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On pedestrian traffic management in railway stations: simulation needs and model assessment

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Abstract

Mass transit rail stations make up complex systems in which passenger flows have significant influence on operations and traffic conditions. Are there pedestrian simulators that can effectively contribute to the management of crowd flows? To answer this question, an assessment grid is built to address scientific principles as well as operational and organizational needs. The scientific principles encompass real-world features to be described, especially causalities to reproduce. The grid is applied to several commercially-available software (including PTVVisWalk, Legion, Anylogic, MassMotion and SimWalk) as well as to research-sourced pedestrian simulators.

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1. Introduction

Railway lines in metropolitan urban areas serve massive passenger flows, which keep increasing in growing cities. Many commuter stations in greater Paris daily accommodate more than 100,000 passengers with high-frequency train services. In case of disruption, massive amounts of passengers can accumulate in stations and platforms. A management system could help station managers in activating regulation levers to control large pedestrian flows (Kabalan et al., 2017). Such a system requires simulations that are suitable to provide relevant results both relevant in real-time. Simulation results rely notably on the scientific hypotheses and assumptions that were postulated in the underlying model of pedestrian dynamics and behavior. Such models have already been partially described, classified

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and analyzed according to several criteria (Caramuta et al., 2017; Duives et al., 2013); however, we did not find models that address the specific needs of pedestrian traffic management in the setting of a railway station (as passenger flows are much more massive as in airports or bus stations, and differently managed).

(Hoy, 2017) compares different agent-based models and assesses their performance in two Toronto stations while (Castle et al., 2011) compares two commercially-available models in two UK stations: yet both papers deal with model performance rather than focus on the relationship between the model and the system under study. (Nelson, 1995) sets up an interesting series of questions that pertain to evacuation models and constitutes a first list of topics.

This paper is aimed to clarify the contribution of pedestrian simulation tools in the perspective of traffic management. It provides an analysis grid for simulators in that field, and applies it to several software programs.

Our scope is limited to railway stations, even if the grid can be adapted to other domains. We take a selective approach by restricting our benchmark to a dozen of models, selected in such a way as to span commercially-available models as well as research models. The selection is based on their expected ability to fulfil the needs which was estimated from available information in academic literature, commercial material provided by the editors, and current industrial use of the commercial programs.

We first provide a systematic description of the features of real-world systems that are relevant to traffic management. Then, we build the analysis grid to assess a model's scientific principles, together with its usability in the operational setting of station management. Finally, we introduce the candidate models and apply the grid to assess their respective suitability.

2. Systematic description of railway stations

2.1. Station as a system

In his analysis related to capacity constraints, (Leurent, 2011) proposes to decompose the public transport systems into five subsystems: Passenger, Vehicle, Station, Line and Global Management. The main function of the station subsystem is permitting boarding and alighting of passengers, which involves *(i) passenger access from outside to platforms and inversely; (ii) passenger transfers between platforms; (iii) passenger waiting*. However, its functions broadly exceed that main purpose and include passenger's information and ticket selling, urban functions, commercial functions, operational functions. Each of these functions can impact pedestrian flows inside the station; vice versa, intensity of flows can impact operations related to these functions. For instance, commercial functions can be affected by insufficient flow. Pedestrian congestion, on the contrary, impacts most of the functions in the station: train operation can be disrupted by massive boarding and alighting flows, access to shops is difficult, and quality of service decreases, which impacts all aspect of the railway functions, including the urban one.

2.2. Spatial subsystems of the station

Station system is itself composed of subsystems. Part 10 of Transit Capacity and Quality of Service Manual (TCQSM) details a list of pedestrian circulation elements and their capacities (Walker et al., 2013). Elements of the station are categorized as access elements (doorways, fare purchase or control elements), horizontal circulations (walkways, multi-activity areas, moving walkways), vertical circulations (stairways, escalators, elevators, ramps), platforms and waiting areas (platforms, waiting rooms, etc.). Using a sample pedestrian flow diagram, such as described in (Demetsky et al., 1976), is also proposed. TCSQM also underlines the importance of using microsimulation software when designing a station.

However, there are different ways of considering the station subsystems; the TCQSM approach is mostly physical and technical. A functional approach would look at the role of each element in a station's functions (that would group platform and its accesses in a subsystem, fare collection in another, etc.). A management approach would group elements according to the entity responsible of their actuation. The authors believe in a process of subsystems identification that is both spatially consistent and sensitive to flow sizes. Station and Passenger subsystems as identified in (Leurent, 2011) are actually much linked in most of these subsystems. The complete description of them is beyond the scope of this article, but they need to be carefully identified in order to provide accurate simulations.

