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ProSFeT Project

Promoting **S**ustainable **F**r**e**ight **T**ransport in Urban Contexts:
Policy and Decision-Making Approaches

Deliverable 2.2 – Work Package 2

*A report about practical implementation
of decision support systems
for freight transport planning in real-world contexts*

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Introduction

This report forms part of the deliverables for Work Package 2 (WP2) of the ProSFeT project. The objective is to provide a summative overview of some preliminary findings from empirical work which was developed as part of the project on Decision Support Systems (DSS) being employed in the field of Sustainable Urban Logistics.

Urban logistics remains inherently complex with conflicting objectives and externalities for different stakeholders. The literature suggests that most urban authorities still struggle to balance multi-stakeholder objectives and this often places limitations on the effectiveness of policy and operational outcomes (Ballantyne and Lindholm, 2014).

Decision support systems (DSS) can offer mechanisms and metrics that can provide useful basis for informed decision-making at an organisational level. They rely on an extensive use of operational research and data analytics techniques in order to predict and create scenario outcomes that can ease the decision-making process, provide comparisons of alternative courses of action and optimise a variety of objectives.

Although potentially positively impacting, the adoption, on a systematic basis, of Decision Support Systems in urban logistics practice has been limited, so far, by a variety of reasons. Indeed, despite an increasing number of advanced models and powerful algorithms presented in the literature for optimising Urban Logistics, planning-oriented Decision Support Systems (DSSs) are seldom considered by private and public agents as software tools to be adopted for practical purposes. This is partly due to the fact that these models and methods rarely incorporate a multi-stakeholder perspective in their analysis, often resulting in centralised and hierarchical decision-making procedures that might be of little help in contexts where a more participatory approach is required. However, advancements in the scientific and technological development of DSSs, designed and implemented in strict cooperation with potential beneficiaries such as local authorities, transport planners and private sector logistics operators, have the potential to increase the adoption of innovative model-driven DSS approaches in real-world urban logistics.

The ProSFeT project is contributing towards addressing this challenge by evolving multi-stakeholder constructs to support the development of DSS tools that support transferability and integration across the European region.

In the previously published Report 2.1, an overview of the current literature in this field was provided. Such review started from the building blocks of DSSs, such as: the adaptation of classical logistical decision-making problems to the urban context; the development of key performance indicators for evaluating logistical systems within multi-criteria decision-making frameworks; the promotion of integrated decision support tools for advancing the practical application of approaches developed in the academic literature to everyday scenarios.

Building upon gaps identified in Report 2.1, this work highlights some practical work undertaken for aiding local authorities in implementing sustainable urban logistics (SUL) initiatives through the development of Decision Support Systems. In particular, the following practical cases are reported. Sgalambro et al. illustrate the development of a Decision Support System, based on the combination of Mathematical Programming models and Geographic Information Systems, for dealing with freight transport issues associated with the waste management cycle in the Sheffield City Council area (UK). Similarly, Sgalambro et al. illustrate the development of a Decision Support System, based on Multi-Criteria Decision Aid methods, for dealing with some real-world issues associated with freight traffic in the City of Bradford (UK). In the third contribution, Genovese et al. analyse a software package offered by Softeco Sismat (an Italian software house who is a beneficiary of the project), identifying possible areas of future improvement, and understanding how the package could be turned into a strategic Decision Support System for aiding local authorities in implementing urban logistics solutions.

The preliminary work illustrated in the following contributions will support the final deliverables for WP1, 2 and 4 of the ProSFeT project.

References

Ballantyne, E., Lindholm, M. (2014). Identifying the need for freight to be included in local authority transport planning. In *Sustainable urban logistics: Concepts, methods and information systems*, 37-48. Springer Berlin Heidelberg.

A Decision Support System for Urban Freight Transport issues in Sheffield City Council Waste Management operations

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Introduction

During the first phases of the collaboration (which was based on several secondment periods of personnel from CNR to Sheffield City Council), the representatives of the Sheffield City Council (SCC) Waste Management Team had expressed the interests in exploring new configurations of the system of Household Waste Recycling Centres (HWRCs) and in measuring the quantitative impact of such decision. A strategic and operational analysis of the proposed decision-making challenge was then conducted throughout the development of the secondments, together with a translation of the HWRCs reconfiguration problem into original mathematical models based on Decision Sciences and Optimisation methodologies.

In the remainder of this section activities arising from different secondment periods are described and the arising scientific outputs concerning the design of a Decision Support System (DSS) and its implementation on the field.

Design of the Decision Support System

During the first period of secondment from the CNR to the Sheffield City Council (SCC) several introductory meetings were conducted between Dr Melchiori (secondee), Dr Antonino Sgalambro, (Scientific Supervisor on behalf of CNR), and Mr. Alastair Black in his role as Waste Strategy

Officer at the SCC and main responsible for the hosting organisation for the secondment at the SCC, with the aim to define the concrete problem to be coped with during the cooperation.

Such meetings were instrumental in highlighting preliminary information regarding waste management strategies adopted by Sheffield City Council, with a focus on the management of the five Household Waste Recycling Centres (HWRCs) currently operating and on the process of materials transportation from these HWRCs to end-points like Energy Recovery Facilities, incinerators, mills and landfills.

It was clear how the cost for these services has a relevant economic impact for the SCC; moreover, HWRC sites are currently facing congestion issues, such as daily massive queuing of cars blocking surrounding streets.

The main goals and interests of the SCC were summarised as follows: to perform a scientific investigation and a feasibility study towards the development of a decision support system for better decision making and optimisation of the HWRCs system, to support the definition of short-term and prospective optimal policies for the HWRCs management, including recommendations on the replacement of some of the recycling centres with new Supersites.

The role of Waste Transfer Stations has been clarified and Geographical Information System data of the Sheffield area was requested in order to conduct a preliminary study.

Moreover, three different operating HWRCs in Sheffield were visited (Deepcar, Douglas Rd, Blackstock Rd) where customers utilising these facilities were observed anonymously, including the queues of cars at the site entrances and conversation with the site operators were undertaken to get information on the collection tasks performed at the sites and routing operations for waste disposal.

From the scientific perspective, the work developed during the DSS design phase was focused on translating the proposed HWRC management problem into scientific terms under the lens of Decision Sciences. An original research activity has been conducted in order to classify the SCC management problem within the literature on Network Optimisation Problems. The modelling effort would result in a combination of covering, location, routing aspects that have to be simultaneously taken into account. Relevant methodologies and case studies from the literature in the field were considered and some preliminary mathematical formulations for the related decision problem developed as follows.

The Problem

In this report we are concerned with the reconfiguration of the current system of Household Waste Recycling Centres ($HWRCs$) in the Sheffield municipality. These centres are personally used by citizens to recycle the waste that cannot be collected by the regular service performed at streets/kerbside. Citizens access recycling sites by cars, and trash their waste (which can be considered as a special category of freight) into different separated containers. From these centres containers are collected by trucks and trans-shipped to end-points like recycling plants, incinerators, landfill, Energy Recovery Facility (ERF), Waste Transfer Station (WTS) for further processing or disposal. Sheffield City Council (SCC) is interested in reducing the number of $HWRCs$ replacing (some of/all of) the existing ones with two new Supersites. The decision of which recycling centres to maintain/open among a limited number of candidate sites has to account for the coverage requirement of citizens of the local authority area. The minimisation of set up costs and operational costs over a long time period has to be achieved.

Underlying mathematical assumptions

We recall two 0-1 linear formulations to model a generalised problem where one aims at locating p facilities, i.e. designing a p-configuration of operating recycling centres that minimises the total set up costs and operational costs (transportation costs and labour costs) while ensuring the total coverage of the population.

We are given a graph $\mathcal{D} = (\mathcal{V}, \mathcal{E})$, with $\mathcal{V}$ being the set of nodes and $\mathcal{E}$ the set of edges. Nodes are divided into three subsets reflecting the different facilities and stakeholders involved in the flows of waste, i.e. $\mathcal{V} = \mathcal{I} \cup \mathcal{J} \cup \mathcal{L}$ with $\mathcal{I}$ being the set of citizens' aggregations in Sheffield, namely *cells* (the aggregation is based on the Census of the Sheffield Population performed in 2011), $\mathcal{J}$ the set of candidate centres for the $HWRCs$, $\mathcal{L}$ the set of end-points used for waste disposal. Each edge $(i, j) \in \mathcal{I} \times \mathcal{J}$ states the possibility for cell i to use the recycling centre j, and each edge $(j, l) \in \mathcal{J} \times \mathcal{L}$ states that trucks are allowed to transship waste from centre j to the end-point l. Distance traveled for this transshipment (one-way) equals d_{jl}.

We are given a set $\mathcal{K}$ of type of waste and a time horizon T over which we want to observe the impact of the reconfiguration with respect to the expenses to sustain.

Each candidate recycling centre j is described as a potential geographical location in the district with a number b_j of operators that would work at the site each with a salary of w_j per unit of time, n_j^k containers per type of waste k each of them with capacity c_k (we suppose capacities are independent from the site). The opening of a site j occurs in a total of f_j set-up costs (cost of the land, licence, buildings, etc.). If the site is already operating these costs equals the investments for possible expansions. We assume that all recycling centres manage and collect the entire set of considered waste. Furthermore, the following assumptions are made:

- *Estimating waste production at wards:* each block of citizens produces a certain quantity of waste k per unit of time, indicated by p_i^k. We assume these data are available. We can think of $p_i^k \approx (m_i, \alpha_k^i)$ where m_i is the number of citizens/households at cell i and α_k^i is the coefficient rate generation at cell i for waste k.

- *Covering citizens:* a cell i is considered as covered by recycling centre j, $\beta_i^j = 1$, if it is within a maximum distance from the site and the route can be travelled by car within a maximum amount of time; parameters are defined by the SCC.
- *Estimating collected waste in different configurations:* historical data on the amount of tons collected per each type of waste are available for the current operating configuration of $HWRCs$: values λ_j^k for each of the five facilities $j \in \mathcal{J}^* \subset \mathcal{J}$ (Blackstock, Beightond Rd, Douglas, Deepcar, Graves Lane) on a monthly bases from year 2013 to 2017. For modeling purposes we should estimate the same quantities for any possible p-configuration of facilities that could be opened, i.e. $\overline{\lambda}_j^k(\overline{\mathcal{J}})$, is the quantity in tons of waste k collected at site j when the set $\overline{\mathcal{J}} \subset \mathcal{J}$ of p facilities is operating. In the first proposed formulation we assume that any p-configuration will receive in a month the same total amount of waste k collected in the current configuration equally distributed among the sites in the considered potential configuration, i.e. $\sum_{j\in\overline{\mathcal{J}}} \overline{\lambda}_j^k(\overline{\mathcal{J}}) = \sum_{j\in\mathcal{J}^*} \lambda_j^k$ and $\overline{\lambda}_j^k(\overline{\mathcal{J}}) = \overline{\lambda}_j^k \approx \frac{\sum_{j\in\mathcal{J}^*} \lambda_j^k}{p}$, $\forall k \in \mathcal{K}$. This initial assumption ensures that the current production of the city will be covered by any new configuration of the facilities. However, it doesn't take into account the geographical distribution of candidate sites and population. In the second formulation $\overline{\lambda}$ parameters are deduced from decision variables in the model and no more provided as an input.
- *Transportation to the closest end-point:* we assume that there exists an unlimited and homogeneous fleet of trucks. Each truck collects a single full container at a time, delivers it to the closest end-point recycling that waste, see the γ_{jl}^k parameter, and then returns to the original site to give back the empty container. In a third formulation we could assume

that for specific type of waste a truck performs a route to collect it among several recycling sites, with more than one container at a time.

