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Overview and possible approach to street sweeping criticalities

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Abstract

In order to highlight the complexity in planning street sweeping in urban areas, an example is given based on the collection of the number of passages of sweeping vehicles during an observation period of one year. Data refer to a district of a European city whose street sweeping service was kept under monitoring with the aid of a software tracking sweeping vehicles and other operational parameters. The monitoring campaign pointed out the issues occurring during sweeping operations and the available margins of improvements. Two methodologies for optimization were proposed: a theoretical-analytical approach based on the attribution of weights to street characteristics and a hybrid approach, initially based on a previous experience in an urban area and later refined with the continuous analysis of data collected during sweeping operations. The present article shows that the second approach is the easier to adopt and allows for a flexible calibration of sweeping operations.

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1. Introduction

Among waste management services, street sweeping plays the key role of safeguarding the high quality of life and the environment of a city, as demonstrated by the importance given to this service by methodologies developed in the last decades to evaluate street cleanliness and waste management services [1–4].

An Irish study [5] determined that the main causes of litter production are the presence of moving pedestrians (36%), shops (12.5%), moving vehicles (12%) and hangout spots (12.5%). The remaining contribution is given by banks and ATMs, entertainment locations, schools, fast foods, bus stops and other undefined causes. Quantifying the share of organic and inorganic litter is challenging, since such a value may change from city to city. During Autumn, a huge increase in the amount of waste with organic origin is determined by the foliage of deciduous trees, whose presence in urban areas may vary greatly depending on the climate and the environmental choices of the local administrations.

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The removal of street waste (including dust from tire and bitumen wear) entails a double beneficial effect: a reduction in the resuspension of dust in the atmosphere, caused by the turbulence generated by the movement of vehicles, and a reduction in the dispersion of microplastics in the environment (especially stormwater) [6–8]. According to [9], up to 43% of the operators, if unprotected, may develop allergies due to occupational exposure to resuspended dust.

Automated sweeping methods consist in the use of sweeping machines, driven by operators, and equipped with gutter brushes, whose performance may vary depending on dust particle size, sweeping mode and brush shapes [10,11]. Sweeping machines may also perform street washing.

The strategic management of street sweeping should be based on an annual scheduling of the sweeping interventions. Establishing the number of annual passages along each street and coordinating the routes are the main challenges for this service. The total number of passages would be different for each street, since the characteristic features of the streets lead to different litter production and therefore different needs in terms of sweeping.

In order to have a quantitative vision of the role of street sweeping, we can refer to the case of an Italian region: according to a recent report included in the waste management plan of an Italian province [12], street sweeping contributes to 3% of the total municipal solid waste (MSW) generated. In this territory, the majority of this specific waste stream (88%) is sent to recycling facilities, while the remaining part is landfilled. In the same territory, 67% of the total MSW produced is recycled, and about 4% of the recycled waste comes from street sweeping. In this frame, an enhanced system of MSW management must consider an optimized street sweeping service.

Italy has recently drafted a scheme of decree concerning the non-hazardous inert components of the waste collected by street sweeping, as requested from the European Commission [13]. The proposed regulation defines the criteria to determine the end-of-waste status of such component and declare the absence of risk for the environment and human health. This scheme of decree testifies the strong interest in this matter, since attributing the end-of-waste status to such components would bring several environmental benefits: (i) an impulse to recycling and a reduction in the amount of waste sent to landfills, in line with the targets of the European Commission for 2035, which impose a limit (10%) to the share of MSW that can be sent to landfills [14]; (ii) a lower use of natural resources; (iii) a possible reduction in the tariff for waste management paid by citizens; (iv) a reduction in the carbon footprint of the supply chain of construction materials.

According to [15], the average operational cost involved in street sweeping in Italy is about 41 €/t of litter collected. The inert material obtained from the process can be sold for revenue for about 3 €/t [16]. Such plants allow maximizing the recovery of waste from sweeping, thereby reducing the amount of waste sent to landfills and enhancing the recycling of waste as raw material for a second use. In Italy the operational costs for street sweeping and washing are not negligible: in 2014 the costs of street sweeping resulted as 12.6% the total operational costs for MSW management [17], despite the production of litter was only 3%–5% of the total urban waste production. The same report estimated the *per-capita* annual cost for this service: 23.50 €.

Although there is an increasing interest in environmental issues and in the cleanliness of public areas, and despite the relevant capital investments in street sweeping, there is a lack of publications on this topic, especially considering clear criteria of optimization. The present article aims at improving the available literature on this field, discussing the issues involved in planning street sweeping interventions and proposing possible solutions to mitigate the current issues, especially related to the selection of the frequency of sweeping operations (an unoptimized frequency has impacts also on the energy consumption of the activity).

