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Smart Planning of Waste Management System in Saudi Arabia; Challenges and Opportunities

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Abstract. Solid waste management is one of the most critical problems facing urban areas worldwide. It is quickly becoming a significant issue in emerging countries with high population growth. Waste collection is a time-consuming procedure requiring enormous sums of money and meticulous logistics management. The amount of household waste produced in Riyadh has fluctuated over the years, with the majority being dumped in landfills instead of using them. This inefficient method of waste disposal has several adverse financial and environmental consequences, as landfills take up a large area of the city and emit foul odors and infections. An innovative waste management system should be adopted to address these difficulties, beginning with waste reduction and trash disposal in modern engineered landfills. Waste management solutions include reducing, reusing, recycling, energy recovery, and disposal. This research will focus on recycling, recovery, and disposal since social awareness campaigns could implement the first two strategies to reduce and reuse waste. The analysis also gives a sufficient cost analysis for the proposed methodology. This study opens new avenues for incorporating the value recovery aspect into garbage collection planning and the use of new data capture technologies that allow municipalities to track the mix of recyclables contained in various trash systems.

1. Introduction

The waste generation production rate in Saudi Arabia is one of the highest rates in the world, and Riyadh has the highest rate of waste production in Saudi Arabia, which is more than 1.5 kg/day per person, and the total amount of waste arriving the landfills every day is approximately 13,300 tons [1]. So, when the term waste is heard, the first thought about it is the used things like plastic, glass, paper, and food which are mainly trash; people usually tend to throw them because they think they have no benefit, and they think this is the ideal solution, but on the other hand, waste can generate revenue. Most of the products' life cycle does not end in the landfill; most of the time, using this product could be the birth and the start of another product, which is what we call recycling. There are many types of waste utilization rather than recycling; this research will focus on recycling waste, recovery of waste, and utilization of modern engineered landfills.

We will analyse the literature to identify research gaps in waste collection problems in smart cities. Various heuristic and non-heuristic approaches for solving routing problems have been proposed in the transportation literature, to name a few research. [2] suggested an Ant Colony System algorithm-based dynamic model for capacitated vehicle routing challenges. [3] offered a heuristic solution for solid waste collection as a recurring truck routing problem. The collected waste can be transferred to some

intermediate facilities, and not all collection stations must be covered every day. [4] established a heuristic approach for assigning garbage collection zones and routings in Phuket Municipality, Thailand, and proposed a simulation framework for simulating the night shift solid waste collection. [5] developed a model for defining collection vehicle routing with an extended planning horizon for some zones to solve the periodic routing problem in municipal waste collection. Not all zones should be served in one planning horizon, and the planning horizon can be flexible depending on the needs of different regions. [6] developed a routing model that integrates several heuristics algorithms to minimize the number of collection vehicles and total route time while considering several factors and constraints such as multiple disposal facilities, different types of client's demand (e.g., residential, commercial, industrial), different time periods for demands, and different container sizes.

Several dynamic models and algorithms have been developed to help in garbage collection and recovery in the literature. [7] utilized metaheuristics and simulation to present a hybrid algorithm for trash management in clustered metropolitan areas, which considered the influence of cooperation among trucks departing from different depots and the resulting savings. For the case of waste collection in Morón, Argentina, [8] suggested an integer programming model to optimize the dynamic routs of collection vehicles. [9] introduced a memetic algorithm to achieve multi-objective optimization for determining the number of vehicles and trip times considering several constraints such as the time window of waste collection for each region, conflicts between waste characteristics, and the availability of multiple landfills to perform routing enforced with the conflict's context and time windows.

The objectives of this research are: To compare the traditional way of waste management system with the smart management system in Riyadh, to come up with smart solutions for sorting, collecting, transporting, treating, and landfilling, to show the potential opportunities and the positive financial impact for investing in the smart waste management system, and to illustrate the reduction of operational cost in all waste management phases especially collecting and transporting phases. This research will compare the traditional with smart system phases and show the new technology that can be implemented to enhance the system and discuss the advantages and the positive impact for each phase. The phases are separation (sorting), collecting, transporting, treating & recovery, disposal [10]. A case study will discuss the difference in cost between the traditional and the smart waste management system. Related to that case study, a recycling process will be examined for money generation.

