Developing an effective waste management flow model on construction site

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Abstract

The increasing awareness of environmental impacts from construction wastes has led to the development of waste management as an important function of construction project management. Various approaches for managing construction wastes have been developed in the existing research works and practices, and these works can be grouped largely into three areas: waste classification, waste management strategies (avoiding waste, reducing waste, reusing waste and recycling waste), and waste disposal technologies. Nevertheless these approaches give less attention to the management of waste handling process during construction. Form their generation to final disposal, construction wastes will pass through a number of processes where various measures will be used to handle with wastes. It is considered that proper flow of these handling processes can improve overall waste management effectiveness. This paper extends the existing research studies to examining the process of waste management during construction on site by using mapping presentations. This examination is undertaken through analyzing six cases selected in Hong Kong construction. The examination leads to developing a waste management flow model (WMFM), which is designated to incorporate the good operations embodied in the existing practice and function as a standard model of waste management procedures. The model has been tested in two projects.

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The model can provide an alternative tool assisting in planning waste management procedures on site. It also serves as a vehicle to compare the waste management practices between construction sites, thus both good practices and weak areas in managing wastes can be found.

Key words: construction waste, environmental management, waste management, waste management flow model (WMFM), Hong Kong

Introduction

Waste management in construction activities has been promoted for the aim of protecting the environment in line with the recognition that the waste from construction and demolition works contributes significantly to the polluted environment. Craven et al. (1994) reported that construction activity is approximately to generate 20-30% of all wastes deposited in Australian landfills. Ferguson et al. (1995) found that more than 50% of the waste deposited in a typical landfill in UK comes from construction waste. According to Rogoff & Williams (1994), 29% of the solid-waste stream in the USA is construction waste. Cotton et al. (1999) pointed out that uncollected construction solid waste has become a major health hazard, yet municipal waste is still the dominating waste to health hazard. Poon (2000) noted that construction waste takes considerably large share among all types of solid wastes. And his study shows that construction debris resulting from construction demolition works constitute particularly a large proportion of the whole waste quantity in Hong Kong where demolition works have been among the major construction activities. All these studies demonstrate that construction business is a large contributor to waste generation.

In order to improve controlling construction wastes, existing research works have developed various management methods. Spivey (1974) suggested to sort out wastes into specific categories which allows the adoption of specific techniques in dealing with different types of wastes, such as demolition materials, packaging materials, wood, concrete, asphalt, garbage and sanitary waste, scrap metal products, rubber, plastic and glass, and pesticides and pesticide containers. Petts (1995) promoted the proactive community involvement in implementing waste management, and suggested consensus building among the public in order to control waste generation and mitigate the waste impacts to the environment. Coffrey (1999) pointed out that construction solid waste management is generally seen as a low priority when financial constraints are present, and suggested that considerable waste reduction can be achieved if waste management is implemented as part of project management functions. He further suggested that whilst the choice of the optimum waste handling methods should be determined by considering the cost implications, any practices which will induce waste reduction must be encouraged. Lingard et al. (2000) considered it is more effective to provide training and education among staff, and involve employees' participation in implementing waste management. However, they pointed out that employees' participation could only be effective with genuine support from management. In fact a previous survey reported that waste management is generally considered by business senior manager less important than the management for construction cost and time. The cost for implementing waste management is often given more concern than the possible benefits that the organization can gain (Shen & Tam, 2001). In recent years, waste reuse and recycle have been promoted in order to reduce wastes and protect the environment, but the effectiveness of their application has been said of limitation (Chun et al., 1997). The effective application of these approaches is subject to necessary conditions including proper site location and equipment for waste sorting out, good experience in waste recycling operations, trained supervisors and employees, knowledge of secondary materials markets and knowledge of environmental and safety regulations (Chun et al., 1997). Faniran & Caban (1998) considered that, among various existing waste management methodologies, the typical methodology is to adopt a waste management hierarchy, which classifies and prioritizes waste management options in descending options of (a) reducing waste; (b) re-using waste; (c) recycling waste; and (d) disposing waste where the first three options are not possible. An increasingly popular approach in controlling construction wastes is using environmentally friendly construction methods for the aim of reducing the waste generation during construction stage, such as using large panel system, applying prefabrication components, and reducing the application of wet trade (Ho, 2001).

Nevertheless these management methods give less attention to the management of waste handling process during construction. Construction wastes will pass through a number of handling processes during construction. These processes can induce various factors affecting management effectiveness. Thus proper flow of these processes should be given the same attention. McDonald et al. (1998) conducted a survey suggesting that a proper waste management plan for eliminating waste source and controlling waste flows could result in up to 50% cost savings for waste handling charges, 15% volume reduction of the waste generated prior to recycling on site, and 43% waste reduction for landfill. However, there is no standard methodology providing guidelines for producing waste management plan. McGrath (2001) realized that one of the major hindrances to waste minimization on a construction site is the difficulty in establishing a methodology and using this methodology to benchmark future construction projects. For overcoming this shortage, he introduced a waste minimization system called SMARTWaste. This system is a software tool for auditing, reducing and targeting waste arisings on a construction site. The principle of this system is to improve material recovery for reuse and reduce the waste arisings on future sites by using the audited waste arisings as a benchmark. SMARTWaste provides an alternative methodology for identifying the areas where the effectiveness of waste minimization can be gained. This paper extends the existing studies to examining the flow processes of construction wastes on site, supported with six practical cases collected in Hong Kong construction industry. This examination is undertaken through analyzing six cases selected in Hong Kong construction. The examination leads to developing a waste management flow model (WMFM), which is designated to incorporate the good operations embodied in the existing practice and function as a standard model of waste management procedures. The model will be tested in two projects. The model is expected to provide an alternative tool assisting in planning waste management procedures on site. It will also serve as a vehicle to compare the waste management practices between construction sites, thus both good practices and weak areas in managing wastes can be found.

Research Methodology

The data used for this study are from a recent survey of the Hong Kong construction industry. Those selected cases are from different construction processes and construction projects, which can show the strategies for their waste management when their site situations had changed.

What are construction wastes?

Construction wastes are mistures of inert and organic materials arisng from all construction related activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork and building renovation along all stages in implementing a construction project. These wastes are in the form of building debris, rubble, earth, concrete, steel, timber and mixed site clearance materials, whilst some of these wastes are recyclable and reusable, most of them are usually dumped for landfill. The inert wastes are normally used in public filling areas and site formation works. The remaining wastes are often mixed and contaminated, and are not suitable for reuse or recycling but disposed of at landfills. In Hong Kong construction practice, upon their disposal construction wastes are broadly divided into Type I and Type II according to the level of the inclusion of inert wastes (EPD, 2001). In this classification, inert waste materials mainly comprise of soil or mud, concrete, reinforced concrete, asphalt, brick or sand, cement plaster or mortar, aggregate, and rock or rubble. Type I construction waste is defined as containing no more than 20% by volume, or 30% by weight, of inert materials. Type II waste consists of more than 20% by volume, or 30%

by weight, of inert material content. Therefore, type II waste is normally used for site formation or public filling areas. According to the report by Hong Kong Construction Industry Review Committee (HKCIRC, 2001), about 79% construction wastes was reused in public filling areas and the remaining 21% was disposed of at landfills in 1999.

