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Revolutionizing Integrated Solid Waste Management in Punjab, Pakistan

Amn Nasir, Sameer Anwar, Saim Rashid, and Muqueet Shahzad

Introduction

In Punjab, Pakistan, approximately 16.43 million tons of waste are generated each year.[1] As the population grows and urbanization increases, Pakistan, like most developing countries, must address the unavoidable challenge of managing increasing municipal solid waste (Foo 1997). The term "municipal solid waste" is used to describe waste generated from households, commercial areas, and institutional activities (Tchobanoglous and Keith 2002).[2] Solid Waste Management (SWM) refers to the aggregation, collection, packing, transport, storage, and final disposal of solid waste.

Outdated SWM systems can lead to myriad public health issues. Rainwater that passes through piles of waste dumped along roads, railway tracks, and canals can seep into the water table, contaminating drinking water (Asian Productivity Organization 2007). Moreover, illegal dumping of

Amn Nasir is a Master in Public Affairs student at the Woodrow Wilson School at Princeton. She can be reached at anasir@princeton.edu.

Sameer Anwar is project leader at Delivery Associates and works with the Government of Punjab, Pakistan and ihe Government of Albania. He can be reached at sameer.anwar@deliveryassociates.org

Saim Rashid is a former analyst at the Special Monitoring Unit of the Chief Minister's Office, Government of Punjab, Pakistan and has worked with government and private organizations to extract predictive and prescriptive insights.. He can be reached at saim.3d@gmail.com

Muqueet Shahzad works at the Special Monitoring Unit of the Chief Minister's Office, Government of Punjab, Pakistan. He can be reached at muqueet12@gmail.com.

waste creates breeding grounds for mosquitoes and leads to vector-borne diseases.

Various countries across the developed and developing world are now addressing this issue by adopting integrated solid waste management (ISWM) strategies, which entail "sustainable management of solid wastes covering all sources and all aspects, covering generation, segregation, transfer, sorting, treatment, recovery and disposal … with an emphasis on maximizing resource use efficiency" (International Environmental Technology Centre 2009, 3).

In recent years, the influx of low-cost technological devices has allowed the Punjab provincial government to implement Information and Communications Technology (ICT)-based interventions to improve SWM. For instance, a Chinese android phone used for marking sanitary worker attendance can cost as little as $150 USD, while a Global Positioning System (GPS) device can be utilized for tracking waste collection vehicles for under $300 USD per vehicle. More recently, Radio Frequency Identification (RFID) devices have been employed for characterization of waste and identification of waste collection resources, in order to generate granular data on waste collection (Rada, Ragazzi and Fedrizzi 2013) (Anagnostopoulos, et al. 2015).

This paper analyzes the impact of similar low-cost technologies in monitoring various parts of the SWM process and increasing the efficiency and quality of SWM. We present the results of retina scan-based attendance of field staff, GPS and RFID-based monitoring of waste collection trucks, and implementations of an android-based cleanliness scorecard in the seven largest cities in Pakistan's Punjab province.

Literature Review

As technology becomes more pervasive, many governments have begun to use e-governance mechanisms. Technological tools that increase the efficiency of monitoring, data collection, and the collection of citizen feedback improve public service delivery. Local governments, in particular, are using digital and mobile technologies such as tablets, smartphones, and sensors to "fundamentally change service delivery" in a range of city services (Greenberg 2015, 11). New York City, for example, has automated data analytics for its fire department, using an algorithm to determine buildings that are at highest risk of catching fire (Heaton 2015). Seattle uses online crime mapping to identify and respond to hotspots of crime through its "SeaStat" mapping tool (GCN 2014).

Developing countries are also using ICT to streamline city services.

Many cities in the Global South use technology for "easy information flow," which allows for "quicker and cheaper provision of goods and services, faster and better decision-making processes, and unplugged paper bottlenecks" (Ndou 2004, 10). In São Paulo, Brazil and Ahmedabad, India, computerized tracking provides a single platform for accessing multiple city services, such as vehicle registration and acquisition of drivers' licenses (Rinne et al. 2011; Bhatnagar and Singh 2010). In Khajane, India, computerization of treasuries ensures smoother and more transparent cash flows, reducing corruption (Bhatnagar and Singh 2010).

