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Design of an evacuation and addressing system in case of emergency or accident in the port area of Bastia

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Abstract

Port areas, due to the often intense traffic and the potentially dangerous nature of many goods, are exposed to a series of risks that can lead to accidental severe events. Such events may endanger the safety of port workers and passengers. This paper, that follows the studies and the research activities performed within the European Project Alacres 2, introduces a methodology that aims at improving safety and effectiveness in the evacuation phase of the port area following an accidental event. This target is pursued through the simulation of different evacuation scenarios. The methodology is based on a micro-scale pedestrian simulation model applied to the port area of Bastia, in Corsica, and demonstrates how dynamic simulation techniques can be useful in redesigning port spaces in order to optimize the evacuation phase. The simulation reconstructs in detail the port area, both at the level of spaces and punctual elements that can act as obstacles and element of danger during the evacuation phase. Through a thorough data collection and the inductive construction of appropriate statistics, it provides a sort of Digital Twin of the port. This methodology can be easily transferred to other ports of any size and it is flexible enough to be adapted and integrated with simulation models of the spaces inside the port buildings and the movements inside and around the ships on the sea side.

Keywords: Simulation, Pedestrian Evacuation, Port Emergency, Optimization, Safety

1. Introduction

This paper, resulting from the studies and the researches supported by the European Project Programma di Cooperazione Interreg V – A Italia-Francia "Marittimo 2014 2020" Alacres 2, presents an application of simulation that acts as a Decision Support System for a series of interventions on the viability and the interport operations, in order to optimize evacuation procedures in case of a critical event within the port area. Thanks to these evacuation procedures, new and clearer methods of informing passengers and port operators on the behaviors to be adopted are outlined (Farina et al., 2021 and J. C. Pine, 2018).

Interestingly, this methodology can be easily transferred to other ports (Said A.H., 1993) of any size and it is flexible enough to allow the integration to the simulation of spaces inside port buildings (Xiuli et al., 2012) or movements inside and around ships (Trika and Eiichi, 2008).

The hypothesized scenario is the one with the greatest potential danger to humans, that is a collision between two ships one mile from the port, with subsequent explosion and leakage of harmful air substances such as chemical, biological, radiological or nuclear elements. This scenario requires the evacuation of the port personnel, responsible for managing its regular operations, of the personnel operating inside the ships present in the port and of the passengers present both in the ships and in the waiting queues, or, generally speaking, in the port area.

From an operational perspective, the simulation and the analysis have been carried out inside the port of

Bastia, Corsica, in conditions of maximum maritime traffic (corresponding to the average summer conditions) and shows how the simulation tool is useful for securing the port area with respect to the hypothesized incidental scenario.

The paper is structured as follows: paragraph 2 presents the general methodology that has been proposed while paragraph 3 describes the data collection and the statistical analysis. Paragraph 4 shows the scenario modeling and calibration and, finally, paragraph 5 introduces and briefly resumes the four simulation scenarios and individuates the reference scenario to be implemented in the port. Finally, the outcomes of the research are highlighted in the Conclusions.

2. General methodology

The methodology is based on a pedestrian simulation system at a microscale level (or tactical level), capable of taking into account the behavioral factors of passengers and operators in the emergency phase as well as the environmental factors and those referring to the design, the geometry of the road network and the use of port spaces. The general methodology, shown in Figure 1 below, is mainly based on four phases.

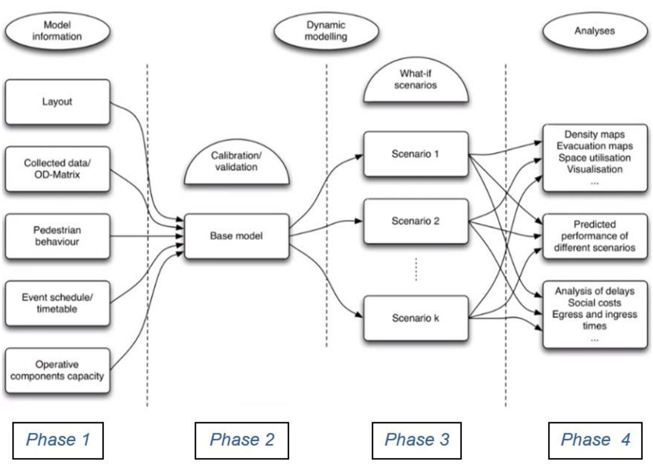

Figure 1. General simulation methodology (Source: Citi EU)

