22nd International Conference on Modeling & Applied Simulation
20th International Multidisciplinary Modeling & Simulation Multiconference

2724-0037 © 2023 The Authors.
doi: 10.46354/i3m.2023.mas.005

Combining TAPAS and SUMO towards crises management based on traffic data

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Abstract

Human-made crisis and natural disasters are major concerns for the society, as they can put in a risk the life of people. Especially in urban area, which are typically highly crowded, the occurrence of a situation of dangers the consequent change of behaviors due to panics can be difficult it's hard to imagine, which affects the ability to be able to define appropriate countermeasures to mitigate the crisis itself. That's thy the use of digital solutions can be beneficial to support the analysis of such scenario and improve the understanding of the behavior in case of crisis. In this context, our paper focuses on the transportation infrastructures and proposes an integrated solution based on the combination of two simulation tools called TAPAS and SUMO to support the modelling and simulation of mobility scenario. The integrated solution is experimented in the context of city of Darmstadt (Germany) by simulating normal and change of behavior in terms of mobility and showing the deriving benefits.

Keywords: Crisis Management; Digital Twins; Mobility; Simulation; Urban Critical Infrastructure

1. Introduction

Human-made crises (e.g. crime, arson, civil disorder, terrorism, war, biological/chemical threat, cyber-attacks) and natural disasters (e.g. avalanche, coastal flooding, cold or heat wave, drought, earthquake, hail, hurricane) represent extreme dangers for the society and its economy (Zibulewsky, 2001). In fact, they can strongly comprise and even fully interrupt system functionalities and their services (such as energy supply, water needs, mobility), which are essential for the well-being of the citizens. Crises and disasters are characterized by being unpredictable and mostly unavoidable, that's why it is important to cope with their impact especially in urban areas for both the protection of the environment and its inhabitants.

Unfortunately, this is not a trivial task, as it requires to deal with several challenging aspects (Abdulova and Kalashnikov, 2022). For example, it is important to understand (i) what the major urban critical infrastructures (CIs) are, (ii) what the main components and actors in the urban area are, (iii) how they behave, (iv) how they are structured and organized, and (v) how they communicate. Thus, it is crucial to monitor and analyze the whole system over time. By understanding that, one can make efforts towards mitigating their exposure to crises, e.g. by predicting a future state of a system given some starting points and based on that developing strategies.

Transportation represents one of the major urban CI, providing the facilities and services for mobility. The aggregation of all individual transportation of citizens using the transportation infrastructure of a city is called urban mobility (UM) (Zhao, 2015). It includes both social (e.g. travelers) and technical (e.g. the road network, railways) components making it a socio-technical system (Herrmann, 2014), (Stranks, 2007), that is to say, a system in which the behavior of the users/citizens plays a determining role for its proper functioning. Within this system, there are many agents (the citizens) making individual decisions. These decisions concern different aspects of transportation such as routing, transportation mode, and time planning that can be even affected by external and environment phenomena (e.g. by weather).

In crisis situations, the assessment of the situation and the development of measures are the basis for maintaining or quickly restoring such infrastructure. The use of digital-based solutions to map the processes of the city beyond the normal life situation can support decision-makers and crisis management in such situations. In particular, we rely on the use of digital twins (Fortino and Savaglio, 2023), (Lin and Low, 2020) that (i) enable not only the simulation of mobility behavior in the city during a scenario of crisis but also (ii) provide additional support for the assessment of the crisis situation and decision-making process through continuous tracking centered on real-time data, thus accurately representing changing situations

The overall objective of this work is to investigate how simulation based techniques and related tools can be employed to enhance the analysis of mobility in urban environment in order to face with crisis situations and or natural disasters which might affect the transportation domain.