When it comes to municipal solid waste collection and management, tremendous potential exists to automate and streamline processes through the use of technology. Existing literature demonstrates that a range of technologies, such as geographic information systems (GIS) and RFID, have proven successful in improving municipal waste management.

Governments across the world also use geospatial analysis for policy implementation (Malczewski 1999). GIS allows users to combine spatial data with other quantitative and qualitative data on a certain locality. In Pondicherry, India and Lemnos, Greece, this technology has been used to select optimal landfill sites and minimize economic, environmental, health, and social costs (Sumathi, Natesan, and Sarkar 2008; Kontos, Komilis, and Halvadakis 2005; Siddiqui, Everett, and Vieux 1996). The same technology has also been used to reduce SWM fuel and transportation costs by determining the most cost-efficient routes for waste collection vehicles in India (Ghose, Dikshit, and Sharma 2006), Praia, Cape Verde (Tavares et al. 2009) and Pudong, China (Zhu et al. 2009).

RFID is also used across the developed world to automate processes in SWM. RFID chips use electromagnetic fields to automatically identify and track tags containing electronically stored information and attached to objects. This device can help identify, separate, and dispose of hazardous material and electronic waste in an environment friendly manner (Abdoli 2009). In Germany, RFID-enabled waste storage bins for households allow the collection vehicle to tag the household, weigh the bin, and charge the household accordingly (Case Studies: Botek 2003).

Integrating both GIS and RFID technologies can revolutionize solid waste management. Faccio et al. (2011) use a model that collects static inputs from waste collection bins attached with sensors and RFID combined with dynamic inputs from vehicles through their GIS systems in order to find out when waste collection bins have reached maximum capacity. Hannan et al. (2011) build a similar model, replacing the sensor with a camera on the vehicle to determine how filled a container is. Anagnostopoulos et al. (2015) use real-time data from St. Petersburg, Russia to demonstrate how an integrated model of sensor-enabled bins, tracked vehicles, and coordination with drivers via smartphones can help to serve the highest-priority areas.

While existing literature shows simulations and pilots of how technology can be used in integrated SWM systems, no study demonstrates the large-scale applicability of this technology for monitoring service delivery. We extend this body of literature by demonstrating the impact of ICT in monitoring each process within municipal SWM: inputs (such as workforce attendance and vehicle activity), outputs (in the form of total waste brought to dumpsites), and final outcomes (such as citizen satisfaction and street cleanliness). This use of ICT in monitoring creates greater accountability of on-the-ground staff and establishes feedback loops for managers. We use panel data from October 2016 to February 2018 to show trends in waste collection efficiency and street cleanliness as a result of rolling out these technological interventions in 698 Union Councils across 7 cities of Punjab, impacting approximately 16 million citizens.

Solid Waste Management in Punjab

Background

Punjab is Pakistan's most populous province with an estimated urban population of around 32 million (Bureau of Statistics, Punjab 2015) out of which more than 50 percent resides in 7 cities: Lahore, Faisalabad, Rawalpindi, Multan, Gujranwala, Sialkot, and Bahawalpur.

Historically, municipalities have maintained responsibility for waste management. Between 2011 and 2014, the waste management function of the municipalities in the seven largest cities in Punjab was transferred to newly formed and publicly run waste management companies (WMCs). The transfer included sanitary workers, waste collection vehicles, and allocated budgets (including staff salaries).

According to the Urban Unit, the amount of waste generated by each citizen of Punjab increases by 1.5 percent each year (Urban Unit 2012), which translates into 4.69 million tons of waste generated by these seven cities by 2020, as shown in Table 1.

Table 1: Projected yearly waste generation (in million tons) in seven cities of Punjab by 2020

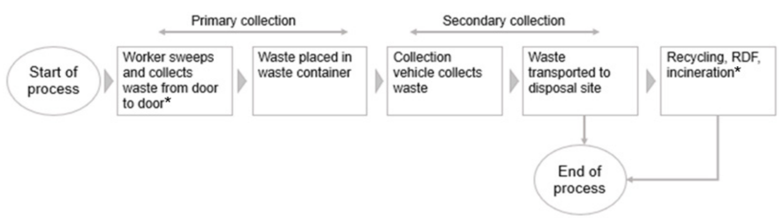
	2017	2018	2019	2020
Yearly waste generated in Punjab (million tons)	4.25	4.44	4.56	4.69

Source: Urban Unit (2012)

Solid Waste Management Process

The solid waste management process in WMCs in Punjab is divided into three sections: primary collection, secondary collection, and disposal, as shown in Figure 1.

