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Integrated Solid Waste Management System Using Distributed System Architecture for Indonesia: An IT Blueprint

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***Abstract*— Indonesia is in the top 5 country that generates solid waste. It is the 14th largest country in the world in managing waste, but unfortunately, Indonesia is not known for its diligence to waste management. In 2019, the coordinating minister for Maritime Affairs and Investment of the Republic of Indonesia, Luhut Binsar Pandjaitan, stated that it is a top priority in the national agenda to keep improving solid waste management due to the growing number of people living in the urban areas and the estimated 105.000 tons of solid waste a day. This paper aims to create an IT blueprint for this waste management through a distributed system that allows an optimum flow of waste out of dense urban centers and into the proper waste disposal facilities. It involves smarter waste surveillance, a consolidated fleet of collection agents of varying mobility and capacity and includes people participation to control unnecessary waste generation. The system should be scalable while using existing resources and systems to manage the problem in the long term. It should maintain the three principles of Integrated Solid Waste Management (ISWM): waste prevention, recycling, and disposal. New technologies, such as a sensor network to monitor waste generation close to the source, can help burgeon localized SWM techniques such as community composting. The country can take the steps necessary to mitigate the problem.**

***Keywords*— Solid waste management; Indonesia; distributed system; integration; sensor networks.**

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I. INTRODUCTION

Garbage is one of the biggest problems that have brought its share of problems to the growing Indonesian population as an Asian developing country suffers from this problem which leads the country to be considered as one of the countries with the highest rate of solid waste (SW). Although there is no one great solution to solve all the problems instead of having multiple integrated solutions to solve the issues, the bottom line is there is always a possibility of improvising the solid waste management system because the economic growth and the waste and consumption resources are inseparable [1], [2].

In developing countries, organic waste is varied, but organic waste is very dominant. As a developing country, Indonesia is in the top 5 countries that generate solid waste at 65.2 million tons in 2021, and this kind of statistic needs to be announced well in a developing country to increase citizens' awareness. In 2025 the global solid waste will reach 148 billion tons, and 56% of it is from developing countries [3]. Managing waste can be daunting without the right infrastructure to support it, and Indonesia is the 14th largest country in the world [4]. Among Indonesia's cities, the most SW can be found in Jakarta. Jakarta was considered the source because the city was the center of goods trading, communication, and even business. In other words, the city is the central market to other cities and areas in Indonesia. The population of Jakarta kept steadily increasing since people from outside of Indonesia and Jakarta mostly searched for their daily needs like jobs, education, and businesses.

This increase in population became a noticeable problem for the government because was difficulty in both organizing and managing them, including the SW they inevitably generate. Only 70% of the waste was collected in a 2007 study. In the same year, they generate up to 6000 tons per day, and a lot of it ends up in the 110-hectare Bantar Gebang landfill, which has a sizable population working on it to collect things of recyclable value. This garbage mountain is not only hazardous to the workers, but it also emits unwanted gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are well-known contributors to climate change. Up to 1000 tons even end up in the ocean [5]. Due to the COVID-19 pandemic, healthcare waste is increasing

greatly and threatening human health and the environment, especially during the COVID-19 pandemic[6], [7]. Besides medical waste, we also need to pay more attention to solid waste from the hospitality industry because the hospitality industry is also growing[8].

Even the government has tried to pass "Regulation No. 81/2012 on the management of household waste", including "to regulate the at-source separation of waste" and managing it before it is collected in the later processes [9]. Unfortunately, lack of awareness has not done this regulation much good. While it is possible to find a larger hole to dump the increasing waste, there is an inherent fault if the larger city of Tokyo can maintain a cleaner city. Moreover, several recommendations have been made in China to improve solid waste management, such as reducing waste generation, increasing recycling, proper landfilling, etc. [9]. This problem continued in an endless loop, and the government and its population are having difficulty solving it. To have a better environment and economic and social development, waste and recycling management must be included in the construction project before the start and after it is finished [10], [11]. The waste generated has only increased as time passes. Even when the government has tried to convince its people by law and regulations such as not to loiter or throw any garbage everywhere, they should throw them in the trash bin that has been provided. However, they were still persistent in their bad habits, and the consequences of their actions have affected many people until now. All technical and non-technical must be analyzed and improved because both are needed to draw holistic solutions [12]. The constantly changing composition of waste is one of the reasons we need integrated systems to manage the available facilities [13]. This paper aims to provide a way to tackle waste management from the perspective of a distributed system because the waste management issue involves many parties, such as human health, social, economic, and social Fields[14]. As technology is getting more advanced [15], using technology or ICT is the best way to solve such problems because ICT can be applied in management, such as solid waste management.