In this context, we propose a solution for supporting crisis situations management based on traffic data in urban area resulting into a Traffic Simulation and Analysis tool. In particular, in the rest of the paper the comprehensive approach to deal with crisis situations centered on traffic data, along with a mechanism to enable their monitoring and traceability and support their analysis through simulation is illustrated. Moreover, the full description of the simulation tool and its simulation components will be provided by highlighting how their interconnections and interactions have been realized. In particular: (i) the description of the Darmstadt Traffic Data will be given incluS, for example, relies on inputs such as a syn- thetic population, activity locations, traffic analysis zones (TAZs), and travel time matrices between these TAZs. For every new study area these data has to be prepared and, even if some processes can be automatised, a bunch of manual work is still needed. A more deep insight in the preparation of a scenario for TAPAS can be found in (?). A scenario was constructed to depict tding how they have been processed and used to specify TAPAS4Darmstadt; (ii) the model behind the Traffic Simulation and Analysis tool for the management of crisis situations in the urban area of Darmstadt will be fully elaborated and its features presented; (iii) moreover, the details of the design of the tool will be provided, with particular focus on the coupling of SUMO, TAPAS and TAPAS4Darmstadt, by highlighting how it has been realized, thus making possible to represent mobility behavior and traffic in the area of Darmstadt under both normal and crisis situations. Finally, a case study will be conducted to show the effectiveness of the proposed solution. The experimentation is conducted with reference to the urban area of Darmstadt, from which the real-data has been extracted and then employed for supporting the design and evaluation of the proposed approach as well as the mobility. How to obtain a continuous picture of the normal and crisis situation during later operation through the connection of various data sources will conclude the discussion.

The rest of the paper is structured as follows: Section 2 provides background information on the main tools that have been used in work, whereas in Section 3 a summary of the most relevant related work has been given. Section 4 elaborates the proposed model, its major components and how they are related to each other, whereas the results of its experimentation, as well as planned improvements, are described in Section 5. Finally, conclusions are drawn in Section 6.

2. Background

2.1. Study area

Our study area covers the city of Darmstadt and two neighboring smaller cities, Griesheim and Weiterstadt, all located in the federal state of Hesse, Germany. Together, these areas boast a population of approximately 200,000 inhabitants.

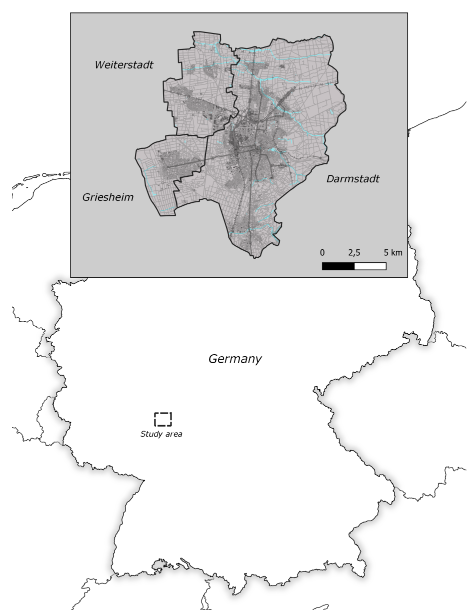

Figure 1. Study area

2.2. Description of TAPAS

TAPAS (Travel and Activity PAtterns Simulation) is an open-source microscopic agent-based travel demand model developed at the Institute of Transport Research (see https://github.com/DLR-VF/TAPAS). It simulates the travel demand of a city or region based on a typical weekday, specifically targeting Tuesdays, Wednesdays, or Thursdays. This choice is influenced by two factors. Firstly,