2.3. Heterogeneity of pedestrian behavior and traffic conditions

Pedestrian behavior can change from one element to another. Therefore, special attention is needed for each element during modeling. These subsystems can also be critical in another manner: accumulation of passengers in a single part of the platform, poor quality of travel in exchange areas due to massive cross flows, bad access to service areas due to congestion in front of them, and of course saturation of links, leading to dangerous situations with high pedestrian densities.

A critical situation in any of these subsystems (typically a gridlock due to high pedestrian demand and insufficient capacity), could lead to a global critical situation for the entire station (gridlock of stairs, then platforms or exchange areas, etc.). Simulation accuracy should be maximal in all these subsystems, including their specificities, to handle these cases. However, using a single simulator for the entire station system is not mandatory. With a *lean* approach, as proposed in (Kabalan et al., 2018), it is possible to focus only on critical subsystems or even parts of subsystems: critical elements are identified by on-ground observation and data analysis. Then, simulation focuses on the identified critical elements.

3. Practical use of simulation software

We want to underline different uses of simulation software in the context of a railway station. (a) In most cases, these tools are used when designing or redesigning the station: validate a proposed spatial organization in regards to a particular transport service, help to design and dimension different parts of a new station, etc. Both evacuation and operational conditions can be considered. (b) Using simulation software with operational purpose relies on the same theoretical basis but addresses different needs. These tools can provide data, indicators and visualization about the current state of the station, help to anticipate pedestrian incidents or discomfort. Hence, they have to maintain precision for different scenarios (station reaching overcapacity, train service disruptions), reach real-time performance with the number of pedestrians present in the station, and be compatible to operational industrial IT systems (as running manually a simulation when managing an incident is non imaginable).

The grid presented in Part 4 was built considering these particular needs, which diverge from the predominant use of simulation software within stations.

4. Assessment of pedestrian simulators and corresponding models

4.1. Methodology

The assessment grid has first been build taking in account industrial needs (as we target to use simulation software in real-time in an operation industrial system), knowledge from research about crowd behavior, and specific criteria for railway stations, derived from our systemic analysis. That grid is shortly described in Part 4.2 and will be published on our laboratory website (<http://www.lvmt.fr/equipe/marin-dubroca-voisin/>).

Industrial software from the market leaders was selected, as certain stability is required for use in an industrial system. Some implementations of research models were also chosen.

We then wrote a questionnaire where the answers provided allowed us to fill the grid. We chose not to directly link the questions to items from the grid.

We send the questionnaire to 6 companies in February 2018 (without providing the assessment grid). We also asked for price estimation to purchase between 1 and 10 licenses in order to compare prices and to purchase software for further work. All 6 companies answered between late February and early March 2018.

Thanks to the answers, academic papers and studies provided by companies, we started to complete the grid provided in paragraph 4.4. Each time it was possible, we checked if studies had been made to confirm statements from the answers. In some cases (MassMotion, SpirOps), we met the teams from the company for a quick presentation. There were also some exchanges in order to clarify certain questions. The grid was slightly modified to integrate certain aspects brought up during the meetings with the editors.

In the case of academic models, research papers were available and we did not need to contact the authors.

After completing the grid, the analysis presented in section 5 was conducted.

4.2. Evaluation grid

First part of our grid is dedicated to ease of access: availability of documentation (unpublished software, black boxes, open-source software with more or less documentation), information about provider, quality and type of interface, and cost. Second part is dedicated to technical characteristics: operating system that needs to be used, level of compatibility expected with other software, level of automation (from software that needs to be used by hand to software creating simulations managed by a global system), IT safety (is software reliable? is data secure?). Third part evaluates if models uses are able to reproduce known crowd phenomena, and focuses on high-density situations as they could lead to crowd disasters. Lastly, the fourth part addresses modeling approaches: finesse and limits of areas description, pedestrian behavior (how are pedestrian routes computed? can characteristics of pedestrians be edited?), compatibility with railway models (in general and in the case of platform-train interface, notably as described in (Elleuch et al., 2017)), flexibility (capacity to handle non-generic situations and pedestrian management), ability to be improved, and finally speed of execution, which is critical when targeting real-time use.

Our generic indicator ranges from 0 (“Cannot deal with that item.”) to 3 (“Perfectly deals with that item”). For most items, we refined our criteria. Complete evaluation grid is available on our laboratory website.