2. Methodology
The research will analyse data through a quantitative approach and will be validated by triangulation. Interviews will be conducted with contractors and municipality representatives in the field of the waste management system. A questionnaire will be distributed to a sample of Riyadh's population from different levels to measure the awareness and their knowledge about recycling. A case study will compare the traditional waste management cost with the smart management cost after applying smart solutions in the system.

2.1. Separation
The journey of the waste usually starts from houses, and this is the source of waste with a production rate of 1.5 kg/person daily; all types of waste are thrown together in trash bags without any separation; after that, people place the trash bags in the trash bins which are located in the streets, the waste now is mixed, and the separation process after that will cost a lot of money in the separation plants, so to overcome this issue specially designed trash bins inside the home should be introduced to place each type of trash in its section, the bin sections are organic waste with green bag, plastic waste with a blue bag, glass waste with orang bag, paper waste with a brown bag.

These different bags could be thrown in separated municipality trash bins for easier separation in the separation plant, or they could be thrown together in the trash container and then separated through a special auto sorting machine which detects the color for each bag and then sorts them according to their colors. Another solution is by introducing a new technology for sorting the waste by its specific weight and transparency.
According to [11], as shown in figure 1, when the IR detects some type of substance being placed on the system tray, the system activates. The weight sensor is subsequently activated to determine the

weight of the waste, after which the metal and glass sensors begin their functions. A servo motor will place the trash in bin three if a metal sensor classifies the material as metal (which is dedicated to metals). If the glass sensor finds glass, the same action will be taken, and the trash will be placed in bin 4. The LASER and LDR are activated if both sensors fail to detect. If the LASER goes through the trash, it is classified as transparent and is redirected to bin 2. If the LASER fails, the item is classified as paper and is moved to Bin 1.
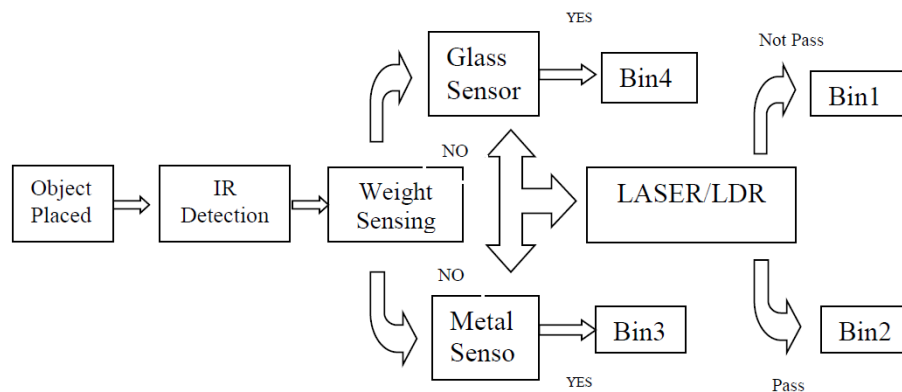

Figure 1: Process of Sorting [12]

2.2. Collection

2.2.1. Traditional. Waste in Riyadh is collected daily by following a designed route for waste collection in every neighborhood; this traditional way is time-consuming because the drivers have to pass by each trash bin every day, and it is also a cost consuming, a lot of the trash bins are not filled when they have been collected, but the drivers and cleaners have to stop and empty them.

2.2.2. Smart. New technology has been developed to install a leaser sensor inside each trash bin and container to measure the waste level inside the bins and containers and to decide whether to collect or not, this system is like a network system where it shows the locations of the bins and containers, and it also shows the remaining capacity for each one, this system is connected with the waste collection truck as shown in figure 2 and it designs a special route for waste collection based on the filled trash bins and containers so empty/ half-empty bins and containers will be excluded from the new route [13].
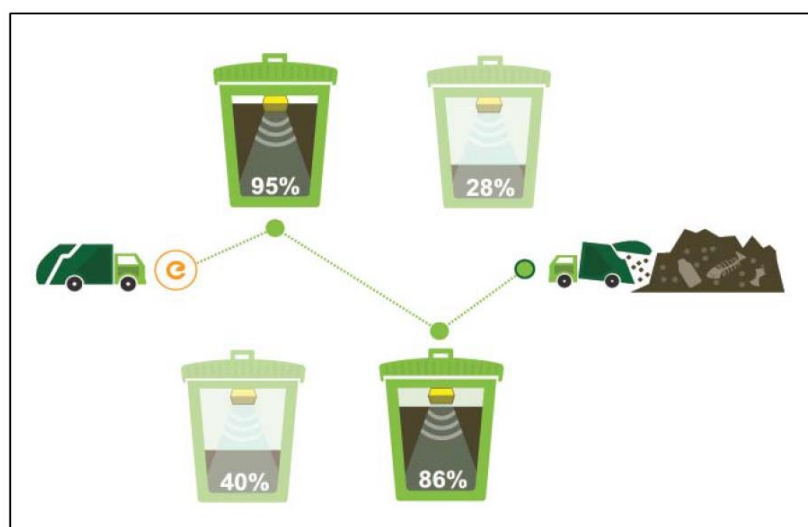