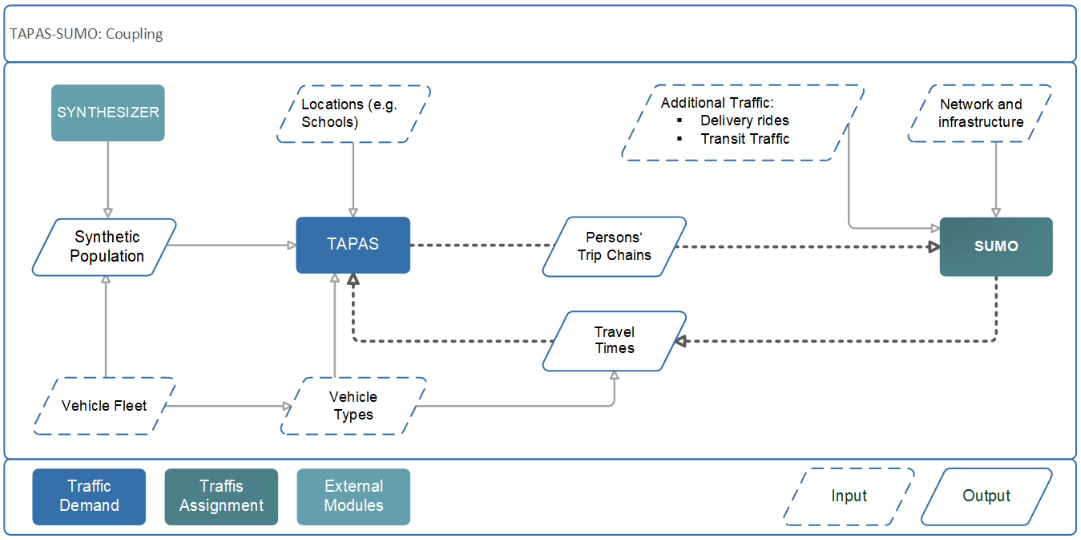

Figure 2. Coupling of TAPAS and SUMO.

weekdays provide a larger pool of available data. Secondly, Mondays and Fridays present distinct mobility patterns due to factors such as remote work, non-working days, and commuting to or from different locations.

In a TAPAS run a daily activity schedule is assigned to every agent of a synthetic population created using the module SYNTHESIZER (more information in Section 4). Then, depending on the type of activity, destinations are assigned, as well as the modes of transport used to reach those locations. Both location and mode choice are based on different models. Furthermore, the travel times are derived from travel time matrices between TAZs (traffic analysis zones) for every mode of transport. The result of a TAPAS run is a table with the travel demand for a whole day, that is all the trips made by the population, as well as their characteristics, such as start and end time, mode of transport or activity on destination. Since the travel times are not yet accurate, TAPAS is assisted in the step of traffic assignment (routing) by SUMO (2.3). Figure 2 shows the interconnection between TAPAS and SUMO, and between TAPAS and the tool SYNTHESIZER.

2.3. Description of SUMO

SUMO (Simulation of Urban Mobility) is a microscopic traffic simulation package with different application areas. For this work it was used to calculate the route of the trips resulting from TAPAS and with it new (more accurate) travel times. In the event of discrepancies in the activity schedules after calculating the new travel times, new schedules will be recalculated or adjusted. Each road user is simulated individually. This requires a description of the infrastructure used (e.g. road network, traffic light switching) that is as realistic as possible. Moreover, it is possible to analyze different scenarios on the basis of changes in travel demand and changes in the transportation infrastructure (e.g. blockages) Lopez et al. (2018).

3. Related Work

In this section, a summary of the previous research contributions, which deal with transportation domain and related tools for supporting the analysis of urban mobility, is provided.

The work in Ito et al. (2018) dealt with simulation of society on large-scale with particular focus on traffic and crowd simulations. On the one hand, agent-based paradigm has been employed to support the modeling of the behavior of vehicles, drivers, and pedestrians, whereas holon analogy has been adopted for modeling structure of the system. Unfortunately, little attention has been paid to the experimentation phase, in fact a greater description of a specific scenario, for example, linked to a crisis situation, would have allowed a better understanding of the benefits of this tool.

Whereas, a different aspect has been investigated in Chapuis et al. (2022). In particular, the study of a mass evacuation scenario in an urban area has been carried out by proposing an agent-based model that uses a traffic submodel in order to represent mixed and non-normative traffic. Such model were then used to support the evaluation of different strategies for the evacuation of the population. As the assumptions for the evacuation scenario do not include any time-dependent variation of the population distribution the significance of the results is limited.