Covering Location models

This subsection details some fundamental mathematical models which can be adopted for dealing with the problem under investigation.

The Set Covering model with fixed number of facility

$$
\begin{aligned}
\min \quad & \sum_{j\in\mathcal{J}} c_j\, z_j \\
& \sum_{j\in\mathcal{J}} \beta_i^j\, z_j \geq 1 \qquad \forall i \in \mathcal{I}. \\
& \sum_{j\in\mathcal{J}} z_j = p \\
& z_j \in \{0,1\} \qquad\quad \forall j \in \mathcal{J}.
\end{aligned}
$$

In this first model we formulate the problem of interest as a Set Covering Location model. We make use of binary variables to express if a site has been selected or not and to ensure the citizens' coverage. The set of available sites is here restricted to the new 5 identified locations and the Beighton and Douglas sites which could be extended. The objective function minimises the total costs of each opened site $c_j = f_j + 2T_1 \sum_{k\in\mathcal{K}} \sum_{l\in\mathcal{L}} d_{jl}\, \gamma_{jl}^k \lceil \frac{\overline{\lambda_j^k}}{c_k} \rceil + T_2 b_j w_j$ where the first term expresses the set up costs and the remaining terms the operational costs over the considered time horizon, i.e. the transportation costs for trans-shipping the collected waste from recycling centres to end-points (and the way back) and the labour costs incurred for work force. Note that the considered time horizon might be discretised into a different number of time units to separately deal with transportation and labour costs, see T_1 and T_2. Transportation costs for each time interval are calculated by multiplying a unit cost for a single go and return trip, that directly depends on the distance between the two locations, for the number of trips that are estimated to be required.

In this model we assume that the number of trips exactly equals the number of full containers that are produced at the site by the estimated collected amount of materials, $\frac{\overline{\lambda_j^k}}{c_k}$. In order to increase the accuracy of the model, we should add the route performed by the truck from/to the depot.

The first set of constraints ensures that each cell is covered by at least one opened centre. Note that in this model each cell is completely free to decide by its own where to go for trash waste, as no allocation here is determined/suggested. The second constraints imposes to select exactly p facilities to open. Varying the p input parameter allows to identify the minimum number of facility to be activated in order to ensure a total coverage of the population.

The Maximum Covering model with budget constraint

In the following model the total coverage requirement is relaxed in order to explore possible alternatives in the HWRC configurations that respect a given available budget. The outcome is an insight on the maximum percentage of population covered (weighted with respect to its waste production) by a feasible reconfiguration.

$$
\begin{aligned}
\max \quad & \sum_{i \in \mathcal{I}} \sum_{k \in \mathcal{K}} p_i^k \, y_i \\
& \sum_{j \in \mathcal{J}} \beta_i^j \, z_j \geq y_i && \forall i \in \mathcal{I}. \\
& \sum_{j \in \mathcal{J}} c_j \, z_j \leq B && \forall i \in \mathcal{I}. \\
& \sum_{j \in \mathcal{J}} z_j \leq p \\
& y_i \in \{0,1\} && \forall i \in \mathcal{I}. \\
& z_j \in \{0,1\} && \forall j \in \mathcal{J}.
\end{aligned}
$$

The Covering Location-Allocation model

The following model can be viewed as an extension of the previous one as it further includes the allocation of each ward to a single opened centre.

Accounting for allocation can be beneficial to improve the service quality by providing the citizens a recommendation of the "best" facility among their accessible ones and to increase control on the citizens' utilisation of sites, the last could allow for a more precise forecast of the collected waste and a higher awareness in designing layout sites and in the planning and management of operation tasks.

$$\min \quad \sum_{j\in\mathcal{J}}(f_j + T_2 b_j w_j) z_j + 2T_1 \sum_{j\in\mathcal{J}}\sum_{k\in\mathcal{K}}\sum_{l\in\mathcal{L}} d_{jl}\,\gamma_{jl}^k \left\lceil \frac{\sum_{i\in\mathcal{I}} p_i^k\, x_{ij}}{c_k} \right\rceil$$

$$\sum_{j\in\mathcal{J}} \beta_i^j\, x_{ij} = 1 \qquad \forall i \in \mathcal{I}.$$

$$\sum_{j\in\mathcal{J}} z_j \le p$$

$$\overline{\lambda}_j^k = \sum_{i\in\mathcal{I}} p_i^k\, x_{ij} \qquad \forall j \in \mathcal{J},\, k \in \mathcal{K}.$$

$$x_{ij} \le z_j \qquad \forall i \in \mathcal{I},\, j \in \mathcal{J}.$$

$$z_j \in \{0,1\} \qquad \forall j \in \mathcal{J}.$$

$$x_{ij} \in \{0,1\} \qquad \forall i \in \mathcal{I},\, j \in \mathcal{J}.$$

In this formulation the problem is modelled as a Covering Location Allocation problem, where in addition to location z variables of the previous model, binary variables are used to allocate each ward to a unique operating recycling centre. This additional variables can be used to estimate the tons collected at each site as $\overline{\lambda_j^k} = \sum_{i\in\mathcal{I}} p_i^k\, x_{ij}$, if $z_j = 1$. Note that this represents a better estimation than the previous one based on an equal distribution of waste among the recycling centres.

The objective function equals the previous one except for the λ parameters that are replaced by the equivalent expression in the allocation variables. The first set of constraints ensure that ward i is entirely allocated to one among the potential recycling sites covering it. The second constraint is the same as in the previous formulation, while the third set of constraints express the previously mentioned relation between material productions at wards and collection tons as site: all wards allocated to centre j concur with a production of p_i^k tons to the total amount of waste k collected at the site. The final set of constraints ensures the coupling of link activation variables z's to allocation variables x's: if a site is not opened, then no wards in the district can utilize it. Note that capacity constraints per each recycling site could be needed in order to avoid an over-capacitated allocation of blocks. This could be something as $\sum_{i \in \mathcal{I}} p_i^k x_{ij} \leq \delta_j^k(c_k, n_j^k)$.

The Location Allocation Routing model

We could need to model the same problem where for a specific type(s) of waste each truck is able to trans-ship multiple containers and to perform a cumulative collection among the recycling sites. In this context routing decisions have to be simultaneously included into the model.

Analysis to be performed

The steps of the analysis to be performed are reported in the following:

- Perform a What-If analysis forcing some sites to be opened or restricting $\mathcal{K}$ to a single type of waste (give thus priority to one type of waste e.g. green waste). In the second case, run independently the models then integrate results.
- Force to open just the current configuration of sites. Check with the second formulation if the production rate p_i^k are correct. (In this situation we know $\overline{\lambda_j^k} = \lambda_j^k$ from the monthly data collected for each type of waste).
- Compare the two formulations.
- If $p = 2$ one could enumerate all the possible pairs of facility to open that cover the entire population and deduce the set up costs and operational costs and find the best solution for the first formulation.

- Analysis of historical series of data *on queues at sites* to identify customer trends among days and explore possible alternative management strategies,
- Analysis of historical series of data *on collected tons of waste at recycling sites* to accurately forecast values for next years.

Input list

To make use of the previous formulations the following data are required:

- Distribution of the population of Sheffield into 28 *wards*;
- *Production rate at wards* for each waste per unit of time; if these quantities are not available we could look at the data in the current operational setting of $HWRCs$ and assume a citizens' distribution among recycling facilities (to the closest, gravitational model);
- Types of *waste* managed in the $HWRCs$ sites (3 macro and 26 micro categories);
- *Candidate locations* for $HWRCs$ (set up costs, $\#$ of operators, unit work force cost, $\#$ and type of containers and eventually the capacity);
- *Covering radius parameters*, i.e. the maximum distance a citizen must travel by car to reach a site and the maximum time spent for traveling to the site;
- *End-point locations* and type of waste treated;
- *Amount of collected waste* per type at each currently operating $HWRC$ per unit of time (e.g. 2013-2017 on a monthly basis);
- *Depots* for the trucks;
- *Time horizon* and unit of time of interest.

Objectives and Tasks

The problem posed by SCC can be recognised as a *semi-structured* decision problem, as the challenge *how to reconfigure the HWRC system* presents multiple potential actions and procedures, involvement of subjective judgements, not fully reliable and sharp information.

This second part of the cooperation has been focusing on the implementation of a Decision Support System (DSS) to provide the SCC with a user-friendly tool to measure the economical investment, test and visualise the impact of different HWRCs configuration scenarios. A first prototype of the DSS has been designed during this period of secondment and presented to the Waste Management Team of the SCC.

More in detail, the designed DSS, integrated with the open-source Geographical Information System QGIS, asks for the input of the features of the scenario to be tested such as the number of facilities to be opened and on the selected coverage distance, then interacts with a mathematical programming solver in order to find an optimal solution for the generated instance of the optimisation model; such a solution is then displayed graphically. The architecture of the DSS is shown in Figure 1.

For the realisation of the plugin, several activities have been performed. In particular, the mathematical programming models (Location Problem without/with Budget restrictions) have been implemented in an OPL language; several computational experiments were performed in order to test the implemented mathematical models by using the CPLEX optimisation solver. With respect to the creation of the plugin within the QGIS open-source software, a close interaction took place with the Waste Management Team at SCC in order to collect and organise GIS data related to the Sheffield districts and the currently operating system of HWRCs. Then, the plugin was implemented in the Python programming language; a graphical user interface was designed, through which input parameters can be set-up. Such graphical interface was connected to the CPLEX solver (sending requests and retrieving optimal solution); a further graphical interface was designed in order to display output messages. The last part of the secondment was devoted to debugging and testing the plugin, discussing and investigating with the Waste Management Team some improvements and additional extensions that could be addressed in the future.

Some screenshots of the plugin are reported in the following Figures 2 and 3. Figures 4, 5 and 6 report an overview of the graphical user interface and of the representation of the results.

