INTELLIGENT SIMULATION FOR TOURISM AND CULTURAL HERITAGE MANAGEMENT

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ABSTRACT
The paper addresses an intelligent simulation approach to tourism and cultural heritage management. Emergent information technologies, modelling approaches and simulation paradigms provide new capabilities for intelligent and interoperable management of tourism and cultural heritage. Nowadays mobile applications for tourism organisation at heritage sites have become quite popular. Smart mobile applications with embedded simulation capabilities can significantly increase intelligence of managerial decisions and improve the quality of customer services. The concept of a mobile application that for a particular tourist place suggests objects to be visited preferably at the moment is introduced in this paper. A simulation-based case study for intelligent management of pedestrian tourist flows at heritage sites is given. An agent-based modelling paradigm is applied to simulate tourists' behaviour and analyse operational solutions. Post-experimental analysis to explore behaviour of the developed simulation model is performed.

Keywords: intelligent and interoperable management, agent-based simulation, pedestrian flows, smart mobile application, heritage site

1. INTRODUCTION

All over Europe, cultural heritage, being part of the human history, traditions and creativity and having a social function while creating economic value, attracts millions of tourists. This sometimes creates difficulties for visitors to have easily access to a particular heritage site. Also, overcrowding may lead to the destruction and degradation of heritage buildings (HBs) (Lyu et al. 2016).

The overall idea of the intelligent tourism organisation to provide both more comfortable environment for visitors and less stress on the heritage is rather topical (Xiaowen et al. 2012). As computing power is growing and new IT technologies appear, many visitors can use mobile applications to gain more information from the local organisations. As the number of smart mobile devices in use is continuously growing, it would be reasonable to provide visitors with intelligent applications that would guide them and suggest tourist objects or attractions to be visited preferably at the moment (Marie-Theres 2016).

The development of such application for a particular tourist place could require advanced forecasting and planning in order to consider all local peculiar properties and manage crowd. Nevertheless, many aspects of local spatial information and pedestrian crowd behaviour could be assessed in a simulation process (Lyu et al. 2016). Such mobile applications would not be useful for pedestrian tourists in case of large, extensive geographical areas. But they would be highly effective for heritage sites, which can be investigated within walking distances, such as small historic city centres and medieval monasteries.

This paper addresses some issues and application of an intelligent and interoperable approach to tourism logistics and cultural heritage management. The emergent information technologies, modelling approaches and simulation paradigms that enable enhancing the effectiveness of decisions in managing tourism and cultural heritage are discussed. A simulation-based case study in intelligent management of pedestrian tourist flows in a historical city centre is described. It is aimed to analyse pedestrian tourist flows and evaluate possible outcomes of application of smart technologies to control them. An agent-based modelling paradigm is employed for simulating tourists' behaviour. A structure of a simulation model and its layout are presented, and behaviour of intelligent agents is detailed. Post-experimental analysis to explore the model behaviour is performed.

2. APPROACH AND MODELLING PARADIGM

Information exchange and knowledge sharing is a prerequisite for collaborative good decision making about HBs' protection, rehabilitation and operation processes. This requires an intelligent and interoperable approach to collaborative management produced with process interoperability when human beings share a common understanding across a network, business

