# Pervasive Computing in the Large: The SOCIONICAL Approach

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***Abstract*— The SOCIONICAL project aims to develop complexity science based modeling, prediction and simulation methods for large scale socio-technical systems in an AmI based smart environment. Focusing on one of the two scenarios of the project (i.e. crowd evacuation), in this paper, we have presented the *scenario based modeling approach* utilized. The position of ambient technology of choice (i.e. LifeBelt) in the modeling approach is discussed with realization of required enhancement to support sensing of the collective behavioral patterns (group formation) and information spread. After an overview of the crowd simulation strategies used in previous small scale simulation setup, we present a mixed-level simulation exercise after scaling up the simulation on a large scale. The experimental results of a real evacuation trail at local railway station are incorporated to compare the evacuation efficiency for three strategies: (i) Potential Map, (ii) Evacuees' familiarity of the exits and (iii) Exits usage optimization. A comparison with the earlier results from small scale simulation suggest that a real large scale simulation results may not be similar to that of small scale simulation due to dynamics of crowd built up and complexity of building structure.**

***Index Terms*—Ambient Intelligence, Crowd Modeling, Crowd Simulation, Complexity Science, SOCIONICAL**

## I. INTRODUCTION

THE SOCIONICAL PROJECT[1] (under European Seventh Framework Programme (FP7)) aims to develop complexity science based modeling, prediction and simulation methods for large scale socio-technical systems. SOCIONICAL focuses on the specific example of Ambient Intelligence (AmI) based smart environments. The ambient intelligence embedded in such an environment, not only, provides an opportunity to monitor users, but also, assists users in taking most suitable decisions in accordance with ever changing dynamics of the situation. Thus, the system reacts to human behavior while at the same time influencing it. This creates a feedback loop and leads to a tight entanglement between the human and the technical system. Such interaction between technology and technology-assisted users is essentially complex in nature and is being investigated using two well defined case studies, namely an evacuation and a transportation case study.

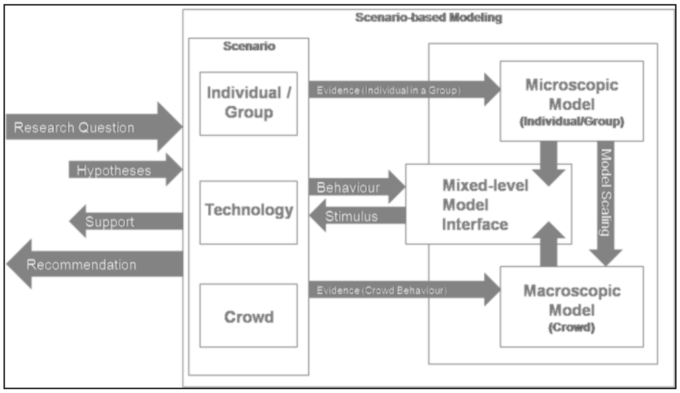

Fig. 1. Scenario-based Modeling Approach addressing the two case studies.

### A. *Scenario based Modeling Approach*

For the purpose of investigating the two case studies, we have devised a *Scenario based Modeling Approach*. Fig. 1 shows a generic view of this approach. In a scenario based modeling, a simple scenario is created with only one or few related individuals (a small group). The *research question* asked about that individual may be supported by a theoretical hypothesis. However, we do not intend to formulate the models merely on the basis of a hypothesis. The reason is that the focused systems are social systems involving cognitive entities which have complex attributes. Towards this end, no single theoretical formulation can claim to encapsulate all possible dimensions of a complex human cognitive system. That is the reason we propose to collect related evidence to accept a theory or otherwise revise it. The collection of real evidence, in this context, is not a very challenging task as we are interested in a single or a few individuals.

A careful amalgamation of small scale real evidence and established behavioral theories can be used as an outline of the *microscopic behavioral model*. The model is simulated using a suitable simulation methodology. The simulation results are considered as "validated" as far as these are predominantly in line with the theoretical model. Otherwise, the behavioral models are refined after each iterative simulation. The emphasis on simulation as a behavioral validation tool inherits its importance from the fact that the designing of a process in emergency as well as traffic situations is heavily dependent on understanding of dynamics of crowd. Due to non-availability of real data which could provide information about evacuee's mental state and microscopic moves, an overwhelming

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[1] http://www.socionical.eu/

majority of experts involved in crowd behavioral modeling rely on simulation based analysis. To this end, we coined the concept of *Evidence based Simulation*. In our evidence based simulation approach, we collect user’s response to different local and global situations in a target environment. This evidence formulates the basis of microscopic behavioral rule acting as an entity in the dataset of simulation rules.