Figure 1: Solid Waste Management process in Punjab. Asterisk denotes that the process may vary across cities.



Primary Collection

During primary waste collection, sanitary workers with brooms and handcarts sweep streets to collect solid waste at the start of the day. These workers are divided into groups of 10 to 30 and they report to sanitary supervisors. They are permanently assigned areas or beats which they cover every day. In some areas, door-to-door collection from houses is also carried out. Sanitary workers create piles that are transferred to strategically placed containers through the use of handcarts.

Secondary Collection

During secondary collection processes, routes are defined for waste collection vehicles (WCVs) to pick up waste from these containers. WCVs then transfer waste to disposal sites.

In larger cities like Lahore, Multan, Gujranwala, and Rawalpindi, temporary storage points (TSP) for waste are created within the city. The purpose of these points is to maximize the time WCVs spend collecting waste from containers and minimize the time transporting waste to disposal sites. WCVs collect waste and transfer it to one of the TSPs. Specific vehicles with large carrying capacities are used to transfer waste from the TSP to disposal sites.

Disposal

Disposal methods vary in the seven cities of Punjab. Lahore has a built-for-purpose landfill while the other six cities dispose of waste at temporary dumping sites. The exception is Multan city, which, in addition to its landfill sites, sells approximately 500 tons per day to a cement manufacturer for refuse-derived fuel.

Integrated Solid Waste Interventions

In November 2016, the chief minister of Punjab launched the Solid Waste Management roadmap. The theory of change that motivated this initiative was that monitoring waste management would create greater accountability of field staff, and allow service providers to solve problems, course-correct, and track progress towards pre-determined goals.

Prior to this roadmap, the waste collection process was riddled with inefficiencies. Anecdotal evidence was utilized for accountability with regards to sanitary workers. Their attendance was manually marked by supervisors and was often inflated due to collusion between sanitary workers and the supervisor.

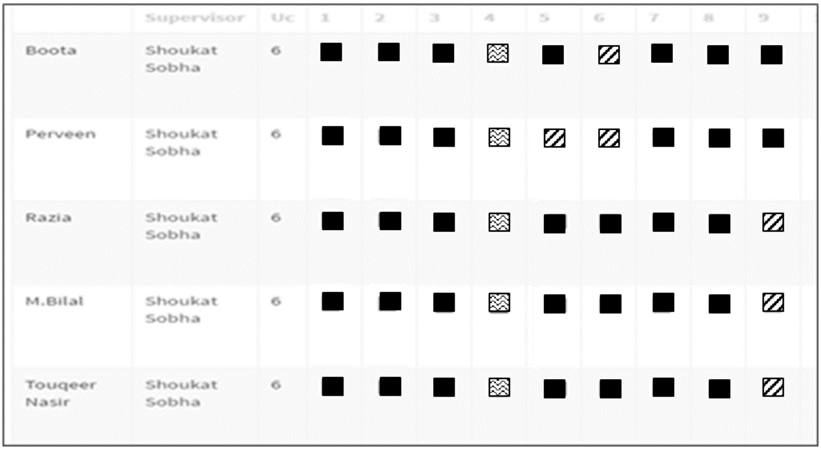
Secondary waste collection was also performing below targets due to fuel pilferage and vehicle inactivity. Fuel was allocated to each vehicle based on its traditional route and recorded manually. However, there was limited monitoring carried out to ensure that WCVs completed their routes every day. In addition, vehicle downtime in workshops was not monitored regularly. As a result, functional vehicles were often left sitting unused for long stretches of time.

To address these issues, the provincial government introduced technology-based interventions at each stage in the waste collection and disposal process, ensuring that inputs, outputs, and outcomes were accounted for. These interventions monitored a) worker attendance through android phones, b) vehicle activity through GPS trackers, c) waste collection through weighbridges, and d) street cleanliness and citizen perceptions by way of a scorecard.

a) Android Based Attendance

As part of monitoring worker attendance, the sanitary supervisor is given a low-cost android phone with an application developed to monitor workers' attendance using a hand-held retina scanner. Each morning the sanitary workers assemble at designated spots for attendance and the supervisor marks their attendance using the scanner. The time and geolocation of each entry are stored and sent wirelessly using general packet radio service to an online server. The collective entries from all six cities can be viewed on a dashboard (see Figure 2).