The first phase consists in the collection of the data that are necessary as input to the simulation, such as the layouts of the internal/external spaces, pedestrian flows and any Origin/Destination matrices. It involves as well the introduction of behavioral elements typical of the simulation objective, the temporal scheduling of the simulation and the eventual known constraints. A second phase consists in the calibration and the validation of the model, mainly through the verification of the simulated behaviors and its evaluation. Often this involves the possible modification of some input data and the evaluation of the realism (reliability) of the simulation. The third phase allows the construction of significant alternative scenarios. For each one, simulations are carried out and the consequent data are properly collected and analyzed. Finally, in the fourth phase, the outcomes of all the different scenarios are compared to the basic one (also called Business as Usual) and are analyzed in depth in order to identify the Project scenario. This represents the true scenario that will be the final result of the analysis and that could/should be implemented in the field in the port real world.

The following paragraphs describe the steps in detail.

3. Data collection

First of all, the layout of the port area and the immediately adjacent areas has been built, through a CAD processing and starting from satellite georeferenced data, in order to frame the project area and all its parts. Figure 2 shows the final layout, elaborated and imported into the simulator.

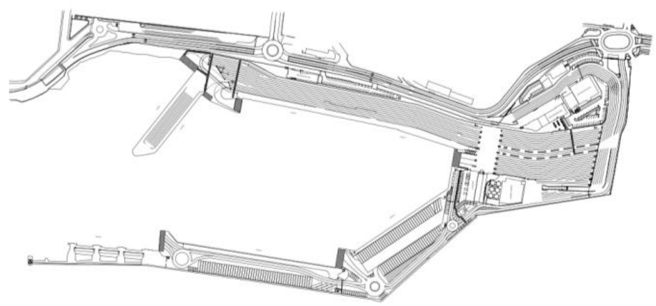

Figure 2. Reconstruction of the port layout

In addition to the rough layout, the use of port spaces has also been deeply analyzed, as far as possible, differentiating the access areas of passenger vehicles, the access areas of freight vehicles, where containers are left waiting for the ship, and the communication and general control areas. Noticeably, the port viability related to the emergency access, the lanes reserved for accessing and boarding the ship and the lanes for the exit of vehicles accessing the Corsican territory have also been identified. Thus, it was possible to define that the eastern area of the port is dedicated to port handling. Briefly, there are. 125 stalls for freight vehicles, 50 of which are reserved places for tractors waiting for trailers. The entry part can contain up to 280 light vehicles, while the passenger entrance part can hold up to 1,500 passenger vehicles. The larger flows of passengers and the consequent larger concentration of human presence is in this last section, that becomes, also due to the greater number of ships that dock there, the main object of the analysis. In addition, in absence of further information on the operation of some port areas and on the areas of attestation of vehicles for the various docks, the study focused on quay number 1, usually reserved for traffic between Bastia and Livorno or Vado Ligure (Savona) and quay number 3, relating to traffic from Bastia to Genoa, Marseille and Portoferraio (Piombino) (see figure 3).

Figure 3. The different docks of the port of Bastia, with the two docks subject to simulation and the safe area (source: CCI de Bastia et de la Haute Corse)

In addition, a safe area and the corresponding access zones have been identified and reconstructed. In the hypothesized incidental scenario, these consists of the internal spaces of the Passenger Terminal (Gare Marittime Sud), which become the safe point for the simulated scenario (see the green area in figure 3). Starting from a series of information on the average and maximum loads of ships during the summer season, provided by the Chamber of Commerce of Bastia and Upper Corsica and relating in particular to the passenger ships in transit in the port on the days between 26 and 29 August 2019, we have calculated the average composition of a standard summer ship, reconstructing, as well, the average subdivision in the different vehicle classes. Owing to these information and some additional considerations, we built the models adopting one single passenger for freight vehicles and commercial vans only, while using an average number of 2.5 passengers for passenger vehicles (cars, campers).

Further, on the basis of the indications of the tourists themselves and analyzing the collected satellite images, the following positioning of the vehicles waiting for boarding has been outlined:

1. Two-wheeled vehicles: at the head of the queue, in a single delimited area;
2. Heavy vehicles and vans: at the head of the queue (they are the first to be loaded onto the ship);
3. Passenger vehicles: after heavy vehicles and vans;
4. Camper: queuing after passenger vehicles.