Realizing the importance of technology (AmI technology in particular) for a socio-technical society, we augment the models' specifications with the behavioral data provided by sensing modules somehow attached with individuals. We have named these models as *mixed-level models*. The simulation based on the mixed-level models is more behaviorally realistic as it is based on earlier models of empirical evidence now supported by a real documentable trial. In addition, we have a possibility of assisting individuals with the ambient technology that is available to them. To do so, we need to re-model the behavior keeping basic cognitive behavior (in case of no AmI) intact.

The reasoning about the *macroscopic modeling* is similar to the microscopic modeling, except that these models can be interpolated from microscopic models by scaling up. Although, it would not always be possible to realize a mixed-level macroscopic model in case of a personal assisting device, however, a representative section of a crowd can be equipped with technology to record the desired results.

### B. Scenario based Modeling for Evacuation

Fig. 2 shows a more detailed view of Fig. 1, when adopted for evacuation case study. In case study related with evacuation, an empirical evidence of individuals’ behavior during a crowd evacuation was collected from a video analysis of such an event. The results extracted were examined in accordance with a crowd behavioral theory thus formulating an initial behavioral model. On the technology side, we have developed an assisting device for evacuation purpose which exploits the attributes of relative displacement and orientation by sensing distances and angles of nearby devices. We have named this device the LifeBelt [1]. We have already performed a comparison between evacuation efficiency of individuals with and without LifeBelt [2]. As the next step, we collected the behavioral evidence of few individuals wearing the LifeBelt in a real setting (in Linz main railway station). In this way, we were able to refine our initial behavioral model to come up with more realistic model in the context of SOCIONICAL. For example, in this case, the questions that are asked (so far) are:

i. May AmI technology help in evacuations?

ii. Do people trust AmI technology in such situtations?

With our previous work, we have tried to answer the first question by performing simulation on a small scale level. The second question is related with the users' trust in device and her willingness to follow it (which is not the case in former models where we consider an unconditional following of device's notifications). We have already submitted the results of this analysis in an upcoming research event.

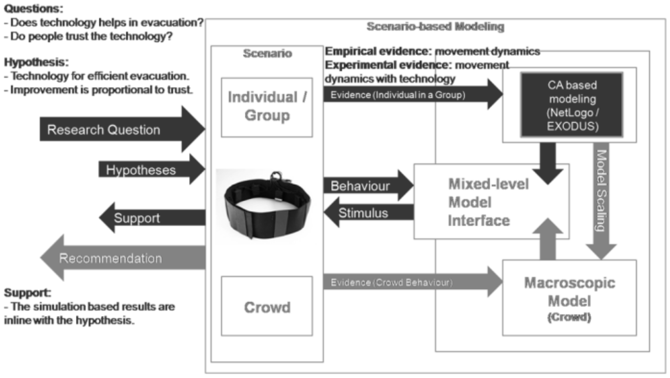

Fig. 2. Scenario-based Modeling Approach Evacuation case study.

In the near future, we plan to scale up the modified models on a large scale. Since mixed-level behavioral evidence in case of LifeBelt was difficult to realize due to non-availability of unlimited number of belts, we opted to perform a selective deployment, concentrating more on formation of group and kinship behavior. In this way, the present group and kinship behavioral models (reported in evacuation simulation literature) would be used to validate the simulation results of these dynamics. We will discuss related aspects of group behavior in next sub-section.

### C. Collective Behavioral Patterns and Information Spread

For modeling behavior of a group of related people (e.g. kinship) during evacuation simulation, it is necessary to find mechanisms to detect (sense) such a group and facilitate ad hoc network formation (information spread) for collective behavior. To this end, the LifeBelt must be engineered to sense a group in its proximity. In addition to profile based groups, it should be equipped with sensing behavioral based groups. As an enabling technology, it should also incorporate an ad hoc network formation, thus facilitating information spread within target proximity.