Figure 2: Leaser detector for waste level in bins [14]

Another solution for collecting the waste is by introducing a specially designed underground network for waste collection and storing in the collection station in the neighborhood, as shown in figure 3 and 4, where you can throw the trash inside a trash bin for each type of waste (organic, recyclable, etc.) connected to a network designed to transport the waste to the collection plant or station by using the air pressure, however, this solution could work better in the congested areas with a high rate of the population where there are a lot of high rise buildings because the production amount of waste is high where the area is relatively small compared to the population, the design of the waste collection network will be feasible, but in Riyadh, it will cost a lot because population rate compared to the neighborhood areas is relatively small.

Figure 3: Integrated waste collection system by Envac [15]

Figure 4: Integrated Collection System [16]

2.3. Transportation

The transportation phase is the journey of the waste from the trash bins to the treatment and recycling plants or to the landfills.

2.3.1. Traditional. This phase is combined with the previous phase, where the workers collect the waste and transport it directly to the landfills.

2.3.2. Smart. After using the smart solutions which are mentioned in the collecting phase, the transportation phase will be less complicated and less time-consuming, which will directly affect the

operational cost for transporting the waste either to the recycling plants or the landfills. One of the transportation solutions is by transporting the waste containers which are in the collection plant as shown in figure 5 in each neighborhood, each container is separately transported by its type; for example, recyclable materials container goes directly to the recycling plant, and non-recyclable materials containers go directly to the landfill or the incinerator [17].

Figure 5: Collection station in residential district by Envac company [18]

2.4. Treating and Recovery

2.4.1. Traditional. In Riyadh, almost about 6% of the waste is subjected to the incineration process, which generates a lot of green gases quantities like CO_2 gas and produces a bad odor; on the other hand, only 1% of Riyadh's waste is recycled.

2.4.2. Smart. According to the statistics of Riyadh's waste, almost 40% of the waste is recyclable, which is approximately 2,000,000 tons per year. These recyclable materials contain (glass, plastic, metals, papers, and textiles) with the following data: the average price of recycled aluminum is 1322 $ per ton. [19], the average price of recycled plastic PET is 333 $ per ton, the average price of recycled paper is 32 $ per ton, and the average price of recycled glass is between 85$ to 155$ per ton [20].

