THE NEW MOBILITY DATA AND SOLUTIONS TOOLKIT (NUMIDAS): SHARED-MOBILITY SERVICES USE CASES IN MILAN AND THEIR TRANSFERABILITY

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1. INTRODUCTION

The mobility ecosystem is rapidly evolving, whereby we see the rise of new stakeholders and services. Examples of these are the presence of connected and automated vehicles, micromobility, and MaaS (Mobility as a System) ecosystem. Through an iterative approach, nuMIDAS creates a tangible and readily available toolkit in the form of a dashboard. nuMIDAS, started at the beginning of 2021 under the Horizon 2020 programme and it is being developed by a European Consortium, composed of 9 partners from 6 countries: Belgium, Czech Republic, Greece, Italy, The Netherlands, and Spain. In order to provide a geographic coverage of the EU, project actions are implemented in four pilot cities: Barcelona (Spain), Milan (Italy), Leuven (Belgium), and Thessaloniki (Greece).

Sharing mobility is one of the strategies that cities are using to reduce motorisation rates and car ownership, especially in large urban centres. The city of Milan, through its Agency for Mobility, Environment and Territory (AMAT), partner in the project, has identified two main challenges for the future of sharing mobility. The first one is the

definition of a fleet (for each mode of transport) of sharing vehicles that is, at the same time, able to satisfy user demand and guarantee a profit for the operators offering the service. Whereas the second one, concerns the identification of operational zones for each mode of shared transport, which also include areas where operators' profits are often lower.
The paper, after outlining the methodology of development of the algorithms (tools) on sharing mobility, describes the case study of Milan and tests, through a series of simulations, the two tools implemented.
Finally, in order to have a wider dissemination of the project results, the approach for the transferability of the methodology used for the realisation of the algorithms is briefly described.

2. METHODOLOGY

In recent years, new technologies have enabled the implementation of new forms of mobility (sharing mobility, micro-mobility) which have generated new forms of data and new needs (e.g. new algorithms, user-oriented development). For these reasons, within the nuMIDAS project, the use case methodology was used, which was able to respond to these needs also thanks to the realisation of computer tools to be visualised within a dashboard.
Use cases constitute a well written description of how a person who is involved in the system could accomplish its goal by following a specific process. In other words, a use case is the interrelation between the user and the system focusing on the prerequisite steps that a system must follow so that the user achieves the final desired result (Leffingwell and Widrig, 1999). Additionally, according to Booch et al. (1999), a use case is a description of a sequence of actions, including variants, that a system performs to yield an observable result to an actor. Use case modelling is a very useful and concrete technique to depict and illustrate the entire process to be followed for the development of a tool. By designing in a rigorous and explicit manner the use cases of a tool, many benefits may arise. Firstly, once the use cases are explicitly and elaborately designed, the manner and order of the tasks and activities to be carried out by the tool becomes readily observable. Furthermore, the process of identifying and presenting user needs and requirements get easier and more readily understandable by any stakeholder. As it has been already mentioned, any person or other (external) system can contribute to the final outcome of the tool. In this respect, the documentation of such intervention(s) facilitates transparency and understandability of the outcomes of the tool on behalf of all stakeholders (Leffingwell & Widrig, 1999). The first step for the design of the nuMIDAS set of methods and tools (hereafter referred to as the nuMIDAS toolkit) is the identification of the scope of the use cases to be addressed. This scoping exercise follows an agile approach consisted of two iterations. The first iteration includes the initial definition of the use cases scope taking as input the outcomes of: 1) a close cooperation and discussion among the project's partners, including representatives of the project's pilot cities (Milan, Leuven, Barcelona, Thessaloniki), focused on the problems faced by these cities; 2) a questionnaire sent to these cities partly oriented to gather input concerning the desired

purpose and functionalities of the nuMIDAS toolkit, the shortcomings of any currently utilised methods or processes, as well as data availability in these cities ; 3) the state-of-the-art and business modelling analysis (Pribyl et al., 2021); 4) the outcomes of a survey targeting key stakeholders and experts (Pribyl et al.2021), focusing on the identification of challenges and trends in the urban mobility ecosystem. Subsequently, the results of this iteration were handed over to second iteration in which the contents of the derived use cases have been once again discussed by all project's partners. The main goals of the second iteration are ensuring that the problems reported by the pilot cities are addressed, increase the innovativeness of the nuMIDAS toolkit, and ensure that trends and challenges identified for the urban mobility ecosystem are properly covered. Furthermore, a literature review was performed to provide a critical review of existing methods and tools that are relevant to the project's use cases, which provided useful insight into the design and development process of the use cases (Shchuryk et al.,2021). After the definition of each use case, a flow chart was generated in order to indicate the process flow, which was later translated to software (Python). In the next subsections (2.1 and 2.2.) the Use Case 1 regarding of pre-planning of sharing mobility services and Use Case 2 regarding operative areas analysis will be described.