systems interoperate, and work processes are coordinated (Sarraipa et al. 2010).
Advanced and emergent information technologies create new capabilities for intelligent and interoperable management of cultural heritage. Particularly, they provide methods and tools for heritage data sensing, processing and management; imaging and visualization of heritage; modelling and simulation (such as 3D modelling, crowd simulation, agent-based simulation); socio-economic modelling of the environment; climate impact and risk assessment for cultural heritage; modelling for interoperability of HBs and mobile application services.
Nowadays, specific mobile applications for heritage sites are developed to amend or supplement tour guides and provide application also reducing tourist crowds users with additional information about them (Rolando et al. 2013). Examples of such heritage sites which extensively address mobile device users are Barcelona and Malta (Mobile Apps 2016, Malta Tourist Mobile Apps 2016). They provide a wide range of specific and free to use mobile applications for different types of tourists' purposes and could be grouped as follows.
The first group allows interactive orientation in a new unknown location and provide geographical and navigational information for the attractions to visit. The second one mainly focuses on providing additional textual, audio and other media information within a covered area. The third group covers applications, which include both navigational and descriptive options. The present work is focused on applications with a navigation opportunity.
However, most of such applications do not include enough information on a current tourist activity within the covered area, which could be sensitive to mass tourism destinations and the most popular tourist attractions. Mobile applications which will incorporate such information would be useful here (Li and Wang 2011). These applications could allow navigating the tourists to less-crowded sites. Also, more advanced information, such as visitor's preferences, real distance, times to reach the site and optimal routes could be considered.
To make these mobile applications more intelligent by providing suggestion on the next object to visit and taking into account various factors, different decision making techniques may be used. Usually, the evaluation of the alternatives is based on the distance and value of heritage or touristic attractions. Complementing it with the information on the current state of the object will allow the holder of such application visiting less overcrowded attractions, while avoiding visiting the objects, for which currently it is necessary to wait a long time in a queue. Due to complexity of real-life experiments, it is assumed to evaluate the alternatives by means of simulation experiments.
In practice, modelling and simulation are used at two levels of a system description (Merkuryev et al. 2014). Macroscopic modelling processes geographic objects and regions in an aggregated form based on the black-box principle where each region is specified by prescribed average statistical indicators, such as land and heritage building use, status of objects, population, transport nets and services. The small amount of the necessary data and a small number of computational resources make macroscopic modelling one of the most widely used approaches in spatial planning.
Microscopic modelling provides the depiction of the real system in a very detailed manner and execution of simulation activities with homogeneous spatial units. Microscopic models are gaining ever broader application area in recent years due to the rapid development of information technologies and increase in computing power resulted in higher speed and accuracy of simulation processes. So, the microscopic simulation of pedestrian flows (Liu et al. 2014) has attracted increasing research attention since a reliable simulation model for pedestrian flow may greatly benefit in transportation management, as well as in urban planning and architecture. Microscopic models may have stochastic behaviour.
With regard to the use of modelling paradigms, so called System Dynamics paradigm (System Dynamics Society 2016) enables analysis of complex dynamic systems, such as population dynamics, ecological systems and economical processes. It assumes a high level of aggregation of system's objects and mainly is used for long-term strategic decisions in tourism and heritage management. Nevertheless it can be used also for short and mid-term models, where structure and dynamics of a system should be investigated. System dynamic simulation allows easier interpretation of systems structure and internal relationships. Examples of efficient tools that provide system dynamic simulation are Vensim DSS and AnyLogic simulation software. The last one allows combining system dynamics with other powerful simulation paradigms such as agent-based modelling and discrete event simulation, which allows expanding the model to higher detailing of internal processes.
The agent-based modelling provides an intelligent approach and advanced methodology for building microscopic models. It becomes the dominant approach in social simulation as worldwide social systems are complex, highly decentralised and composed of a multitude of heterogeneous objects called by agents. These agents act with some purpose and their interaction, usually through time and space, generates emergent behaviour, often at higher levels than those at which such agents operate (Crooks et al. 2008).
In traffic simulation, such agent-based models allow considering various aspects of pedestrians behaviour. Here, pedestrians are modelled as independent agents, which interact among themselves and within a defined spatial environment. This allows considering individual characteristics of pedestrians, revealing weak elements of pedestrian infrastructure, and providing highly detailed model and visualisations (Camillen et al. 2009).
The case study is built on an agent-based simulation model applied to simulate tourists' behaviour and

support decision making for individual tourists on the attraction to be preferably visited next, as well as to assess possible outcomes of application of smart mobile applications to control tourist flows and crowds.

3. CASE STUDY

The cultural heritage site represents a central part of the original and historical area of the capital of Latvia, which is known as the Old Town of Riga (often called also "old city"). It is the most popular tourism area for pedestrian tourists including 5 open-air sites or tourist attractions and 3 indoor sites. The open-air sites represent either large squares with a number of heritage objects or vicinities of historic buildings with crowds of people gathered around buildings. The indoor attractions include two museums and the Riga Cathedral hall. It is assumed, that indoor attractions have limited capacity. The heritage has three entrance points, from which tourist agents come into a heritage site with a constant rate. It is assumed, that tourists would like visiting all attractions within a certain period of time. Also, incoming tourists are individual, not organised in groups, and do not have any predetermined sequence of visited attractions.