II. Materials and Method

Design Science Research, or DSR, has been chosen for the method of this research paper. DSR solves a real-life problem by creating an innovative artifact and contributing to science, as evidenced [16]. DSR combines an emphasis on the IT artifact with a strong emphasis on the application domain relevance [16]. In DSR, six sequential activities can be shown in the DSR process model (Fig. 1).

Activity 1 is the problem identification and motivation, which in this research paper is that waste management in Indonesia is still a problem and make Indonesia the top 5 country that generates municipal solid waste [17]. The second activity is to define the objective for a solution to this activity and the importance of solid waste management, no other than increasing public health and reducing the environmental impact in the future [18]. The third activity is design and development; in this activity, the artifact needs to be designed, and the IT artifact needs to be created based on the objective of the second activity. Activity 4 is a demonstration; in this activity, the developed and designed IT artifacts must be demonstrated to any involved parties. The result of activity four was used in activity 5. The fifth activity is the evaluation process. Based on the result of the demonstration in activity 4, in activity 5, we evaluated the IT artifacts based on the feedback. The last activity is communication; in this activity, is the design developed to solve the problem, or are there any new theories generated based on the new IT artifacts? All of this needs to be communicated for further research opportunities.

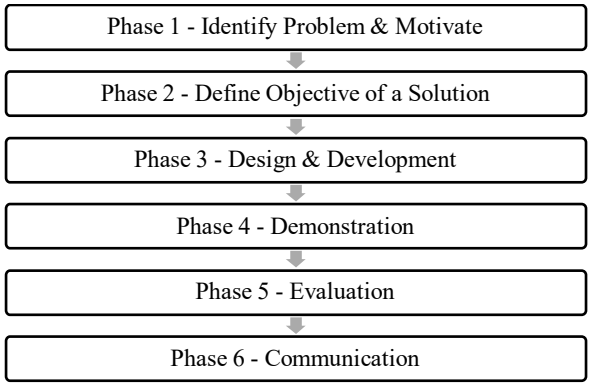

Fig. 1 Design science research process model [19]

There are many problems associated with Indonesia's waste management practices. The effectiveness of the current system can be doubted. Fig. 2 illustrates the general overview of SWM. The endpoint of this operation usually involves landfills that may not even be closed. Some aspects of the SWM in Indonesia need to be addressed to alleviate the unkempt appearance of the country, even in its most developed city.

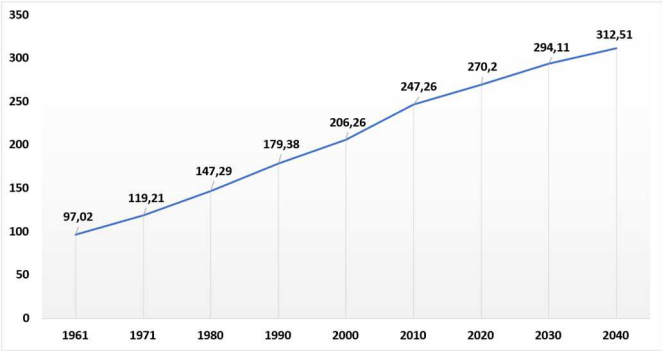

Fig. 2 Indonesia's growth projections [20]

A. Rapid Growth

Indonesia is already a large country with almost 240 million as of 2014, with at least 10 million in Jakarta alone and a growth rate that exceeds Beijing and Bangkok [21]. As mentioned, Jakarta was already generating a lot of waste back in 2007, which had fewer people. With more people living and generating all sorts of waste, this figure is expected to rise, straining existing disposal sites. With a definite increase soon, such as what Fig. 1 shows, a guaranteed result is that the volume of waste generated is not going down. This means the system can cope with a steadily increasing amount of waste. Already, landfills are straining to hold the amount of disposed waste at current levels. Jakarta's waste-generating potential will strain a system that cannot effectively cope with the fluctuating demands.

B. Collection and Storage

The first part of waste management is to collect the waste at the site it is generated. This is where the waste collection proceeds from, and an important aspect to note is the ease with which these points can be accessed by whoever collects them. UN-HABITAT also admitted that collecting waste from residents is a challenge [22].