2. Materials and methods

The present study considers a district of a town located in the north of Italy. The selected town has a high availability of digitalized data. The residential population in the analyzed district is 19,245 (16% of the whole city population) in an area representing 4.4% the extension of the whole municipality [18]. The movements of the vehicles used for street sweeping were recorded and analyzed. This was possible because the vehicles are equipped with GPS systems, which allow tracking the position of the whole fleet constantly. The present paper considers a one-year cycle of sweeping operations in the reference district. Details on the year of reference and on the area analyzed were omitted to preserve the anonymity of the operators.

The Company that operates street sweeping uses the Mawis u2.0 software developed by MOBA Mobile Automation [19]. This software samples the position of all the Company's vehicles with GPS with a frequency of

1 min. Mawis u2.0 also saves the vehicle speed, the distance traveled and the activity of the brushes. The collected data allowed obtaining the total number of sweeping operations.

The methodology proposed in the present considers a comparison between a theoretical approach and a hybrid empirical-theoretical approach. The theoretical approach is based on the collection of a large number of data (with surveys and mapping services) to create maps of litter production and select the best type of sweeping interventions. The hybrid approach combines the automated collection of data through mapping services with the operators' experience.

Both approaches have in common the use of tools like Mawis u2.0. The collected data allow creating tables with the streets interested by the sweeping operations for 48-h time intervals. A simple scheme was developed to count the sweeping passages: (i) each complete passage is flagged with the value "1"; (ii) whenever the operation is not completed in the 48 h examined, the value "0.5" is used; (iii) whenever 6 days are needed to complete the sweeping operations, the value "0.33" is used. This procedure allowed considering only the streets that were totally cleaned, avoiding erroneous counts of partial sweeping. The "0.5" value does not necessarily imply that the streets need four days (96 h) to be cleaned: for instance, weekends or holidays may extend the timeframe needed to complete the operations. The same reasoning applies to the "0.33" values. Once the complete table was available for each street, it is possible to calculate the sum of the values entered and obtain the total number of sweeping operations.

Tools like Mawis u2.0 play a key role in optimizing the routes and passages of sweeping activities and, thus, in reducing the energy consumption of this service. This would bring both economic and environmental benefits (e.g., lower costs for waste management companies and citizens, lower emissions of air pollutants and greenhouse gases, lower noise pollution, etc.).

3. Results and discussion

3.1. Results of the survey on the reference district

Fig. 1 reports a graphical representation of the frequency distribution of sweeping operations during the one-year period considered. Different colors describe the frequencies of passage of the sweeping vehicles with the brushes active. Thanks to this representation, it is possible to notice that three streets show a particularly high frequency. The reason for this can be the presence of a hospital nearby, attracting a relatively high number of people. However, this representation shows other parts of the city with a high frequency of sweeping operations that is not so easily justifiable. As an example, one street, located in a non-residential area with a few buildings, shows 16 sweeping passages during the reference year. The total number of passages in the period analyzed was 503, with an average of 7.7 sweeping operations per year per street and a 3.0 standard deviation.

The choice of the ideal access route that connects the sweeping vehicle station to the district is usually provided by GIS services available online. Since sweeping vehicles are particularly slow, the preferred route is usually the shortest one. For the district under consideration in the present paper, it is possible to identify four points of access/exit and one for exit only (Fig. 1). This is due to the presence of one-way streets in the area.

Table 1 shows different percentages for the routes of access to and exit from the district suggested by online GIS services. It is thus possible to make a comparison with the frequency of vehicle passages along each street. The easiest way is to consider only the streets directly connected with the access/exiting points and sum up the number of annual transits of the sweeping vehicles.

Table 1. Percentage of use of the access and exit points of the reference district.

	Access/Exit point I	Access/Exit point II	Access/Exit point III	Access/Exit point IV	Access/Exit point V
To the district	26%	26%	28%	14%	6%
From the district	17%	2%	69%	12%	0%
Round trip	22%	14%	48%	13%	3%

To balance the theoretical approach on the actual case, it is necessary to weigh the percentage already shown with the real frequency of transits calculated during the period analyzed. This methodology is not perfect because each street subject to sweeping is associated with one correspondent access and exit from the district, but it is possible that some streets were cleaned in multiple days, therefore with multiple accesses and exits form the district. However,

Fig. 1. Map of sweeping frequency during one year of observation and entering/exiting points.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

this eventuality is very small. We can consider this method sufficiently accurate for the comparison with real data. Fig. 2 shows a good correspondence between the paths chosen by drivers and the optimal routes. Probably, if the drivers were informed on the best access and exiting point of the district, the wasted time and kilometers driven could be reduced. This kind of comparison, even if simple, is able to highlight potential important issues to address.

3.2. Key parameters influencing litter production

For each street, it is possible to compare the needs for sweeping with the expected accumulation rate of the litter. The factors that influence litter formation can be classified as direct production factors, accumulation factors and prevention factors.