4.3. Presentation of selected models and software

VisWalk is a commercial software program, integrated in the PTV software suite. It was created around 2008 (Kretz et al., 2008) from the social force model by (Helbing and Molnár, 1995). It is currently one of the market leaders. It has been used in numerous cases, as La Défense and Saint-Lazare stations during RER A summer maintenance work.

Legion has been based on the works of G. Keith Still (Still, 2000). Unlike most of the other solutions, it does not use the social force model but a specific agent-based model with 2D continuous space and 0.6-second time-steps. Pedestrian agents try to minimize their effort, which is characterized by inconvenience, discomfort and frustration. It is one of the market leaders too, and is currently used for main French stations.

Anylogic is a generic simulation product with two specific libraries: Pedestrian and Railway. Although it is generic software, it has been used in railway context, such as Chinese subway stations (Li F. et al., 2014; Li J. et al., 2014).

MassMotion is a challenger in commercial simulations. According to (Caramuta et al., 2017), it has been developed since 1976. The company, Oasys software, is a branch of the important engineering company Arup. It has been used in major stations, as Union Station in Toronto.

SimWalk has been created in 1996, and currently implements both simplified version of the social forces model by (Helbing and Molnár, 1995) and route choice model by (Moussaïd et al., 2011). An impact evaluation of the simplification of the social force models is provided in (Steiner et al., 2007).

SpirOps is a research company who created its own agent-model. The economic model relies on paid model development by corporate partners, which beneficiate to following partners. The scope is not limited to humans in stations, as it covers the entire human behavior, but that particular space has been developed throughout a research work with SNCF Réseau (Elleuch, 2015).

A hybrid model using MATSim and ORCA has been developed in (Lämmel et al., 2014). Although it is not published, it offers an interesting case of using different kinds of models, depending of the nature of space considered. The use case, New York Central Station, illustrates well the interest and the efficiency of this kind of solution. However, platforms are not modelled.

JuPedSim is a framework which is also developed at FZ Jülich. It provides different open-source modules for simulation, and several microscopic models are implemented both at tactical and operational levels. It is described in (Wagoum et al., 2015) and available at jupedsim.org

Lastly, AnisoPedCTM is a model from (Hänseler et al., 2017). It introduces anisotropy in an efficient macroscopic model that has been used in the case of the Lausanne railway station (Hänseler et al., 2015).

4.4. Assessment

Table 1. Ease of access of the evaluated simulators

Name	Availability	Provider	Nature of provider	Usability	Cost (1 or 10 licenses)
VisWalk	2. Good research	PTV Group (DE)	Company	2. Based on web demonstration	1: 24 000 € + 15 % maintenance 10: 140 000 € + 15 % maintenance
Legion	2. Important research	Legion Ltd (UK)	Company	-	1: 28 600 € (workstation) 1: 42 900 € (network) 10: 257 400 € / 386 100 €
Anylogic	1. Partial documentation. Research uses it but does not control its behavior.	The AnyLogic Company (RU)	Company	2. Based on web demonstration	1: 16 800 € (professional version) 10: 105 500 € (desktop), 115 500 € (server)
MassMotion	2. Good documentation and research to check	Oasys Software, branch of Arup (UK)	Company	2. Based on screenshots and demonstrations of the UI	Purchase : 1: 22 000 €, 10: 144 000 € Rental : 1: 24 000 € / 2 years, 10: 159 000 € / 2 years Academic licenses available.
SimWalk Transport	2. Core of the model is secret but based on research Model is well documented	Savannah Simulations (CH)	Company	2. Based on screenshots of the UI	1: USD 17 500 + 7 000/ supp. year 10: USD 58 000 + 7 000/supp. year
SpirOps	0. Model is only available by a partnership 0. MATSim is open source and well documented,	SpirOps (FR)	Other	2. Using Maya Autodesk	Depending of the partnership
(MATSim), ORCA	ORCA is well described, but hybrid model code has not been published	FZ Jülich (DE)	Academic	-	-
JuPedSim	3. Open source	FZ Jülich (DE)	Academic	1. Basic interface	Free
Aniso-PedCTM	3. Open source	EPFL (CH)	Academic	0. No graphic interface, used via line command.	Free