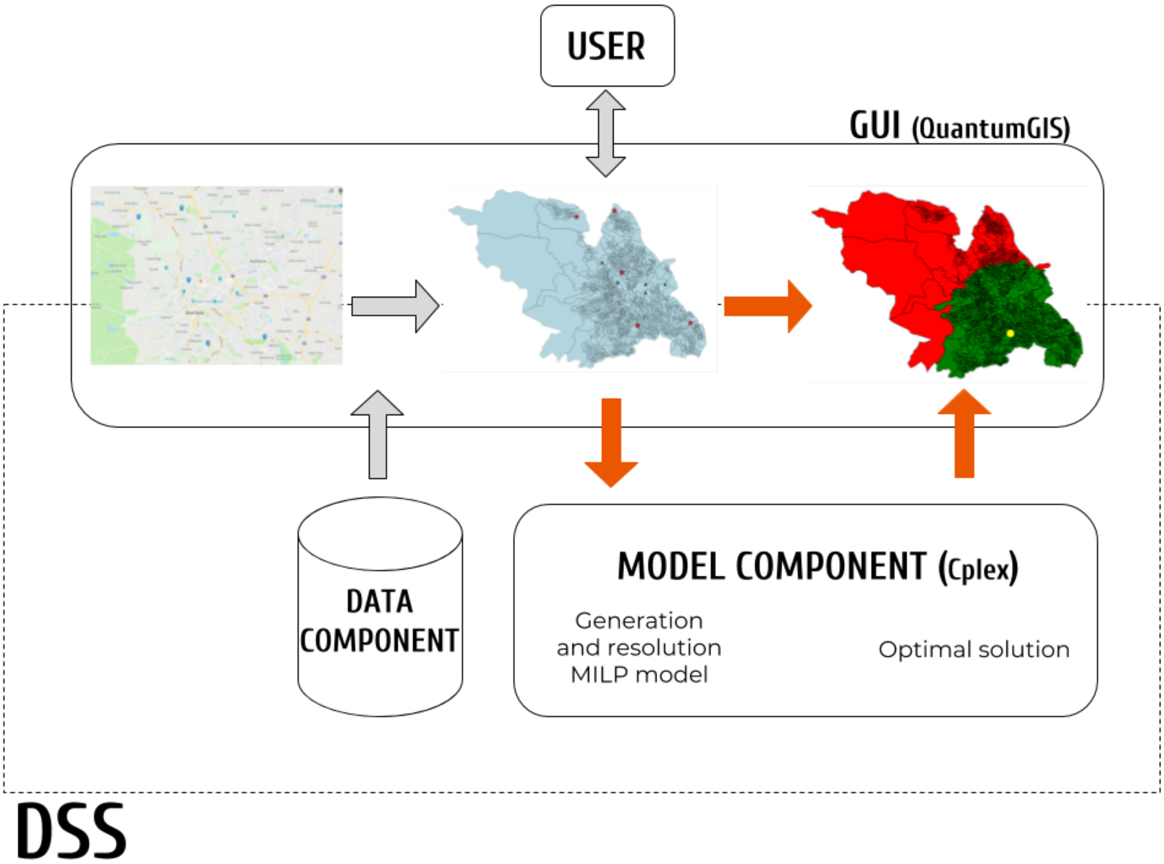

Figure 1 – Architecture of the DSS components and interactions

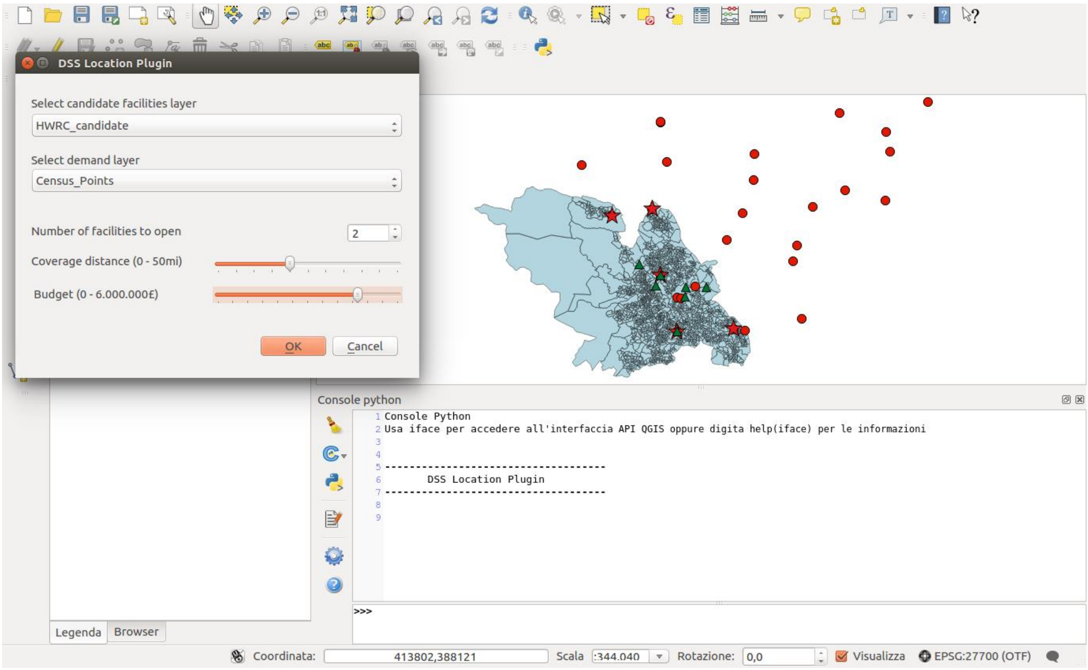

Figure 2 – A screenshot of the DSS input interface

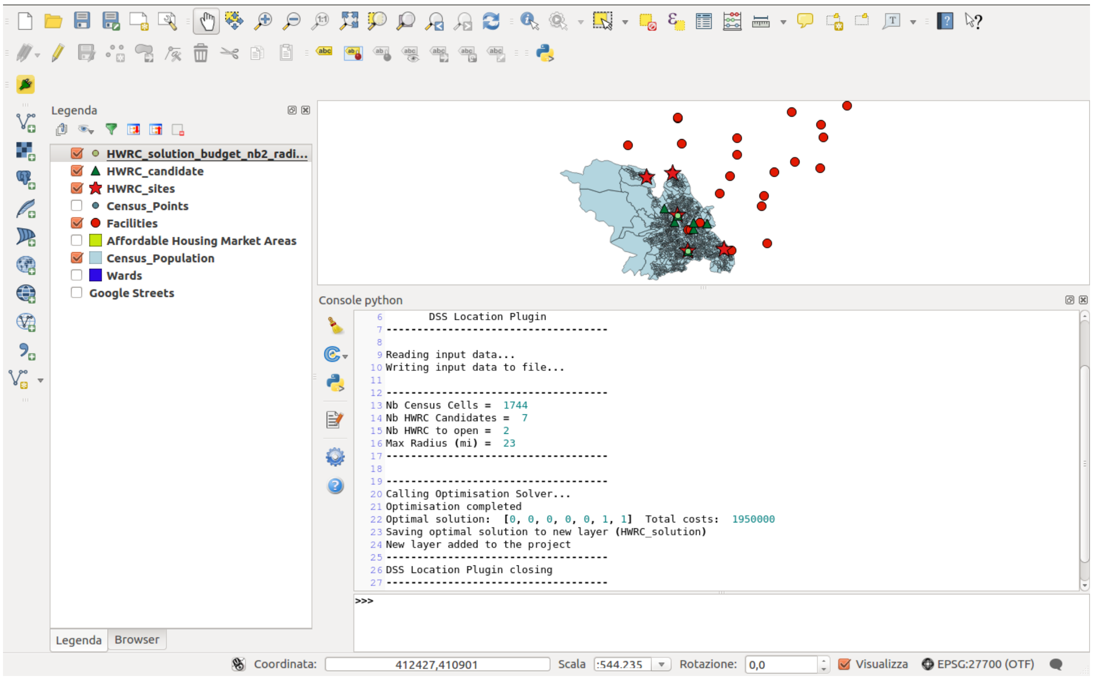

Figure 3 – Computational process output

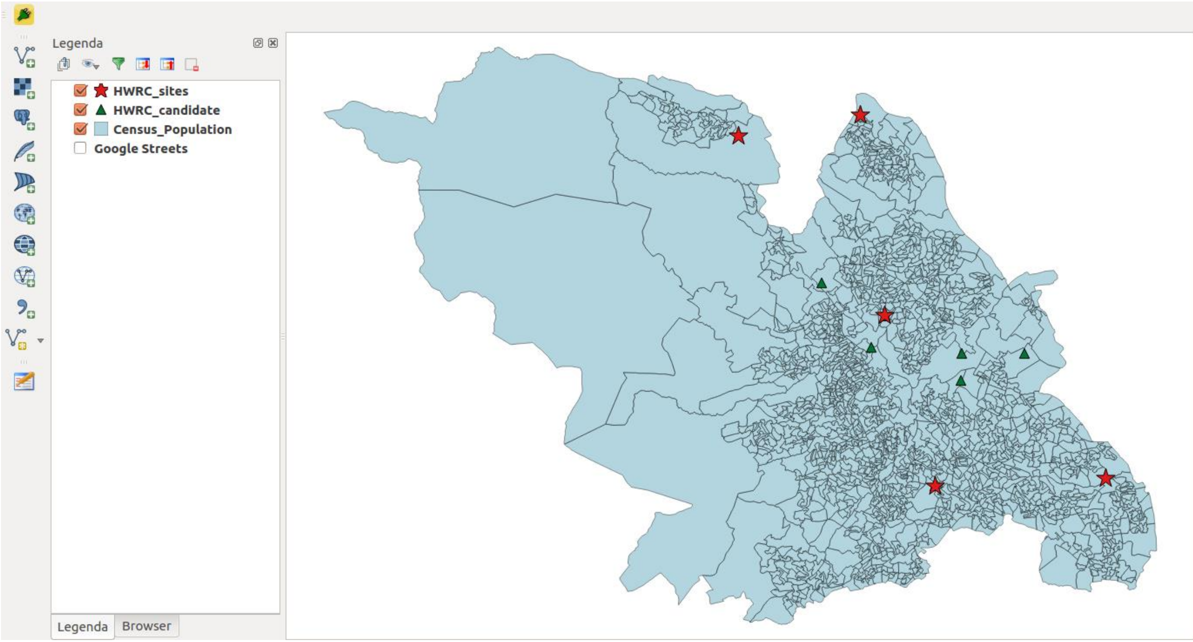

Figure 4 – Graphical visualisation of DSS outputs

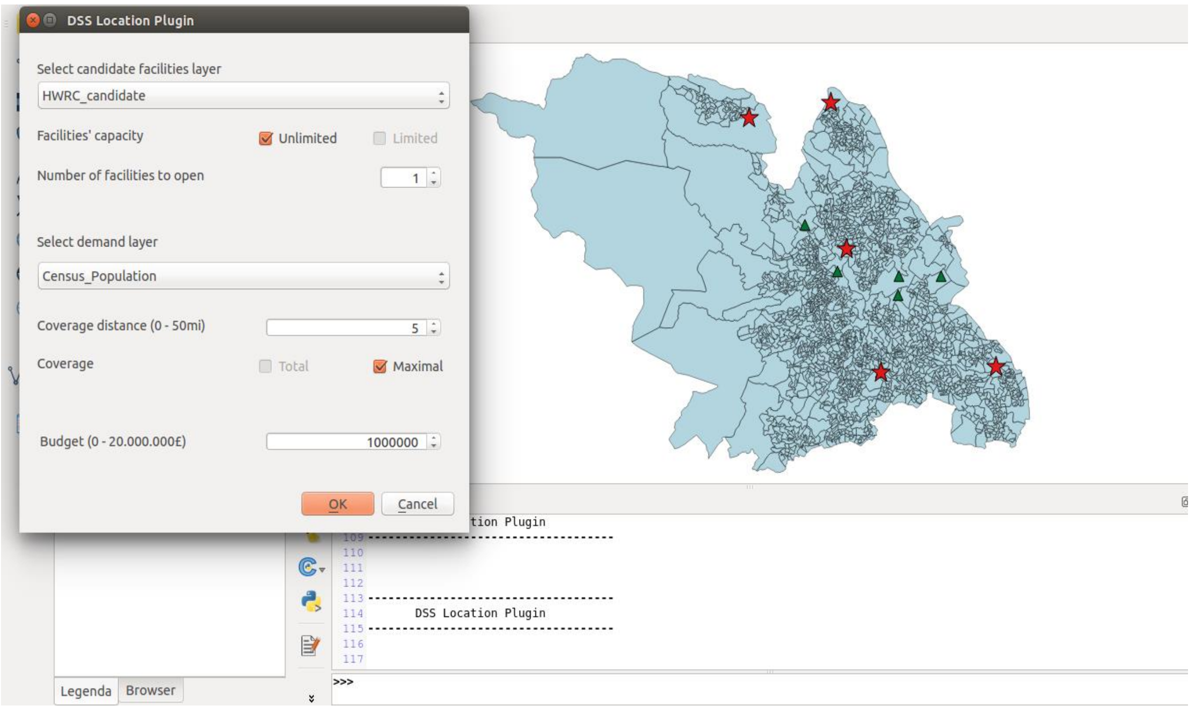

Figure 5 –Usage of the DSS user interface to elaborate output results

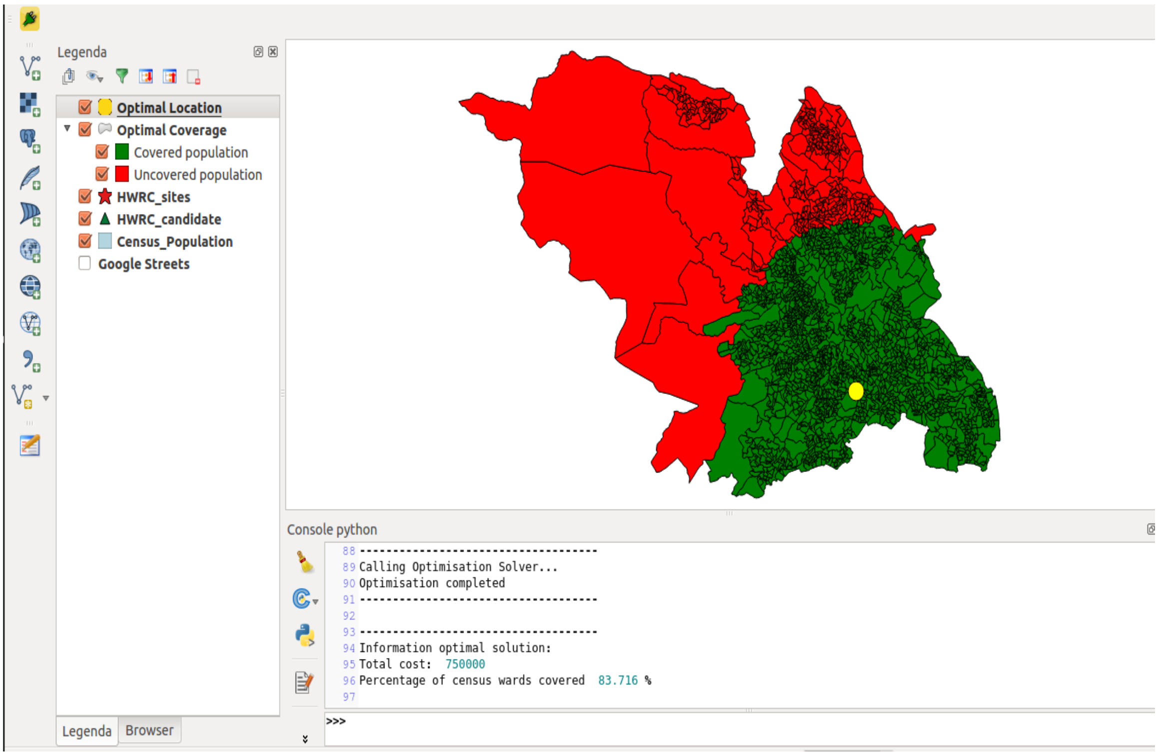

Figure 6 – Graphical representation of the coverage results within the DSS outputs

Further actions and future developments

The DSS integrated in the QGIS software has been shown. It allows for the optimal location of a fixed number of HWRC facilities chosen among a set of candidates sites that minimises the total costs (price of the land, set up costs), respect a given budget, and covers the whole Sheffield population within a given radius. This tool is based on the Set Covering Problem.

Discussions have already been held with SCC in order to perform further improvements to the designed DSS; in particular, both sides agreed in improving the DSS by integrating the following additional features:

- Maximal coverage option: the possibility for the user to relax the assumption of a total coverage, that it might often cause infeasibility and so no solution provided by the DSS, and to select a different option, namely the maximal coverage, that aims at identifying the optimal facility location that maximises the coverage of the population. In this sense it will be interesting for the SCC to know (and to easily visualise in the QGIS) which region of the district remain uncovered. In fact, there are some rural areas which present a very low density of population, low level of services and structure. The Maximal coverage option corresponds to the Maximal coverage location problem.

- Capacitated option**:** the possibility for the user to account for capacitated/uncapacitated HWRC facilities. In the Set Covering or Maximal Covering Location Problem the facilities are considered with unlimited capacities. Moreover, no indication is given w.r.t. the allocation of the population to the selected open facilities. With the Capacitated option, the user gets the optimal location of the facilities and the correspondent allocation of the citizens that respects the capacity constraints.

SCC has also expressed interested in:

- Understanding how big should be the facilities in order to serve the population at a non-congested level; In other words, fixing the number of facilities to open, the radius, the budget, the SCC would like to know the minimum amount of capacity of the facility needed to obtain a feasible solution to the Set Covering or to the Maximal Coverage. Sensitivity analysis on the capacities?
- Understanding if adding a new candidate site location with a certain capacity could improve the coverage and service level. There is no predetermined candidate location, but any new location might be considered at this level.

In the future the following data will need to be estimated:

- Distribution of the population;
- Capacity of the facilities (i.e., expressed in the number of people that can stay inside without causing congestion issues);
- Estimate distribution of population on sites.

Further considerations emerged:

- At one of the HWRCs, for a very short period, postcodes of the citizens arriving at the site have been collected. This might give some information (maybe not consistent enough) of the utilisation and distribution of the population
- SCC is considering a modification of the layout of two HWRC facilities, both in the sense of increasing if possible the parking space and of reconfiguring the type and position of containers (in particular electronic containers requires the users to wait for the compression of the disposed waste).

A Decision Support System for the freight lorry parking location problem in the City of Bradford (UK)