The analysis of satellite photos and other data sources have also given us indications on the organization of access and exit flows from ships, always with reference to docks 1 and 3. These are schematized in figure 4. In practice, the western lanes (left in Fig. 4., in blue), closer to the Passenger Terminal are usually used for boarding at platform 1, while the inner lanes (orange) are used for boarding at quay 2 and 3. Finally, the easternmost lanes (near to the ship) are used jointly by the three docks for the disembarkation of vehicles and removal from the port area (outgoing green arrow).

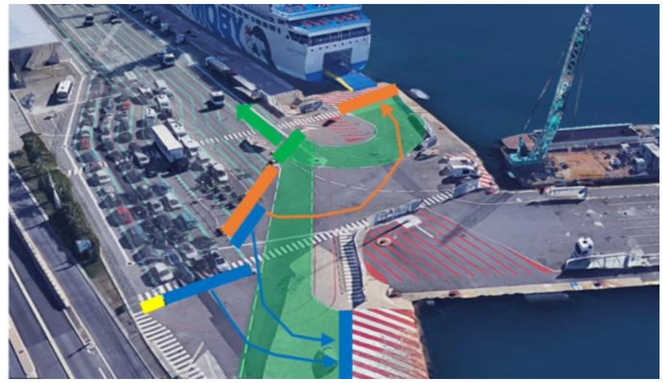

Figure 4. The organization of entry and exit flows and waiting queues for boarding

In addition, we note the presence of a service access lane (also indicated in yellow in Fig. 4), which can also be used as an emergency lane in case of intervention, and the presence of two parking areas that overlap with the evacuation flows and constitute an obstacle and a danger to human safety. Once the functional spaces and the amount of the involved vehicles have been identified, the probabilistic distribution of two different phenomena was represented, such as the gap between vehicles waiting for boarding and the irregularity of passenger vehicles in the queue. In both cases, we referred to information derived from satellite images that allowed, with adequate precision, to measure the corresponding lengths. Referring to the distribution of inter-vehicular distances, it emerged that almost 85% of vehicles are at distances of less than 60 cm, a value below which the transit of people is not allowed at a regulatory level. In addition, the distribution of different lengths of passenger vehicles generates a phase shift that often nullifies the presence of the few distances above the aforementioned limit of 60 centimeters. This difference in length has been actually imported into the simulation, to respect real world conditions. In practice, the vehicles form a wall that is difficult to cross. Finally, at the behavioral level, the characteristics of the pedestrian were designed: we supposed that, in the case of an evacuation, passengers move with no luggage and at a travel speed higher than the typical one in conditions of non-evacuation. This resulted in a speed ranging from 2.1 to 2.4 m/s (stochastically distributed). Starting from the ferry schedules, the overlap possibilities for users entering/leaving the ships at embarkations 1 and 3 at the same time were highlighted and, therefore, the contemporary presence of ferries arriving/departing from these two docks was the worst scenario taken as a reference. At the end of the data collection phase, the design of the vehicles inside the port, as shown in Figure 5 below, was completed.

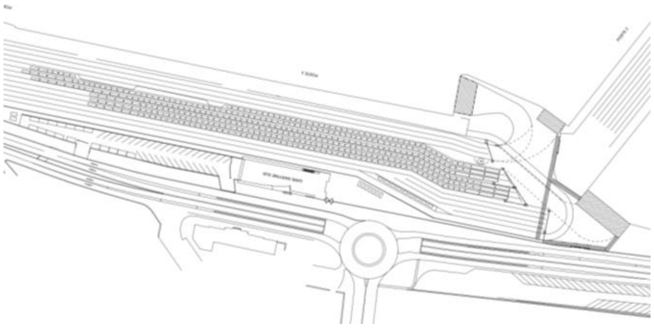

Figure 5. The layout of the port and the distribution of vehicles awaiting for boarding