Figure 2: Dashboard displaying attendance of sanitary workers. Boxes with diagonal lines signify absence; solid boxes mean present; boxes with waves denote a holiday.



Android-based attendance reduces the chances for collusion between the workers and supervisors. For attendance to be marked, workers must be present at the assigned location at least twice a day (at the start and end of a shift). Secondly, attendance can only be taken during specific timeslots, as a time check is placed on the attendance application. This ensures that attendance is taken and operations begin at the assigned times.

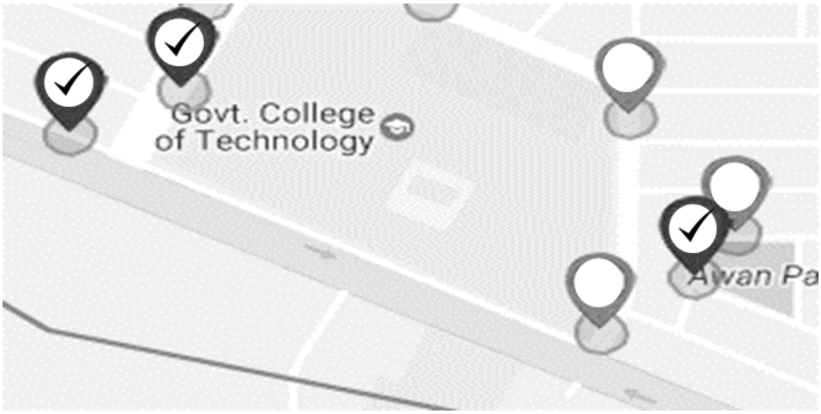
b) Vehicle Tracking

Vehicle tracking entails installing GPS devices or trackers on each WCV to monitor its route, speed, and other measurements. The route taken by the vehicle and the distances covered are recorded with the GPS trackers. As a result, vehicles that have not carried out trips throughout the week can be identified, and managers can stay abreast of vehicle downtimes. In Multan, the tracking data is triangulated with fuel issued to WCVs to limit fuel pilferage.

All waste containers have also been geotagged to monitor vehicle trips to each container. A polygon of radius 20 meters is drawn around each waste container (see Figure 3). A waste container is marked 'emptied' when a WCV has spent two minutes (the average time it takes for waste trucks to empty a container) within the polygon around the container. At the end of each week, the percentage of containers collected is calculated as follows:

$$Waste\ containers\ collected\ (\%) = \frac{Containers\ emptied}{Total\ waste\ containers}$$

Figure 3: Dashboard displaying container monitoring polygons. Tick marks signify that the container was emptied in a particular week while empty circles signify that the container was not emptied that week.



c) Weighbridges and RFID

A weighbridge is a weighing device used to monitor the weight of WCVs. The weight of the WCV transporting waste is taken, and the empty weight of the WCV is subtracted to calculate the net weight of the waste collected.

RFID systems are combined with the weighbridge to automate the waste measurement process. Electronic tags are placed on each vehicle and are read by RFID readers installed at weighbridge sites. Once the RFID reader reads the WCV tag, it automatically calculates the net weight without the need to enter the empty weight. A modification of this system is seen in cities with two sets of weighbridges, one for entry and another for exit. After filled vehicle weight is taken at entry, the weight of the empty vehicle is taken at the exit and the net weight is attributed to the waste collected by the vehicle.

The waste collection data collected from weighbridges is used to calculate the waste collection efficiency (WCE), which is calculated at the end of each month.