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Introduction: on the freight lorry parking location problem

The relevant role of freight lorry parking facilities as a tool to reduce nuisances and impact of economic activities in densely populated urban areas is widely recognised in the literature, with many interesting contributions addressing the related decision-making and management issues. For example, Malik et al. (2017) present a comparison of parking practices and problems experienced by freight-vehicle drivers in Gothenburg and Delhi. The study considers parking practices of freight lorry drivers and their opinions about parking availability, using a comparative descriptive method and data from official documents and surveys. The study concludes that freight parking problems are strictly related to local factors; therefore, it is mandatory to consider each case separately. Moreover, authors highlight that solutions to freight lorry parking problems cannot be based on car parking models as driver behaviours introduce different issues.

Carrese et al. (2017) conduct a large and complex survey in order to define a method for analysing how to improve security inside freight lorry parking areas. To this end, authors evaluated the need for parking slots for freight vehicles by comparing current parking slots provision with future demand calculated using the model developed by Coleman and Trentacoste (2002); such model was calibrated on the characteristics of the area under investigation. Security being among the many issues stressed in the survey, the paper evaluated different policy options in relation to EU standards and associated financial costs. Based on an analysis of the drivers' willingness to pay for a high level of security with the financial costs to achieve it, the authors conclude that such high security parking areas are unlikely to generate any profit.

Nourinejad et al. (2014) propose a more complex approach for understanding how urban areas would respond to a new parking policy. For this purpose, authors developed a freight transport traffic simulation model. Then, they applied this simulation to model a small study area with two simple policy scenarios. In order to measure the differences between such scenarios, different elements such as time to find parking and walking distance to the final destination were calculated. The results of this study provide a fairly accurate description of the consequences of different policy scenarios; however, given that this kind of approach apparently requires a deep understanding of local freight vehicle flows, it would be hard to apply over a large area.

Although the above mentioned articles provide useful insight on freight transport logistics problems and guidelines on the elements and classes of data that mainly affect decision-making on freight transport logistics, none of these articles addresses the need for practical decision support for locational purposes. Many examples of spatial decision support systems (SDSS) proposed in the literature have integrated simple Multiple Criteria Decisional Analysis (MCDA) methods with the use of data visualisation techniques in order to enhance understanding of the spatial characteristics of location decision problems (Sugumaran, 2010). Nevertheless, the literature currently lacks specific contributions addressing the use of a complex MCDA approach for coping with the localisation of freight lorry parking facilities in the urban context. Therefore, this paper intends to contribute to filling this gap by analysing a real-world case study motivated by the problem of intense freight vehicles traffic around the city of Bradford, Yorkshire (UK). Since it is necessary to include multiple analysis perspectives, reflecting the different classes of involved stakeholders, the study proposes to adopt the Analytic Network Process (ANP) approach to support the Council in selecting and evaluating alternatives for a freight lorry parking facility, followed by design of software based on this approach. Further details of this process are provided in the following of this report.