Chemical wastes and other special wastes are also generated from construction activities, and they are normally regulated under more strict regulations for special treatment as they can easily cause pollution to the environment or become a risk to health. For example, the Waste Disposal Ordinance (WDO, 2001) in Hong Kong regulates the method of dealing with chemical and other special wastes generated from construction activities. In the Ordinance, special wastes are described including abattoir waste, animal carcasses, asbestos, clinical waste, condemned goods, livestock waste, sewage treatment and waterworks treatment sludge, sewage works screenings and stabilized residues from Chemical Waste Treatment Centre. The separation of the chemical and special wastes helps the adoption of special methods for dealing with the wastes before they are delivered to dumping areas.

Construction wastes originate from various sources in the whole process of implementing a construction project. Faniran & Caban (1998) conducted a survey examining the construction waste sources, and formulated five typical waste sources, namely, design changes, leftover material scraps, wastes from packaging and non-reclaimable consumables, design / detailing errors, and poor weather. Bossink & Brouwers (1996) considered that construction wastes are generated from the application of various building materials and classified the waste sources according to the nature and the technology of using the materials, including stone tablets; piles; concrete; sand-lime bricks and elements; roof-tiles; mortar; packing; and other small fractions of metal and wood. Gavilan & Bernold (1994) grouped construction waste sources into design error; procurement or shipping error; materials handling; machine operation error and residual or leftover scraps. Rounce (1998) pointed out that the major construction waste sources are at design stage, such as design changes, the variability in numbers of drawings and the variability in the level of design details.

Managing construction wastes is to control the genedration of waste and manage the handling process???????

Investigation to the waste flow practice on construction site

This research team has examined the waste handling processes of six construction projects in the Hong Kong construction industry. The examination is presented by mapping out the waste flow processes in these cases. Mapping presentations have been considered advantageous in presenting flows of processes logically, clearly and in the simplest way (Fisher & Shen, 1992). The major information presented in the mapping of the investigated cased includes four key elements, namely, waste source, waste facilitator, waste processing, and wastes destination. In order to conduct comparative analysis between different practices, the standard symbols are used for representing the four elements, as shown in figure 1 (a) (b) (c) (d).Waste source denotes the generation of wastes and various locations where wastes originate; waste processing denotes various handling processes where waste-handling activities are undertaken, for example, transporting or sorting out wastes; waste facilitator denotes the assistance or tools used to facilitate the implementation of various waste-handling activities, including labors, tools, mechanical plants, and so on ; and waste destination denotes the final status of the wastes, such as reuse or recycle, or the final places where wastes are transported to, such as dumping or reclamation areas. By using these four elemental symbols, a simple waste flow mapping can be presented as shown in figure 1 (e).

<Insert Figure 1>

In order to conduct comparative analysis between different practices, consistent terminologies are used for describing waste processing and waste destination, and standard symbols are used for denote waste facilitator. These terminologies and symbols are shown in Table 1.

<Table 1>

By using the constructed waste flow symbols and the abbreviations in Table 1, the six waste management practices are mapped and presented in Figures 2, 3, 4, 5, 6 and 7 separately. The mappings for the six cases are constructed based on this research team's on-site observations and the discussions with the site management staff who were operating the concerned projects. Based on the observations and discussions, a list of weaknesses and advantages in the application of waste management are formulated as follows:

<insert Figure 2, 3, 4, 5, 6 and 7>

Weaknesses:

W_1 Too many waste handling processes
W_2 Lack of sorting-out process
W_3 No consideration to recycling wastes
W_4 No consideration to reusing wastes
W_5 Causing severe air pollution by generating dusty
W_6 Intensive labour works involved in handling wastes
W_7 Increased waste handling time due to various waste collection locations
W_8 Double-handling in collecting wastes
W_9 Expensive cost for setting up waste delivering facilities including rubbish chute and hoist
W_{10} Time consuming for long distance travel among scattered waste collection locations
W_{11} Safety problem by allowing more labors collect wastes on site
W_{12} Ineffective coordination among various waste handling activities
W_{13} Inefficiency due to less application of mechanical system in delivering waste
W_{14} Causing severe noise pollution from delivering waste
W_{15} Severe air pollution when delivery
W_{16} Generate packing wastes
W_{17} Environmentally unfriendly in using plastic bags in collecting waste
W_{18} Free throwing of waste bags from high position

Advantages:

A_1 Fewer waste management processes
A_2 Wastes sorted out into different categories
A_3 Use of reusable waste
A_4 Compliance of waste recycling
A_5 Income made from the sale of reusable wastes
A_6 Less expense in setting up waste delivering facilities
A_7 Efficient waste delivery in using rubbish chute
A_8 Reduction in air pollution by using rubbish bags or bins
A_9 Efficient waste collection in packs
A_{10} Less labor works involved in delivering waste
A_{11} Avoiding double-handling with waste
A_{12} Clean construction site as the result of properly collecting and storing waste
A_{13} Fewer waste collection locations with seeable distance
A_{14} Well informed procedures of handling waste among site staff

The evaluation on the weaknesses and advantages of each practice is comparatively conducted between six cases, and given in Table 2 and 3. The results are generated from research team's observation and the discussions with the site managerial staff concerned in the six cases.

<insert Table 2>

<insert Table 3>

The investigation indicates that different projects are different in practicing waste management. Project case I is a high rising residential project located in town center and the survey was conducted at superstructure construction stage. The typical weaknesses observed in this practice include that: (1) There was no sorting out at waste generation locations, resulting in the difficulty of sorting out wastes at later stage; (2) Severe dusty and air pollution were generated from uncovered delivering activities by using handcart extensively; (3) Intensive labour works was involved and less mechanical system was used in waste handling, resulting in more staffing costs and more time consumption on waste handling; (4) Lack of packing or container for waste collection resulted in double handling in collecting waste; and (5) The use of plastic bags for waste collection was not environmentally friendly practice. Nevertheless, the interview discussions with the site managerial staff revealed some advantages in this practice, including that (1) It was a simple waste management practice, and there were fewer processes for handling wastes on site, involving less supervision costs; (2) Waste materials were sorted out thus the benefits of waste reuse and recycle were gained; (3) Certain amounts of income were generated from the sale of reusable waste materials; and (4) Less expense was devoted for setting up waste handling / disposal device on site, and accordingly less energy was consumed for operating mechanical device.