The waste is collected into two broad services in Indonesia: the collection from households to a transfer point (TP) and from the transfer point to landfills and other final disposal sites (FDS) [23]. The difference primarily scales. The former is handled locally and manually with carts, travels short distances, and is the lowest collection level. While not all waste generators use this, many do, and the only ones that do not utilize the temporary transfer stations are high-income households and public areas. The remaining generators need this two-stage collection system because these places are not as accommodating to the large trucks. Despite this elaborate collection system, not all waste is collected, with up to 30% not collected and disposed of properly. An integrated system of solid waste management systems is needed and will be the most appropriate solution in developing countries like Indonesia [24].

C. Fleet Age and Routing

The second consideration is the age of the fleet. The vehicles used for the collection vary from hand carts pulled by people to large trucks. Older trucks become increasingly more costly to run continuously. Scheduled maintenance can keep the vehicles running, which means vehicles cannot run all the time. Frequently, the vehicles are taxed to their limits, carrying more weight than is optimal for them to travel. This also taxes the vehicle's structure, which would result in more maintenance. In essence, old vehicles will become an unfeasible transport resource, and optimally using them becomes a bigger consideration. It even made the government consider replacing them with [25]. Routing them optimally can be difficult as Jakarta is notorious for its sub-optimal traffic, which can stress the vehicles even more. The routing problem also can impact the environment because of the nature of the transport network [26].

D. Sorting

An important aspect of waste management is sorting the waste. This can be done at any point on the line, but it is generally preferred to be done as early as possible as the load becomes greater as the waste travels further away from the source. The current system segregates the waste manually at the transfer stations, exposing the workers to potentially hazardous waste households throw out. The workers, while not scavengers, are categorized in the informal sector and aren't monitored formally by the authorities.

While a problem, this stage is important in waste separation, ensuring that waste management down the line becomes easier. These transfer points are temporary caches for the latter service of transporting the waste to final disposal sites.

E. Citizen Awareness

As the ultimate source of the waste itself, the citizens are either unaware or indifferent to their contribution to the growing waste. Lacking awareness is not just the main problem, but it can be considered as an excuse only, while the lack of willingness to look or search for the solution, including the execution of it, is the main problem [27]. Mostly, the citizen is dependent on their respective government system, considering that the rule that has been implemented has given negligible effect; in other words, it cannot last for a few years. Regarding technology, Indonesia is still behind in waste disposal compared to other developing countries such as Japan, Europe, and America. Citizen awareness and education are something common in previous studies' recommendations. The citizens' willingness to pay for the solid waste management system reflects their responsibilities [28]. However, education had little impact compared to the actions of the citizens. In Indonesia, awareness is still the main issue that the government needs to raise knowledge and awareness of a healthy lifestyle [29]. The awareness needs to be built since they were in school to create good cleanliness characteristics and other fields. Community involvement and strategic policy are proven effective enough to reduce and improve waste recycling [30].

III. Result and Discussion

To solve those problems with technology, an IT Blueprint is needed to guide the project because more than 70% of IT projects fail due to being over budget, exceeding time, or not meeting the requirements [31]. To develop an IT Blueprint, it is necessary to analyze the business process from end-to-end to understand the flow of the business and the proper requirements. Combining the five pillars in the IT Blueprint and the methodology, the IT Blueprint framework is available to follow.