Morshed et al. (2021), Khaghani and Jazizadeh (2017), and Fan et al. (2021) focus to different degrees on the measurement of resilience in the mobility sector.

A model called "8R Resilience Model" - centered on the principals of 'Redundancy', 'Resourcefulness', 'Reliability', 'Robustness', 'Responsiveness', 'Recoverability', 'Replacement' and 'Rendition'- for assessing transportation infrastructure and network resilience has been proposed and presented in Morshed et al. (2021). Although the potential of such solution, the adoption of a statistical approach limits in our opinion, the study of the phenomenon under consideration, in terms of understanding its dynamic, what-if analysis, as well as emerging behaviors, which instead are typical of complex systems and consequently observable with more advanced analysis tools such as simulation techniques.

The other two papers evaluate the resilience in urban transportation with the help of concrete examples.

In particular, Khaghani and Jazizadeh (2017) defined a framework consisting of 2 layers: (i) a People-Centric Contextual Data Layer that was centered on collecting data from Waze geosocial network through the Twitter feed; and (ii) a Resilience Evaluation Layer, which was based on a probabilistic approach in order to quantify the resilience of the system. While the experiment was carried out in the Washington, D.C. metropolitan area, the measurements for evaluation are limited to three regions in the area. Due to the chosen data source only car traffic is included in the framework, thus excluding other modes of transportation. These limitations only provide limited hints to complex phenomena, especially when such phenomena are dynamic such as the mobility and the related urban infrastructures.

In contrast, Fan et al. (2021) conduct their analysis on the whole Houston area and use data from the 2017 hurricane Harvey to estimate the performance of their approach. With the help of adaptive reinforcement learning they define a model to be able to learn trajectories of human mobility under normal circumstances. With adaptions to their model they derive mobility patterns in the context of the flooding after hurricane Harvey. The comparison of the patterns with real world data from the crisis show a precision of 0.76. As with many machine learning applications, there are certain limitations to this model as well. Instead of the real traffic network the model uses a grid overlay for the study area and only takes trips with a minimum distance between origin and destination into account. Also the output does not contain any information about the modal split of the mobility pattern.

In Zhang and Zhang (2022), the authors focus on the role of digital twins in the transportation domain on the basis of the digital twin of Wellington, New Zealand. The authors highlight the main differences and benefits in comparison to conventional simulation techniques. In particular, they point out some aspects enabled from digital twins, such as: (i) including the public during the design phase and to received feedback from it, (ii) making the spatial simulation more efficient; and (iii) assisting the design of the transportation system in a more interactive way. In contrast to other models, which often focus on car traffic only, the presented work includes multi-modal transportation systems. Despite the authors' discussion, unfortunately the work provides neither examples for the benefits in crisis scenarios nor experiments about the predictability of future traffic development.

As it is possible to notice, many research efforts are in progress related to the modeling of urban mobility. Some lack in evaluation, others focused on the conceptual part, still others faced different scenarios. In the next section, an approach based on the combination of two traffic modeling tools with particular reference to crisis situations is described.

4. A Traffic Data-based Model for the Evaluation of Crisis Situations

Travel demand models, particularly microscopic models, require detailed data to depict complex transportation patterns. TAPAS, for example, relies on inputs such as a synthetic population, activity locations, traffic analysis zones (TAZs), and travel time matrices between these TAZs. For every new study area these data has to be prepared and, even if some processes can be automatised, a bunch of manual work is still needed. A more deep insight in the preparation of a scenario for TAPAS can be found in (von Schmidt et al., 2021).

A scenario was constructed to depict the year 2019, which was selected as the most recent normal year before the onset of the COVID-19 pandemic. It can be considered as an extension of TAPAS for the cities of Darmstadt, Griesheim and Weiterstadt and we call it TAPAS4Darmstadt. Next, we will delve into the process of data preparation and provide an overview of the diverse data sources (Table 1) used in this work.

