inspections includes checking all conditions.
		Hasty (careless) movements	Friction on hard objects, hitting objects around	Bruises, scratches, abrasions	administrative control	Provision of First Aid Boxes
		The process of transferring B3 Medical Waste from the B3 Waste TPS to a third party transport vehicle	Sun exposure	Dehydration, fatigue	Administrative Control, Personal Protective Equipment	Provide breaks during transport for drinking
			Position & duration of work	Fatigue, back pain and lower back pain, lack of concentration	administrative control	1. Provision of first aid boxes 2. Provide a break during transport 3. Adjust your body position properly when transporting waste 4. Stretching muscles during work

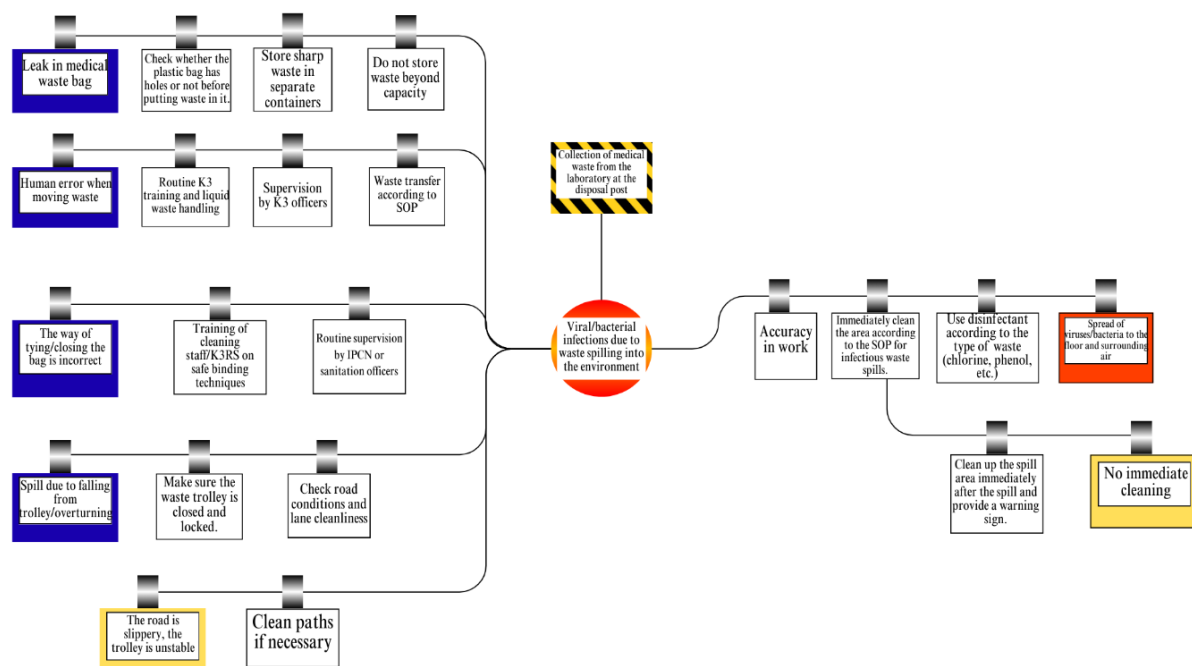
Source: Analysis Results, 2025.

The Bowtie Analysis method is very effective for identifying and analyzing risks, given that this method allows for clear visualization of cause-and-effect relationships and the necessary mitigation measures [13]. The Bowtie Analysis diagram illustrates these risks and the preventive measures that can be implemented [14]. The following is a diagram of the Bowtie Analysis that has been analyzed:



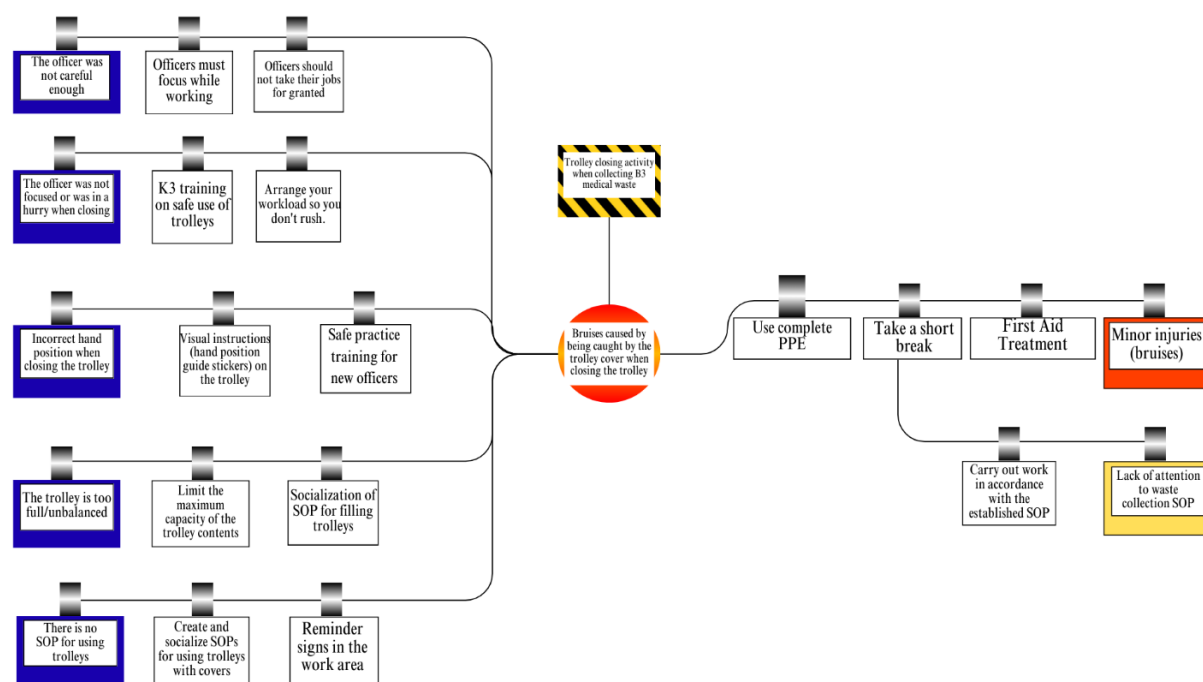
Source: Data processing results, 2025

Figure 1. Bowtie Analysis Diagram of being Pierced by a Sharp Object



Source: Data processing results, 2025

Figure 2. Bowtie Analysis Diagram of Virus/Bacteria Infection due to Waste Spillage into the Environment



Source: Data processing results, 2025

Figure 3. Bowtie Analysis Diagram of Bruises caused by being Pinched by the Trolley Cover when Closing the Trolley

Discussion

Identification of potential hazards in the workplace through the Bowtie Analysis and HIRARC approaches shows that the collection of hazardous medical waste carries various risks that can lead to workplace accidents. These risks must be managed strictly, including conducting regular inspections and supervision by the environmental health manager to ensure that all functions are working in accordance with applicable standards. Negligence such as being pricked by needles or other sharp objects, getting caught in trolleys, and spilling waste into the surrounding environment can have serious consequences if not handled properly immediately.

Escalating factors such as lack of focus and disregard for SOPs can worsen the situation. In waste management, the implementation of proper procedures, from separating waste based on characteristics to using appropriate containers, is very important to prevent negative impacts on health and the environment.

4. Conclusion

Based on the results of this study using the Hirarc method, it can be concluded that there are three high-level risks in the management of hazardous medical waste at Hospital X, namely needle stick injuries/sharp objects, bruised hands from closing trolleys, and waste spillage into the surrounding environment. The bowtie analysis method was used to determine the factors causing these high risks and their impacts. The results of the bow tie analysis produced 30 preventive barriers and 13 recovery barriers from the three top including wearing complete PPE, complying with SOPs, and using disinfectants appropriate for the type of waste.

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