Project II concerns a three-block high-rising housing estate at project finishing stage. The disadvantages observed in this practice include: (1) There was intensive involvement of labour works in waste handling, resulting in high labour costs; (2) There was no sorting-out process and no recognition to the benefits of waste recycling and reuse; (3) Significant amount of costs was involved for employing manpower, lorry, hoist and rubbish chute in dealing with wastes; (4) The scattered waste collection locations increased handling time; (5) Higher chance of safety accident was presented by allowing more people to travel and collect waste materials on the site; (6) The coordination was weak among various waste handling activities; and (7) The use of plastic bag for waste collection was not environmentally friendly practice. The advantages in this waste-handling practice were suggested as: (1) Use of rubbish chute for delivering wastes contributed to energy saving and the higher efficiency of waste-handling; (2) Waste collection by using bags and rubbish bin reduced dust dispreading, resulting in less air pollutions; and (3) Higher efficiency was obtained in collecting waste materials in packs than that of dealing with pieces of waste materials.

Project III is a high-rising office-building project during superstructure works. Typical disadvantages in this practice are identified including: (1) There was no waste sorting-out and little recognition was given to the benefits of waste recycle and reuse; (2) There was no waste packing and no container for waste collection, and double-handling in waste collection was induced; (3) The delivery of large-size waste materials through refuse chute presented the chances of blockage and caused noise pollution as well; (4) Higher cost was involved in dumping wastes because of the volume increase of waste materials due to the lack of sorting-out process; and (5) Higher costs was involved in establishing refuse chute and the use of waste-delivering lorry. Typical advantages observed in this practice include: (1) Time saving in delivering wastes was gained through refuse chute; (2) Less labour works was involved in waste handling; (3) Air pollution was under control by use of refuse chute with running water; and (4) Usable waste materials were reused.

Case IV was a large housing estate project at finishing stage. The weaknesses discussed in this case include: (1) Waste handling involved intensive labour work; (2) Long traveling distance of delivering waste materials on site to waste collection locations consumed more time in handling wastes; (3) There was lack use of mechanical device for delivering wastes, resulting in low efficiency in waste handling; (4) Less consideration was given for recycling waste materials; and (5) The practice presented severe air pollution due to the dusts from uncovered wastes in process of delivery. Advantages in handling wastes in this practice were suggested as (1) Double handling of wastes was avoided as the result of using top-open rubbish collector connected directly to the lorry that delivered the wastes to dumping areas; (2) The practice presented a clean construction site as wastes were properly collected and stored in rubbish collectors; (3) Reusable waste materials were collected and tidily placed; and (4) Wastes collection locations were seeable and easy for labors to find.

Project V 5 demonstrates the mappings of the waste flows in case V. The disadvantages observed in this practice include: (1) There were too many processes for handling waste materials, consuming more time and resources; (2) The practice involved intensive labour works in delivering waste materials, involving high staffing costs; (3) Less use of mechanical device such as refuse chute reduced the efficiency in delivering wastes; (4) Using passenger lift for delivering waste bags engaged in double handling operation as wastes had to be transported in and out of the lift; (5) No consideration was given for recycling waste materials; (6) Spreading of waste collection locations on site increased the traveling distance of waste delivering activities and demanded for more supervision efforts; and (7) The use of plastic bag for collecting wastes was not environmentally friendly practice. The advantages of this practice are considered as (1) Well packed wastes reduced the dusty air pollution; (2) The practice presented a clean construction site as waste materials were tidily kept; (3) Usable wastes were collected and reused; and (4) The procedures of handling wastes were not only communicated to waste-collectors, but also to all working staff on site, raising the awareness of waste reduction and environmental protection.

Case VI concerns a redevelopment project for a high rising commercial building at finishing stage. The major disadvantages observed in this practice include: (1) The free throwing of waste bags from 8/F podium down to G/F was considered unsafe and dangerous; (2) There was no waste sorting out and no consideration for recycling or reusing wastes; (3) The practice engaged serious air pollution due to the dusts generated from throwing waste materials; and (4) The packed waste bags were often broken due to throwing from high position, thus double handling operation of wastes was involved. The advantages in this practice were said as: (1) The procedures of delivering waste were reduced; (2) Less labour works was involved for waste handling; and (3) Higher waste-handling efficiency was gained through throwing wastes and by refuse chute.

From Table 2, it can be seen that the common weaknesses are: ??????????

In summary, the general problems pertaining to the surveyed six cases include that: (1) There is no organization policy or specific training program for the working staff who handling wastes; (2) Less consideration is given among managerial staff to the environmental impacts of the wastes; (3) Less consideration is given to waste recycling and reusing at project earlier stage; (4) There is lack of standard waste handling procedures; and (5) There is no review exercise on the effectiveness of waste handling practice.

Table 3 indicates the common advantages including ???????

Developing an effective waste management flow model (WMFM) on construction site

The investigation on the six cases in the previous section demonstrates that different site management practices engage different waste handling procedures. However, all the activities involved in handling-waste can be grouped in three major stages namely waste generation, waste assembly and waste destination. At waste generation stage, various types of wastes are generated, and bottom-layer subcontractors and labors collect and sort out the wastes at various locations. As a proper practice, reusable and recyclable waste materials must be identified and sorted out at this stage, such as marble, kitchen cabinet, timber flooring, false ceiling, waterproofing materials and etc. In fact, it was pointed out in the interview discussion when examining the six cases in this study, the waste marble and wall tiles can be sorted out as spare parts and effectively used in the process of defect rectification. Separate purchase of marble and wall-tiles are often found with colour deviation and texture incompatible from the first batch of purchase, thus reuse of these waste materials can avoid such deviation problem. On the other hand, waste reduction for dumping can be gained if proper sorting-out is taken at waste generation stage. All workers should be trained to work in the way that leads to minimum waste generation and maximum waste reuse and recycle.

At waste assembly stage, it is the main contractor to co-ordinate and assembly waste handling processes in the aim of reducing wastes and reducing the resources required for handling wastes. The investigation on the six practical cases suggests that main contractor can improve waste handling effectiveness through properly coordinating subcontractors or specialist trades and adopting more effective waste handling measures. For example, these measures include: (1) using open-top lorry container in assembling wastes to avoid double waste handling; (2) assembling waste materials to one or few collection points within construction site to reduce supervisory efforts; (3) utilizing rubbish chute in delivering wastes to increase delivering efficiency; (4) sorting-out wastes after normal work hour in order to minimize the interference to other construction operations; (5) reusing usable wastes or recycling valuable materials to contribute to environmental protection and to reduce waste volume for final dumping. In fact, the experience in the local construction industry suggests that the sale of recyclable wastes such as timber and steel bar can offset the recycle overheads; and (6) delivering the residual wastes to dumping area / reclamation area designated by government to avoid the convictions by dumping wastes illegally.

At waste destination stage, the residual wastes are delivered to specific destinations, such as dumping area or for reclamation. These destinations are specified in relevant government policies. Waste sorting-out will be further conducted at this stage, so that specific disposal measures can be used for different types of wastes.