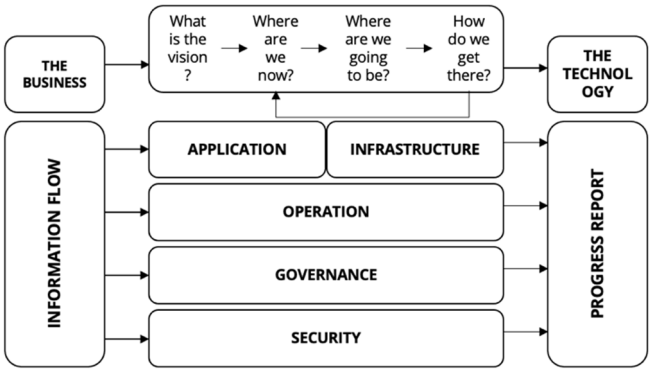

Fig. 3 IT Blueprint framework

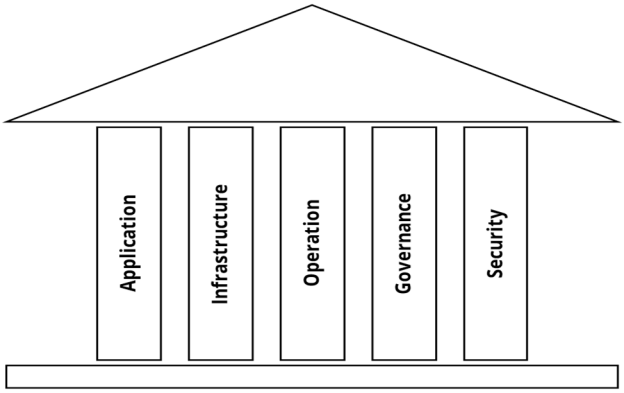

Fig. 4 The 5 Pillars of IT Blueprint

Based on Fig. 3, the IT Blueprint framework consists of many elements, but we focused on the five elements of the application, infrastructure, operation, governance, and security. Those five elements are the most important, or we can call them the five pillars of the IT Blueprint, as shown in Fig. 4. The Application and Infrastructure pillars have the same importance in IT Blueprint because no matter how good the application is, it will be useless if no infrastructure supports that application to run properly. Furthermore, if the infrastructure is very decent, but no application uses the capabilities of that infrastructure, then the infrastructure will be wasted. Because of that, the application and infrastructure must be aligned and support each other. For example, having a business intelligence system with cloud computing for reporting and monitoring systems [32].

The operation pillar deals with how to operate and have a support system to make the most of the application, reach the objective, and make it as useful as possible. The operation pillar involves internal and external entities. Not just the application, infrastructure, and operation but how to make a policy of the system are some of the most important things that need to be done. The governance pillar can handle and aim to improve IT management and ensure the IT strategy is aligned with the business strategy.

The last pillar is the security pillar. The security pillar is responsible for ensuring the overall IT organization's security to ensure that the application and infrastructure are secure to be used by internal and external entities. The flow of using the IT Blueprint framework is shown in Fig. 5.

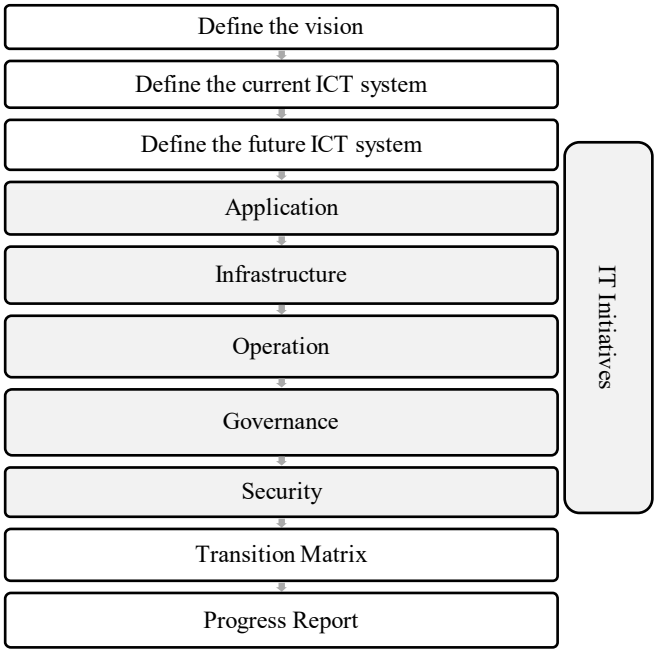

Fig. 5 IT Blueprint flow

According to Fig. 5 IT Blueprint flow, we define the vision of the company, business, or organization. The vision can be used as the same previous vision if it still matches the company's future or comes up with a new one. After defining the vision, we assess the current ICT system to see where it is the current ICT system. The next step is to define the future ICT system that matches the company's future.

When defining the current and the future of ICT systems, the process will continue with the development of the five pillars of the IT Blueprint, IT Initiatives. The five pillars are application, infrastructure, operation, governance, and security. Those five pillars will produce an IT Initiative result, shown in Table I and Table II.