2.1 Use Case 1-Pre-planning of shared mobility services

The scope of the UC1 is to support policy makers to determine properly the fleet size of shared mobility services to be operated within a given area. In this respect, policy makers will be able to include rational terms and conditions during the preparation of relevant tenders for services within the area of their jurisdiction. The fleet size is determined considering both the perspective of service operators and the perspective of end users. By that means, the suggested value enables the provision of beneficial services for service operators that will jointly comply with minimum level of service requirements, e.g. fleet size will not be extremely large to exceed the desired operational costs and concurrently the end users are adequately served without having to wait for a long time or walk long distances. To this end, the tool provides solution to an optimization problem, which will involve the minimization of an objective function reflecting the total cost of the system. This function is multi-parametric to cover both perspectives mentioned above. The first term of this function relates the time spent by users either to acquire access to these services or to reach their destination by using these services with the value of their time. The second term involves the financial losses of service operators caused by the inability to serve a fraction of existing demand, while the remaining terms will involve the maintenance, operational, and capital costs induced by service operators. This optimization problem also includes constraints reflecting the maximum waiting and walking of end users. The parameters mentioned above is either user-defined or approximated by the tool itself using geometric probability distributions. Having defined these parameters and constraints, the tool executes iterative calculations to identify the optimal value for the fleet size. Based on the nature of the micromobility service under investigation (e.g. dockless vs. docked) the tool also identifies and suggest an optimal value for the number of vehicle deposits/stations.

In the context of these services, end users arrive at rental stations to rent a vehicle or book a vehicle via an app at some point in time, they use it for some amount of time, and they either return it in a nominated place (e.g., another or the same station) or drop it off near their destination. In line with the suggestions of Sayarshad et al. (2012) the fleet sizing problem should be formulated considering both the multi-periodic and stochastic dimension of the demand for such services. The multi-periodic dimension implies that the rate of end users arriving at a rental station or requesting to book a vehicle from an app is not constant during a day. In contrast, there are time intervals within a day during which the level of demand is higher (peak period) and time intervals during which the level of demand is lower (off-peak period). The stochastic dimension implies, among others, on the exact time at which users arrive in a rental station or request to book a vehicle is subject to uncertainty. These two dimensions are respected by the first tool of the project's toolkit. Its overall computational flow is schematically represented in figure 1.