$$WCE = \frac{\sum Net\ weight\ of\ vehicle\ crossing\ weighbridge}{Waste\ generated\ per\ capita\ per\ day * Population * (n-2)}$$

where n = number of days in a month

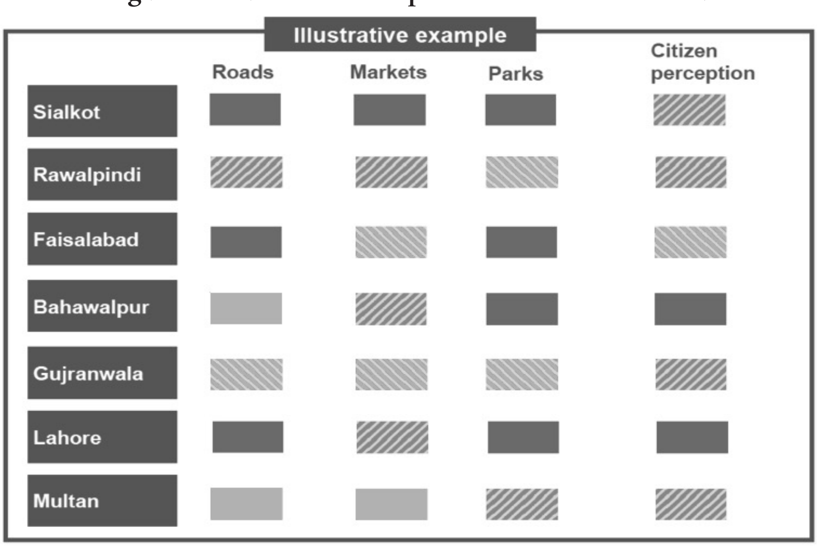
d) Street Cleanliness and Perception Scorecard

The focus of the roadmap has now shifted towards improving outcomes for citizens. For this purpose, a scorecard has been developed, to assess the cleanliness of cities and to determine how well changes in waste collection efficiency correspond to street cleanliness (Van Ryzin, Immerwahr, and Altman 2008; Srivastava 2015; Miami Beach 2009).

Independent Monitoring and Evaluation Assistants (MEAs), equipped with an android tablet and mobile data, visit nearly 9,200 public places identified in the seven cities each month. These MEAs determine the cities' cleanliness on a scale of 1 to 4, as illustrated in Figure 4. The MEAs also interview a representative sample of citizens in each city, in order to get monthly data on citizen perceptions of SWM and performance of WMCs.

WMCs can now compare their performance across union councils and across various types of locations, such as roads, tourist locations, and markets. This has bolstered the integrated solid waste management approach and enabled targeted, location-specific interventions.

Figure 4: Illustrative example of the SWM scorecard



Discussion

ICT-based interventions in solid waste management in Punjab have made service delivery more rigorous and have increased the accountability of staff in each tier of the waste collection process.

As part of the solid waste management roadmap, regular data has been collected and reported on input indicators such as primary workforce attendance and vehicle activity as well as the main output indicator, which is waste collection efficiency. While GIS data from trackers installed on waste collection trucks and weighbridge data from dumpsites was available from October 2016 (except for Lahore, where these interventions had been rolled out earlier), worker attendance monitoring faced several teething problems, ranging from data network issues to bugs in the android attendance application. Due to these issues, supervisor attendance (the percentage of supervisors using the system instead of worker attendance) was very low from October to mid-December (see Figure 5). Therefore, the worker attendance data from October to mid-December might not be reflective of the reality on the ground. A revamped attendance monitoring application was launched in mid-December 2016 with practical training for supervisors in each city and consequently, the supervisor attendance increased in the following months.

As per our theory of change, the monthly data from October 2016 to August 2017 shows that both the input and output indicators have improved over the period when the ICT-based monitoring interventions were rolled out.

Between January 2017 and February 2018, the number of field supervisors using smartphones to monitor daily attendance of primary workers in their jurisdiction increased by 35 percentage points, (Figure 5), as more supervisors became accustomed to the new technology. During the same period, the number of workers present each day increased from 55 percent to 74 percent (Figure 5) on average.

The availability of reliable data on worker attendance to middle-managers in the operations departments of waste management companies enables them to hold supervisors accountable and question them whenever they fail to report attendance or when specific workers are recurrently absent for long stretches of time. Similarly, managers can also hold secondary waste collection workers, such as truck drivers, accountable when vehicles are not travelling on designated routes. Consequently, this direct monitoring mechanism has increased the number of containers being visited by vehicles by 24 percentage points (Figure 7).