To enhance the LifeBelt with these two functions, we intend to collaborate with partner within SOCIONICAL consortium. In [3], the authors have proposed a mechanism of detecting the elements of collective behavior patterns by means of body-worn sensing technology. The collective behaviors of herding, grouping and dancing are investigated and initial results are reported. The authors argue that for the detection of complex crowd behavior phenomena, a reliable detection of multiple primitives serving as building blocks is required. Thus, research could go into developing methods for detecting a multitude of these primitives and evaluating combinatorial methods to detect more complex phenomena.

In [4], the authors have presented an example of example of the use of analytical models to predict global properties of large-scale information technology systems from the parameters of simple local interactions. In particular, the study focuses on how the spread of information through ad-hoc interactions between mobile devices depends on simple local interaction rules and parameters such as user mobility and physical interaction range.

### *D. Small scale vs. Large scale Simulation*

For the purpose of this paper, we evaluated another aspect of mixed-level simulation. As mentioned earlier, the experimental evidence collected through LifeBelt was used to formulate the rules for movement dynamics to be used in a small scale simulation (in NetLogo [5]). Now the question is: *Does simulation methodologies incorporated for small scale simulation scales up for large scale simulation and produce the similar results?* A quick analysis reported a negative outcome. We implemented a real scenario (Linz main railway station) focusing on the dynamics of exit (s) awareness and directional guidance (by LifeBelt) and their relation to the real building structure. To this end, we suggest that before reaching to a conclusion based on a small scale, the simulation must also be performed in an environment representing the real building structure.

The rest of the paper is arranged as following. In section II, we have very briefly discussed the necessity of simulating a crowd during evacuation. Section III describes the simulation models adopted. Section IV describes how the large scale simulation environment is setup using EXODUS. Section V is focused on large scale simulation outcomes. In section VI, we discuss the outcomes of the large scale simulation in the context of the focal question of this paper.

## II. CROWD SIMULATION

The need for evacuating a large crowd from an emergency situation is becoming evident in modern age. Due to population explosion particularly in urban areas and interest of people in mass events, the crowd gatherings are becoming larger each day. On the other hand the tendency of a natural disaster as well as a formulated one - as evident from recent experience of emergence of anti-social elements (like terrorists) - has enhanced the need for dealing with such a situation. Most of these situations demand expulsion of population from disturbed areas as quickly as possible. However this is not an easy task to perform due to its complex nature. The complexity in such a situation is inherited from the complex crowd dynamics which is necessarily an aggregation of a variety of factors. The primary factor obviously is large number of involved individuals (humans) each having an emotional state / preferences of her own. Additionally, the ever changing states of phenomena of interest such as spreading of fire, demolishing building infrastructure, dynamic human and material obstacles, and related physical consequences like power breakdown or bursting of gas pipes, provide a very challenging task to handle.

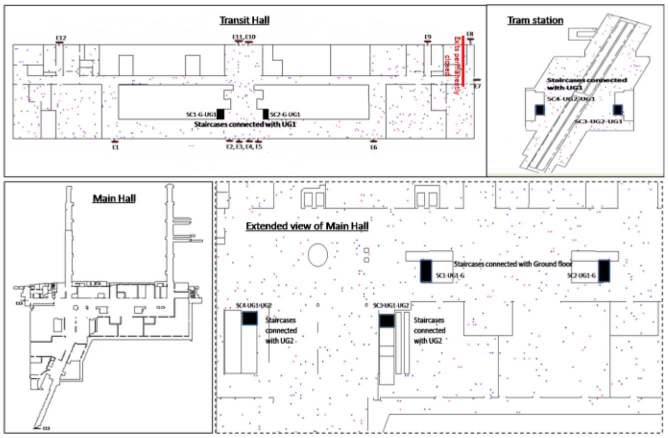

Fig. 3. Linz Station geometry in EXODUS. Transit Hall: Only exit 1 to exit 6 is in operation. Two stair cases are connected to main hall. Tram Station: exit 14 and exit 16 are not considered as an option for evacuation. Main Hall: two stair cases are connected with transit hall.