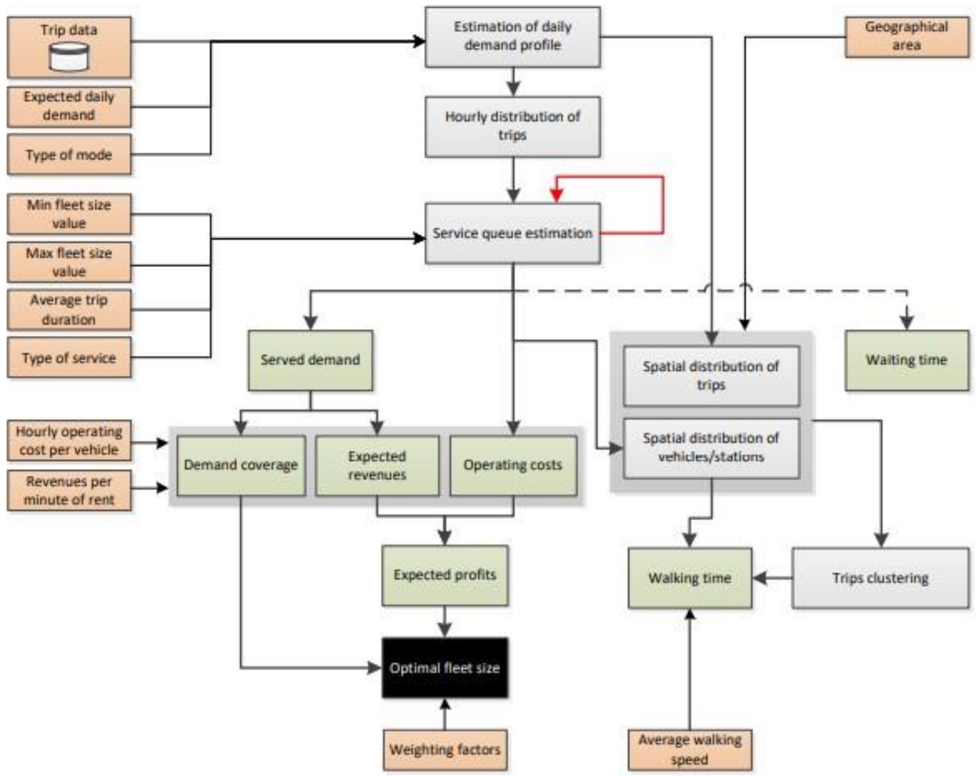

Fig.1 Computational flow of the first tool of nuMIDAS toolkit (Mylonas et al., 2021)

The first step involves the estimation of the daily demand profile. This is achieved through demand factors calculated based on acquired input or implied by the tool itself. In the first case, the acquired input includes historical data from the operation of the same or comparable service within the area of interest or an equivalent area in socioeconomic terms. The demand factor corresponding to each daily interval i (day hour) is quantified through the following formula:

$$DF_i = \frac{\sum_j T_{i,j}}{\sum_{i,j} T_{i,j}} \mid i \in [0,24) \text{ and } j \in [1, N_{days}]$$

where $T_{i,j}$ denotes the number of trips recorded during hour i of day j and N_{days} the number of days for which information is available. In the second case, the demand factors are prespecified through an off-line approach building upon data provided by the pilot city of Milan. Having defined the demand factors, the demand profile is calculated through the following formula:

$$D_i = DF_i \times Expected\ daily\ demand, \ i \in [0,24]$$

where D_i denotes the level of demand (trips/hour) corresponding to each day hour i. The next step of the analysis involves the distribution of D_i during each day hour i. With the aim of taking into consideration the uncertainty characterizing the arrival rate of end users in stations or the rate with which end users demand to book a vehicle via an app, a uniform probability distribution is utilized. The choice of this type of probability distribution is based on the analysis of historical data from taxi services in the pilot city of Thessaloniki, covering a total period of 3 months.

Having distributed the hourly demand, the next step involves the quantification of the number of served demand for each value of the fleet size falling into the range stated by the user (i.e., minimum and maximum fleet size). This quantification is achieved by adopting a queue theory approach. According to this approach, a demand unit (end user) can be served only in the premise that a vehicle is available. Occupied vehicles become re-available after a period of time equal to the average trip duration. Furthermore, it is assumed that end users who are not served until the upper bound of each daily interval disappear from the queue. By that means, the effect of the provided level of service to the level of demand is taken into consideration (i.e., end-users may choose an alternative transport mode if they keep waiting for long). End users are served through the First-In-First-Out (FIFO) principle if the analysed mobility service is station-based. In contrast, end users are randomly served (irrespective of their arrival time) if the analysed mobility service is free-floating.

For the calculation of the optimal fleet size, the decision variables utilized by the tool include the demand coverage and the profitability corresponding to various values of the fleet size. The former is assumed to reflect the perspective of travellers (or end users), while the latter is assumed to reflect the perspective of service operators. From a mathematical point of view, it should be borne in mind that shape of the demand coverage curve closely resembles the shape of a square root function's curve, while the profitability curve is concave. Given that end users always wish to enjoy a greater level of service, the demand coverage curve is monotonically increasing. This does not hold true for the shape of the profitability curve, which is increasing for a lower range of fleet size and decreasing for a higher range of fleet size. This is attributed to the fact that while service operators require a considerable fleet size to serve demand and thus increase their profits, there is a certain value of fleet size beyond which the profits are decreasing given that the utilization rate of vehicles gets steadily lower. Furthermore, for considerable high values of fleet size, the profits may become even negative given that the cost of operating a large size of fleet exceeds the revenue margin of service operators. The optimal solution derives from the weighted combination of the fleet size values corresponding to the optimal solution from the operator's perspective and the second-best solution from the perspective of travellers. The overall formulation of the problem is as follows:

$$maximise\ [(w_{traveler} \times demand\ coverage) + (w_{service\ operator} \times profits)]$$ subject to

$$w_{traveler} + w_{service\ operator} = 1$$

$$profits > 0$$

$$\min fleet\ size\ value \leq fleet\ size \leq \max fleet\ size\ value.$$

On the public administration side, this tool will permit the Municipality of Milan to make analysis within the planning phase of sharing mobilities of the different modes differentiating them also by type, namely, station-based or free floating. Being able to choose the mode of which the analysis is made will allow the public administration to achieve the required level of detail to carry out analysis in the most accurate way possible tailored according to each sharing mode characteristic. Each sharing mode holds a specific authorized fleet size, per minute fare, daily rides and geographic coverage that may differ from each other, in this sense the tender requirements are different depending from each mode.

2.2 Use Case 2- Operative areas analysis

UC2 deals with the allocation of existing shared mobility services' supply (i.e. operable fleets) to specific sub-areas of a metropolitan area. Its goal is to minimise economic losses of service providers while at the same time guaranteeing a satisfactory level of service to the users. The request arises from the observation that in Milan some areas are more profitable than others, even if there is the necessity to delimit service areas that include, not only the city centre, but also its peripheral zones. For this purpose, the tool calculates the operational areas in which operators can implement their services in a large part of the Milan metropolitan area, without losing much of their profit in low-demand areas.

The tool receives as input the value of the fleet size that should optimally be operated in each sub-area from the tool associated with the UC1. Subsequently, the tool is capable of approximating the profitability of service operators during a day for a given allocation of their capacity into specific sub-areas. The suggested value of the operable fleet per service operator and transport mode seeks to optimise the level of service and the profitability of provided services in each area in a manner similar with the tools associated with UC1. Taking into consideration that the land uses in European metropolitan are organized in such a manner so that a city centre exists in each city (and typically city centres constitute attractive areas), service operators may have to overlap within this area.

Being able to assess the operative area where the sharing mobility modes operate geographically in the City of Milan will give the public administration more accurate information to structure more comprehensive tenders. This tool will permit to find a good balance between increasing the geographic coverage of the sharing mobility service and the economic viability for operators. Moreover, the nuMIDAS toolkit will allow planners to test different scenarios and being able to decide amongst specific outcomes when defining tender requirements.

3. MILANO SHARED MOBILITY USE CASES

The City of Milan has a population of 1.4 million and an area of 182km^2, with a density of 7000 inhabitants/km^2. Before the Covid period, Milan mobility systems satisfied the demand of over 4,2 million city users. Moreover, the Milan city area modal split is shown in fig.2.

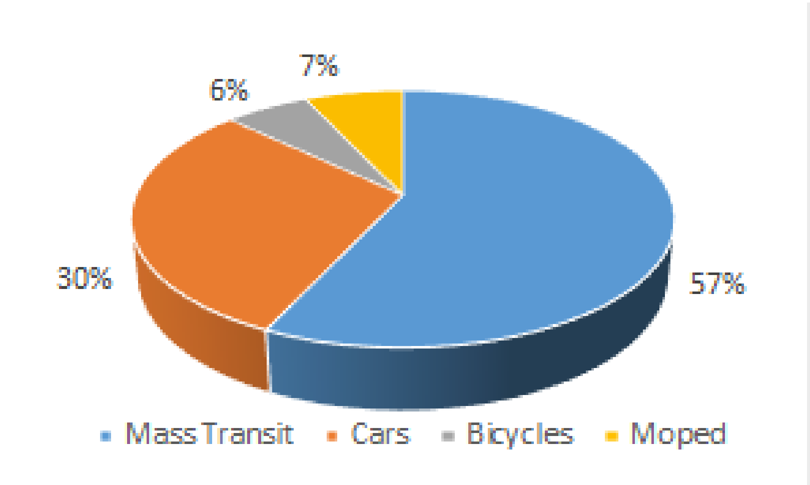

Fig.2: Modal split in Milan (Municipality of Milano,2018)

Regarding shared mobility in Milan, at the moment there are 20 shared mobility services provided by 18 operators divided as presented in Table 1.