The examinations on the weaknesses and advantages in handling construction wastes in the six practices provide valuable references for investigating a more effective and standard waste management flow model (WMFM). With considering the advantages embodied in these practices and the results of discussing with site managerial staff who participated the mapping of these six cases, the major guidelines for constructing such an effective WMFM are proposed as follow:

- To minimize the cost used for waste management by i) minimizing the number of processes for handling wastes; ii) involving less labour hours / efforts for handling wastes; iii) using more mechanic means in handling wastes; iv) choosing low energy consumption tools /

plants for handling wastes; v) avoiding double handling operations; and vi) engaging proper supervision on waste-handling activities;

- To protect the environment in the process of handling wastes by i) controlling the waste pollution (air pollution, water pollution, noise pollution and other types of waste pollution) to its minimum level; ii) maximizing waste recycle and reuse; iii) promoting environmentally friendly operation to all production activities among all working staff; iv) adopting clean construction practice by keeping tidy and hygiene on construction site; v) maximizing the use of environmentally friendly building materials and construction methods; vi) adequately purchasing the quantity of building materials, thus resulting in the reduction of waste generation; and vii) using the construction plants that have less environmental impacts.

- To minimize the time consumption for handling waste by i) reducing the number of waste handling processes; ii) simplifying the operation of each handling process; iii) avoiding double-handling operation on wastes; and iv) increasing operation efficiency by using mechanical devices and less using labour operations.

By incorporating the above guidelines and the six practical cases presented, an alternative WMFM is proposed as shown in Figure 8.

<Figure 8>

This model begins with waste management planning (WMP). This plan must be produced before starting to undertake construction activities. In this plan, resources for handling wastes and waste mitigation measures will be specified. The implementation of waste management plan will start when construction commences. The model suggests to collect those reusable waste materials as soon as they are generated for recycle and reuse. Such practice can also avoid the increase of waste volume when project proceeds and provide clean work condition. Having collected reusable and recyclable wastes, the wastes left can be generally called construction debris. The debris will be further sorted out into different types of wastes, for example, inert and non-inert materials. The sorting-out at this stage also leads to further identification of reusable and recyclable wastes. It is emphasized that waste sorting-out should be undertaken at the waste generation stage as it is more difficult to do this at later stages.

Following the sorting-out of construction debris, the debris will be delivered to waste collection locations through refuse chute, hoist and by hand. The application of different waste delivery methods depends on the type of debris and different site environments. For example, large-sized debris will be delivered through refuse chute, middle-sized debris will be transported through hoist, and the small-sized debris will be handled by hand. The practice of waste delivery should aim for simple procedures, high efficiency and less labour works involved. Workers who handle wastes should be encouraged to use less plastic bags or use repeatedly.

Waste sorting-out at earlier stage can also avoid the possibility that the usable and recyclable waste materials are spoiled in the mixture with other debris. In the local practice in Hong Kong, waste sorting-out is uncommon. Often only major reusable wastes are collected at project late stages. This practice is considered as one of the major reasons of having massive production of construction wastes in the local construction industry (Ho, 2001). The proposed WMFM recommends that the workers collect the usable wastes immediately after finishing the work and deliver to specific locations. It is suggested to place a number of recyclable boxes on site, which allows workers to collect usable wastes easily. The allocation of recyclable boxes can also increase the environmental awareness among all working staff.

At final stage of this model, the sorted construction debris are transported by lorry to waste destinations including dumping and reclamation. The choice of waste destination needs to be in line with government policies. For example, Hong Kong Environmental Ordinance requests that the paint and chemical wastes generated from construction activities must be specially treated before dumping (WDO, 2001). Nevertheless, it seems that the existing practice in Hong Kong often ignores waste sorting out on site and few construction sites engage special treatment procedures for controlling chemical wastes.

Furthermore, the model suggests applying a review exercise on the effectiveness of waste handling operations at all procedures. The purpose of engaging this review process is to identify those weak procedures, examine the reasons behind the weakness, and take necessary activities to improve the weak procedures. The waste management review should involve the participation of all working staff on site, thus the results of the review can be effectively responded on site.

Conclusion

The benefits of implementing waste management in construction activities are multiple. McDonald et al. (1998) suggested that the main advantage of engaging proper waste management is cost saving, 50% of waste handling cost could be saved in their case studies. However, the business cost reduction by controlling wastes is difficult to achieve in short term, rather it will increase cost due to additional investment on staffing, technologies and facilities. The examination on the Hong Kong construction industry demonstrates that in the current practice, it is the governmental enforcement to push contractors to implement waste management. There is limited effectiveness as there is a lack of contractors' initiatives of engaging proper waste management procedures. One of the reasons for the absence of such initiatives is the lack of standard guidance for setting up proper waste management procedures. The investigation on six cases in this paper demonstrates that different site management practice engages different waste management procedures, whilst they have some common weaknesses and share some good procedures. The mapping presentations of these cases lead to the development of an alternative WMFM as a sample practice for guiding the waste controlling procedures on construction site. WMFM incorporates the advantages embodied in the current practice. The model provides a tool for comparing the waste management practice among different construction projects, thus weak areas can be identified, followed by corrective measures. The standard WMFM model can also build up the further waste management strategies, in which the concepts of waste management can be done in the early project stages.

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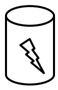
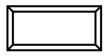
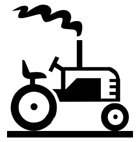
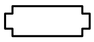
Table 1 Terminologies and symbols used in mapping waste management flow practice

<table>
<tr><td colspan="5"><u>Waste processing:</u>
Collecting debris; Collecting reusables; Loading waste; W(waste)-deliver by hoist; W-deliver by refuse chute; Waste sorting-out; W-transport by hand; W-transport by lorry</td></tr>
<tr><td colspan="5"><u>Waste destination:</u>
Dumping area; Land filling; Reclamation; Reuse; Recycle;</td></tr>
<tr><td colspan="5"><u>Waste facilitator:</u></td></tr>
<tr><td>Labour
</td><td>Rubbish bin
</td><td>Handcart
</td><td>Waste container
</td><td>Lorry
</td></tr>
<tr><td>Hand tools
</td><td>Recycle box
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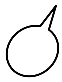
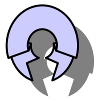
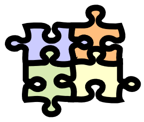
</td><td>Mechanical tools
</td><td></td></tr>
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R & I: Reviewing and improvement
SM: Site management
ST: Special Treatment
T: Transportation
WMP: Waste mitigation planning