4. Construction of the basic model and its validation

The main problem we encountered during the simulation of the evacuation phase was represented by the absence of ancillary data with which calibrating the system. In practice, calibration in the micro-simulation phase is often carried out with respect to monitored data, such as the length of queues detected and/or the actual network crossing times. Noticeably, this information was not present for previous cases of evacuation and, therefore, the only verification that could be attempted is given by the visual analysis that the simulated behaviors are consistent with what is expected. An example of incorrect behavior, highlighted in the simulations and that led to the necessary modification of the model, can be resumed as follows: in the case of an evacuation, the algorithm tries to find, for each passenger, the shortest path to the safe area. Thus, a large number of passengers may be routed on the same path, independently of the number of other subjects that have already followed that route. Usually, this lead to very long, unrealistic queues in a limited number of paths. Calibration allowed to modify this behavior towards a more realistic one, where passengers, during the evacuation stage, are divided, more or less proportionally, between the available spaces, as evidenced by the image taken from the dynamic simulation in Figure 6. Once the system was calibrated and validated on screen, the results of the simulation of the current scenario (Business as Unit-BaU) were collected.

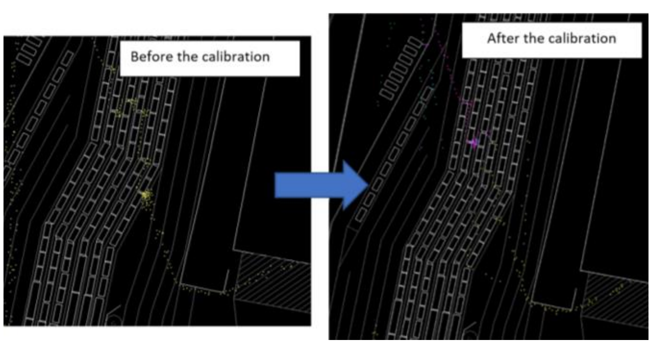

Figure 6. Detail of the evacuation phase from the ship parked at quay 3

The gathered data showed the lengthening of evacuation times due to queues that are created within the rows of vehicles. Maximum evacuation times are just above 7 minutes (see Figure 7).

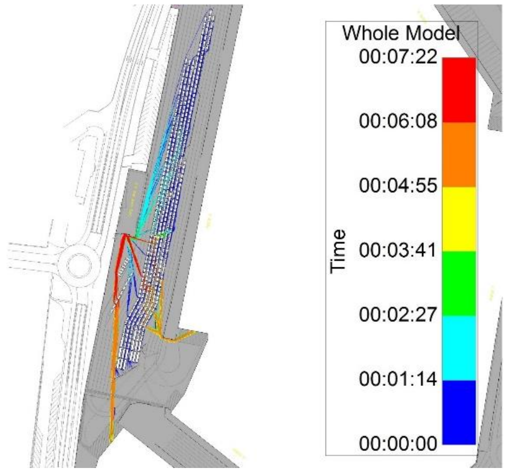

Figure 7. Tempi di evacuazione rispetto all'inizio della simulazione

Analyzing the density maps of the passengers, they effectively highlight the queues within the rows of vehicles, that originate the slowdowns and the aforementioned long evacuation times (see figure 8).

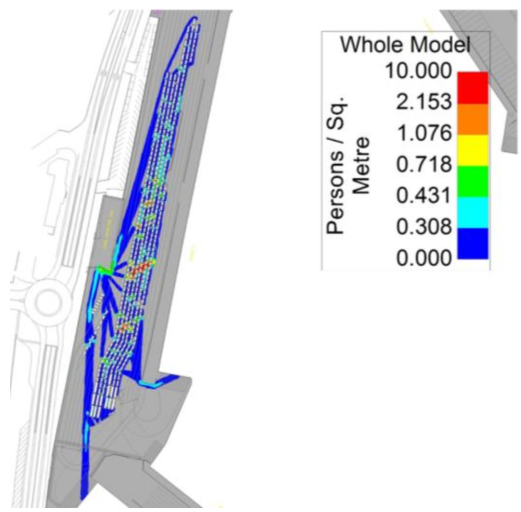

Figure 8. Density map for people in evacuation

Analyzing the trend of the accesses (see the two indicators in Figure 9 and 10) to the system (considering that the departure of a pedestrian from his car coincides with his entry and the exit coincides with the access to the Gate), we may see that they are much more concentrated in the first 20 seconds, referrable to passengers waiting for boarding, with a second more homogeneous entry due to the exit of passengers from the ships. There is a queuing effect that leads to a significant delay, due to the the mixing of the two streams with a strong interaction that generates further delays and congestion, finally homogenizing the exit dynamics of all passengers.

