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# Ergonomics and human factors in waste collection: analysis and suggestions for the door-to-door method

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**Abstract:** Waste collection work is associated with a variety of physical, chemical, and biological hazards. The risk of fatal occupation injuries of waste collectors is higher than in general industry. Despite being a relatively small sector in terms of employment, the fatal injury rate in waste collection is significant. This paper shows a detailed analysis of the door-to-door waste collection system in the historic center of an Italian city. Waste collection in urban areas is characterized by high number of small waste containers that need to be tipped into the waste collection vehicle. The aim is to identify risk factors for work-related musculoskeletal disorders (WMSDs) in waste collection and to provide recommendations for reducing the risk of WMSDs to waste collectors.

The analysis of the waste management strategy, the process characteristics and workers' behavior are described, together with several proposals to improve the ergonomics of the waste collection activity and the safety of waste collectors.

*Keywords:* Waste collection, door-to-door, manual material handling, human factors, ergonomics.

## 1. INTRODUCTION AND BACKGROUND

Waste collection is the first part of the process of waste management, in which the waste is transferred from the point of disposal to the point of treatment. Municipal solid waste (MSW) collection is an essential task for city authorities and it causes 5–25% of public authorities' expenditures (McLeod & Cherrett 2011). Citizens and companies separate MSW by type, e.g. food waste, green waste and recyclable materials (paper, glass, plastics, metals, etc.). MSW management is often performed with different modalities, depending on the agreement between municipality and waste collection companies. There are different collection systems, e.g. kerbside bins, containers, pneumatic systems and door-to-door. Specifically, door to door refers to the collection system where citizens place domestic waste on the street in personal containers. Using a door-to-door system, all domestic fractions can be collected from the street or only specific fractions. Door-to-door systems allow higher results in terms of amount collected and quality of separation (Agència de Residus de Catalunya & Generalitat de Catalunya 2017).

Previous studies have demonstrated that the kerbside system is better from an environmental point of view (Mora et al. 2013) and it allows critical benefits for global human wealth. Unfortunately, such collection system is also characterized by a higher number of manual activities required to waste collectors. Indeed, following a defined collection round, waste collectors reach each kerbside collection box and collect waste into the collection vehicle. This activity requires manual material handling (MMH) of loads, as lifting, lowering, pushing and pulling of collection boxes, bins, bags and carts. The weight of such containers is variable, depending on the type of waste, the container features, the collection frequency, the time of year and other variable factors. Such characteristics impact on the workers' exposure to the risk of MMH of waste containers and on the risk of developing work-related musculoskeletal disorders (WMSDs).

The UK Health and Safety Executive (HSE) reports that the number of MSW workers fatally injured at work in the last year has more than doubled in comparison to 2015/16 (Slow Elisabeth 2017). Figure 1 shows that the annual average fatal injury rate of waste and recycling, over the last five years, is around 9 times as high as the construction industry rate. A common non-fatal injury affecting MSW workers is the ankle sprain while getting off the waste collection vehicle. Other common injuries are fractures, ocular trauma, and bites (Dorevitch & Marder 2001). A research published by the Washington State's Department of Labor and Industries stated that WMSDs account for 41 percent of the cost of workers' compensation claims (Silverstein et al. 2005). The same research showed that waste management industry caused 769,989 lost work days from 1994 to 2002 and $147,302,364 in claims costs. The choice of the waste collection system is strategic as waste collection causes up to the 75% of the total MSW management costs (Sonesson 2000). Selective collection achieved in municipalities by means of door-to-door systems leads to higher results in terms of collected amount of waste and quality of separation. The implementation of door-to-door collection is simpler in areas with lower population density, compared with high-density areas where it is not easy to recognize individuals' waste. A recent study has compared pneumatic and door-to-door collection systems. The results show that the economic

performance of a vehicle-operated door-to-door waste collection system is stronger than a pneumatic system (Teerioja et al. 2012).