The heritage site includes separate buildings or building quarters separated by streets. Some of these streets are pedestrian and can be passed by agents at any place. But other streets that have motor car traffic can be crossed only at specific places. Outdoor attractions are located in the pedestrian street areas, or around some specific objects. The outer walls and fences of such building quarters create insurmountable obstacles for moving of tourists in the environment.

There may be two types of tourists visiting the heritage: (1) ordinary tourists without mobile applications for a tour guide; these tourists follow the closest attractions, however their behaviour can be unexpected or random; and (2) advanced tourists equipped with mobile applications, which try to adhere to the attractions proposed by mobile guides. Relative numbers of ordinary and advanced tourists may vary. Usually, all tourists visit each attraction only once.

The aim of the study is to analyse if introduction of applications would avoid tourist crowds in the old city and significantly reduce waiting times at the most popular attractions.

4. AGENT BEHAVIOUR MODELLING

In the model, tourists are simulated as intelligent agents having their own decision-making capabilities. Each agent has its speed and width, which are not deterministic and defined by uniform distributions within ranges [0.4; 0.8] and [0.4; 0.6] m/s, correspondingly. The dynamic behaviour of tourist agents is defined as follows (Bolshakov and Merkuryeva 2016). Each agent created in the model performs a sequence of actions:

1. Selects one of non-visited attractions. For each attraction the probability of being chosen is defined in section below. For ordinary tourist agents and ones equipped with applications, the logic of the action is different.
2. Moves to the chosen attraction in the defined environment, which has walls and non-accessible areas.
3. Arrives at the attraction and stays there for a short period of time if the attraction is of an open-air type. The time period is randomly defined within the time ranges that vary between different attractions.
4. Arrives at the attraction. If the attraction is of an indoor type, first waits in a queue in case its current capacity is overloaded. When leaves the queue, stays at the attraction for a longer period of time. All time periods are randomly defined similar to ones in the previous action.
5. Leaves the heritage environment if all the attractions visited or being tired after certain time has passed.
6. Otherwise, selects the next attraction (step 1).

For each attraction the probability of being chosen is defined by the formula:

$$p_i = \frac{w_i}{\sum_{j=1}^{n} w_j},$$

where p_i is a probability of attraction i to be selected, w_i is attraction weight for a particular agent, and n is the total number of attractions.

For ordinary agents, the closest attraction will have higher probability of being selected, so weight w_i is calculated as follows:

$$w_i = \begin{cases} 0, & visited \\ \frac{1}{d_i}, & otherwise \end{cases}$$

where, d_i is a distance from the current agent's location to the i-th attraction.

In case of advanced agents equipped with smart mobile applications, weights are calculated considering the current load of attractions, i.e.

$$w_i = \begin{cases} 0, & visited \\ \frac{1}{d_i}\left(\max(\frac{s_i - l_i}{s_i}, 0)\right), & otherwise \end{cases}$$

where s_i defines the maximal capacity of i-th attraction, and l_i is the current number of agents at i-th attraction.

Finally, tiredness of the agent is modelled by a state chart and timeout transition which is randomly defined within the range from 1 to 4 hours.

5. SIMULATION MODEL

The layout of the agent environment (Figure 1) is built based on the city map developed by OpenStreetMap contributors (OpenStreetMap 2016). Attractions' areas are bordered by green dotted lines. Building quarters and non-accessible areas are surrounded by walls shown as orange lines. Queues of tourists waiting at the entrance of indoor attractions are marked by dark blue lines. Agents have three entry points into the environment, i.e. on the left, right and bottom edges of the model screenshot, shown with green solid lines. The entry rates are 2500, 5000, and 3000 agents per hour correspondingly. The capacity of indoor attractions is limited by 200 visitors.

Figure 1: Layout of the Heritage Site

Figure 2 presents a screenshot of a fragment of the model visualisation in more detail. The agents are marked by red, black or blue dots. Red and black dots correspond to ordinary tourists without an application and tourists with it, while tired tourists, which exit the environment, are marked by blue dots.