Table 1: Shared Services in Milan

Sharing Services	Free Floating (n°)	Station Based (n°)
Bike	3	1
Car	3	1
Kick-scooter	7	0
Moped	5	0

Moreover, as can be seen from Table 2, bike sharing has the largest number of vehicles followed by mopeds. In particular, in the case of both bikes and cars, it is the free-floating mode that prevail.

Table 2: Number of vehicles per each sharing services[1].

Sharing Services	Free Floating (n°)	Station Based (n°)	Total
Bike	11.500	5.250	16.750
Car	2.118	100	2.218
Kick-scooter	4.407	N/A	4.407
Moped	5.250	N/A	5.250

In the next sections, some simulations were run in order to tests and calibrate the tools through the use of data provided by project partner AMAT.

3.1 Application of Use Case 1- Pre-planning of shared mobility services

To assess the validity of the tool, at AMAT's request, the created Python code was tested by simulating three different scenarios with two different transport modes. In particular, station-based bike sharing and free-floating car sharing were tested.

In the next lines the input parameters, that are required to run the tool, have been described (see also tab.3). Specifically, the following data inputs are requested:

- Selection of the type of mode to be analysed (bike, moped, kick-scooter, or car-sharing): it is the mode of transport utilised in the simulations.
- Selection of the type of service to be analysed (station-based or free-floating): this data can only concern bike sharing and car sharing as mopeds and kick scooters are always in free-floating mode.
- Expected daily demand (trips/day): this data concerns the average value of the daily trips made with the selected mode of transport.
- Size of the area of interest (in km2): It is the square root of the area in which the service is present.
- Operating costs per vehicle per minute (in Euros): are the expenses which are related to the maintenance of the car (parking costs, insurance, car maintenance costs).
- Expected revenues per minute of rent (in Euros): these are the earnings that the operator of the service obtains and derives from the payment by the user of the rental rates. Average user walking speed(km/h): it is the average speed of a pedestrian. In this case, the default value is 3,6 km/h.
- Mean trip duration (in minutes): it is the average of the vehicle usage time of a certain mode of transport.
- Weighting factors assigned to service operator’s and end-user's perspectives: the weights are the coefficients that measure the relative importance of single elements (in this case end-users and operators). The sum of the two weights always equals 1.

[1] All data of Sharing Mobility services fleets refer to 31 December 2021 except for Car Station Based that was collected on the 30th November 2020.

- Minimum and maximum value of the fleet size: it is the lowest and highest number of vehicles to be considered as the operational fleet.

Table 3: Input data

Input	**Scenario 1**	**Scenario 2**	**Scenario 2**
Type of mode	Car Sharing	Car Sharing	Bike Sharing
Type of service	Free Floating	Free Floating	Station Based
Expected daily demand (trips/day)	16400	8100	6407
Size of the area of interest (Km2)	14	14	10
Operating cost per vehicle per minute (Euros)	0,05	0,05	0,01
Expected revenues per minute of rent (Euros)	0,29	0,29	0,02
Average users walking speed (Km/h)	3,6	3,6	3,6
Mean Trip duration (minutes)	30	50	16
Weighting factors assigned to service operator	0,5	0,5	0,2
Weighting factors assigned to user	0,5	0,5	0,8
Minimum value of the fleet size	1860	1260	4887
Maximum value of the fleet size	3100	2100	5430

At the end of the calculation, the tool has the following parameters as output (see also tab.4):

- Demand coverage: It is the percentage of the demand that is covered by the service carried out by the optimal fleet size.
- Average walking time: It is the time that it takes a user to reach the closest selected sharing vehicle.
- Average waiting time: It is the time that is needed by the user to arrive at the position of the vehicle.
- Optimal fleet size: Is the combination of the optimal fleer size end users' perspective and optimal fleet size operators' perspective. It depends on the

weight that is assigned during the creation of the scenario.