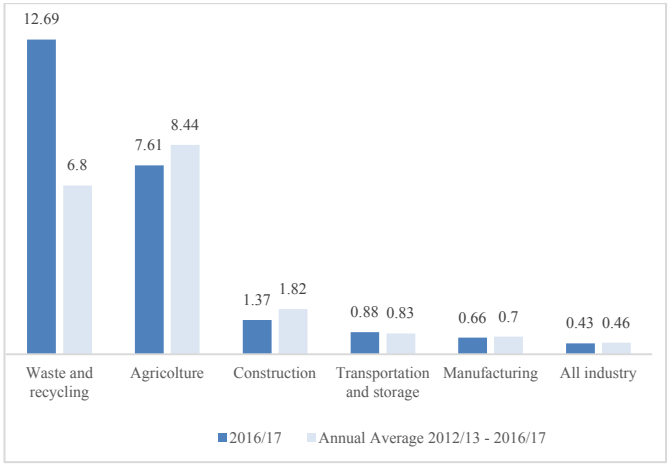



Figure 1. Rate of injuries by industry in UK, 2016/17 and annual average for 2012/13 – 2016/17 (Safety Executive 2017).

Furthermore, the greenhouse gas emissions of pneumatic collection are three times higher than the values retrieved with the door-to-door system (Mora et al. 2013). The University of Central Florida has developed a comprehensive ergonomics study of waste collection tasks of three different types of collection including manual, semi-automated and automated. The study reports an environmental analysis of potential alternative fuel technologies for waste collection vehicles. Results show that manual waste collectors are exposed to severe occupational injuries due to lifting, heavy load handling, repetition and awkward postures (Mccauley Bush et al. 2012).

In 2006, the UK Health and Safety Laboratory (HSL) has conducted an investigation into the risks for WMSDs to waste/recycling collectors engaged in door-to-door. The aim was to provide authoritative guidance on control measures to limit risk within existing systems (Oxley et al. 2006). The HSL has provided recommendations to waste collection employers and employees for safe manual material handling of MSW containers, regardless the type of waste. In 2014, an Italian study on the ergonomics of the waste collection activity has investigated the correlation between ergonomic risk factors for WMSDs and the characteristics of waste collection vehicles (Attaianese & Duca 2008). The aim was to identify possible improvements in the design of collection vehicles and equipment. The study compared the collection vehicle features (e.g. platforms dimensions and height, handles, feet supports, etc.) and the anthropometric measures of waste collectors. Results showed that collection operators are forced to assume awkward postures of legs, back, arms and other articular segments because of the poor design characteristics of waste collection vehicles.

This paper shows the results of a detailed investigation of the door-to-door collection system, with focus on waste collectors engaged in door-to-door collection of organic waste in a historic centre of an Italian city. Waste collection in urban areas is characterized by high number of small waste containers that need to be tipped into the waste collection vehicle. The aim of this work is to analyze the ergo-quality level of a specific door to door waste collection process with the final purpose to provide indications to managers on how they can minimize operators fatigue in order to finally maximize the overall quality and productivity of the process (Battini et al. 2011; Botti, Ferrari, et al. 2017; Botti, Mora, et al. 2017).

The following Section 2 describes the door-to-door system, showing the waste containers features and the characteristics of the waste collection scheme of an Italian waste collection company. Section 3 introduces the ergonomic risk assessment of waste collectors in the reference case study. Finally, Section 4 and Section 5 describe the results and provide suggestions for reducing the risk of WMSDs to waste collectors.

## 2. THE DOOR-TO-DOOR COLLECTION SCHEME

The door-to-door collection scheme is operated by a waste management organisation. The scheme includes the collection of different types of waste: paper, plastics, glass and cans, organic (or wet) waste, grass clippings and residual refuse. Residents collect waste in different types of containers, depending on the waste typology. The municipality or the local company responsible for the management of the services related to the environment provides the kerbside containers to each family unit. Residents are asked to keep different materials separate in the containers. The waste management organisation collects the containers on a weekly or bi-weekly basis, depending on the waste typology and the time of year. This collection method requires crewmembers to lift or push the containers at the kerbside to the waste collection vehicle. The number of people in the crew depends on the waste typology, e.g. either a single or two-person crew typically mans the recycling rounds of organic waste, while a three-person crew is necessary for the collection of grass clippings. In case of single-person crew, the waste operators will drive the collection vehicle and collect the waste containers. In the two and three-person crews, one crewmember will typically drive and the other one or two collect. Such numbers may vary during the year, as in winter when residents produce less waste and the amount of waste containers at the kerbside is lower.