TABLE I
IT INITIATIVES

Needs/Target	Solution	Important (!)	Urgent (^)	Cost ($)	Time (#)
	Application				
Native apps	Develop native apps	!!!	^^^	$$	##
	Infrastructure				
Cloud model	Saas or Paas implementation	!!!	^^^	$	#
Internet bandwidth	Sufficient internet bandwidth	!!!	^^	$	#
	Operation				
Training	Internal training	!!!	^^^	$	###
Socialization	User socialization	!!	^	$	#
	Governance				
ICT Governance	Data protection, privacy, and policy	!	^	$	#
	Security				
Advanced security system	Encryption	!!	^	$$	#

TABLE II
IT INITIATIVES LEGEND

Important (!)	Urgent (^)	Cost ($)	Time (#)
! = Less important	^ = Not too urgent	$ = <$4999	# = < 3 months
!! = Important	^^ = Urgent	$$ = $5000 - $9999	## = 3 – 6 months
!!! = Very Important	^^^ = Highly urgent	$$$ = > $10000	### = 6 – 12 months

After defining the five pillars of the IT Blueprint and producing the IT Initiatives, the process will continue to produce the transition matrix as our guidelines to transition from the current to the future. Normally the transition matrix will span 3-5 years, depending on the organization. The template of the transition matrix is shown in Table III.

TABLE III
TRANSITION MATRIX TEMPLATE

Security				
Governance				
Operation				
Infrastructure				
Application				
	Year 1	**Year 2**	**Year 3**	**Year 4**

According to the IT Blueprint flow, we must also produce a progress report after the transition matrix. The progress report template is shown in Table IV and Table V.

TABLE IV
PROGRESS REPORT TEMPLATE

Item	Status			
	Phase 1	Phase 2	Phase 3	Phase 4
Developing native apps				
Implementing SaaS or PaaS cloud model				
Increase internet bandwidth				
Internal training				
User socialization				
Developing IT Governance				
Enhance IT security				

TABLE V
PROGRESS REPORT LEGEND

Status	Symbol
Done	v
Not Started	x
Pending	*
On Progress	>

It would help to see existing strategies for managing waste to tackle the problem. According to the US Environmental Protection Agency, creating an Integrated Solid Waste Management (ISWM) involves considering three broad areas: waste reduction, recycling/composting, and final disposal. While these systems must be integrated, having one system grind to a halt because of another is also inefficient.

To help with waste collection, it is important to know where the collection points are and to add Blockchain technology to track operations and products. A study was done in a Greek municipality using a Geographic Information System (GIS) to map to optimize collection routes effectively can improve them by as much as 12.5%. That study was limited to a single municipality of a Greek city. The study created a spatial database to model the real-world road network. This is then used to reallocate the waste bins based on the bin's location and proximity to the waste sources with larger but fewer bins for the vehicle to collect from, and an optimal route was mapped out. The study recommends further study into the sector of a wider collection area and using separate collection schemes for different waste streams. Another GIS use is finding new FDS in places that do not have one, as it did for a town in Nigeria.

Implementing such a system in Indonesia's larger cities can provide noticeable savings per vehicle. Due to the diversity of vehicles and routes, an integrated system allows the different levels of waste collection to communicate and coordinate the available resources. This makes the system more adaptable by allowing for load balancing as cyclic loads change over time. The longer and more updated the GIS is implemented, the better the system can deploy the waste collection resources. Moreover, certain routes are more suited to different collection vehicles. Larger trucks are primarily for large trunk routes to FDS or in-between TPs, while the handcarts can be dispatched for shorter routes in dense neighborhoods.

The collection must also employ sorting at multiple points to make this system more robust. Sorting done near the source is the best point since the volume of SW increases as multiple waste streams converge at TPs. Biodegradable waste can be diverted to composting facilities, and recyclable materials can have their stream. In essence, cities' sectors must manage some of the waste and be self-sufficient in smaller areas. A Solid Waste Neighborhood Self-Management (SWNSM) study in Bogor emphasized the importance of a decentralized system to manage waste over a centralized solution that could fail. Another study in Jakarta shows the economic advantage of a localized, community-based composting program over four other SWM programs, including the traditional landfill method [23]. Although landfill is the most popular solution, the municipal solid waste management system is much better due to less environmental impact [33]. These autonomous communities can benefit from a system that can manage the waste they take in and the compost they output. While using compost within the community is generally advised, areas with greater or lesser compost requirements require some load balancing.

One technology that could be leveraged is a sensory network that provides direct feedback on the waste bin's capacity.