The designing of evacuation process in emergency situation is heavily dependent on understanding of dynamics of crowd. Due to non-availability of real data which could provide information about evacuee's mental state and microscopic moves, an overwhelming majority of experts involved in crowd evacuation design rely on simulation based analysis. To this end, we coined the concept of *evidence based evacuation simulation*. In our evidence based simulation approach, we collect evacuee's response to different local and global situations in an AmI environment. In our recent work we have presented evacuation strategies to deal with local (e.g. congestion control, obstacle avoidance etc.) as well as global (optimal exit selection in a multi-exit environment) factors towards time-to-evacuate and panic reduction [2]. The evidence of human behavior is collected by using a sensors rich wearable (LifeBelt) [1]. In addition to collection of microscopic behavior and emotions of her subject, the LifeBelt is used as silent assisting device for evacuation. The vibro-tactile actuators in the waist band of the evacuee provide her with the directional guidance based on a variety of sensed measures including relative exit area dynamics.

Given that the evacuee is provided with the directional guidance, in this paper, we have reported the extension of our small scale models on a large scale. We have also implemented a real scenario (Linz main railway station) focusing on the dynamics of exit (s) awareness and directional guidance and their relation to the real building structure. To this end, we suggest that before reaching to a conclusion based on a small scale, the simulation must also be performed in an environment representing the real building structure.

## III. SIMULATION MODEL

The simulation model is based on cellular automata technique in which each agent (evacuee) is contained within a square cell and each cell can only contain one agent. The next step (move) towards an exit is dependent on occupancy of neighborhood cells. On the global level (exit selection), the decisions are made based on the following:

--Potential Map
--Evacuees' familiarity of the exits
--Exits usage optimization

The *potential map* is the floor field based measure of each of the cell in the environment representing the nearest exit (displacement based). In this strategy, each of the agents follows the direction map towards the nearest exit. Depending on the geometry of the building, the potential map can be inefficient.

The human factor of exit (s) *familiarity* plays an important role when making a decision about navigation plan in real setting. In a scenario like a train station, the familiarity of an evacuee with the environment can vary from almost none to almost everything. Still even the most frequent visitors may not know some of the building structure (exits in this case). To get a quantitative evidence of exit familiarity, we conducted a survey at the Linz railway station and used it in the simulation.

The *exit usage optimization* based on exit area dynamics was introduced in our previous research outputs. Essentially the simulation was conducted at small scale. For a large scale simulation, we have fabricated the intended usage for target exits without implementing the methodologies introduced in [6, 7].

## IV. SIMULATION SETUP

### A. *Linz Main Railway Station - EXODUS Model*

Linz main railway station is a newly constructed building uniting rail, road and tram traffic in a single facility. At the ground level (EG), a *transit hall* connects the station with the road network. The *main hall* (UG-1) under EG is the main activity center having tunnel offshoots to the train platforms, restaurants and customer service centers. Further under the UG-1, the *tram station* (UG-2) connects the station with mass transit facility. All three levels have outer exits as well as inner connection through stair cases (escalators) and elevators.

The simulation was carried out using buildingEXODUS 4.06 [8]. One of the reasons of choosing EXODUS as simulation platform is its ability of importing CAD of target structure (autoCAD file in this case). In Fig. 3, the geometry of the three floors (after import into EXODUS geometry mode) of the Linz station is shown.

### B. *Evacuation Scenario*

In our evacuation scenario, we consider a disturbance at the tram station which resulted in blocking the exits at tram station (exit 14 and exit 16). This inevitably forces the evacuees at the tram station to move to the main hall (using one of the connecting stair cases). From main hall the evacuees can either use exits located at the main hall (exit 13 and exit 15) or climb up to transit hall using connecting stair cases. The same navigational strategy is also valid for evacuees originally present at the main hall. However, the evacuees from transit hall do not opt to descent to the main hall. They as well as evacuees coming from main hall exit through exits connected to road (exit 1 to exit 6).

### C. *Exits Familiarity Survey - Results*

A survey was conducted at Linz main railway station to collect the data related with exits familiarity. At least 80 evacuees were interviewed. In addition to other measures, the question related with this paper consisted of following statement:

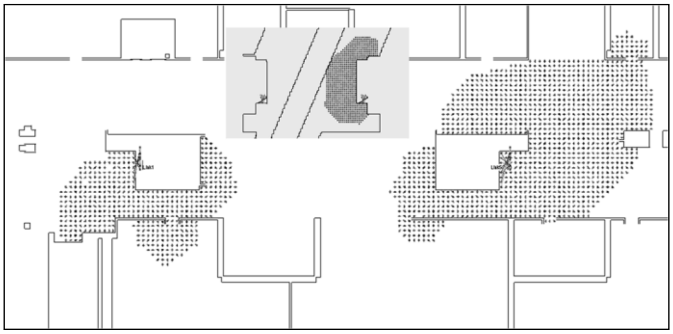

Fig. 4. Potential map based simulation in EXODUS: 2D view of the Main hall. The small image with gray background shows the congestion at tram station right staircase (the left is evacuated) which is heading to stair cased on left main hall.