Figure 5: Supervisor attendance and worker attendance percentage (Oct 2016 to Feb 2018)

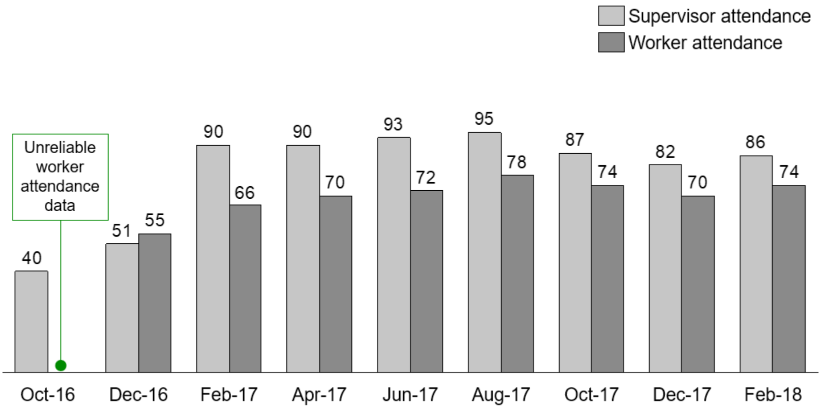


Figure 6: Vehicle Activity percentage (Oct '16 vs Feb '18)

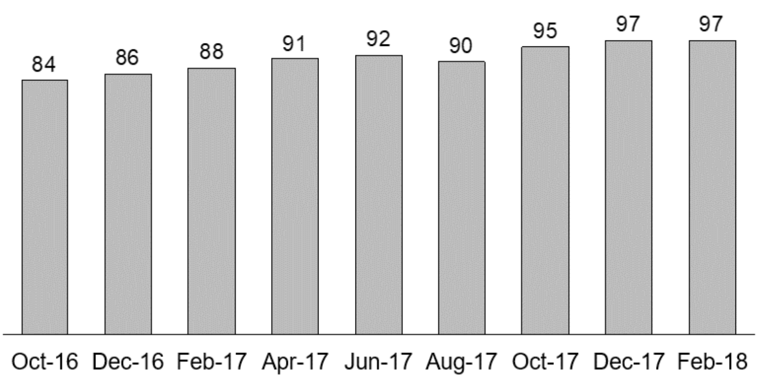
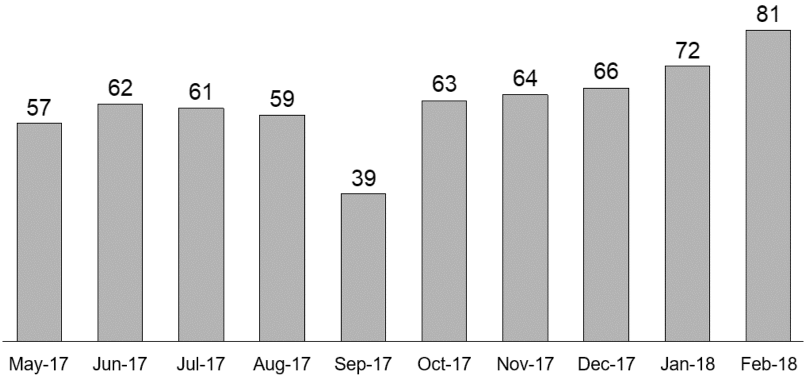
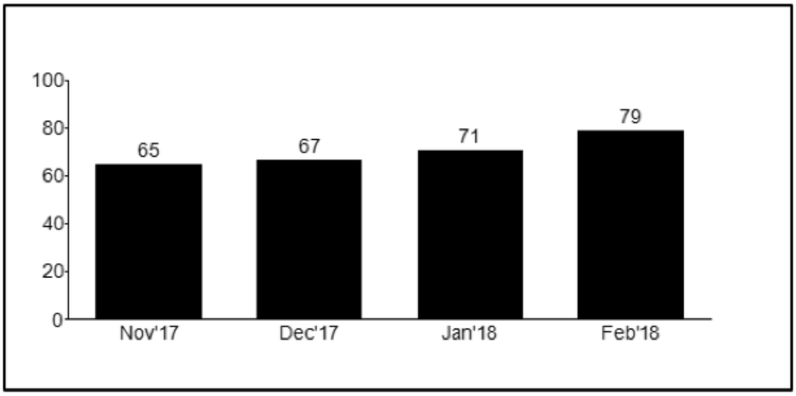


Figure 7: Trend in container collection efficiency (percentage)



Overall, improvements in inputs translated into improved street cleanliness. According to the newly launched scorecard, overall street cleanliness rose from 65 percent to 79 percent within four months of the launch. This increase can be attributed to the increased granularity with which SWM outcomes can now be monitored using the scorecard tool, since union-council level rankings are available.