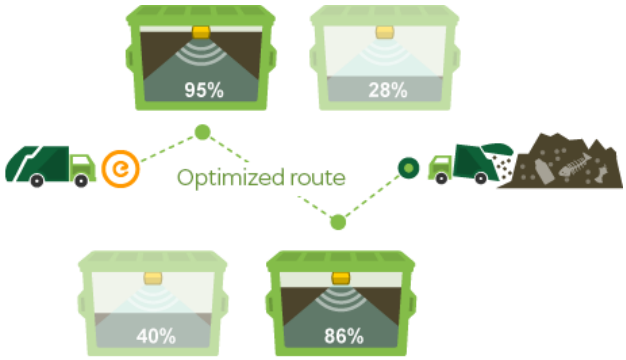

Fig. 6 Enevo's sensor can route collection to where it most needs it.

A Finnish company named Enevo has developed a device that monitors waste bins and a service to process and disseminate waste data known as ONE [33]. A system of sensors on key waste locations such as TPs can provide an autonomous method to gather this data to further or optimize routing and load balancing, improving response time. In conjunction with distributed SWM programs over a given city, this could provide data on the effects of these programs as it happens.

With data that can be gathered in close to real-time, these statistics can be made available to the public, helping to provide a window into the state of the city's waste management. This makes the public aware of the waste management process by showing something close to the city's waste-generating pulse. Putting waste generation at the forefront of the public consciousness can lead to more effective programs in waste management as people seek a cleaner environment. All the studies cited in this paper have similar messages: educating people on SWM and its effects is a step that must not be overlooked.

Eventually, there comes a need to create a multilevel distributed system for administrative purposes across a wider spectrum of the country's policymakers [34]. Local systems enforced with local policies can be tracked in their influence on the wider SWM of the country. The community above composting could be just one of many programs that contribute to the wider SWM, and that distributed system can

manage that contribution. When the solutions are already implemented, just like in Brazil, the Indonesian government needs to do a regular assessment that covers social, economic, and environment to see what action needs to be taken in the future [35]. The assessment results can be as the decision assessment support [36].

IV. Conclusion

In conclusion, an integrated system to manage waste in Indonesia can potentially manage and reduce the amount of waste. Many experts have tried brainstorming, gathered ideas, and searching for solutions. Many developing countries have used an autonomous sensor network to keep track of and manage their waste daily [33]. Indonesia is still used in the waste reduction, recycling, and final disposal method, which has been used in handling and processing waste in Bantar Gebang. However, one noticeable problem is that the government and citizens lacked awareness of handling the waste, including the cause and effect.

Moreover, the technology in Bantar Gebang was not updated in the past few years since the government lacked both budget, co-workers, and materials. One of the examples is that the production of trucks is still low, which is the reason for his lack of budget and attention to the [25]. A lot of the waste Jakarta disposes of goes to Bantar Gebang, yet the landfill has not been expanded, resulting in the waste being scattered around the area, including the residents becoming victims[37]. As a result, managing waste in Bantar Gebang is still not successful until now. The government can include waste pickers in the program to improve the socioeconomic aspect. Therefore, it will create jobs, cut costs, etc. [38]

If this problem continues, the waste will be uncontrolled soon to come. The solution that may reduce the increasing waste is by encouraging both governments and the citizen to be willing to handle the waste problem properly and warning them that it cannot be taken lightly and that if the waste is not taken care of the result will be dire. Regarding the lack of technology, the government should find a way to negotiate with other countries that Indonesia needs the support of vehicles and technologies. If it comes, the government and citizens should support deploying units capable of supporting the workers, such as the Enevo sensor [33]. Despite the costs, the government could build a foundation to support the spread of waste and manage what it can and will generate. The government also needs to keep advertising about waste management to every citizen with SMS because the phone user cannot deny the message, which makes waste management advertising more efficient [39].

Integrating multiple solutions and systems and having proper assessment tools to monitor will lead to better policy management and better strategies for the future [40]. Whatever the government solutions that will involve technology, it is highly recommended that the government start with the IT Blueprint before executing the plan to increase the higher rate of success of the project. It uses the IT Blueprint framework and follows the IT Blueprint flow to guide the government in executing the project. The five pillars of the IT Blueprint are crucial to be followed by anyone, not just the government if there is any technology-related project. The solutions for the waste management systems must be effective, affordable, and acceptable to all involved parties [41].

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