*If there is an emergency situation right now, which exit would you use to evacuate?*

The above question was asked at four different locations, which are:

--Two platforms of the tram station
--Left section of the main hall at access tunnel near exit 15
--Right section of the main hall at access tunnel.

At the platforms of the tram station, most of the people voted in favor of tram station exits. Since, in the scenario, we are not considering tram station exits as a valid option, these datasets were discarded. Out of the remaining (at least 50%), the following results were compiled:

--60% for exit 15 (main hall)
--30% for exits at transit hall
--10% for exit 13 (main hall)

As a whole the evacuees interviewed at the main hall responded as:

--67% for exits at transit hall
--25% for exit 15 (main hall)
--8% for exit 13 (main hall)

The second evacuation strategy used in the simulation is based on these exits familiarity survey results.

## V. SIMULATION IN BUILDINGEXODUS

The simulation was conducted for 10000 evacuees which is equal to the predicted passenger flow in 2015 [9] having considered the time to evacuate measure. The following population distribution was reproduced for each of the strategies (simulation runs):

--tram station: 2000
--main hall: 6000
--transit hall: 2000

### A. *Strategy 1: Potential Map (Nearest Exit)*

The obvious disadvantage of this strategy is over utilization of some of the exits. For example, if we consider 2000 evacuees at the tram station, nearly distributed in two halves (1000 each) for two platforms, the one half would always target exit 15 (main hall) whereas the other half would target exit 2 (transit hall). This factor is evident from Table. I. Similarly, some exits would be underutilized. For example, exit 13 (main hall) does not get any passenger from transit hall. The only portion evacuated from exit 13 is consisted of evacuees within its potential map at main hall. That is the reason exit 5 (or right staircase connecting main hall to transit hall) is more populated (see Fig. 4), i.e. exit 13 and exit 15 sharing the load from left half of the main hall within themselves, whereas there is no such exit on the right side of the hall. It is also important to note that exit 1, exit 3, exit 4 and exit 6 has static flow of evacuees which cannot be changed.

### *B. Strategy 2: Exits Familiarity*

The simulation results of strategy 1 revealed that the amount of evacuees attracted by potentials of exit 2, 5, 13 and 15 is roughly the same as that of the survey results. Hence there is no changing of navigation plans at main hall. However, the navigation plan for evacuees at tram station was changed representing the familiarity count which suggested a favor for exit 15 (1200). Surprisingly, this resulted in load shedding for exit 2. However, the load at exit 15 remains the same hence producing improvement in overall evacuation time, but slightly (see Table. II).

### *C. Strategy 3: Equal Exit Utilization*

The main feature of this strategy is the target based navigation based on equal exit utilization. As seen is Table III, we set target of 1000 out of 6000 evacuees explicitly to exit 13 (being the least utilized exit). This retained 600 more evacuees to main hall. However the overall improvement is still marginal. This is due to the fact that all the evacuees who needed to navigate from center and right of the scene were blocked behind a built-up (congestion) near the main hall staircases, waiting till the later stages of the simulation before escaping. Also, the exit 13 is practically the farthest exit to reach which needs time. Overall the productivity of exit 15 is the most due to its nearness to tram station staircases.

These environmental based constraints are specific to this environment. There would be different constraints for different settings. Most exit selection strategies are based on the dynamics of an area near an exit (to save processing time needed to find global optima in case of large number of entities). The strategy applied here is simply a count based as opposed to our exit selection strategies based on exit area dynamics. However it approves the focal point of this paper, i.e. the exit selection is influenced by environment type as much as that of exit area dynamics.

As a variant to the equal exit utilization strategy as described above, we enhanced the load of exit 15 by 800 more evacuees from tram station to shed the load from exit 2. Table. IV describes a substantial improvement in overall evacuation time. We will further analyze the improvement phenomena in next section.