Real problem description

Bradford is the UK's fifth largest city, with $522{,}452$ living within the city boundaries, and has the youngest and fastest growing population of any city outside London (Office for National Statistics, 2011). The main connection of this large city with the national motorway network is via the $M606$, a spur of the $M62$ motorway which is located south of Bradford. Considering these factors, it is not surprising that the road network to the south of Bradford is affected by intense freight vehicles traffic. In fact, in 2016 the $M606$ was estimated to have an average daily flow of 5644 freight vehicles. The flow is illustrated in Figure 7, with a green to red scale used to indicate the intensity of daily freight transport on the main roads.

The *Driver Hours Regulations* is the main set of laws governing day-to-day working time and break/rest period requirements in the EU, imposing mandatory breaks and rest periods of different extent for freight vehicle drivers. Given the inherent challenges of driving work, it is generally not possible for drivers of freight vehicles to take break periods at their home depots and they therefore need to park their vehicles while these break periods are undertaken. That implies a demand for suitable lorry park facilities where vehicles can be safely parked. Given a deficit of such facilities in the Bradford area, drivers are likely to park inappropriately on the public highway shoulder or other unsuitable locations.

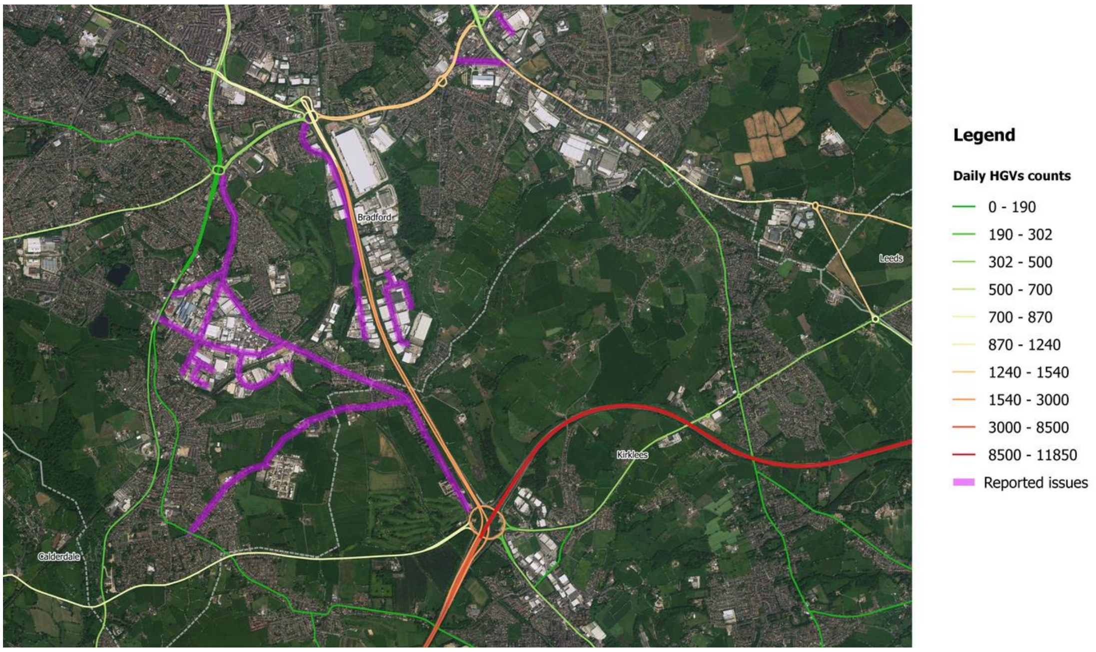

Figure 7 – South Bradford map with daily HGVs data

As a consequence, in the last decade, the southern part of the Bradford district has been subject to sporadic but constant issues related to inappropriate parking by heavy goods vehicles (HGVs). The observed consequences include:

- Traffic flow interference and congestion;
- Depositing of various types of litter by HGV drivers;
- Theft of goods from trailers;
- Noise pollution (running engines, refrigeration units) emitted by lorries;
- Damage to pavement or footpath infrastructure;
- Visual intrusion of lorries.

To tackle such issues, the City of Bradford Metropolitan District Council (CBMDC) is planning to establish a dedicated lorry park facility and has selected some possible sites from which to identify the optimal location in the area.

A lorry park facility, although highly useful in reducing nuisances arising from freight transport, is also considered to be an *undesirable facility*, hence the location process usually draws social opposition from citizens, and requires collection and elaboration of a large quantity of social, economic and environmental data. For these reasons, the location of a lorry park can be considered as an inherently complex strategic decision-making problem, as it involves different interconnected elements and must achieve objectives that are often in conflict.

The Analytic Network Process

In this study, we consider the use of MCDA methods to rank all the potentially available locations for siting a freight lorry park. Although we considered using the Analytic Hierarchy Process (AHP) method, we soon realised that the complexity of the problem rendered this method unsuitable. A complex problem cannot in fact be hierarchically structured since it often involves interconnection between elements in a complicated dependency structure that allows elements to influence each other. Moreover, a hierarchy model cannot take into consideration that the pool of alternatives can influence the weight of the criteria. Since in the lorry park location problem the elements influencing the decision-making process are highly interconnected, we decided that the Analytic Network Process (ANP) would enable us to model the problem in a more complete way by controlling and estimating all the element interconnections. That is possible because ANP is able to generalise the AHP approach by allowing the presence of any type of possible mutual influences among the elements (Saaty, 1996).

Using the ANP method, the problem is structured as a network, and then the elements in the network are evaluated through a pairwise comparisons approach to measure their weights in the model, which, after some matrix calculations, allows ranking of the alternatives considered in the problem.

The work will focus mainly on the process of constructing the ANP network model for the specific lorry park location problem, which will be described in two subsections. The first subsection relates to the analysis of the stakeholders and their objectives. The main task here is to identify the relationships between different classes of stakeholders and the issues they care about most, as these will constitute the basic elements in developing our ANP network model. In the second subsection, we first outline the main phases of the ANP and then construct the ANP dependency network model based on the stakeholder analysis.

Stakeholder analysis

In the process of making a decision on an issue of public relevance, the starting point for the theoretical model should be the various stakeholders and their interests. The stakeholders are those individuals or organisations that have personal interests and influence in the decision process because they have goals directly or indirectly affected by the problem and its possible resolution (Dente, 2014). Consequently, the first essential step in a public decision-making problem process is classification of the stakeholders involved and their interests. The stakeholders identified in our decision-making problem alongside their main objectives are drafted in the following Table 1.

Stakeholders	Main Objectives	Resources
Local residents	maximize distance from residential areas	cognitive/political
Freight vehicle drivers	minimize deviation from planned routes	economic
City of Bradford MDC	minimize nuisances	political/economic
Local business	maximize delivery security	cognitive
Freight lorry parking owners	maximize profitability	economic

Table 1 - Involved stakeholders and their objectives/resources

As expected in a real problem scenario, we can see that there are multiple stakeholders with different and conflicting interests. Local residents are directly affected by inappropriate HGV parking, and their main interest is to maximise the distance between their homes and HGV traffic and hence the freight lorry parking. Local residents are the primary source of information on inappropriate parking through their reporting of nuisances to local authorities, and such complaints contribute to motivate political action to tackle the problem. Local businesses are also affected by inappropriate parking, as road congestion causes delay in incoming deliveries. Because local businesses are the main factor in the generation of HGV flow, through their involvement it is possible to obtain information about the HGV flow that would otherwise be difficult to obtain, such as the number of daily deliveries in the area. Bradford Council has an indirect interest in the problem since is concerned with the general well-being of the local population; hence, it could decide to provide financial support for construction of a freight lorry park and enact policies to discourage inappropriate parking. To ensure a positive revenue stream, a freight lorry park needs to be attractive to drivers, which means it should offer security for their goods and access to amenities while avoiding costly HGV deviations from their original routes. In the case of the Bradford study we were able to involve a freight lorry park owner who was interested in in the project as a long-term financial investment.

Building an ANP model for the considered problem

Let us start by outlining the main phases of the ANP method as a MCDA tool as described by Saaty (2005). The ANP is a generalisation of AHP; it is considered more appropriate for dealing with real decision-making processes which often have a complex dependency structure between the considered elements.

The first phase is to develop the network representing the decision-making process. This task first requires clear definition of the decision objective. Then, all the criteria specifically affecting the decision-making process need to be classified into *groups* or *clusters,* each group containing criteria with similar meaning. The last elements to be identified are the alternatives or options from which the best solution can potentially be selected. The relations among the elements (criteria and alternatives) within the network dependency structure are represented by arrows and these relations are the key factors in gaining a more precise representation of a real problem than would be possible using a more rigid hierarchical structure. For example, it is possible to identify feedback relations linking the alternatives and the criteria and dependency between criteria of any cluster. Additionally, clusters are correlated to each other through inheriting relations from their elements. The second phase entails making pairwise comparisons. These can be divided into two main types: comparison between clusters, which provides a general understanding of the problem, and comparison between elements, which is more in depth and specific. This process is needed to determine the relative weight of two elements with respect to another criterion in the network influenced by both elements. These comparisons can be either qualitative or quantitative. In qualitative comparisons, first, two elements are compared by choosing the appropriate verbal assessment from a list to express which one has more weight and how much weight they have in relation to a third criterion; then, the verbal assessment is translated into a number between 1 (when elements have the same importance) and 9 (when one element has much greater importance than the other). In this way it is possible to cope with intangible criteria, since it is not necessary to assign values to the criteria. Meanwhile, in quantitative comparisons, value is assigned to the two alternatives in relation to the criterion being considered, with the larger alternative value considered as a multiple of the smaller one, but bearing in mind that the ratio should always be between 1 and 9.

Given an element of the network and a cluster, the associated comparison matrix is defined as a matrix where the entries are the numeric values of all the pairs of elements in the cluster influencing the selected element. The cluster comparison matrix is defined in the same way but with the difference that the entries are pairs of clusters. The main eigenvector of these matrices synthesises the judgements determined with the pairwise comparisons.

The third phase is the gradual generation of three matrices. The first to be generated is the unweighted or initial super-matrix, in which the entries are indexed by pairs of elements of the dependency model, and the column associated with an element is made by the main eigenvectors of all its comparison matrices. The cluster comparison matrix eigenvector is used to weight the elements of the corresponding column blocks of the initial super-matrix, resulting in the creation of the second matrix, or weighted matrix, which is a column stochastic matrix. The weighted matrix is then raised to a limiting power, in order to converge into the last matrix, or limit matrix, thereby producing a long-term stable set of weights that represents the final priority vector, as stated in the Perron–Frobenius theorem (Perron 1907).