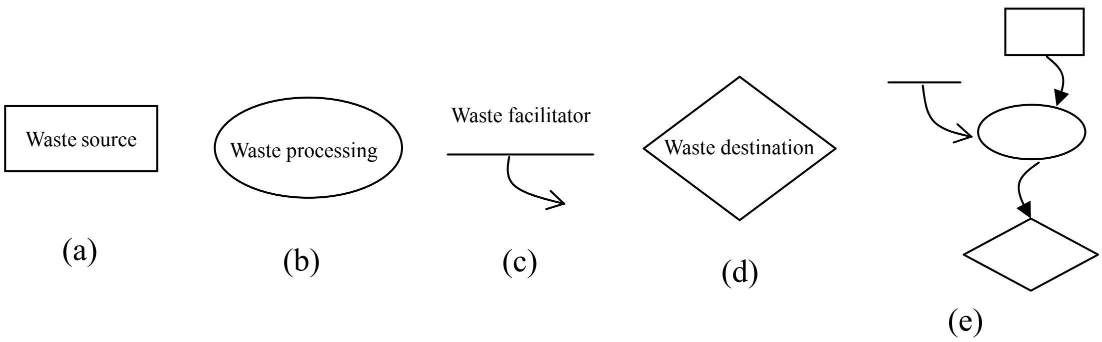


Figure 1 Waste flow symbols

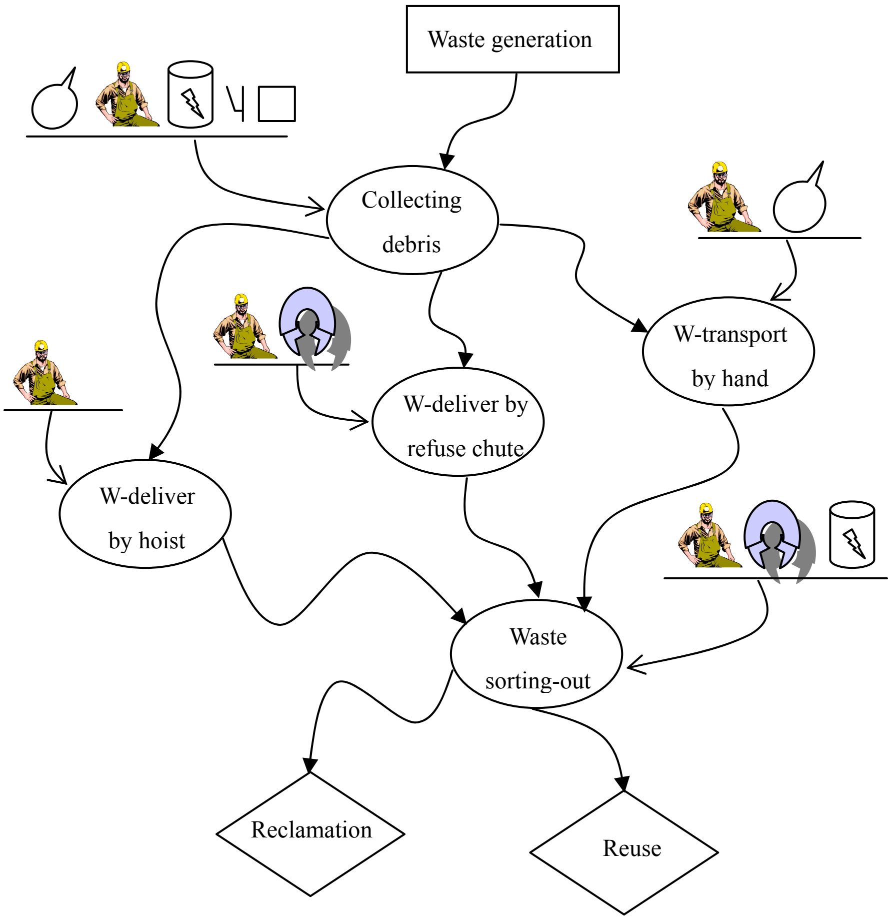


Figure 2   Mapping of waste management practice for a high rising residential building project