The door-to-door collection scheme analysed in this paper refers to the collection of organic waste operated by an Italian waste management company. The company is responsible for the collection of organic waste of different residential areas. Organic waste containers are collected on a bi-weekly basis. Each residential area is characterized by a recycling round. Specifically, 14 crews man 28 recycling rounds. One crew drives one recycling round per day, and the same crew is responsible for one to three different recycling rounds. Residents collect organic waste in a 25-litre capacity bin (see the following Table 1).

**Table 1. Dimensions of the waste containers**

| | *Volume [l]* | *Height [cm]* | *Average weight [kg/container]* | *Average number of containers per recycling round* |
|---|---|---|---|---|

| | | | | *[units]* |
|---|---|---|---|---|
| *Bin* | 25 litre capacity bin with handle | 43 cm | 7.94 kg | 812 (569 actual)<br>90% |

Bins are the 90% of the total waste containers handled by waste collectors during the day. The actual number of kerbside containers is about the 70% of the total containers provided to residents. The waste collector lifts each bin, transferring the waste inside a truck container attached to the collection vehicle. When the truck container is full, the automatic lifter on the vehicle overturns the waste into the hopper. Section 3 introduces the ergonomic analysis of the waste collection activity in the reference case study. Specifically, the study includes the ergonomic risk assessment of manual activities as lifting and pushing the waste containers, together with the posture analysis for waste collectors.

## 3. ERGONOMICS STUDY

Waste collection is a physically demanding task that is associated with multiple occupational and musculoskeletal disorders. Several risk factors and working conditions affect the health and the safety of waste collector. Frequent lifting of heavy loads, high repetitive tasks, long work duration and insufficient recovery are significant risk factors that may result in chronic injuries and diseases. In addition to the musculoskeletal risks, working outdoors may cause other occupational disorders due to weather conditions (e.g. extremely hot in summer and cold in winter), air and noise pollution, and traffic (Mccauley Bush et al. 2012). This Section describes the characteristics of the door-to-door collection scheme for waste collectors in the reference waste management organisation. The ergonomics study focuses on the workers of the single-person crew. Data presented in this paper refer to urban waste collection in the historic center of an Italian city, in summer. Waste collector activity consists of two main tasks: kerbside collection and driving the vehicle to the landfill. The first task requires the workers to drive the waste collection vehicle to the kerbside bins and tip waste containers into the vehicle hopper. This task is performed for about the 70% of the total time of MMH. One third of such 70% is necessary to drive the vehicle from bin to bin. The second task is performed for the remaining time. Waste collectors start the first recycling round early in the morning, at about 5 am. The work-shift finishes at about 11.30 am. Two breaks of 15 minutes each are possible in the morning. Furthermore, workers stop collecting waste for about 50 minutes to reach the landfill and unload the vehicle hopper once a day (twice in summer, from May to July). The average time of MMH is about 260 minutes per day.

### *3.1. Manual lifting and lowering of waste containers*

The ergonomics risk assessment in this study includes the NIOSH Lifting Equation, developed by the National Institute for Occupational Safety and Health (NIOSH), to assess the risks associated with lifting and lowering the waste containers (Waters 1993). The following Table 2 shows the input data of the reference case study.


Figure 2. Two-handed tip into the bin.

**Table 2. Characteristics of waste collection in an Italian urban area in summer. Average values of 28 recycling rounds.**

| Work-shift length [min/day] | Breaks [min/day] | Time required to unload the vehicle [min/day] | Effective time of bin collection [min/day] |
|---|---|---|---|
| 389.79 | 30 | 100 | 259.79 |
| Bin weight [kg] | Bins per day | Lifting frequency [lifts/min] | Total waste collected [kg/day] |
| 8.43 | 569.21 | 2.12 | 7,023.85 |

Table 3 shows the resulting NIOSH Lifting Index (LI) for each recycling round at the origin of the lifting task (lifting the bin from the floor) and at the destination (tipping the bin type 1 into the bin type 2). The colour green indicates the low risk range, yellow indicates moderate risk range, red indicates the high-risk range and purple indicates the highest risk range. Table 3 confirms the presence of the ergonomic risk for waste collectors, i.e. the NIOSH LI is higher than 1 in several recycling rounds.