Figure 8: Aggregated street cleanliness scores from November 2017 to February 2018



To understand the impact of these monitoring tools on the subjects being monitored, we held focus group discussions with 12 vehicle drivers from Lahore Waste Management Company to find that the new monitoring system had been seen in positive light by these ground-level users.

According to these drivers, the system has improved accountability and reduced opportunities for fuel theft by other drivers. In case of vehicle breakdowns, the tracking devices enable central control rooms to pinpoint vehicle location to dispatch repair teams in order to reduce downtime. This reduces the load on drivers who were previously solely responsible for transporting dysfunctional vehicles to workshops. There have been no reports of protests by drivers or sanitary workers after introduction of new monitoring systems.

While technology has helped waste management companies improve their overall performance, there is a limit to which these interventions alone can change outcomes. Issues related to human resources are one of the key challenges in improving primary waste collection. WMCs have little control over their workers' performance management. The services and asset management agreement signed by the WMCs with municipalities only allows the WMCs to utilize the sanitary workers, who remain the employees of municipalities. The companies' management do not have firing power, which still lie with the municipalities. As a result, it is difficult to hold workers accountable even when they underperform.

WMCs are administrated by a board of directors (BoD) comprising of political representatives, government officers, and technical personnel. The Chief Minister himself sanctions the constitution of BoDs. In February 2017, BoDs of all WMCs were dissolved and delays in their reconstitution exacerbated human resource and procurement issues. In the absence of a board, procurement of equipment of vehicles and hiring of essential staff were stalled. In Gujranwala, for instance, the contracts of 900 primary workers and vehicle drivers expired in March and could not be renewed. The workers' strike that ensued led to a reduction in worker attendance, from 94.5 percent in February to 81.5 percent in March. There was further drop in attendance to 70.3 percent in April because the Management Information System manager, who monitors worker attendance via a dashboard, resigned, which shows that regular monitoring is effective in ensuring good performance.

Moreover, other exogenous factors can cause fluctuations in indicators and cannot be mitigated through use of technology. Between March and April 2017, there was a reduction in supervisor compliance (-4.7 percentage points) and worker attendance (-0.6 percentage points), which can largely be attributed to Easter, when a large proportion of Christian staff was absent.

Despite the limitations of technology, the improvements in WMC performance that have been driven by the application of ICT have translated into improved perceived outcomes for citizens. According to the citizen perception surveys across the seven cities, 63 percent of the respondents in the first survey were satisfied by the work done by WMCs, which rose by 4 percentage points in the following four months. The proportion of citizens who are aware of the WMCs' services or have engaged with these companies in some way has also increased since the monthly perception surveys began, as can be seen in the figure below.

Figure 9: Citizen Perception Survey Results

	Nov 2017, %	*Feb 2018, %*	*Change in Perception, pp*
Satisfaction	63	67	▲ 4
Awareness	55	61	▲ 6
Engagement	4	19	▲ 15

Conclusion and Next Steps

Successful and efficient SWM requires regular monitoring of both inputs and outputs to track progress. This paper demonstrates how low-cost ICT solutions can be used on a large scale to collect and report real-time data on a municipal SWM system in a developing country. According to our results, using technological tools for monitoring has made data collection on inputs such as worker attendance and vehicle activity more reliable and transparent. In turn, this not only improves performance management of workers, but also helps improve outputs in the form of increased waste collection efficiency.

However, this paper also demonstrates that technology alone is not a silver-bullet solution for all issues in SWM in a context such as Punjab. Management issues including strikes by sanitary workers, bureaucratic hurdles in hiring and procurement, and a lack of landfill sites result in WMCs performing below their potential. Since WMCs currently depend upon supplementary government funding through annual grants, the sustainability of these interventions poses yet an additional concern. Long term funding mechanism should be formalized into the province's Annual Development Program.

Notes

[1] Estimated using average generation figures of 0.45kg/capita from "*What a Waste*" report published by World Bank (2012).

[2] This does not include waste generated from construction, demolition, agricultural, or industrial activities.

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