TABLE I
EXIT USAGE (TARGET EXITS ONLY) – POTENTIAL MAP

| Exit-2 (T=2587) | Exit-5 (T=2489) | Exit-13 (T=203) | Exit-15 (T=1085) |
|---|---|---|---|
| EG (87) | EG (87) | EG (0) | EG (0) |
| UG-1 (1616) | UG-1 (2352) | UG-1 (662) | UG-1 (1369) |
| UG-2 (1000) | UG-2 (0) | UG-2 (0) | UG-2 (1000) |

T = Time (iteration) last evacuee used the exit, EG = Transit hall, UG-1 = Main hall, UG-2 = Tram hall.

TABLE II
EXIT USAGE (TARGET EXITS ONLY) – FAMILIARITY

| Exit-2 (T=2283) | Exit-5 (T=2519) | Exit-13 (T=2303) | Exit-15 (T=2299) |
|---|---|---|---|
| EG (87) | EG (87) | EG (0) | EG (0) |
| UG-1 (1615) | UG-1 (2347) | UG-1 (656) | UG-1 (1381) |
| UG-2 (600) | UG-2 (0) | UG-2 (200) | UG-2 (1200) |

T = Time (iteration) last evacuee used the exit, EG = Transit hall, UG-1 = Main hall, UG-2 = Tram hall.

TABLE III
EXIT USAGE (TARGET EXITS ONLY) – EXIT UTILIZATION

| Exit-2 (T=2501) | Exit-5 (T=2185) | Exit-13 (T=2395) | Exit-15 (T=1068) |
|---|---|---|---|
| EG (87) | EG (87) | EG (0) | EG (0) |
| UG-1 (1383) | UG-1 (1976) | UG-1 (1528) | UG-1 (1113) |
| UG-2 (1000) | UG-2 (0) | UG-2 (0) | UG-2 (1000) |

T = Time (iteration) last evacuee used the exit, EG = Transit hall, UG-1 = Main hall, UG-2 = Tram hall.

TABLE IV
EXIT USAGE (TARGET EXITS ONLY) – EXIT UTILIZATION - ENHANCED

| Exit-2 (T=1790) | Exit-5 (T=2207) | Exit-13 (T=2285) | Exit-15 (T=1809) |
|---|---|---|---|
| EG (87) | EG (87) | EG (0) | EG (0) |
| UG-1 (1419) | UG-1 (1974) | UG-1 (1527) | UG-1 (1081) |
| UG-2 (200) | UG-2 (0) | UG-2 (0) | UG-2 (1800) |

T = Time (iteration) last evacuee used the exit, EG = Transit hall, UG-1 = Main hall, UG-2 = Tram hall.