To identify the elements that influence the location of the parking facility problem we took into account all the information gained during the stakeholder analysis. These elements along with brief descriptions are listed in the following Table 2.

Elements	**Descriptions**
Level of use	Potential use for a new parking areas based on data collected through manual counting of the highway network flow
Distance to residential areas	The residential areas are all currently or potentially inhabited areas
Running costs	Preliminary estimate of the annual maintenance costs related with the built facility
Profitability	Preliminary estimate of the revenues associated with the facility and the level of use
Building costs	A preliminary estimate of the construction costs related with the size and the facilities
Nuisances covering	The coverage of areas subjected to inappropriate HGVs parking
Size	The physical dimension that can be used to build
Land cost	A preliminary estimate of the land purchase costs related with the land size
Land policy	It is a constraint for the possible uses of the land
Accessibility	This attribute evaluate how easy is to reach the location from the mains truck routes

Table 2 – ANP elements and descriptions

After the identification of all elements we constructed the relationship network, working in collaboration with Bradford MDC.

Analytic Network Process dependency graph

In Figure 8, the arrows between elements represent the dependency relations, and the arrows that connect the central area with other elements are considered as connected to each element of the delimited area. According to the ANP method, elements with similar meaning are grouped to form clusters, and the groups identified in this case and their relations are shown in the following Figure 9.

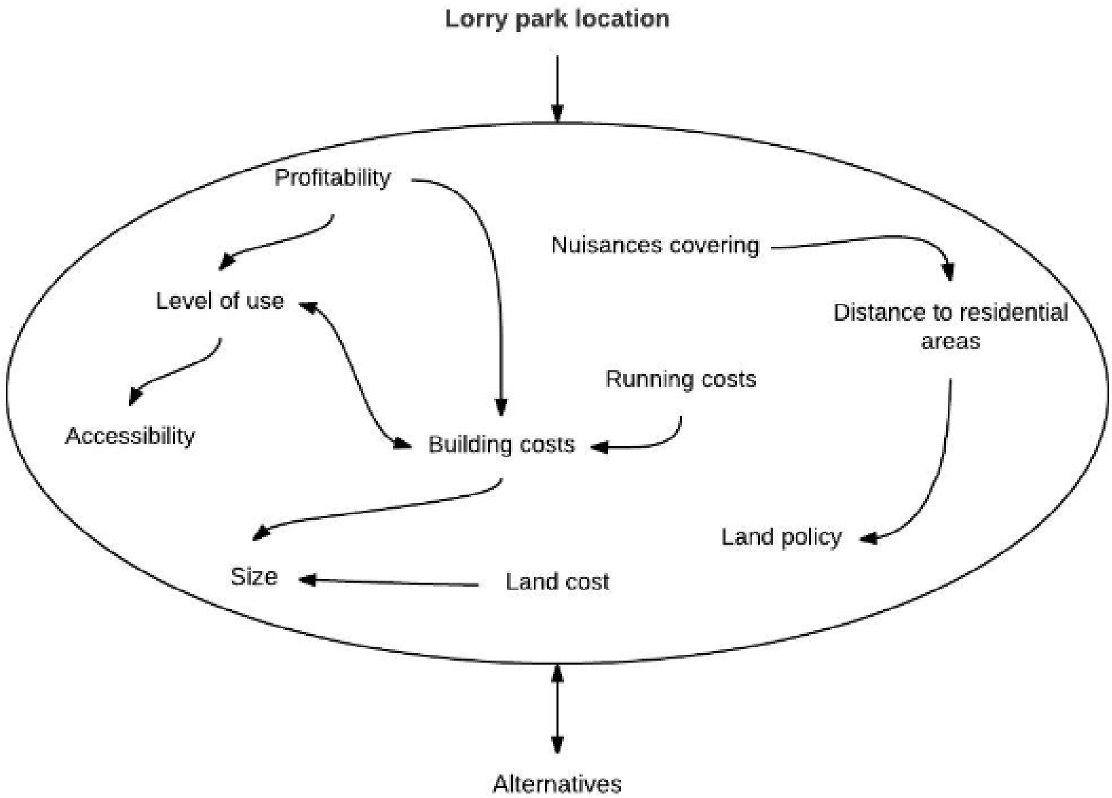

Figure 8 – Analytic Network Process dependency graph

Analytic Network Process cluster graph

In the following graph (Figure 9) the Benefits cluster includes elements that make some form of favourable contribution, whereas the Costs cluster includes those that make an unfavourable contribution, and Constraints includes those elements essential to some extent for the feasibility of the facility.

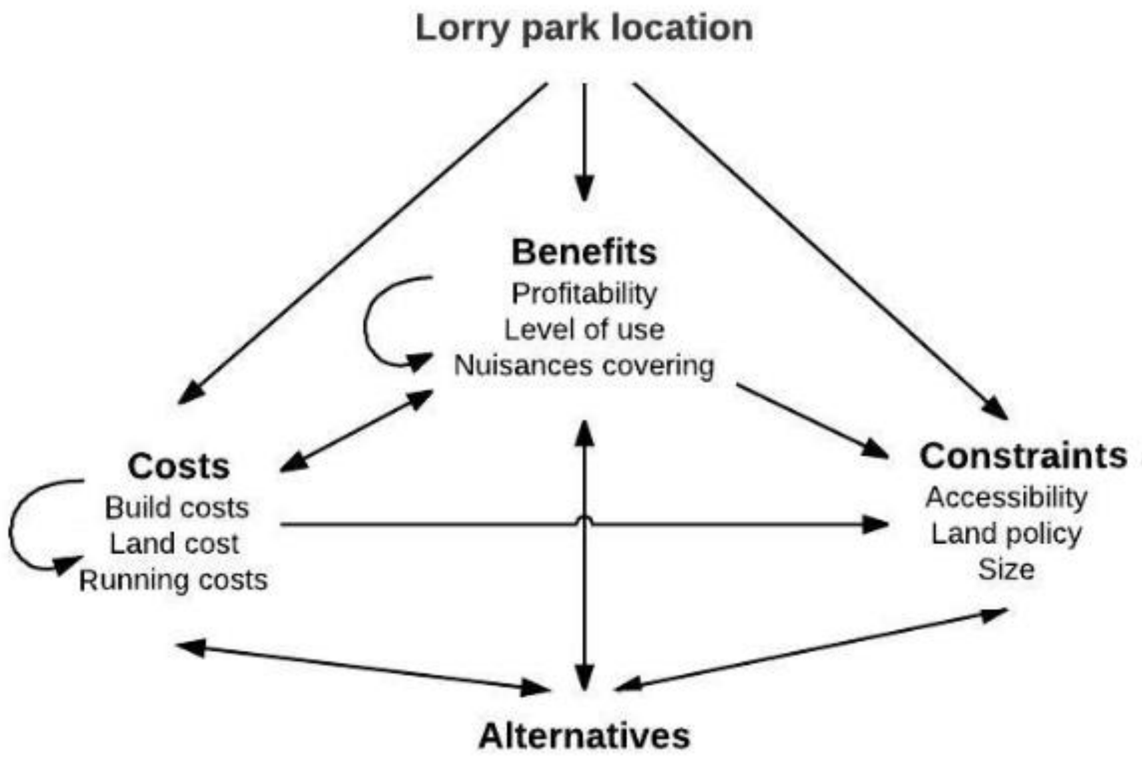

Figure 9 – Analytic Network Process cluster graph

Designing a web-based spatial decision support system

A web-based spatial decision support system (WSDSS) is a web based system designed to assist in the handling and visualisation of geographical data (also called spatial data) relevant to the decision-making process (Sugumaran, 2010). Such software has the potential to deal with a large variety of location problems including those posed by the freight parking location problem. Developing a specialised WSDSS would be an important tool in addressing the abovementioned issues and would also encourage stakeholders' participation in the decision process. Hence, in this section we discuss a possible architectural design for a specific WSDSS to rank the identified alternatives, using the ANP method.

To elucidate how the WSDSS should operate, the next subsection gives a generic description of the interaction process between the user and the software. We then give specifications of the components considered necessary in the current case and the technologies best suited for dealing with each component.

WSDSS general process description

The process described in this section can be followed on Figure 10. The first web page provides a map that the user can navigate to select the area of interest for the location problem. Once the area is selected the software identifies all spatial data sets in that area already present in the software database and enables the user to select spatial data sets relevant to the location problem. If the existing spatial data are not sufficient to model the location problem, users can also add or create their own spatial data set using Geographic Information System (GIS) tools, and new spatial data sets can be stored on the user online library for future use. All spatial data sets in use can be visualised on the web map, which makes it easier for the user to select an appropriate existing ANP dependency model and modify it to best match the decision problem or to create a completely new model. When possible each criterion in the model should be associated with one of the spatial data sets to minimise the qualitative comparison needed, which will speed up the pairwise comparison phase. When the user has completed the dependency model the software can then generate the comparisons tables for filling in. The comparisons tables and the dependency model can be also shared with other users, a facility which allows participation of stakeholders and experts in the decision-making process, through inputting their own opinions into the tables. Involving stakeholders is particularly important in cases of public decisions, where a single problem can affect a multitude of people, who could have an interest in directly influencing the decision process. Once all the interested persons have had the opportunity to fill in the tables, the software uses a mean to synthesise all the input values and fill in the comparison matrices that will be used for subsequent calculations.

Process chart

The stakeholders' judgements could also be seen as a survey giving insight on the general perceptions of the problem under consideration. Based on the filled in comparisons tables the software calculates the main output of the software, the priority vector of the alternatives, which should also be represented as a results layer on the web map, where each alternative is represented based on its final score. To ensure the overall transparency of the decision-making process, the model and all spatial data sets and tables should be made accessible to the public through on-line sharing.

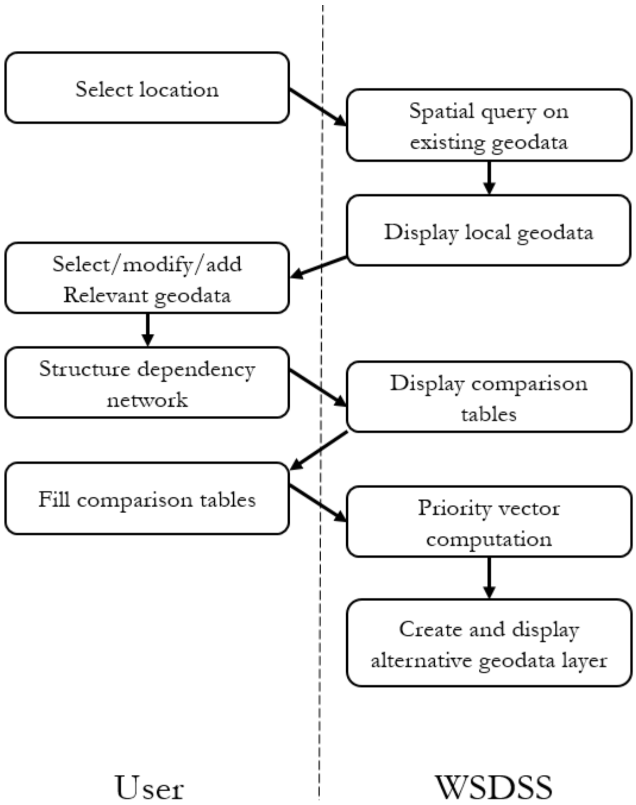

Figure 10 – Process chart

Proposed WSDSS architecture

The proposed WSDSS architecture is schematically represented in Figure 11.