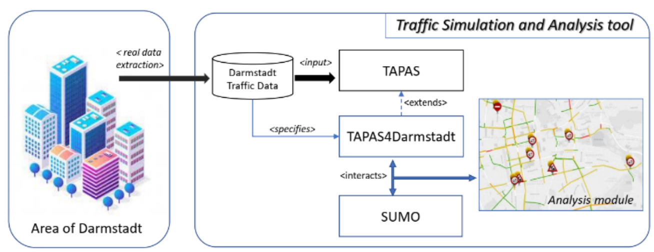

Figure 3. Coupling of components: TAPAS, SUMO and TAPAS4Darmstadt

Synthetic population. In TAPAS, a synthetic population refers to a representation of households and their members, each possessing specific characteristics such as age, sex, occupation, and income. It was generated with the tool Synthesizer, also developed at the DLR-Institute of Transport Research. By using a sample of the population and considering marginal distributions, synthetic individuals and households were generated. In a further step mobility options, such as transit ticket or bike ownership (at the personal level) or availability of cars (at the household level), are assigned. In the last step the households are distributed over georeferenced addresses (von Schmidt et al., 2017).

Activity locations. Along with the households, activity locations are the destinations of the trips of the synthetic population. These are, for example, supermarkets,

Table 1. Data sources

Used for	Data	Source	Description	Year
synthetic population	aggregated population data	Nexiga GmbH	marginal totals	2019
synthetic population	disaggregated population data	Mikrozensus (German Federal Statistical Office)	sample data	2019
synthetic population	further aggregated population data (at district, communal and state level)	statistics departments in Darmstadt and Hesse; Bundesagentur für Arbeit	marginal totals	2019
synthetic population	car stock	Kraftfahrt-Bundesamt (KBA)	at different levels	2019
synthetic population	addresses with number of inhabitants	German Federal Agency for Cartography and Geodesy (BKG)	georeferenced addresses	2019
	mobility options	Mobility in Germany (MiD)	survey data	2017
locations for activities	company addresses	Nexiga GmbH	address and company size	2019
locations for activities	Points of Interest (POI)	OpenStreetMap		2019
locations for activities	parks, forests, religious facilities	OpenStreetMap	relation/polygon and node/point	2019
travel time and distance matrices, SUMO	road network	OpenStreetMap	way/linestring	2019

cinemas or workplaces. Apart from their coordinates, they are characterised by their type (education, work, personal matters, free time and shopping) and their capacity (number of workers and/or customers, pupils, students, etc. throughout the day).

Traffic analysis zones (TAZs). The division in TAZs is widely used in transport planning and travel demand modeling. TAPAS uses them to make some aggregations and they also can be used to create travel time and distance matrices. They are available for some regions but this was not the case for our study area, so we created the zones ourselves. Since the extent of the area is not so big we draw the divisions more or less manually following some recommendations such as that the subdivisions should coincide with administrative divisions or considering the homogeneity of land uses (Miller, 2021). The model also needs the centroids of each zone, which was done using as weight the distribution of the population. This means that the centroids are displaced to zones with more population.

Travel time and distance matrices. Average travel times and distances between TAZs were computed using the open-source tool UrMoAC (see https://github.com/DLR-VF/UrMoAC). All the available addresses (households and activity locations) were used as origins and destinations to calculate travel times and distances between them and then they were aggregated by TAZ using the average. Data needed for this computation are a road network and GTFS-data, an open standard for public transport systems.

Coupling of TAPAS and SUMO. SUMO needs as input data the travel demand calculated with TAPAS and the road network sourced from OpenStreetMap. This has to be converted into a SUMO-network and corrected with a tool called netedit. Specifically, attention is given to refining interconnections and directionality at crossroads and the synchronization of traffic light phases. Routes for the travel demand were generated and considering the busiest crossroads these were corrected and so a first version of the network is ready. In a next step the travel demand will be routed again with SUMO and new travel times will be used in TAPAS. More information about the combination of TAPAS and SUMO can be found in Heinrichs et al. (2018).