Table 2. Technical characteristics of evaluated simulators

N.	OS	IT compatibility	Automation	IT security
VW	Windows	2-3. APIs	2. Can use data from APIs for simulation	0-2. Multiples use cases and daily log checks. Most of the data safety relies on the final user.
Leg.	Windows 7, 8, 10	2. Partial APIs, which should be sufficient for data exchange	2. Should be able to use data from APIs	2. Uses passwords and logs and has a small attack surface on networks
Any.	Linux, MacOS, Windows	2. API for data exchange	2. Should be able to use data from APIs	0. Relies on the final user
MM	Windows	2-3. (quite) complete SDK	2. SDK makes use of external data possible	0. Relies on the final user
SW	Windows	2. Import API	2. Should be able to use with Import API	1. Secured databases and ongoing code verification
SO	Windows with Maya Autodesk (editor and visualizer), Windows or Linux (crowd engine)	1	2	-. Local use only
M+O	? Not precised	-	-	-
JPS	Linux, MacOS, Windows	1. Developments are needed	0-1. Needs development too	-. Local use only
APC	Any OS supporting Java	0. No APIs.	0-1. Most of work has to be done by hand	-. Local use only

Table 3. Reproduction of crowd and high density phenomena in evaluated simulators

	Reproduction of known crowd phenomena												High pedestrian densities	
	a. Crowd dynamics				b. Collective phenomena				c. Coherence in transportation context				a. 3 to 5 pax/m ² Including stop-and-go waves , accumulations, non-desired speeds	b. >5 pax/m ² Including injuries, fatalities and crowd disasters
	a1	a2	a3	b1	b2	b3	b4	b5	c1	c2	c3	c4		
VW	3	3	3	3	3	3	?	?	2-3	3	3	?	2. Possible to choose between a stable behaviour and turbulences, depending on the context.	0
Leg.	3	3	?	?	?	?	?	?	2	3	3	3	2. Calibrated and verified by Legion team	0
Any.	3	3	3	3	3	3	?	?	2	2	3	?	1	0
MM	3	3	3	3	3	3	?	?	3	3	3	2	1. No turbulences, slow movements.	0
SW	3	3	3	3	3	3	?	?	3	?	3	?	3. Route choice model : fluids and turbulences	0
SO	3	3	3	3	3	3	?	?	3	3	3	?	0. Not tested except tendance of pedestrians to take less space	0
M+O	3	1	1	2	?	?	?	?	0	0	0	0	0. Maximal density seems fixed at 5.4 ped/m ²	0
JPS	3	3	?	?	?	?	?	?	0	0	0	0	?	0
APC	0	3	3	0	0	0	0	0	0	0	0	0	0	0

Known crowd phenomena in Table 3 include: a1. Crowding at bottlenecks, a2. Fundamental diagram, a3. Reduced flow if multidirectional flows, b1. Lane formation, b2. Herding, b3. Zipper effect, b4. Faster-is-slower effect, b5. Freezing by heating, c1. Irregular repartition on platform, c2. Multidirectional platforms, c3. Massive unidirectional flow at train arrival, c4. Fail-to-board.

Table 4. Modeling approaches for evaluated simulators (part 1)

	Description of areas		Description of pedestrian behavior		Compatibility with rail way models	
	a. Finessness of areas description		a. Calculation of pedestrian routes	b. Choice of characteristics	a. Ability to be plugged to a railway model	b. Finesse of platform-train interface description
VW	3. Accurate descriptions are important for ped. choices		3. From O/D matrixes with simple heuristics	3	2. With Vissim, unclear if they can be plugged real-time	2-3
Leg.	3. Accurate descriptions are important in critical spaces		3. Agent-based	2-3. Library included, unclear which charact. can be edited	1. PTI is modeled but models can not plugged in real-time	
Any.	3. Each element could be modeled as an agent		3. Agent-based	3	Two libraries of the same model	2. Simple interface between two libraries
MM	3. Needs precise descriptions		3. Agent-based	3	2. Yes (OpenTrack, via Nexus controller)	2-3. Interface has several flow parameters
SW	3. Accurate descriptions are important in critical spaces		3. From O/D matrixes on tactical level	3	Yes with OpenTrack	2-3
SO	3		3	3	0. At date. Train modelization ongoing.	2. Studied in a PhD thesis
M+O	1		3. Managed by MATSim	?	0. Platforms are not modeled.	0. Not concerned
JPS	0-1 Areas are simple but space is continuous		1. Goal has to be given for ped. created	3. Several models and, agents, editable	1. Needs strong dev., notably with platforms	0 Not modeled
APC	0. As a graph		1. O/D matrixes	2. Via choice of fundamental diagrams	1. Needs strong dev., notably with platforms	0 Not modeled

Table 5. Modeling approaches for evaluated simulators (part 2)