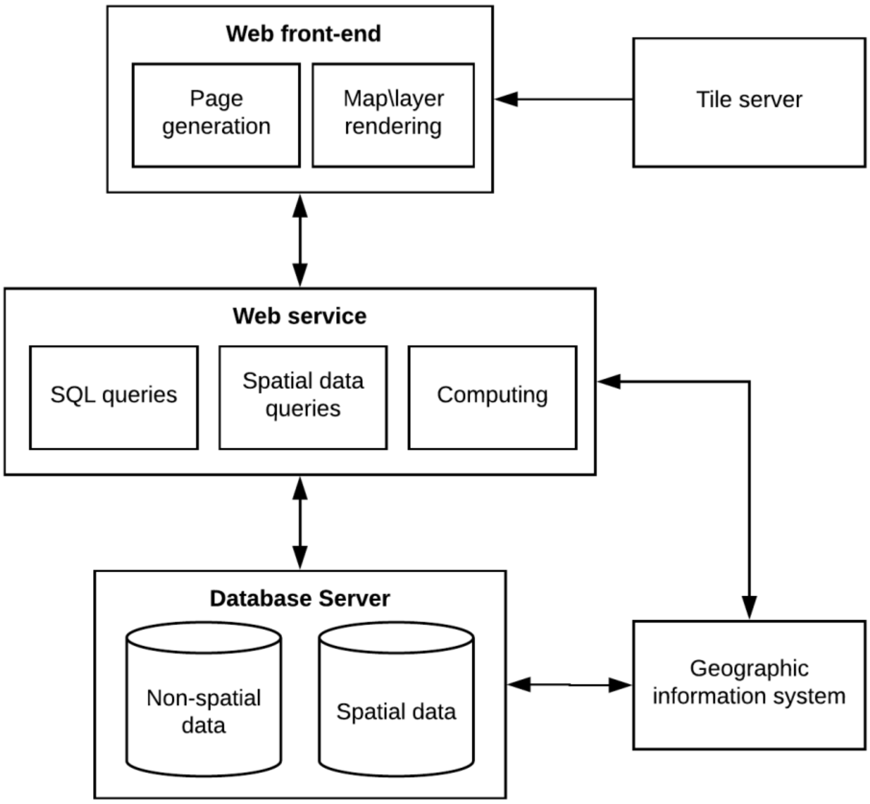

Figure 11 – WSDSS architecture

Python is the programming language suggested for the software development due to its flexibility and easy integration with all the components. The front-end of the software oversees the interaction with the user and is responsible for the acquisition of inputs that are then sent to the appropriate component. We also suggest using Flask web framework for the main development of this component. Flask is written in Python and has a simple, easy to use core, but supports a large variety of extensions capable of doing everything necessary. A popular way to display and navigate maps on-line is via the tiled web map, also called simply the map, which is constructed through seamless joining of individual small image files. The tiled map has several advantages over older methods which usually display a single large image; for example, when the user moves around on the map only new tiles are loaded but most of the tiles can be kept displayed, which greatly improves the movement fluidity compared to loading a single map image for the whole view-port.

For this kind of map, it is essential to use an existing public tile server or build it with Mapnik, a free tool-kit for developing mapping applications, preferably Mapnik because it allows greater customisation. Mapnik is written in modern C++ and has Python bindings. Then the map generated by the tile server and data layers coming from the web service component can be downloaded and displayed using Leaflet. Leaflet is an open source JavaScript library widely used to build web map applications. All the shaping tools for spatial data layers displayed in the front-end should be connected with tools accessible on QGIS, a geographic information system application that supports viewing, editing, and analysis of spatial data.

The data created needs to be stored, and PostgreSQL is a classic choice in Python for storing data with fixed structure such as: users account information, past queries, model structures, etc. PostgreSQL can be extended with PostGIS to support specific spatial data storage tasks, allowing location queries to be run in Structured Query Language (SQL).

The last and arguably most important component is the web service, which can deal with all the logic necessary in this WSDSS. The web service should be written in Python and extended with libraries for each specific task. SQLAlchemy is an open source SQL toolkit that is commonly used to retrieve and query SQL databases, and which needs to be extended with GeoAlchemy 2 to add support for spatial data. Once the pairwise comparisons have been submitted by the user, the web service can, by using NumPy library, deal easily with the large matrices generated and compute the final priority vector.

The priority vector for the alternatives is then sent to QGIS to generate spatial data that is displayed on the front-end map as a final result.

A summary of the potential technologies to be utilised for the software implementation of the tool is shown in Table 3.

Component	Technology	Motivation
Tile server	Mapnik	customizable
GIS	QGIS	open-source, easy integration with Python
Page generation	Flask	easy, supports extensions
Map/layer rendering	Leaflet	open source, small code footprint
SQL queries	SQLAlchemy	efficient, high-performing database access
Spatial data queries	GeoAlchemy 2	extensions for spatial database access
Comuputing	NumPy	supports the calculation of large matrices
Database	PostgreSQL	advanced relational database
Spatial database	PostGIS	extensions for spatial database

Table 3 – WDSS components and suggested technologies

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Towards a Decision Support System for the strategic design of Urban Consolidation Centres

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Introduction

Even if the concepts of City Logistics and Urban Consolidation Centres have been around for a very long time, the impact on the logistical practice of these has been very limited to date. Many initiatives have been implemented by municipalities across Europe in the field; however, the success of such initiatives has been questionable. This is due to a variety of reasons that can be listed as follows:

- Most of these initiatives were developed on the basis of very limited understanding and partial data about city logistics. Indeed, most of the focus has been about distribution to retail stores and similar establishments; however, this just constitutes a fraction of the logistical flows happening within urban areas, often already involving some form of consolidation from the shipper. Traditionally, other forms of flows (such as the ones related to construction materials, waste management, materials needed in the facilities management cycle, catering industry remained out of the picture).
- UCCs have traditionally failed to attract stable and significant revenue models that could be attractive for the whole set of stakeholders involved; for instance, delivery operations involving the usage of an UCC might end up being significantly more expensive for shippers, failing to create a convincing economic case.

- UCCs operations can be significantly affected by political decisions; often, in the European context, local political situations might be uncertain and volatile, producing significant changes in the administrative landscape. This is not ideal for the stability and certainty requested for the success of UCCs.

UCCs can certainly be valuable facilities, but they should not be seen as a quick *one-size fits all* solution for any sort of problem related to logistic in urban areas.

As highlighted by Lagorio et al. (2016), so far UCCs effectiveness has been assessed mainly through multiple or single case studies analysing best practices and pilot projects. However, little is reported about the reasons for the failure of such facilities; being very difficult finding information on failed UCC projects and initiatives.

Empirical evidence suggests that their design and implementation should be guided by a careful assessment of their estimated impacts. For this reason, the availability of adequate tools, capable of addressing also strategic issues (for instance, related to the investment planning phase) rather than just operational ones (concerned with the day-to-day functioning of already established logistical platforms) could be of interest to stakeholders involved in the policy- and decision-making process.

These notes have been put together during several secondments undertaken by researchers from the University of Sheffield to Softeco Sismat, which took place between June 2017 and April 2019 at the company's sites in Genoa and Naples (Italy). They constitute an initial reflection about further work which is currently being performed, thanks to further secondments within the ProSFeT project. Such notes start from the analysis of the current software package (eMILE) offered by Softeco Sismat, and analyse how this could be turned into a strategic DSS which could be used to perform crucial decisions about the implementation of UCC solutions.

eMILE: a Decision Support System.

Softeco Sismat is currently distributing a software package named *eMILE* (Softeco Sismat SRL, 2017; see Figure 12), which deals with the management of Urban Consolidation Centres (in the following, UCCs).

Figure 12 – eMILE screenshot

Currently, the main functionalities of the package can be summarised as follows:

- *Load consolidation and mission planning*. Incoming goods are represented at a fine level of detail, with the possibility of breaking them down into single parcels and specifying weights constraints. Incoming vehicles are then unloaded and virtually *unpacked*; considering their due dates and the location of customers who are requesting these products, items are then sorted and assigned to outgoing vehicles (typically low-emission vans).
- *Optimisation: delivery plans, routes*. Outgoing vehicles are assigned a load, based on considerations that involve the due dates of related orders and the location of customers. Once this step is finalised, the routing for these vehicles is developed.

- *Delivery operation*. *eMILE* allows keeping track of other operations, more strictly concerned with fleet management aspects, such as vehicle dispatching, vehicle location, fleet monitoring, track-and-trace.

eMILE operates on a customised library of maps, that allow a detailed representation of the road network. This is the setting where problems are solved.

From a Decision-Making point of view, the optimisation routines at the back of *eMILE* work according to the following assumptions. The objective function is generally a measure of operational cost of the vehicles. Constraints include the following aspects:

- A limitation on the capacity of the outgoing vehicles, which must not be exceeded. Currently, the capacity is mainly expressed in terms of weights (as this is thought to be the most constraining aspect; excessive loads have the potential of damaging the functionalities of the vehicle).
- An upper bound on the maximum distance that a vehicle can cover during a single delivery route (depending on the characteristics of the vehicle itself). This constraint is particularly relevant if low-emission delivery vehicles (for instance, electric) need to be considered. In this case, indeed, the limited battery life can represent a serious limitation that needs to be taken into account for arranging delivery plans.
- The possibility to specify requested delivery time windows for outgoing orders; these produce very binding conditions for the arrangements of delivery plans.
- Also, times of unloading and loading operations can be specified, in order to get more realistic solutions and a better representation of delivery times.
- Thanks to the extended mapping capabilities, the possibility of reproducing, on the network, pedestrian areas, low-traffic zones, temporary closures, and other sort of variations that might affect the delivery routes.

- The possibility of reproducing, on the network, *service areas*, in order to specify districts of the territory under investigation that could be served by specific vehicles or to be given special priority.