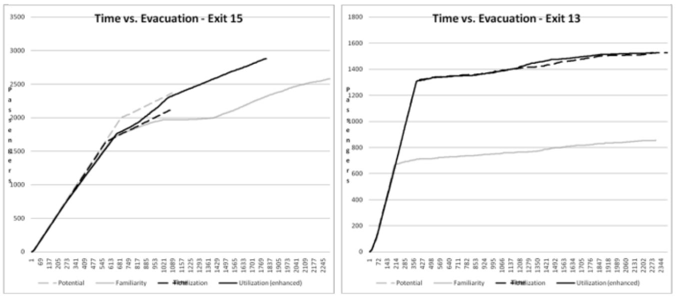

Fig. 5. Time vs. Evacuation: Exit 15 and Exit 13

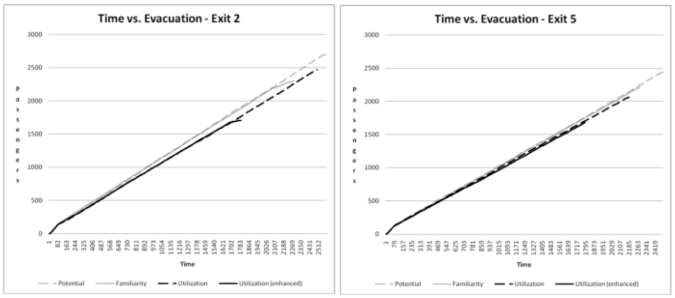

Fig. 6. Time vs. Evacuation: Exit 2 and Exit 5

## VI. DISCUSSION

As we have mentioned in the previous section, a change in evacuation strategy only influences four out of eight usable exits. When using potential map, exit 15 at the main hall, in addition to its local influence attracts evacuees from left platform of tram station. Exit 13 only attracts its own influenced evacuees. Exit 2 attracts all the evacuees from right platform of the tram station (almost 1000 in number) whereas exit 5 does not get any evacuee from tram station. The difference between total number of evacuees assigned to exit 2 and 5 is not substantial due to the reason that left side of the main hall has exit 13 and 15 to share the load whereas there is no such assisting exit on the right side of the main hall. Both exit 15 and 13 turn out to be more productive as compared to exit 2 and 5 (see Fig. 5 vs. Fig. 6 for comparison). The reason for degradation in productivity in case of exit 2 and 5 is due to involvement of narrow staircases between main hall and transit hall which results in a congestion on both sides. Fig. 7 shows a graphical view of productivity of the exits. The y-axis of the graph represents the measure PPM (Average Persons per minute). It is important to understand that a higher value of PPM does not mean a higher productivity. The productivity as we define it is the throughput of the exit. Whereas the value of PPM is averaged for the time span it is used for. For example, in case of potential map, the least number of evacuees escaped are through exit 13 (662). Since it did not get any evacuees from tram station, it lasted only for 202 seconds thus resulting in highest PPM. The goal of optimization is to balance the exit usage time as much as possible while keeping the PPM value reasonably high (as in case of exit 15).

In the exit usage utilization strategy, on top of potential map, we assigned 1000 evacuees from main hall to target exit 13 (being the least utilized exit). The reason for selecting a static number of evacuees to target a particular exit is to use EXODUS as a large scale simulation platform for a quick proof-of-concept study. In the next stages of the simulation effort, we will implement the dynamic optimal exit selection strategies [6, 7] based on exit area dynamics which would essentially be more complex and time consuming. In this particular case, exit 2 remained the most time taking exit because the majority of *new* evacuees now targeting exit 13 has to pass through congestion around left main hall staircases. Therefore optimal exit selection that worked for small scale simulation is not working as expected due to congestion and blockage due to geometry of the building. Hence, in the enhanced optimal exit utilization strategy, we shed the part of tram station load from exit 2 to gain relative load optimization. It is important to note that the enhanced strategy is by no means an optimal strategy. It’s just serving as an example of focal point of this paper.

## VII. CONCLUSION

Crowd modeling and simulation attempts to understand and explain complex phenomena. In addition to modeling of crowd dynamics with and without Pervasive Computing technology (wearable systems, localization and positioning, multimodal interaction, wireless communication), the issue of scale becomes a prevalent one. Based on case study we have illustrated, how the small scale Pervasive Computing system studies (a typical study involves some 5-25 entities, either devices or users) can be leveraged to scales of 10^4-10^6. Evidence based simulation is considered as a promising approach, where empirical evidence is collected at the microscopic level, to inform a model on the macroscopic level. The validity of the large scale model is supported by model parameters coming from empirical data, but also from model-reality feedback loops at runtime.

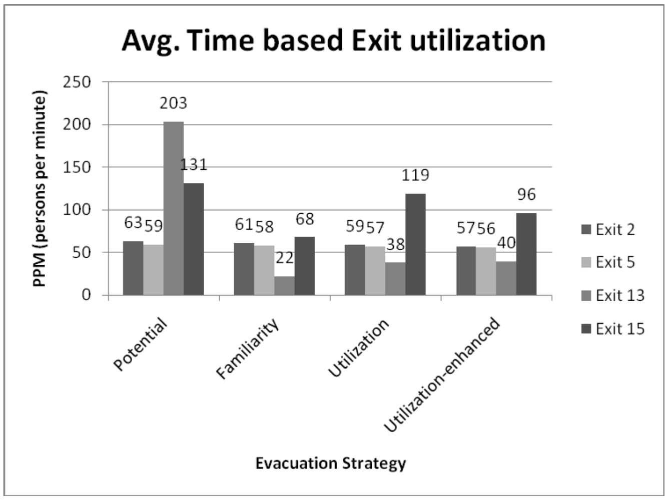

Fig. 7. Average persons per minute measure.

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