- Optimal fleet size end users' perspective: The number stands for the optimal fleet size in order to have the lowest value both for average walking and waiting time.
- Optimal fleet size operator perspective: It represents the optimal number of vehicles that maximise the providers' profits.
- Profit service providers: It is the daily profit for a shared mobility provider. This value depends on both the demand and the optimal fleet size

Table 4: Output data

Output	**Scenario 1**	**Scenario 2**	**Scenario 2**
Type of mode	Car Sharing	Car Sharing	Bike Sharing
Type of service	Free Floating	Free Floating	Station Based
Demand Coverage (%)	100	100	100
Optimal fleet size	1860	1260	4887
Optimal fleet size end users 'perspective	1860	1260	4887
Optimal fleet size operators 'perspective	1860	1260	4887
Profit service providers (€)	6.334	25.597	-68.385,2

The simulations conducted refer to some very difficult scenarios. In particular, they refer to the part of the service operators' business plan that takes into account activities purely related to the technical part, i.e. it only takes into account the costs and profits of hiring the vehicles.
Consequently, by not taking into consideration a whole series of possible revenues, such as advertising, the profits that emerged from the simulations, which, in one case, is negative, are to be considered overestimated.

3.2 Application of Use Case 2- Operative areas analysis

Also following the indications of the project partner AMAT, for Use case 2 it was decided to test the free-floating bike sharing service. The input data are some of those already seen for UC1 with the addition of two new inputs (see also tab.5):

- Average trip duration: representing the average duration of trips using the analysed transport mode
- The mandatory areas: these are the zones into which the city of Milan is divided and in which the service must be present.

The algorithm makes use of the origin-destination matrix (related to 380 areas), customized on transport mode, and attractivities of areas to estimate the sharing vehicles demand.

For this tool, which at this stage of the project is in the calibration phase, the test data used by the developers was used.

Table 5: Input Data

Input	Data
Operating cost per vehicle per minute (Euros)	0,1
Expected revenues per minute of rent (Euros)	0,8
Mean Trip duration (minutes)	10
Weighting factors assigned to service operator	0,5
Weighting factors assigned to user	0,5
Mandatory Areas	City Centre (areas within the trolleybus circle)

The tool returns the following output:

- System cost (€): these are the costs incurred by the operator
- System profit (€): these are the revenues relative to the service operator
- Population covered (%): it is the percentage of city population covered by the service
- Served areas: the ids of the areas served by the sharing service in the given scenario.

Since the tool returns all possible combinations of the mandatory areas and the areas to be added, due to length limitations, the following table will show the numerical outputs for the scenario without added zones (scenario 0) and the scenario in which all new areas have been added (scenario 1) (tab.6), instead for the served areas, reference is made to figures n°3 and n°4.

Table 6: Output Data

Output	Scenario 0	Scenario 1
System cost	90288	94608
System profit	332216	348664
Population covered	38%	41%

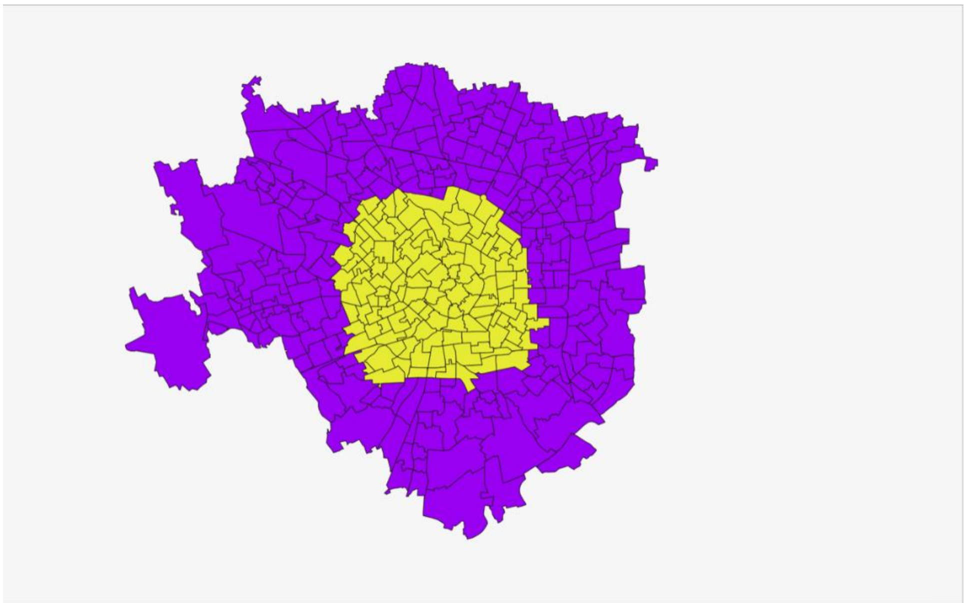

Figure 3: Mandatory service areas (in yellow)