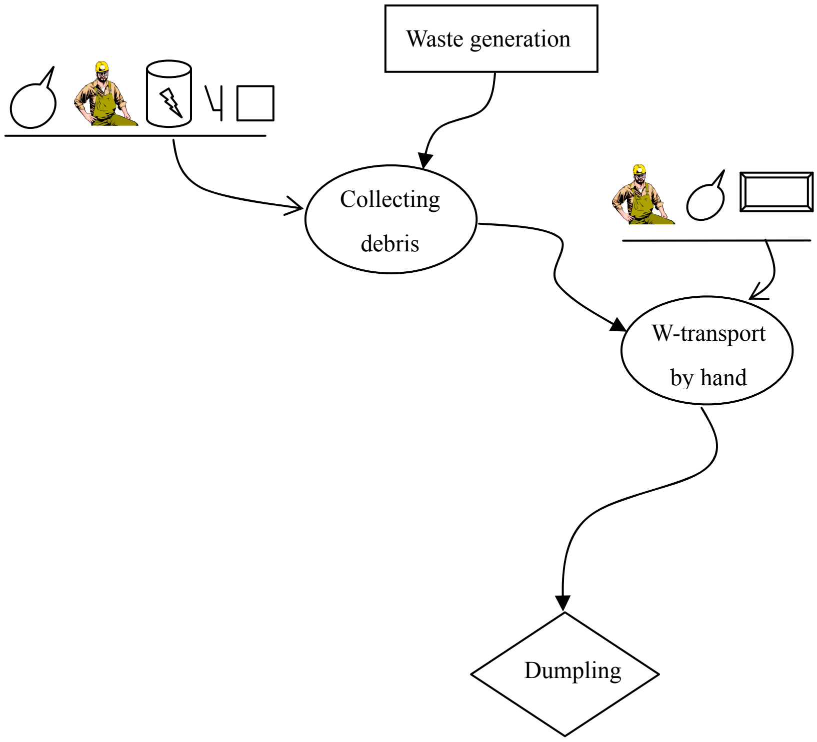


Figure 3 Mapping of waste management practice at project finishing stage

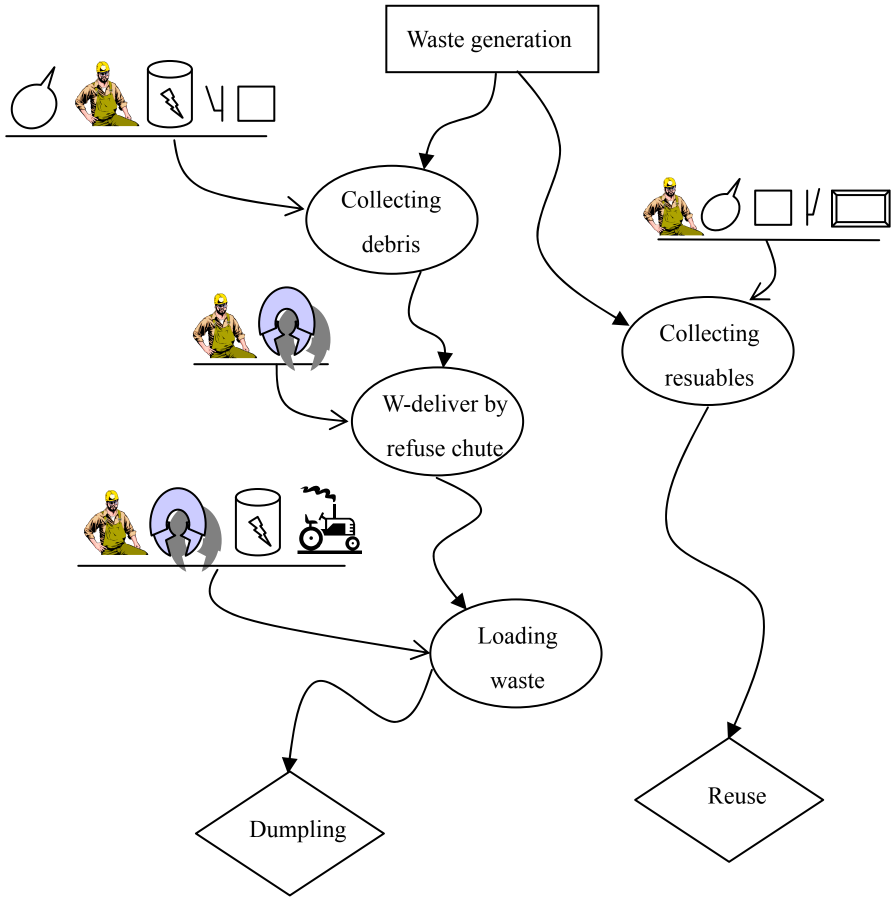


Figure 4 Mapping of waste management practice for a high-rising office building at superstructure works stage

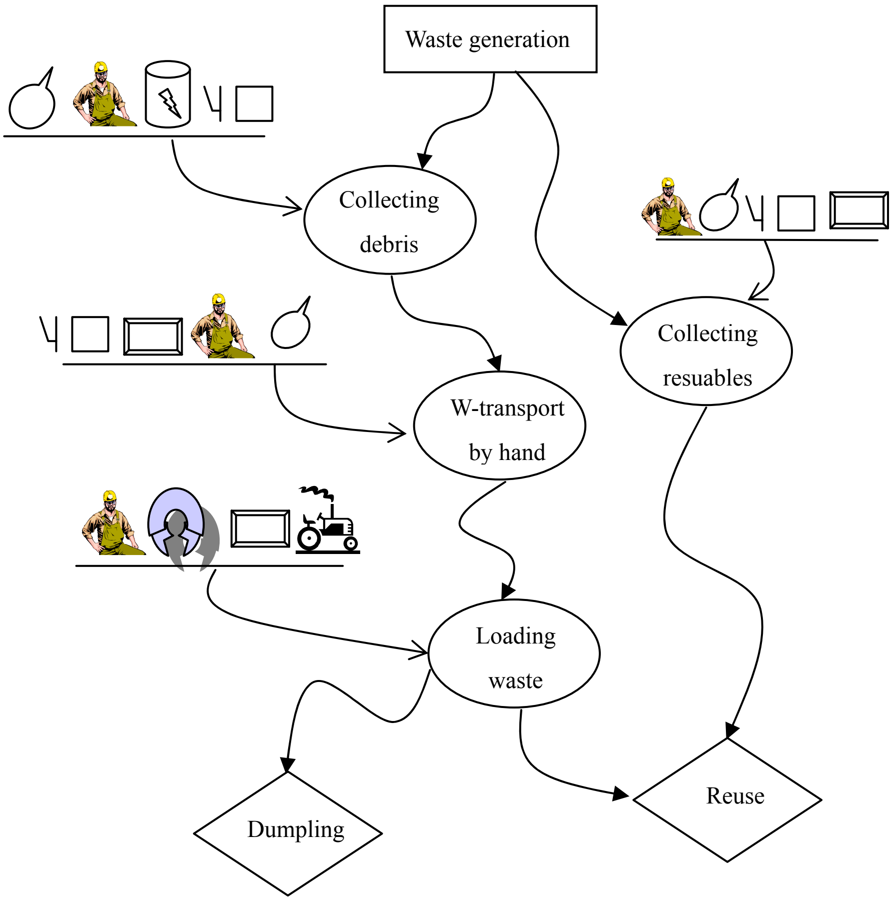


Figure 5 Mapping of waste management practice for a housing estate project at construction finish stage

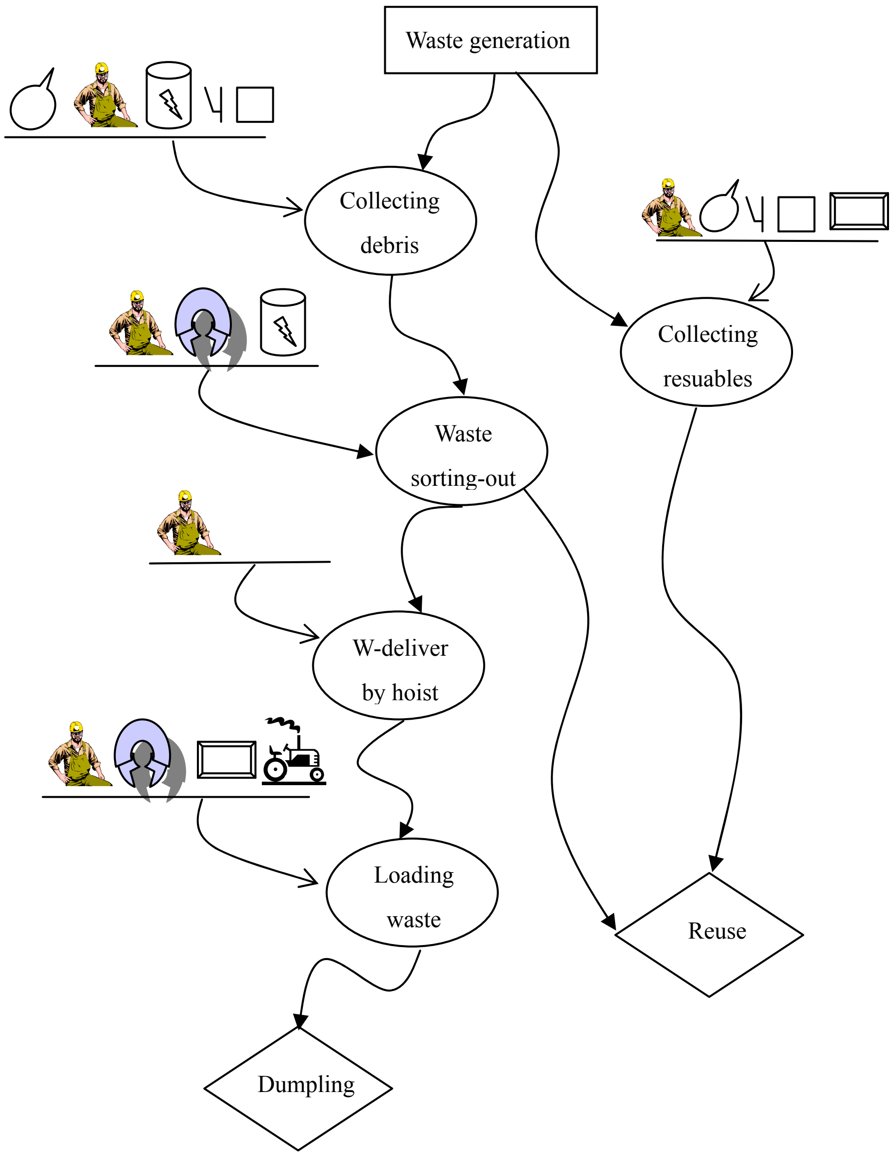


Figure 6 Mapping waste management practice for a high rising office building project at finishing stage