As regards the flow of materials within the UCC, *eMILE* gives the user the possibility of specifying different states. Items are *received*, then inspected and *checked-in*, when they become ready for being assigned to a delivery mission.

eMILE appears to be extremely well-suited for representing and solving *operational* decision-making problems happening at Urban Distribution Centres and related to their day-to-day functioning. The next sub-section describes potential improvements which have been identified; such improvements could highly enhance the suitability of the package to real-world situations.

Identification of potential improvements

This sub-section discusses the potential improvements which have been identified and discussed for *eMILE*. Such improvements are classified in operational and strategic ones; details are illustrated in the following.

Operational Improvements

As regards the operational and day-to-day functioning of an UCC, the following aspects are to be investigated, as these could be representing improvements for getting a more detailed and advanced decision support tool:

- The representation of the *inbound* side of the UCC could be improved. The scheduling of the arrival and processing of inbound trucks should be taken into account, as this can be a very constraining process, especially if resources devoted to the receipt of incoming shipments are limited, and congestion at the entry point might arise. This can affect the availability of goods that need to be shipped for the last-mile delivery (given that, supposedly, most of these goods will have a due date). The synchronisation of incoming and outgoing orders is a fundamental step (and it is the current major trend in the optimisation literature concerned with cross-docking problems).

- Currently, the tool does allow specifying volumes of parcels; however, this is not taken into account when formulating the delivery missions. This could be a serious limitation when fragile products and items need to be considered, as typically these products are stored in much larger parcels (involving extra layers of packaging) for safety reasons. Of course, capturing this element would increase massively the computational complexity of the optimisation problems to be solved, as, in order to produce feasible delivery plans, a bin-packing problem should be preliminarily solved; since these problems (especially in their 3D version) are particularly complex, a simplified check on volume capacity (just pointing out that unfeasibility might arise as the result of the combination of some items, when suggesting the delivery missions) could be a good compromise at this stage.
- It is not clear how the model deals with the maximum distance constraint on the single delivery route. Clearly, this is influenced sharply by the type of vehicle; also, road distances might not be the sole parameter to take into account when dealing with this issue. Indeed, road conditions (in terms of slope, surface, congestion, obstacles) could have a dramatic impact too. At the moment, *eMILE* is just considering a normal travel distance value; more complex measurements could be utilised in order to get a more realistic estimate of fuel/battery consumption dynamics, and to produce a more accurate solution to routing problems.
- It is not clear if the model captures the issue of the availability of charging stations and charging times for electric vehicles at the UCC. Clearly, this has the impact on the immediate availability of vehicles. The implicit assumption is that vehicles are charged

overnight, or that there are enough charging stations given the size of the fleet. This could be improved.

- Flexibility in handling different types of products should be improved. For instance, at the UCC flows involving food items and other perishable goods might be processed. This is a very common usage of this type of facilities (especially in historical towns, where there is the need to supply grocery stores and catering establishments). In UCC facilities, this involves setting up a very strict policy, where no intermediate storage at all is allowed.
- Since the whole objective of implementing last-mile delivery systems is concerned with the alleviation of the environmental burden created by logistical activities, it would be good to capture explicitly environmental benefits in the system. This could be easily done by extending *eMILE* with some sort of Life-Cycle Analysis (LCA) capability, that could associate environmental impacts with the different stages of the UCC operations. In the simplest way, some key environmental indicators could be included in the tool; *intensities* for common processes across such indicators could be retrieved, in order to produce some simple LCA reports.
- At the moment, *eMILE* seems to be focused on settings where just a single UCC is operating. However, in larger cities (especially in presence of very densely populated areas), this could be an unrealistic assumption. Multiple UCCs could be operating at the same time, with specific UCCs serving specific areas. This could significantly increase the complexity of problems being dealt with, as more sub-problems would arise, such as: assignment of trucks to UCCs, optimal design and assignment of service areas for the UCCs (as a sort of *districting* problem), definition of *transfer services* among UCCs.
- Currently, the possibility of managing the flow of materials *within* the UCC is left to the user, who has to manually update the states of the incoming goods. In some circumstances, especially when operations of an UCC become busier, users might want to get some

suggestions about goods processing sequences (for instance, understanding, based on required delivery due dates, which goods should be checked-in first).

- Staff scheduling issues are not explicitly implemented at this stage. It is possible to include drivers as resources in the system. These could be further interesting aspects to be explicitly included in the planning cycle (including constraints such as the unavailability of drivers, the requirement to achieve a balanced load across the set of considered drivers).

Also, it would be useful to implement alternative objective functions (for instance, minimising the number of utilised vehicles or minimising the variance of the loads assigned to each single vehicle) and employed algorithms for solving it (even though modifications are outside of the scope of this project, this could be looked into for future purposes).

Strategic improvements

Another side that would deserve some form of investigation is the possibility of turning what at the moment is a very operational tool (mainly designed for companies managing UCCs) into a strategic decision support system (that could be utilised also by other stakeholders in the industry). In particular, some sort of *scenario planning* functionality could be very useful in the phase of strategic design of an UCC. In this specific functionality, a decision-maker (who, for instance, could be a transport planner in a city council) could just insert some hypothetical demand for the last-mile delivery services (in terms of typical incoming trucks per day and number of customers that need to be served, with their operating time windows). The tool could then provide an indication about some issues that need to be considered in the planning stage for the design of an UCC, such as:

- The location and recommended number of UCCs to be located in the urban area under investigation.

- The required fleet size to be operational at the UCC (and, consequently, the number of charging stations needed for them, in case of electric vehicles).
- The number of incoming and outgoing doors that are needed for the UCC, and, consequently, the overall area required for the warehouse.
- Workforce planning issues (required drivers, warehouse operatives and other workers required for the functioning of the warehouse).
- A measure of the savings (in terms of cost, of overall travel distances and of environmental impacts) that the implementation of the UCC could imply.
- A minimum level of subscription to the services offered by the UCC in order to have viable operations from a financial point of view.

Assessing all these dimensions, such strategic Decision Support System could:

- Facilitate better informed decision-making in the planning stage (for instance, by providing useful elements for identifying a suitable area for the site);
- Provide a rough but helpful estimate about the investment required for setting up an UCC facility (in many cases these estimates are produced by utilising very unreliable models that are completely detached from the way in which such platforms will work in the reality);
- Provide an initial estimate about financing and cost-sharing options in the long run, in order to ensure the sustainability of such facilities.

Evaluation of possible spin-off tools for educational purposes

Another potential focus area for ProSFeT activities could be the development of an *educational* version of *eMILE*. Currently, the system has very similar features to the ones provided by similar packages (that are not much focused on last-mile delivery, though) such as LogVRP (2017) and Routist (Fleetmatics, 2017).

Specifically, this version could be equipped with a limited number of test-maps pre-determined locations for UCCs, and with some pre-loaded incoming orders (with the option for students to customise these). Students could then play with the tool, experimenting its functionalities related to the load consolidation and mission planning, optimisation and delivery operation stages. The educational version of the tool could be proposed to educational establishments delivering courses on Logistics and Supply Chain Management, Transport, Urban Planning. Also, an appropriate version of the tool could be developed for setting up an appropriate Lifelong Learning Programme (such as an *Erasmus+ Knowledge Alliance*) that could be targeting logistics and transport planners working at local city councils.

Dialogue with Local Authorities and Trade Associations

Within the ProSFeT project, there several interaction opportunities with Local Authorities have determined the practical usability of the current version of *eMILE* and its potential usefulness to a variety of stakeholders. Furthermore, several local authorities have expressed interest in the development of *eMILE* into a strategic Decision Support System, which could be extremely useful in order to validate their plans in terms of Sustainable Urban Logistics solutions. During further secondment periods involving Softeco Sismat both as hosting and sending organisation, interactions between company staff, researchers, and stakeholders from the urban freight transport sectors are being organised. This is helping the ProSFeT team to identify the needs of Local Authorities both in terms of Decision Support Systems (thus informing the development of modifications to eMILE) and dedicated training packages (thus informing the development of a purpose-made offer). Nevertheless, some of the suggested improvements cited in this note were identified as critical to the success of a decision support systems in the field of urban logistics by previous literature (Fusco and Valentini, 2006; Gonzalez-Feliu et al., 2014).

In order to foster the upgrade and upscale of the tool, the migration towards a *cloud-based* version of the system is probably required.

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Conclusions – Overcoming the Dichotomy between Theory and Practice

Alternative delivery modes, time-based strategies and urban consolidation centres are some of the main solutions being utilised by local authorities for addressing freight mobility challenges in urban spaces. Some of these solutions (such as UCCs) are becoming increasingly attractive options within Europe and one that is being embraced by local authorities across board. However, a significant drawback to the implementation of such solutions is represented by the high set-up costs and the subsequent operations priority assignments once running (Browne et al., 2005). Additionally, the implementation of urban logistics solutions can create stakeholders conflicts as carriers' operations might be significantly disrupted (Van Duin et al., 2016).

Given the relatively low success rate of urban logistics initiatives (for instance, UCCs) especially in mainland Europe, contemporary and future initiatives have to be based on careful planning and on the usage of appropriate DSSs for maximising success rates. The successful case studies suggest that these elements of implementation are critical and the successful application of appropriate decision support systems is crucial to the implementation.

Unfortunately, at the moment, approaches developed in the academic literature (mainly tested on numerical examples or on ad-hoc case studies) exhibit a low degree of transferability to real-world situations; at the same time, the lack of general-purpose systems aimed at decision-aiding in the field of urban logistics means that local authorities need, in most of the cases, invest significant resources in the creation of ad-hoc tools that might not be reutilised for future projects. Also, such investments might be problematic in an era of austerity, cuts to public expenditure and limited budgets.

Based on initial conversations with public sector stakeholders involved in the ProSFeT project, it emerges that a critical area for impact would be the possibility of turning *common operational tools* (designed, for instance, for the management of existing systems, such as UCCs) into strategic decision support systems (that could be utilised also by other stakeholders in the industry).

In particular, scenario planning functionalities would be very useful in the phase of strategic design of urban logistics solutions.

As such, the development of core strategic tools that offer decision support beyond operational levels is critical to advancement in the field of sustainable urban logistics. Such strategy-based tools with capacity for scenario planning and optimal resource and stakeholder prioritisation can effectively move local authorities beyond the complexities of the many operations tools into single user friendly and optimal decision frameworks.

Building upon gaps identified in Deliverable 2.1, work presented in this report has highlighted some of the practical work undertaken for aiding local authorities in implementing sustainable urban logistics (SUL) initiatives through the development of Decision Support Systems. Two cases of practical custom-made DSS implementation for two UK Local Authorities have been discussed; also, the analysis of the strategic redevelopment of a software package currently offered by Softeco Sismat (an Italian software house who is a beneficiary of the project) has been presented.

The preliminary work illustrated in the following contributions will support the final deliverables for WP1, 2 and 4 of the ProSFeT project.

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