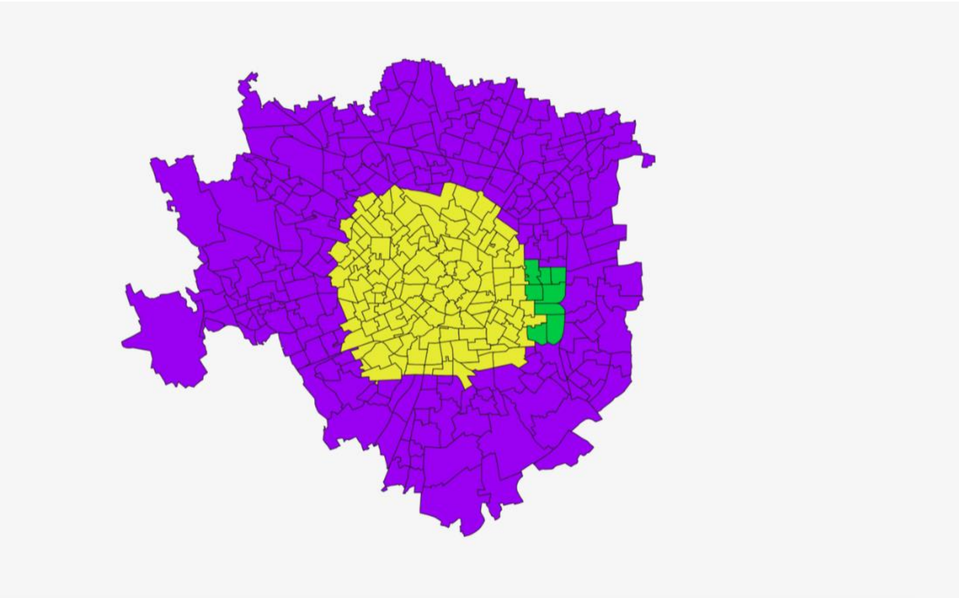

Fig.4: Added areas (in green)

As can be seen from the table, the increase in the areas where the service is present has a double benefit. In fact, the addition of areas allows more people to reach the service, but it also allows operators not to have a loss of profit. Furthermore, Figure 4 shows that the combination with the highest result in terms of service coverage and operator profits is the one that adds 8 zones (in green), contiguous to the mandatory areas (in yellow), in the eastern quadrant of the city.

The tool can help the decision maker to investigate, in an iterative way, which areas are the most likely candidates to be added as operational zones. This analysis cannot be conducted through a single simulation, but the decision maker must perform several analyses by adding different sets of areas in different sectors of the city to the mandatory areas. In this way, once these sets of simulations have been carried out, the decision maker will have a complete overview in order to make his decision.

4. TRANSFERABILITY METHODOLOGY

As regards transferability, each tool was designed and developed to be applied in several pilot cities. In order to maximise the exploitation of project results, and in particular a widespread use of our new mobility toolkit, we will draw up transferability guidelines. These will describe how new cities can implement new instances of the tools within the nuMIDAS architecture framework, and use them for new mobility solutions analysis, assessing, and monitoring.
From an operational point of view, due to the city-specific and location specific parameters and constraints (air quality, origin-destination matrix, etc.), the guidelines will transfer not the models themselves, but rather provide a useful methodology to adapt the model to each city.

For this reason, the transferability methodology will be based on three main types of data clusters:

- Required Data
  - These data must be compatible with the database structure and satisfy certain parameters (format, number and names of fields, units of measurement)
- Default data
  - These are data that are inserted only once into the platform and will be used for each simulation
- Input parameters
  - These are the input data of the individual simulation.

Through this approach, the methodology allows the harmonisation and standardisation of data held by cities, creating data sources that can be used within the toolkit.
However, the detailed structure of the methodology is still being defined and will be presented in the final phase of the project (December 2022).

5. CONCLUSION

The tools described in this paper are certainly important tools for public decision-makers on the topic of mobility sharing. However, since they are decision support tools, their results should not be used so much to monitor the quality and efficiency of the system, but rather, to allow decision makers to know in advance what the effects of decisions that may be made on the sharing mobility system might be. Moreover, thanks to the set-up of the transferability methodology, which will be developed in detail in the coming months, the work carried out on the city of Milan can be transferred, with the necessary adjustments for the different local situations, to other cities where the efficiency of the sharing mobility system is to be improved.

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