5. Experimentation

The resulting proposed solution enables the analysis of the population from a more dynamic perspective by exploiting the advantages of simulation techniques to study its behaviour. In particular, the behavior of individuals is quite regular in the medium term, that means, it is characterized by a set of habitual actions and activities that are repeated over time. Consequently, a change of such "routine" by a group of users belonging to a common environment or to a specific geographical area represents an important indicator from which valuable information related to incidents, dangerous and crisis situations can be identified. That's why the status of the population and its distribution over the area before the occurrence of a crisis play an important role, and it has been the focus of current our study.

In particular, we have considered a delimited area of interest where various application scenarios could be modeled and analysed, such as, related to (i) the identification and definition of an evacuation zone, (ii) a small scale natural disaster (e.g. flooding along a small stream), (iii) an accident in an industrial complex, and so on. In all above mentioned scenarios, the number of affected persons represents a relevant parameter for the identification of the appropriate countermeasures in response to the incident. Moreover, by considering that, since such number might vary over the day - in comparison to statistical approaches - simulation-based valuation helps to obtain relevant indications, especially related to crisis situations, by estimating the population variation in the course of the day.

5.1. Processing steps

The current implementation is centered on three fundamental steps.

- In the first step, the list of all journeys with origin and destination provided by TAPAS (in this case TAPAS4Darmstadt) is used to create a list with the locations for every hour for every agent. If an agent has multiple activities and locations within one hour the last activity is chosen as the relevant one. As TAPAS only takes the duration of a trip into account, the exact routes between two activities are not known. Thus, only agents with an activity are taken into account and agents on the move are not considered.
- The second step consists of the definition of the affected area, which is selected and delimited as polygon (or circle) on a map and then stored in a "shapefile".
- Starting from the configuration parameters of the previous steps, in the last step, the number of agents present in the defined area of interests are derived, counted and observed over the time. In particular, for every hour of the day it is checked if the activity location of an agent lies within the boundaries of the affected area.

Figure 4 shows a summary of the above described steps and related parameters.

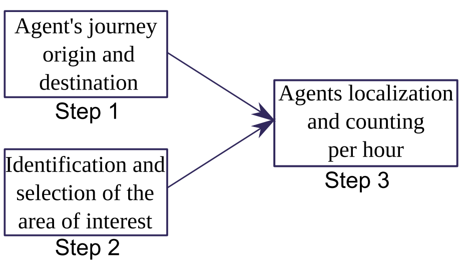

Figure 4. Main processing steps

5.2. Observations and discussion

Figure 5 exemplifies the selected area of interest, which has been highlighted by a dashed circle, in the context of the city of Darmstadt to which the experiment refers.

Whereas, the curves depicted in Figure 6 show daily behaviors of the residents in the "Area of Interest (AoI)" on the basis of people leaving (for example, to go to the office, school, etc.) and return in such zone (for example come back home after work, after school etc.) normalized between [0;1]. Since this phenomenon follows a certain daily pattern (as represented from the curves labeled as Day 1, Day 2, Day 3,..., Day n), it is able to provide important information, not only related to the number of people leaving and returning the area, but also about the leave and return times as well as about the speed with which such changes occur.