	Flexibility		Speed of execution (RT=real-time)
	a. Adaptation to certain conditions, situations, strategies	b. Ability to be improved	
VW	2	1. Scripts (VBA/Python/JS)	4x RT for 10,000 ped. (free-flow)
Leg.	1	1	2x RT for 2,000 ped.
Any.	2-3. Agents are fully editable. Implementation of management strategies is unclear.	2. Should be possible to extend by Java dev.	6x RT for 10,000 ped. (free-flow)
MM	2. Editable agents, implem. of manag. strategies unclear.	1. Scripts using the SDK	RT up to 5,000 ped.
SW	2. Same then MM.	0. No scripts	4x RT for 2,000 ped., scalable (cloud);
SO	3. In case of a partnership	3. In case of a partnership	RT up to 2,000 ped.
M+O	0. Not available	0. Not available	12x RT for 750,000 ped.
JPS	1. Model could adapt with dev., only a small set of characteristics currently	3. Open source	With 20 processors : RT for 22,500 ped.
APC	1. Adaptation is limited to fundamentals diagrams	3. Open source	Around 100x RT for simple case, 200 ped.

5. Discussion

5.1. Maturity of commercial models concerning pedestrian simulation

Commercial software offer consistent solutions, able to deal with most of crowd phenomena, as shown in Table 3. All models used are able to reproduce fundamental diagram and crowding at bottlenecks. Lane formation and reduced flow in several cases are well reproduced while some effects (more controversial in crowd studies, such as zipper and faster-is-slower effects) are not always reproduced. This relative homogeneity can be explained by the fact that a large part of studied solutions use the social forces model or a variant. However, it is not the only solution able to reproduce crowd phenomena and it lacks adequate representation of high-densities in some cases, as stated in (Still, 2000). Legion, using different principles, can reproduce adequately high-densities. Some parameters in VisWalk need to be calibrated. SimWalk also implements a route choice model that is able to reproduce turbulences.

None of the models seem to reproduce injuries or casualties due to crowd pressure: it is not troublesome as these situations are extremely rare in station context, but this particular event should be addressed by other tools while managing pedestrian flows. It is important to note that commercial solutions are primarily design tools and should be submitted to a more in-depth analysis before operational use. On the practical side, commercial simulators offer useful assistance structures and relatively affordable prices at industrial scale. They are also well linked with research teams and the academic world, promising further improvements.

Research or others models have less constant performance but interesting properties. SpirOps offers similar performances to commercial models and reproduce emergent behaviors, with powerful agents, but has not tested for high-density cases. The hybrid model using MATSim and ORCA handles a very large amount of pedestrians (750,000) with short computational time. However, it does not respect the fundamental diagram. AnisoPedCTM uses a much more precise macroscopic model; it conciliates anisotropy, good performance and respect of the main flow properties. JuPedSim takes profit of its great openness and makes easy to compare different models both at tactical and operational levels.

5.2. Railway context and real-time use need advanced research

Models concerning platform-train interface are less convincing than pure pedestrian models. It can be explained by a lack of accumulated research on this complex relation. Moreover, current implemented interfaces in simulators, when existing, should be more precisely analyzed. Precision and efficiency of this kind of model can be extremely important when using the lever of train regulation to manage pedestrian flows or that of crowd management to control dwelling times. Simulators with an interface for a rail simulator, such as MassMotion or SimWalk, are serious candidates when dealing with this use case.

To our knowledge, of the selected models, the only one that has been used for real-time simulations is JuPedSim (Wagoum et al., 2012). However, this use in experimentation has been very limited, with a simple visualization that was not connected to levers nor actual actions. As simulation platforms have developed APIs or SDKs, their integration in a global management system seem to be possible. Potentialities and limits of these links with other

software, including railway simulation, should be submitted to a more in-depth analysis. More generally, performance of state-of-the-art commercial models could be completed by small uses of research models, for instance to check the consistency of results at a macroscopic scale, or to quickly simulate the evolution of flows on a larger period.

6. Conclusion

The objective of this work is to assess the ability of existing pedestrian simulators to meet the needs of railway context in operational purpose. Being real-time or faster and compatible with railway models are two important criteria, but we provided a complete grid based on our analysis of the station as a system. We identified existing simulators and performed an analysis, which was based on information and publications from the editors. The models were not tested by the authors.

With this first analysis, it is hard to distinguish commercial simulations as they seem to offer similar performance for the same price range. Their different abilities to be used in a global management system need further analysis, but they all reach a good level of crowd description. Current commercial pedestrian simulators are suitable to address real-time management. In a global system, they could be used along with research models that are able to use the right tool to simulate a critical subsystem of the station. Real-time use, platform-train interface and model behaviors in high densities need further investigation. It is also needed to better identify the pedestrian behavior that is specific to the railway context, and to perform a more critical and in-depth analysis of the models used.

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