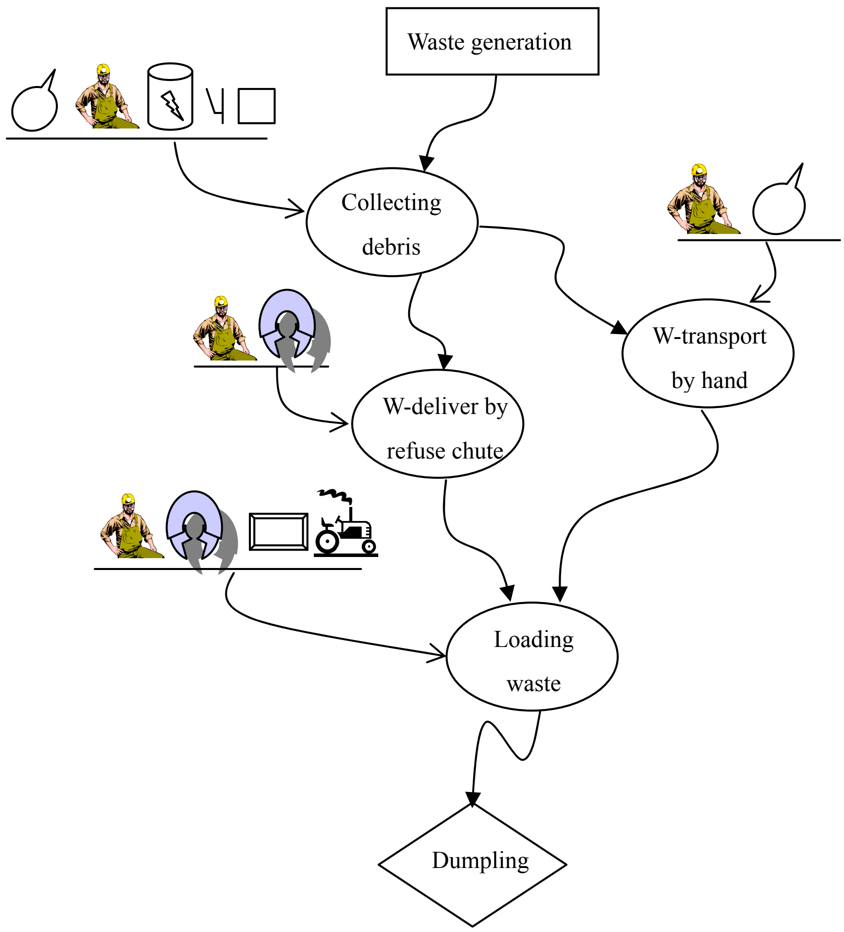


Figure 7 Mapping waste management practice for a redevelopment building project at project finishing stage