Nearly 51% of the waste in Riyadh is organic waste due to the high rate of food consumption; all the organic waste is disposed of in the landfills without getting any benefit of it; there are some ways of treating the organic waste: combustion where the organic waste and non-recyclable waste are combusted and incinerated to produce energy as shown in figure 6, and composting where the organic waste is converted to fertilizer to be used in the agricultural industry as shown in figure 7.
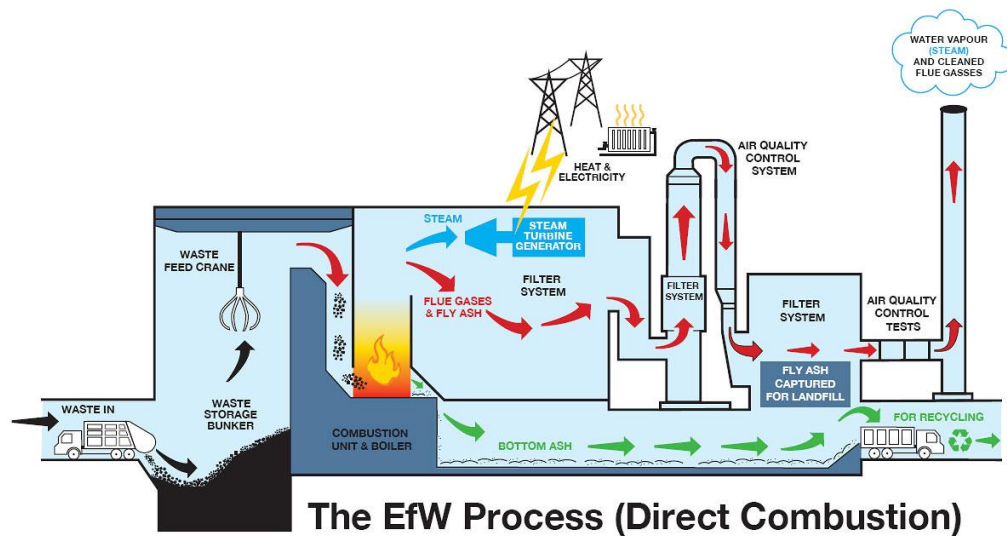
Figure 6: Combustion process of waste to produce energy [21]
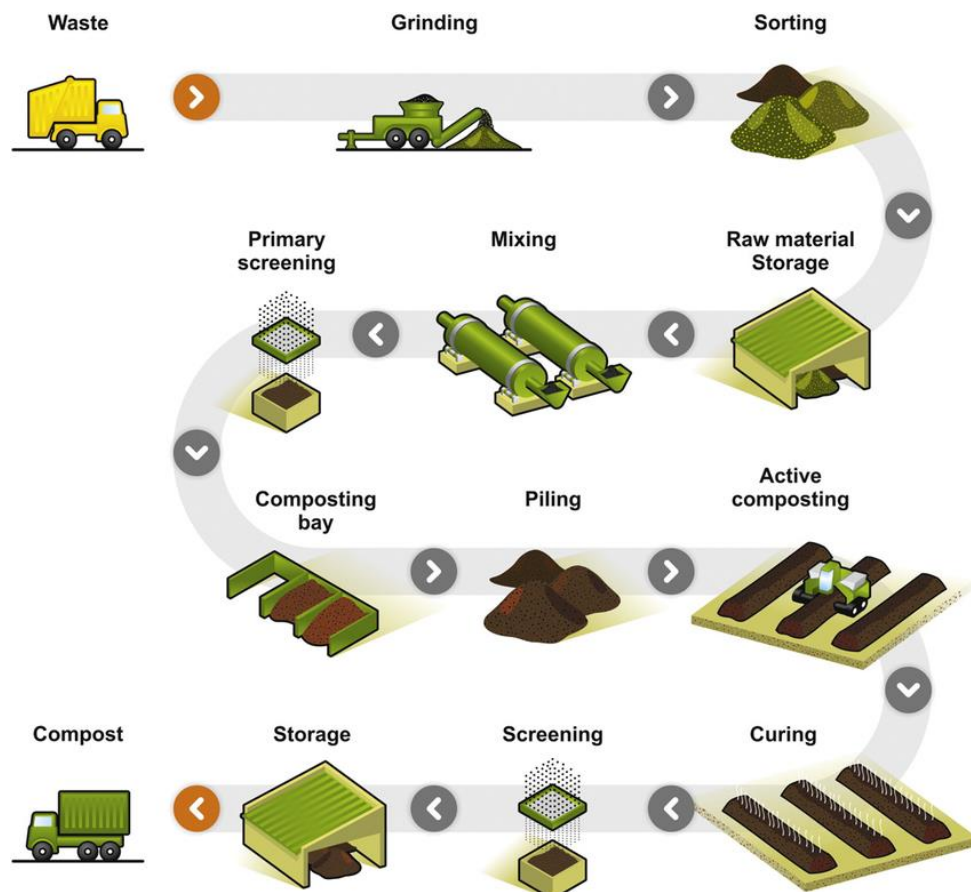
Figure 7: Composting process to produce fertilizers by soil farmer company [22]

2.5. Disposal

2.5.1. Traditional. Almost 93% of the waste in Riyadh is disposed of in landfills, which cover approximately 8,000,000 sqm of land area. This landfill receives daily more than 16,000 tons of waste. The waste is formed in cell shapes where it has a specific trapezoid cross-section (100m*3m) with almost 170m in length and a cover of 30cm between every cell [23]. This way of disposing of waste

generates some environmental problems like untreated leachate, which could penetrate through the soil layers to the groundwater and contaminate it since it has a very toxic impact, the gas (Methane) produced by the natural decomposing process of the organic waste generates the bad odor.