Consequently, sudden changes can be interpreted as

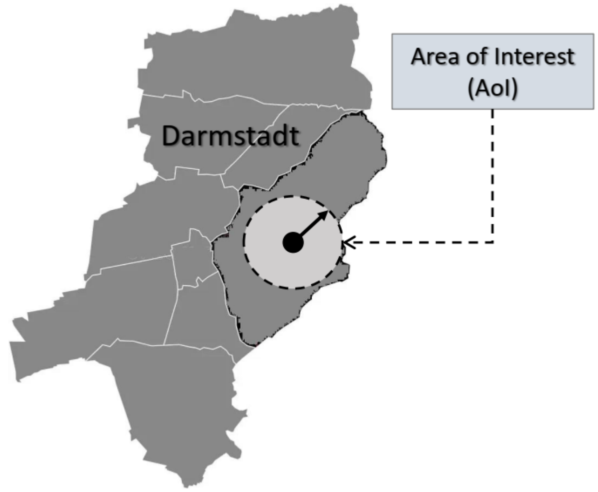

Figure 5. Example of an area of interest

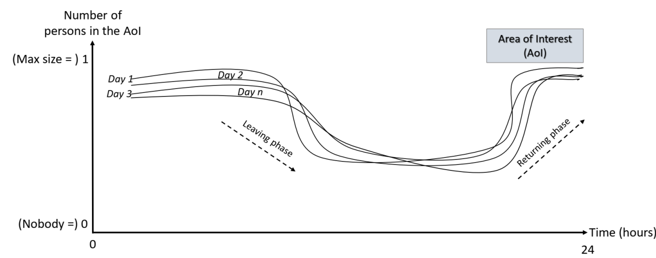

Figure 6. Daily people behavior according to leaves and returns the area of interest

panic conditions from the persons residing in such zone and therefore traced back to emergency scenarios and tendency to "evacuate" the area of interest. Please noting that, this last observation falls in the context of emergency detection which is out of the scope of this work, and therefore needs to be deeper investigated in the future.

5.3. Future perspectives and planned improvements

As above described, the current implementation of the tool provides new capabilities for the evaluation of crisis scenarios. Starting from it, ongoing works are devoted to investigate (i) the identification and connection of real-data from various data source so as to obtain a continuous and live picture of the normal and crisis situation during its operation; as well as (ii) approaches and available technology to allow their acquisition and that support their integration.

In particular, some planned enhancements will deal with the possibility to limit the availability of certain means of transportation, and the full integration of TAPAS and SUMO in the Darmstadt region. Through such coupling it will also be possible to specifically model interruptions in the road network, thus enabling the impact analysis of crisis situations on the mobility behaviour of the population.

This aspect is especially relevant during the recovery phase after a crisis, when the mobility is limited due to repair works related to the road infrastructure. As a consequence, the assessment of specific countermeasures to be applied represents an essential tile to be addressed, in order to support the coordination of the recovery phase as well as to reduce additional inconveniences, risks and dangers for the population that could arise from the ongoing crisis situation.

Whereas, long-term goals foresee the implementation of live and historical traffic data to increase the capability of the models thus dealing with other crisis phases, such as prevention, preparation and identification.

6. Conclusion

The paper focused on modelling and simulation of transportation infrastructures with particular focus on urban environment by providing an integrated solution centered on different features of two traffic simulation environments developed by the German Aerospace Center (DLR).

Such solution consists of a simulation tool that has been defined by combining the benefits of TAPAS and SUMO. In particular, a specific instance of TAPAS, called TAPAS4Darmstadt, has been realized by calibrating the TAPAS tool on the basis of traffic data related to the city of Darmstadt (Germany), in order to model different transportation paths, considering different and available transportation means, distances between starting points and arrival points as well as intermediate points, required time between two points and monetary costs. Then SUMO has been used to enable a more dynamic simulation so as to allow one a better comprehension of the mobility behavior within the urban environment by considering other factor, such as traffic lights and other factors that might influence the traffic flow.

The experimentation has been conducted in the context of the city of Darmstadt by considering a crisis scenario and its aim was twofold: (i) on the one hand, to demonstrate the feasibility of the interoperability of the two simulation tools and their complementary; and (ii) on the other hand, to show the benefits deriving from their coupling in terms of analysis of the mobility behavior, its interpretability as well as decision support especially in presence of crisis situations. Such combination shows as through the simulation of urban traffic and its change it is possible to identify emerging behaviors of the population which in turn allows one (i) to identify potential crisis situations, as well as (ii) to investigate reactions and recommendations including possible counteractions.

Funding

The activities related to this work are conducted in the context of the "DATAMOST" and "urbanModel" research projects that are funded from the German Aerospace Center (DLR).

Acknowledgments

The authors would like to thank Mr. Stefan Jäger, Mr. Alain Schengen and Mr. Marco Marquard for their kind support.

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