**Table 3. NIOSH LI for each risk range at the origin (lifting the bin from the floor) and at the destination (tipping the bin type 1 into the bin type 2).**

| | NIOSH LI Origin (n. of RR) | % | NIOSH LI Destination (n. of RR) | % |
|---|---|---|---|---|
| Green | 12 | 43% | 0 | 0% |
| Yellow | 11 | 39% | 0 | 0% |
| Red | 5 | 18% | 13 | 46% |
| Purple | 0 | 0% | 15 | 54% |
| Total | 28 | 100% | 28.00 | 100% |

Specifically, the most critical values of the NIOSH LI are at the destination of the movement, when the workers overturn the contents of bin type 1 into bin type 2. The main risk factor is due to the horizontal distance between the hand and

the body of the worker (55 cm), i.e. collectors keep the load far from the body while tipping the bin, aiming to avoid squirts and splashes. The vertical distance of the hands from the ground (140 cm) when tipping the bin is critical, i.e. waste collectors lift the arms almost at the shoulder level. This factor impacts on the vertical dislocation and on the final risk index. Lifting frequency is a further risk factor that has high impact on the resulting NIOSH LI. Finally, trunk twisting and bad coupling contribute to increase the exposure of waste collectors to the risk of lifting and lowering of loads. The analysis of the postures of waste collectors is the object of the following Section 3.2.

*3.2 Postural assessment*

This section introduces the postural assessment for waste collectors. Specifically, the postural risk for back, legs, neck and upper limbs has been evaluated by means of the Timing Assessment Computerized Strategy (TACOs) (Colombini, Daniela; Occhipinti 2017) and the OCcupational Repetitive Actions (OCRA) Checklist (Occhipinti & Colombini 1996; Occhipinti 1998). In order to measure with precision the human body postures during the door to door waste collection activity under analysis, the authors applied the innovative full-body motion capture system (made up by a suit and a software) traditionally used for the real-time ergonomics evaluations in industrial environments as described in Battini et al, 2014. This system permits to analyze body movements when all parts of the body are interested during the activities execution. The system is based on inertial sensors with integrated compensation of magnetic interference and long wireless connection that permit its use in several kinds of industrial applications. When the motion capture suit is worn by the operator it is able to collect and show in real time a large set of full-body motion data, that can be used then to calculate the body posture parameters and the relative percentages required in several postural assessment approaches like the Ovako Working posture Analysing System (OWAS), OCRA and TACOs. In this specific work, the data related to the body movements have been collected by using the motion capture system in a testing environment able to reflect the real case in which bins are located closed to each other on both sides of a city center street. The testing environment was setup in an historical city center street by positioning 6 bins, 3 on the right side and 3 in the other side, 8 meters distant each other with the collection truck placed in the barycenter point. The collection of the 6 bins that represents a minimum cycle of task has been repeated for 30 times by the same operator by wearing the motion capture system and during each repetition the software was able to automatically record the full body postures with a frequency of 60 instant detections per second. The data have been then normalized respect to a mean cycle time duration of 133.3 seconds that means 8,000 instant detections per cycle. Finally, the following normalized results have been obtained and the average values are reported in Table 4. The results of the postural assessment are in Table 5. The risk scores for each articular segment identify the corresponding risk range. The colour green indicates the low risk range, yellow indicates some risk range, orange indicates the moderate risk range (not present for the OCRA Checklist), red indicates the high risk range and purple indicates the highest risk range.

**Table 4. Time fractions of different back postures during kerbside collection (the time spent driving the vehicle from bin to bin is not included).**

| | < 20° | 20° - 30° | 30° - 60° | > 60° |
|---|---|---|---|---|
| Back flexion | 84.63% | 3.14% | 6.76% | 5.47% |
| Back twisting | 36.11% | 11.56% | 51.75% | 0.58% |

The results of the postural assessment in Table 5 show high exposure to postural risk factors for the back in standing posture.