2.5.2. Smart. The concept of engineered landfills, such as shown in figure 8, has taken place in the waste management system recently, where these landfills focus on the environmental impact of the waste and how to reduce it, and on how to take advantage of the last phase of the waste management system, and this could be obtained from utilizing the gas which produced by the decomposition of the organic waste. The gas (Methane) is collected from the different layers of the landfills through a specially designed network of pipes that collect the gas and then transport it to the generators which work on gas to produce electricity [24]. These engineered landfills treat the leachate by collecting it from the bottom of the landfill then transporting it to a treatment plant to make sure it will not be mixed with the groundwater.
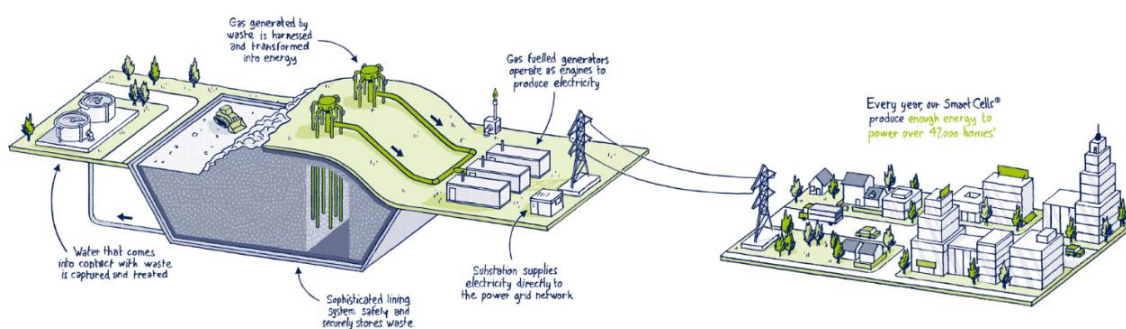

Figure 8: Engineered landfill to produce gas for energy and reduce environmental impact [25]

3. Evaluation Criteria

3.1. Cost of Implementation
The cost of implementing a solution depends upon several factors like availability of technology, the infrastructure required, skills necessary, etc. This is an important criterion before selecting any solution. The capital expenditure and operational expenses should make sense against the benefits to the finances and environment combined.

3.2. Time required for implementation
Few solutions are more time taking than others to implement. The solutions that take too long in the implementation stage normally defy the purpose—looking into the approximate time required for the selected solutions to be set in place.

3.3. Time and resources saving
The major outcome required from waste management solutions is the efficient usage of time and other resources. The solution that saves the most time will most likely be selected. Some solutions might not be practical due to high operational costs, unfavourable weather, imperfect technology, and many other reasons. Each solution will go under this criteria testing.

The following table 1 shows the analysis of proposed solutions for recycling waste tools in terms of cost, the time required, timesaving, and finally, the practicality of the solution implementation in the region.

Table 1. Solutions evaluation according to selected criteria

Solution	Cost	Time Required	Timesaving	Practicality

Pneumatic Chute	SAR 6,400 per dwelling capital expenditure SAR 280 per year per dwelling operational expenditure. [16]	Significant time Infrastructure development Underground tubing Detailed survey	Significant time saving Waste collected in the central collection area Can sort waste at source.	Easy to find experts Require some infrastructural work that can cause problems
Local Combustion Plant / Waste to Energy	2,460 SAR/ton [15]	Moderate time Civil work for construction Building, Furnace, Boiler room and Generators.	Significantly quick in getting rid of waste No change in waste collection	Easy to find experts It increases pollution, which can be a problem
Off-site Sorting	400 SAR/ton [16]	Moderate time	Great time saver Sorted waste easy for recycling, combusting or selling	Easy to implement, no complications
IoT Enabled Bins	750 SAR/unit Capital cost [17]	Quick to implement Major time in planning Bins are imported and placed	Significantly reduce collection time Smart routes help in collecting properly	The solution is extremely practical and very easy to implement.

To select and propose a scenario, it is helpful to sort each solution against the problems that need to be solved as shown in table 2; first, the pneumatic chute system reduces collection routes to almost 99%, bins are completely covered and can be underground, it provides more data than the current system, and material sorting is available on-site and off-site. Second, the IoT Enabled bins reduce collection routes by around 80%, bins are completely covered, it provides more data than the current system, and on-site sorting is available. Finally, to reach higher recycling ratings, off-site sorting plants will provide higher material sorting and processing success.

Table 2. Solutions against existing problems

Solution\Problem	Collections Routes	Exposed Bins	Data Collection	Material Sorting
Pneumatic Chute	✓	✓	✓	✓
Local Combustion Plant / Waste to Energy	✗	✗	✗	✗
Off-site Sorting	✓	✗	✗	✓
IoT Enabled Bins	✓	✓	✓	✓

After forming the required scenarios, an objective judgment is needed to select the best scenario as per table 3.