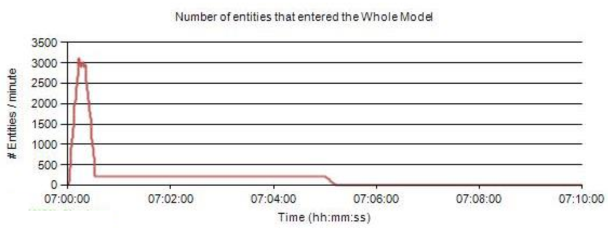

Figure 9. Whole model Ingress Rate Average

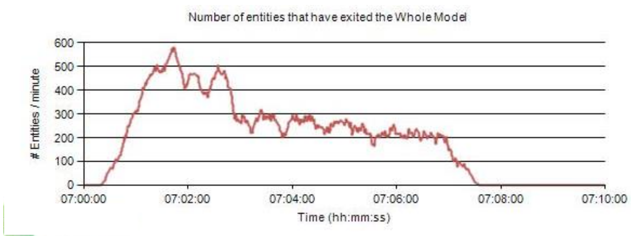

Figure 10. Whole model Egress Rate Average

For the purpose of a comparison with the project scenarios, an Average Indicator of Evacuation Times has been defined, representative of the average time that a user takes to evacuate the area, given by:

$$IMTE = \frac{(\sum_i^n UEX_i * \Delta EX_i) - (\sum_i^n UIN_i * \Delta IN_i)}{\text{N}}$$

where:

UEX_i = number of users exited in the i-th time interval

ΔEX_i = relative passenger group evacuation time from the start of the simulation

UIN_i = number of passengers entered at the i-th time interval

ΔIN_i = passenger group entry time from the start of the simulation

N = number of total passengers evacuating from the system

In practice, the indicator subtracts the integral of the exit curve from that of the departure curve. The IMTU indicator for the BaU scenario, with a total of 1,982 people evacuating from the port area, is equal to 114 seconds. That means, on average, that each user takes just below two minutes to evacuate.

Using this indicator, the Optimal Reference Scenario was chosen among the different scenarios analyzed.

5. Construction of alternative scenarios

Using this indicator, the Optimal Scenario was chosen starting from 4 different project scenarios (alternative to the BaU).
On the basis of the results of the simulations, a series of design elements have been inserted such as to avoid dangerous situations and reduce the evacuation time, eliminating as much as possible congestion phenomena inside the car parking area.
As an example, starting from the density maps analysis, it was evidenced that it is necessary to insert exit corridors between the parking areas (the white area in Figure 11) and some balustrades/obstacles that channel the exits from quay 1, avoiding interference with the parking areas (see the two black lines in Figure 11).

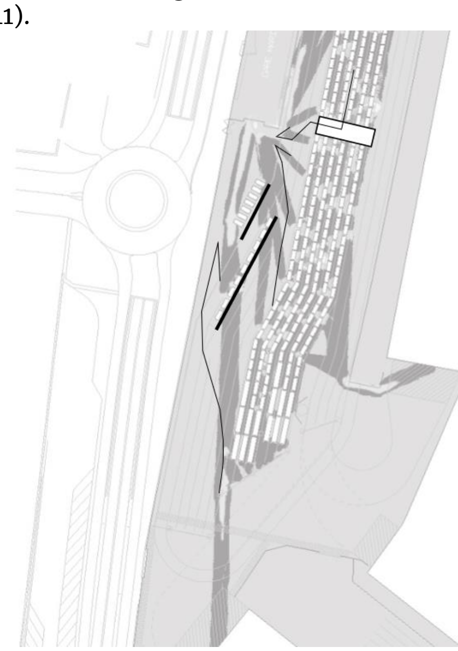

Figure 11. Structural modifications in the port area

In practice, the different scenarios differed in the number and location of the exit corridors, always two meters wide. In the first scenario there was only one corridor in a central position, in the second scenario two corridors, in the third scenario three corridors and four in the fourth, at given and appropriate positions.

6. Results and future developments

The simulations showed how the level of optimization of evacuation times and phases has an asymptotic trend. That is, starting from the 2 corridors scenario onwards the advantage due to the increase in the number of corridors decreases.