**Table 5. Results of the postural assessment with OCRA Checklist and TACOs tool.**

| | OCRA Checklist | TACOs Tool | Risk range |
|---|---|---|---|
| Left hand | 5.99 | - | Green |
| Right hand | 7.32 | - | Green |
| Neck/ Head | - | 0 | No risk |
| Back – sitting posture | - | 1.5 | Yellow |
| Back – standing posture | - | 6.3 | Red |
| Lower limbs | - | 1.5 | Yellow |

Specifically, some risk is present for the legs and the back in sitting posture. Finally, no postural risk is present for the head and the neck. Section 5 shows the discussion of the results, providing suggestions for the improvement of ergonomics in waste collection.

## 4. DISCUSSION

The results of the ergonomics study in Section 3 show that waste collectors are exposed to the risk of developing WMSDs, mainly affecting the back and the lower limbs. Such risk could become higher for lifting activity when waste collectors tip the waste containers into the collection vehicle. Furthermore, the postural assessment has revealed a high exposure to postural risk factors for the back in standing posture. These results suggest critical areas of improvement that waste collection managers should address to improve waste collectors' health and safety. The main risk factor of waste containers lifting is due to the horizontal distance between the hand and the body of the worker, i.e. collectors keep the load far from the body while tipping the bin, aiming to avoid squirts and splashes. Trunk twisting (> 30° at the destination) and bad coupling contribute to increase the exposure of waste collectors to the risk of lifting and lowering of loads. Such risk factors may be reduced by providing proper training to MSW workers. Waste collection managers should train workers to lift the containers keeping the loads in front position and close to the body (25 cm). Finally, waste collectors should be informed about the risk of improper waste container lifting. A further critical risk factor

is the vertical distance of the hands from the ground when tipping the bin. Waste collectors lift the arms almost at the shoulder level (140 cm) to tip the waste containers into the wheeled bin attached to the vehicle. This factor has high impact on the resulting NIOSH LI. The adoption of a lower wheeled bin would reduce the vertical distance of the hands from the ground at the destination of the lifting movement. The vertical dislocation would reduce as well. These adjustments do not require strong efforts and high redesign costs. However, the impact on the NIOSH LI results would be critical (see in Table 6).

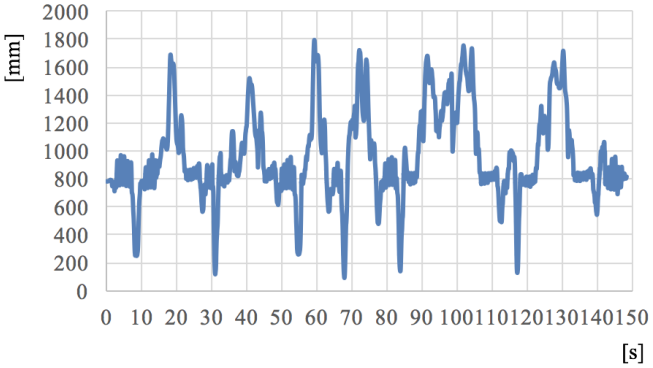
**Table 6. NIOSH LI for each risk range at the origin (lifting the bin from the floor) and at the destination (tipping the bin type 1 into the bin type 2) in the improved scenario.**

| | NIOSH LI Origin (n. of RR) | % | NIOSH LI Destination (n. of RR) | % |
|---|---|---|---|---|
| Green | 25 | 89% | 24 | 86% |
| Yellow | 1 | 4% | 2 | 7% |
| Red | 2 | 7% | 2 | 7% |
| Purple | 0 | 0% | 0 | 0% |
| Total | 28 | 100% | 28.00 | 100% |

Table 6 shows the resulting NIOSH Lifting Index (LI) in the improved scenario, for each recycling round at the origin of the lifting task (lifting the bin from the floor) and at the destination (tipping the bin into the truck container). The results in Table 6 show that minor adjustments would significantly improve the ergonomics of the investigated activity. Specifically, a limited number of recycling rounds would expose the workers to high ergonomic risk due to lifting activity. Such risk could be additional reduced by lowering the lifting frequency of waste collectors and ensuring proper recovery during the work-shift. Such corrections would positively impact on the results of the postural assessment, as well. The results of this study suggest some indications to managers/executives in order to reduce the risk levels shown before:

- Carefully train operators by explaining them a correct working procedure in order to avoid incorrect movements and person-dependent working approaches that can drive to person-dependent risk levels;
- Increase the collection frequency of the bins during the week only in the most critical months;
- Use job rotation in the most critical months adding a second worker to single-person crews;
- Use Waste kind rotation in the most critical months aiming to schedule recycling rounds that allow workers to alternate the type of waste to retrieve;
- Improve the waste collection process by using a different truck container with a lower height in order to permit to the operators to reduce the fatigue during the unload of the waste bin into the truck container. Figure 3 shows that with a shorter truck container it is possible to reduce the hand lift and as a consequence reduce the necessity to rotate and extend the back during this task. As a consequence, the fatigue is reduced and also the cycle time to unload 6 bins is reduced (B) respect to the current situation (A).

A. Truck container height from the ground: 120 cm (Hands 140 cm from the ground)




B. Truck container height from the ground: 100 mm (Hands 120 cm from the ground)

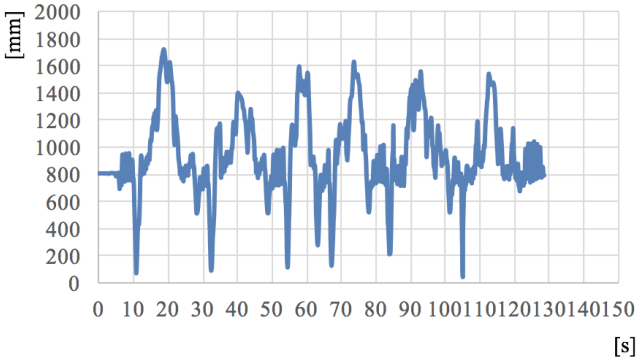



Figure 3. Effect of different bins on the cycle time.

## 5. CONCLUSIONS

Waste collection in urban areas is characterized by high number of small waste containers, e.g. collection boxes, bins and bags, that need to be tipped into the waste collection vehicle. The weight of such containers is variable, depending on the type of waste, the container features, the collection frequency, the time of year and other variable factors. Such characteristics impact on the workers' exposure to the risk of MMH of waste containers and on the risk of developing work-related musculoskeletal disorders. This paper has introduced the results of an investigation on the door-to-door collection system, with focus on waste collectors engaged in door-to-door collection of recyclables in the historic center of an Italian city. The ergonomics study has revealed very high risk due to MMH, when waste collectors tip the waste containers into the collection vehicle. The postural assessment has revealed very high exposure to postural risk factors for the back in standing posture. These results suggest critical areas of improvement. Specifically, workers should lift the bins keeping the load close to the body and avoiding awkward postures, e.g. torsions and other postures that require the operator to move away from the neutral posture toward the extremes in range of motion. Equipment and technology adopted in waste collection should be improved, i.e. waste containers in urban areas are small. Furthermore, workers assume flexed posture with the back when retrieving the kerbside bins, while tipping the bins

on the vehicle requires lifting the arms to shoulder height. The adoption of a shorter truck container on the collection vehicle may reduce the vertical distance of the hands from the ground and the overall dislocation of the lifting task. Finally, the analysis of different recycling rounds has revealed that some urban areas are characterized by higher waste container density. Consequently, the lifting frequency has high impact on the NIOSH LI of such areas. Such risk factor may be reduced by scheduling recycling rounds that allow workers to switch from high-density urban areas to low-density urban areas. These adjustments do not require strong efforts and high redesign costs. However, the adoption of lower wheeled bin would require additional stops to tip the containers into the vehicle hopper. Furthermore, the redesign of recycling rounds and the switch to different urban areas during the day may affect the productivity of the waste collection scheme. Future developments of this study will investigate the effects of such factors on the performances of the waste collection strategy. Finally, this study was limited to the analysis of organic waste collection in urban areas. Waste collection strategies deal with several types of MSW, e.g. green waste and recyclable materials (paper, glass, plastics, metals, etc.), which are collected in different types of waste container. The redesign of recycling rounds will be investigated, including the possibility to allow the same crew to retrieve different types of recyclables.

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