Table 3. Objective judgment for the best scenario in Riyadh

Scenario	Implementation time	Practicality	Benefit-Cost ratio	Sustainability Improvement

Pneumatic Chute System	High	Medium	Failed	Good
IoT Enabled Bins	Low	High	Passed	Good
IoT Enabled Bins + Off-site sorting plants	Medium	High	Passed	Better

After evaluating each solution and keeping in mind the issues faced by Riyadh, It is recommended to implement IoT Enabled Solution with Off-site Sorting if there is enough capital to invest; if not, it's recommended to implement IoT-enabled Bins then implementation of Off-site sorting plan in a later stage.

4. Case study

This case study will discuss the cost reduction if the smart collecting solutions were implemented and will show the amount of money that could be generated if waste recycling is utilized in Riyadh.

In Riyadh, there are around 1400 vehicles that collect waste daily; the annual contract for waste collection is 500,000,000 SR while the daily cost for one cycle per truck is 970 SR. Using special detectors in waste bins in Malaysia shows a reduction of 50% in the direct cost of waste collection and in South Korea by 43% [26], so if a 40% reduction in waste collection cost after implementing the smart monitoring system for waste bins is adopted, the cycle cost per each truck will be 582 SR/Day giving a total annual cost of 297,402,000 SR which is 40% lesser than the traditional way (500,000,000 SR).

Since Riyadh does not have a recycling experience, obtaining the specific percentage of recyclable material in each waste type will be difficult, so the United States environmental protection agency (EPA) statistics about the percentage of recycled material in each waste type can be adopted as a reference [27]; in plastic, if the recyclable amount of plastic is 9.5% then the Annual total amount of recyclable plastic in waste is 61,898 ton, and the average price for recycled plastic is 1250 SR/Ton giving an approximate total annual revenue of 77,372,500 SR. In the case of metal, if 3.1% of the metal waste is recyclable aluminium, then the Annual total amount of aluminium in waste is 5,592 tons, and the average price for recycled aluminium is 4,959 SR/Ton giving an approximate total annual revenue of 27,728,000 SR. By performing the same analysis on glass, if the recyclable amount of glass is 26%, then the Annual total amount of glass in waste is 49,236 tons, and the average price for recycled glass is 450 SR/Ton. This will give an approximate total annual revenue of recycled glass is 22,156,000 SR. On the other hand, If the recyclable number of mixed papers is 65%, then the Annual total amount of paper in waste is 423,510 tons, and the average price for recycled paper is 120 SR/Ton resulting in an approximate total annual revenue of recycled paper is 50,821,000 SR.

The approximate annual revenue after utilizing all the recyclable waste is 178,077,700 SR generated from waste.

5. Conclusion and challenges

Riyadh faces four major problems in its current waste management system which are: Collection routes, exposed bins, lack of data collection, and material sorting.

After researching previous success stories of cities like Barcelona, Philadelphia, New York, etc., several solutions were gathered, the solutions were evaluated in different aspects, and three scenarios were chosen: i. Pneumatic chute, ii. IoT enabled waste bins, and iii. IoT Enabled waste bins together with Off-site sorting plants.

The recommended scenario is to implement IoT Enabled Solution with Off-site Sorting if there is enough capital to invest; if not, it's recommended to implement IoT enabled Bins then implement of Off-site sorting plan in a later stage. However, it is important to note the challenges Riyadh might face in implementing these scenarios: the initial investment, infrastructure disruption, providing technological resources, and engaging the community.

The challenges facing the methodology implementation are:

1. The initial investment: Any system implemented country-wide or even in a major city will require millions of SAR investment. The project must be approved by the Ministry of Finance and be embedded in the year's budget.

2. The infrastructure: solutions like pneumatic chutes might require dismantling public or even private properties and infrastructure. Implementing in a developed city will require regroups planning and approvals before the start of actual work. It can pose some great challenges operationally. It can even disrupt traffic flows at a time.

3. The technological resources: to implement and maintain an IoT-based solution, training local resources for maintenance will be required. Investment in technology will be inevitable, and the cost of servers, networking, etc., will be high.

4. The community engagement: any system can fail if the community doesn't do its part. The masses must be educated to play their part in waste management as they are the source.

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