This is evident from figures 12 and 13 below, in which the Cumulative Curve of the Exit Times and the Average Indicator of Evacuation Times are indicated. The results show that the scenario with only one corridor, despite leading to an improvement compared to the current situation, has a lower number of evacuees both in the initial phase (first two minutes) and in the next phase, compared to solutions with a greater number of corridors. The two-corridor scenario denotes an improvement compared to the scenario with only one corridor but sees, however, lower performance both in the immediate phase and in the long term (4-7 minutes), with the involvement of passengers coming from inside the ships. In the central phase it aligns with the solutions with 3 or 4 corridors.

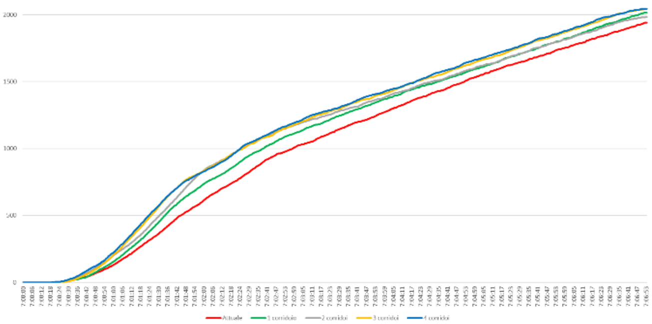

Figure 12. Cumulative exit time curve (comparison among the current scenario and the project scenarios)

The best solution, as it involves a lower use of the parking space for cars waiting for boarding and a lower influence on the geometry of the existing parking lots, is the solution with three corridors. In fact, as evident from Figure 12, this sees an almost total alignment with the 4-corridor solution, both in the short and long term. Moreover, even at the level of indicators, the two solutions are practically identical (see Figure 13).

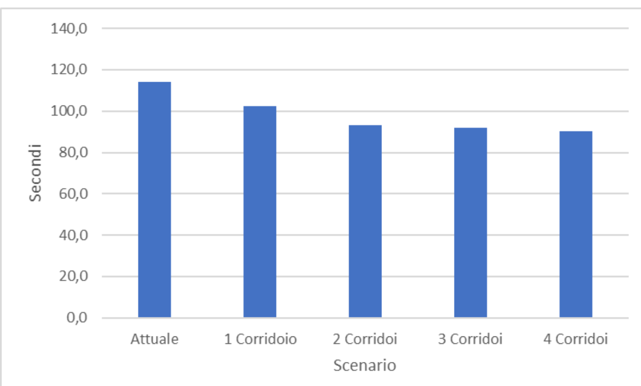

Figure 13. Trend of the Average Global Indicator of the Evacuation Times

7. Integration in the Virtual Laboratory

For the purpose of integration with the Virtual Laboratory for Crises and Emergencies in port (as required by the Project Alacres 2), it is emphasized that the results obtained in the previous paragraphs are based on a very simple equipment, based on a standard PC running the Windows operating system, a simulation software and a CAD software, necessary to reconstruct the geometry of the simulation scenario. The Excel software has been used for the analysis of the results and their graphics processing.

The files containing the dynamic temporal data of the simulations were translated into Excel compatible CSV files, then transferred to the Virtual Laboratory, after defining the technical specifications and the standard data format necessary for the future automatic exchange of the data.

In addition, possible management intervention actions have been defined, to be adopted in the event that the works envisaged by the project scenario have not yet been implemented in the port area (corridors, removal of obstacles, balustrades and so on). These extraordinary scenarios can lead to the temporary and emergency preparation of the corridors indicated in the scenario solution and can be identified as temporary solutions, pending the implementation of the definitive infrastructures.

For example, emergency solutions could be:

1. the use of a bulldozer or other mechanical means to construct, by 'forced displacement' of vehicles, the necessary evacuation spaces as planned (corridors);
2. the movement of the vehicles in line, based on the collaboration between the owners of the vehicles/passengers and the staff responsible for managing the port, in order to reconstruct the spaces necessary to identify the corridors.
3. other extraordinary and temporary interventions.

For each emergency situation, the necessary times must be verified (for example to get the bulldozer into action, or to move the cars in a row) in order to compare them with the simulated times in the current situation. This will allow to identify the lines of management intervention effectively comparing the current situation and the implementation of the best simulated project scenario.

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