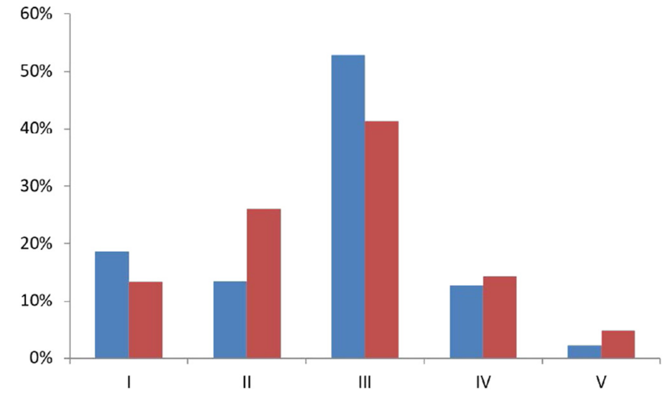

Fig. 2. Comparison between the optimal conditions (blue) and the real cases (red) of the five access routes of the district for the observed period.. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Direct production factors are all the possible causes for the production of litter. As previously mentioned, one significant element is represented by the accumulation of leaves in Autumn. Therefore, the presence of deciduous trees is an important aspect to take into account when programming sweeping operations. Information on the presence and location of deciduous trees can be obtained simply by making an inventory street by street. However, there is often the chance that trees located in private areas contribute to the production of leaves on the public ground. Another approach makes use of satellite imagery or aerial photography to speed up the process. However, satellite imagery or aerial photography cannot provide details on the tree species. Indeed, some species may produce a higher number of flowers and leaves than others, and this may influence litter production.

Another important information is the presence of unpaved roads. This type of streets is a typical source of dust and mud. Information on the presence of unpaved roads can be easily obtained with the use of satellite imagery, aerial photography or simple surveys.

Other factors contributing to the direct production of litter are attributable to the presence of population living in the districts. All the factors that determine the movement of people should be considered. The density of population in a street is the prime aspect that explains the potential movement of people along the streets. Population density can be obtained by the periodical census made by the national or regional governments. However, population density data are usually provided for large areas (e.g., districts or parts of districts) and no specific information can be obtained for single streets. One way to obtain street-specific data is to query a database of the consumers of gas, water and electricity, which local utility companies may make available upon request.

The presence of public buildings and business buildings is with no doubt an element of attraction for the population. Some streets with a high number of commercial and public buildings should be considered of great importance and therefore may require additional sweeping operations. Information on the presence of public buildings in an area or a street can be obtained by consulting phone books or internet maps services. In some cases, databases of water distribution or other services make a distinction in the service contract between private and business/public users.

Bus stops are responsible for a high density of pedestrians. Even bus stops equipped with waste bins are important areas for litter production, due to the potential dispersion of waste from the bins [20]. Bus stops can be easily located by consulting the websites of the local transportation companies. The presence of sidewalks is also an index of pedestrian activity, like the main communication routes. Like other factors, the presence and location of sidewalks can be checked through indirect (aerial photography or satellite imagery) or direct (on-field inspections) surveys. The main communication routes can be identified by analyzing the traffic conditions along the streets of an urban area of interest. An easy way to do this is to consult online search engines offering map visualization and the feature to display traffic conditions. Additional factors that deserve attention are events like fairs, conventions and markets. However, they should not be considered as a constant necessity due to their temporarily or periodical character.

Besides the primary factor (production), accumulation factors are also important to predict the formation of litter on the ground. Meteorological conditions, like wind and rain, contribute to the development of litter and dust in specific places. Underpasses are typical urban locations where the protection from wind and rain creates perfect conditions for litter formation, even if no particular production source is present. Underpasses can be easily identified on cartography maps. Parking lots are places that favor the accumulation and retention of litter, due to the presence of cars parked that provide protection for litter heaps. Knowing which streets host parking lots is also important to define which kind of sweeping intervention the company in charge should implement and possibly impose temporary parking restrictions. Direct or indirect surveys can help identify parking lots on the streets of interest.

To estimate the production of litter, prevention factors are crucial too. Prevention factors are elements or characteristics of the streets that may reduce the production and accumulation of litter on the ground. For instance, waste bins or information plaques with messages that promote the respect for the environment are elements that help prevent the litter production. The position of waste bins in an urban area is usually known to the waste management company in charge for the emptying operations and should not require on-field surveys.

3.3. Parameters examination and discussion

All the factors discussed above can be used to create a map of the litter expected on the ground. In addition, other characteristics of a street, like length, width and number of lanes, would help plan the type of sweeping interventions for each situation. For example, if sidewalks were present, the interventions need the support of a worker who pushes the litter toward the sweeping machine with a blower or a broom.