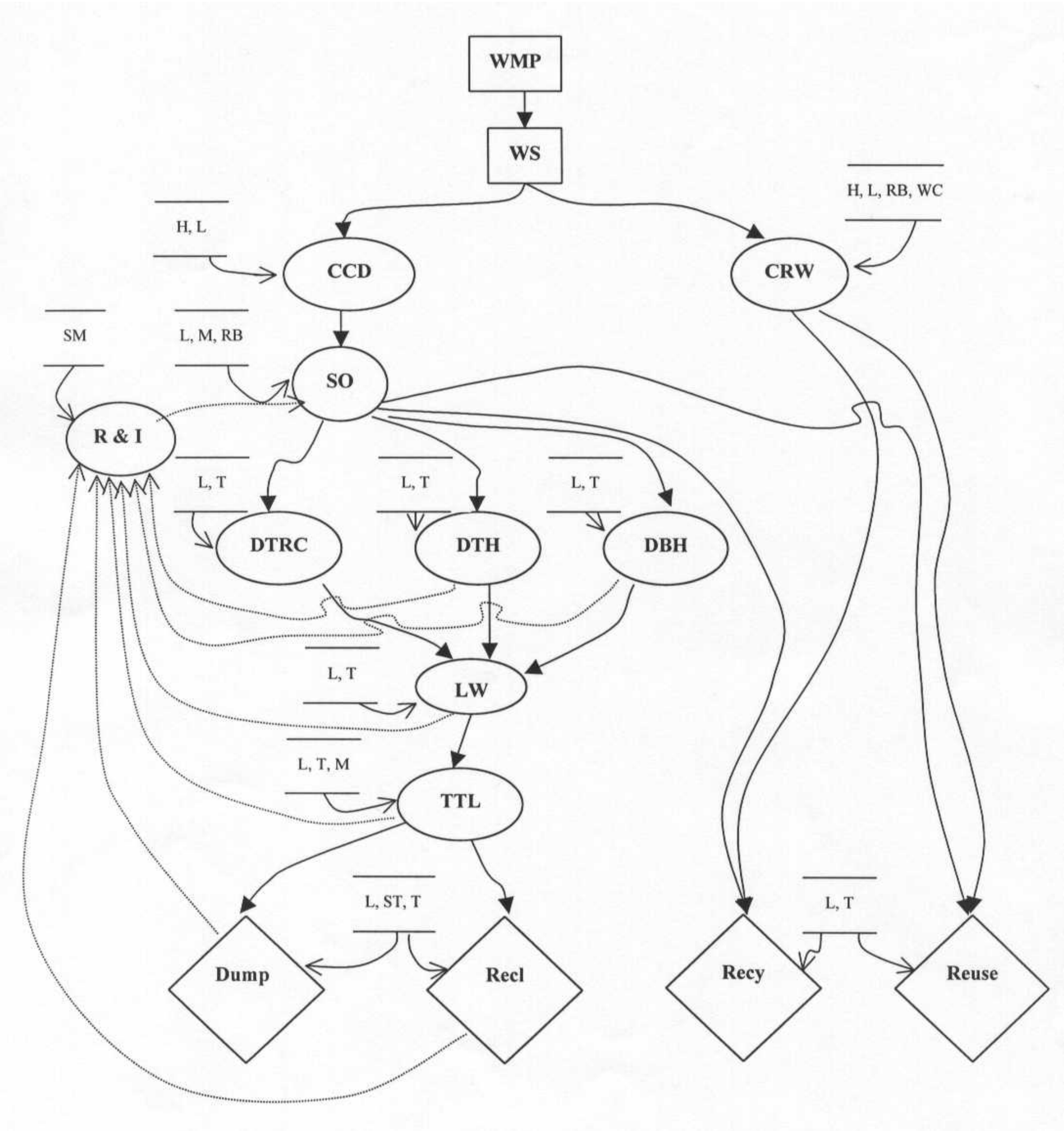


Figure 7 Waste flow management model

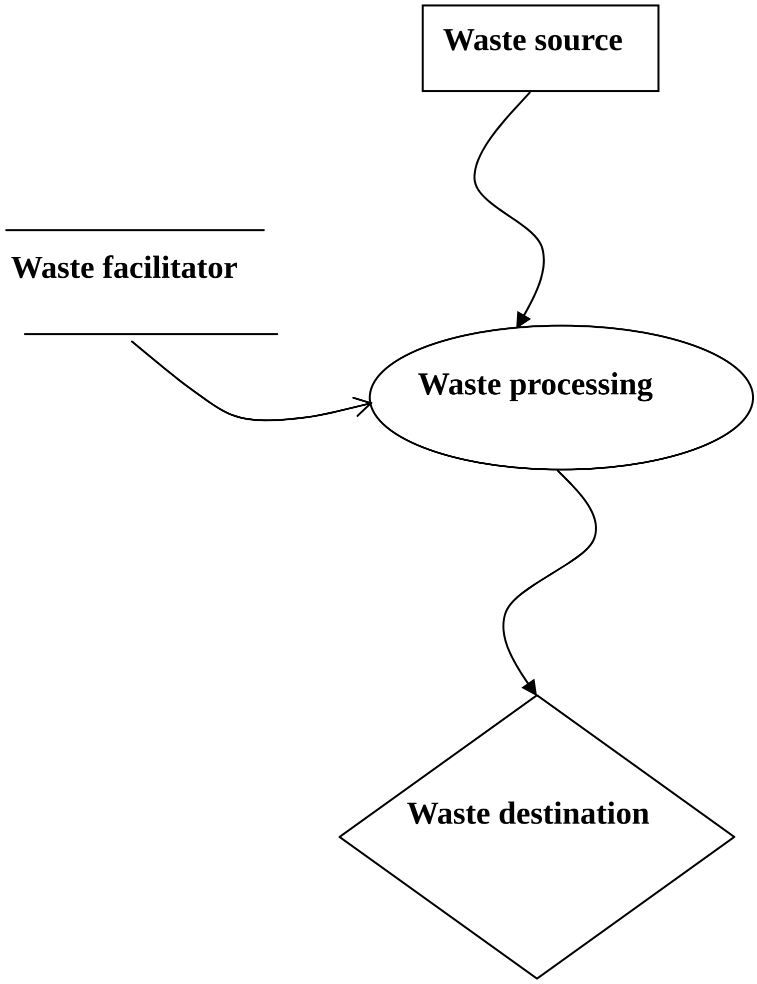

Waste source
Waste facilitator
Waste processing
Waste destination

Table 2 Comparative evaluation on the weaknesses between six cases

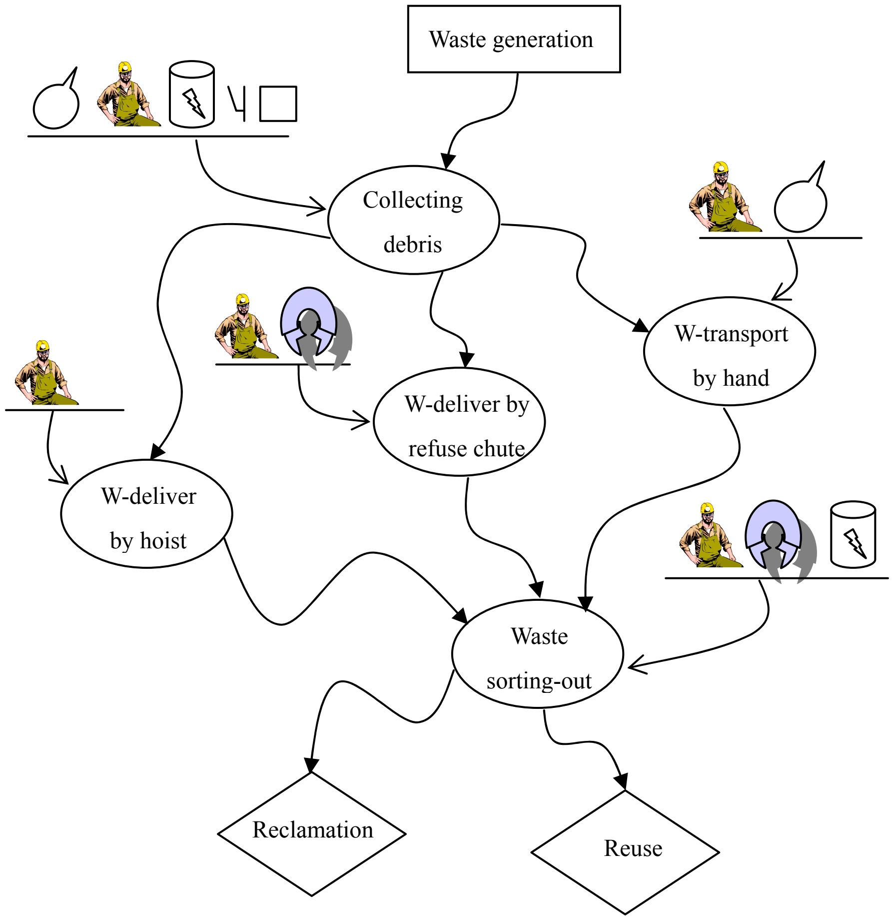
Weaknesses	Case I	Case II	Case III	Case IV	Case V	Case VI
W_1	○	◘			●	
W_2	Yes	Yes	Yes			Yes
W_3			Yes	Yes	Yes	
W_4			Yes			
W_5	Yes					Yes
W_6	Yes	Yes		Yes	Yes	
W_7		Yes	Yes		Yes	Yes
W_8				Yes		
W_9	Yes			Yes	Yes	
W_{10}		Yes				
W_{11}				Yes		
W_{12}	Yes					
W_{13}	Yes			Yes	Yes	
W_{14}		Yes				
W_{15}				Yes		
W_{16}	Yes					
W_{17}	Yes	Yes			Yes	
W_{18}	Yes	Yes			Yes	

○ Weak ◘ Normal ● Strong

Table 3 Comparative evaluation on the advantages between six cases

Advantages	Case I	Case II	Case III	Case IV	Case V	Case VI
A_1	○			◘	●	
A_2	Yes	Yes	Yes			Yes
A_3			Yes	Yes	Yes	
A_4			Yes			
A_5	Yes					Yes
A_6	Yes	Yes		Yes	Yes	
A_7		Yes	Yes		Yes	Yes
A_8				Yes		
A_9	Yes			Yes	Yes	
A_{10}		Yes				
A_{11}				Yes		
A_{12}	Yes					
A_{13}	Yes			Yes	Yes	
A_{14}		Yes				

○ Weak ◘ Normal ● Strong


Waste generation
Collecting debris
W-transport by hand
W-deliver by refuse chute
W-deliver by hoist
Waste sorting-out
Reclamation
Reuse