Ideally, all street parameters allow estimating the specific needs of each street in terms of sweeping. Therefore, it could be possible to plan the optimal sweeping frequency in a whole year. By attributing a weight value to each street characteristic, it could be possible to derive an equation producing a scalar value representing the sweeping frequency (K) needed in the year for a specific street:

$$\begin{bmatrix} Width \\ Treshcan \\ Underpass \\ Busstop \\ Streetconfiguration \\ Sidewalk \\ Tree \\ Publicbuilding \\ Populationdensity \\ Parkingspot \end{bmatrix}^T \cdot \begin{bmatrix} x_{width} \\ x_{treshcan} \\ x_{underpass} \\ x_{busstop} \\ x_{streetconfiguraion} \\ x_{sidewalk} \\ x_{tree} \\ x_{publicbuilding} \\ x_{populationdensity} \\ x_{parkingspot} \end{bmatrix} = K \tag{1}$$

where the row vector contains the values of the i parameters considered and the column vector contains the weights (x_i) chosen for each parameter.

The resulting frequency value could be adjusted if additional sweeping operations are requested in particular streets of interest. This approach would imply some difficulties, since the selection of the weight values is critical. Weight values are supposed to be constant for different streets of the same city. To identify a single weight value, it would be necessary to isolate the influence of that specific characteristic on the litter production over time. This could be done by selecting two almost identical streets, differing only in one parameter. However, a methodology like this would be extremely time consuming: to estimate the influence of a parameter on the litter production, at least a period of one year of observation would be necessary, since factors like tourist affluence and the presence of deciduous trees produce variable effects during the year. At the same time, finding two streets almost identical except for one parameter is not an easy task and may not be possible everywhere. In addition, the weight selection operation should be carried out for each parameter, which complicates the matter. A further element of complication is the occurrence of unpredictable events generating fluctuation in the litter production. Finally, some parameters need a very rigorous definition: for instance, defining the number of deciduous trees is not cumbersome, but trees with different size and canopy produce different quantity of leaves. Thus, this theoretical-analytical approach may result as inapplicable for the many intrinsic issues of this methodology.

Besides sweeping frequency, for an optimal planning of the sweeping service, the company in charge should have a clear idea of the distribution of sweeping operations during the year. Indeed, the information on the annual number of sweeping operations in a street is not sufficient: litter production is not uniform in time and different cities have different fluctuations of litter production determined by tourist fluxes and seasonal waste. A more realistic approach should establish the sweeping frequency and distribution based on previous experiences and adjust these parameters during the course of the year.

A way to create a database of litter production may consist in weighing the load of sweeping vehicles at the end of each shift. The value of total mass of litter collected on a single street in a reference period, divided by the area of the street considered, gives the specific production of litter of that street. This value could be used to compare different streets and determine the optimal sweeping frequency to consider. Such methodology requires a continuous collection of data that would allow optimizing the frequency and type of sweeping interventions.

This second approach would require the sweeping machines to be equipped with an internal scale for real-time mass measurements of the collected litter. The measuring system should also consider the driver's and fuel weight to record the litter mass only. A potential problem concerns the overestimation of the litter mass when the sweeping operations are scheduled after or during the rainy days. A possible solution to this issue consists in comparing the total mass recorded by the scaling system of the sweeping machine with mass measurements performed on the litter after drying the collected waste. The dry mass collected on a street could be estimated multiplying the mass of wet litter by the dry-to-wet ratio of the total mass collected during the journey. However, this approach would require a drying system and entails the strong assumption that the litter composition is the same on every street.

4. Conclusions

Street sweeping reveals as crucial in waste management for multiple reasons: it guarantees the cleanliness of urban areas and the preservation of tourist attractions, it allows reducing the phenomenon of particulate resuspension from roads and the pollutant load to stormwater and, if considered as a part of integrated waste management, it allows for material recycling and resource efficiency and several related environmental benefits. Street sweeping operations, however, must be planned strategically, also considering the costs involved in this waste management sector. The present paper showed the level of complexity in programming and evaluating sweeping operations in an urban area. Two approaches to estimate the optimal sweeping frequency of a street were proposed and discussed: a theoretical-analytical approach and a practical one. The discussion on the first approach showed that the application of this methodology in the real world is not viable. Real situations are so complex that this approach could be applied only in a hypothetical world, due to the high amount of data needed and the uncertainties in the weight attribution procedure. A practical and hybrid approach, initially based on the working experience in this field and later refined with the continuous analysis of the data collected during sweeping operations, might be the key to optimize this service. Additional efforts are necessary to bring this hybrid methodology at a mature stage: specifically, future research should focus on making this transition phase as shorter as possible, due to the undoubted economic and environmental benefits that could be achieved with the optimization of the sweeping service by waste management companies. The latter should invest time and resources to create a complete database of the initial situation in urban areas, allowing for a faster application of the monitoring technique described in the present paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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