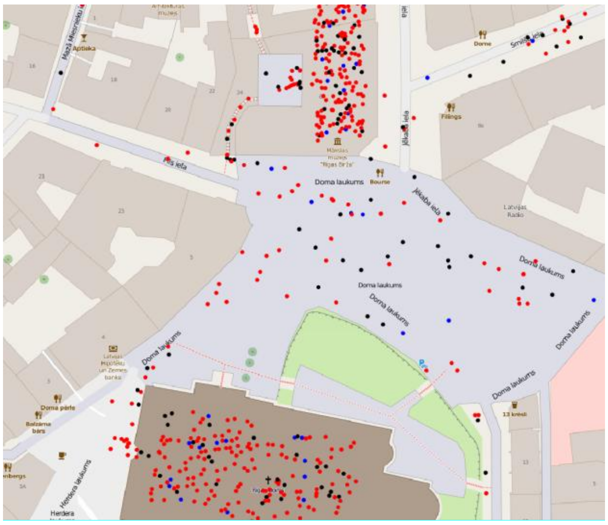

Figure 2: Fragment of the Model Screenshot

6. SIMULATION AND EXPERIMENTAL ANALYSIS

The increasing number of international tourists visiting heritage cities and capacity limits for the most heritage sites worldwide may lead to queuing of tourists at the entrances to popular museums, art galleries, etc. In the case study, long queues appeared at the entrances of some indoor attractions, particularly, at the entrance to the cathedral (Figure 3). Thus the length of the queue is defined as the main performance indicator to validate the proposed approach and assess outcomes of the use of mobile applications by performing simulations.

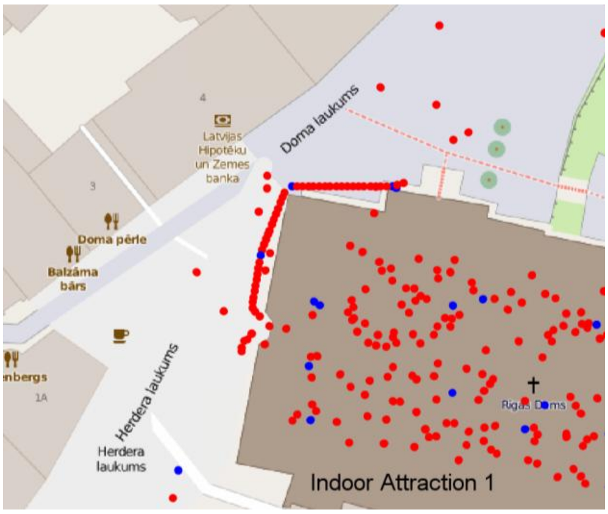

Figure 3: Queues at the Entrance of Indoor Attraction 1

A number of simulation experiments have been performed with different relative numbers tourists equipped with smart applications. Time plots for queue lengths at the entrances of indoor attractions (i.e., museums in the model) received from simulations are shown in Figures 4 and 5. In the case where all agents represent ordinary tourists (Figure 4), queue lengths tend to increase over time (scored in seconds). It can be seen that the distribution of numbers of tourists between museums is very uneven, and there is almost no queue to get to the Museum 3. In the case where about 50% of tourists use smart mobile applications to choose the next attraction (Figure 5), queue lengths are much smaller than in the previous scenario. All statistics are reset at the end of a warm-up period.

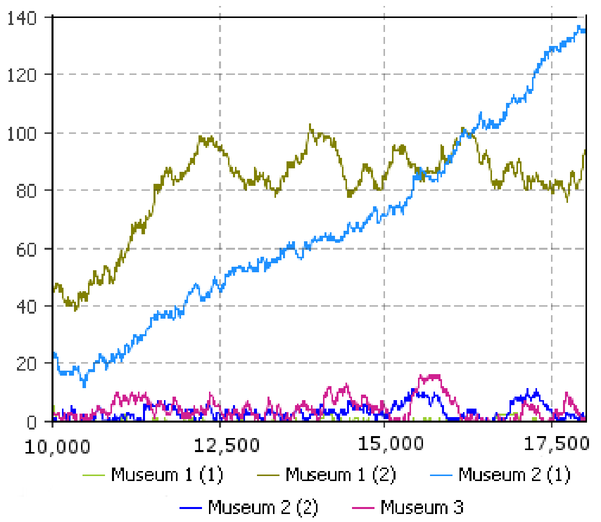

Figure 4: Queue Lengths (no application used)

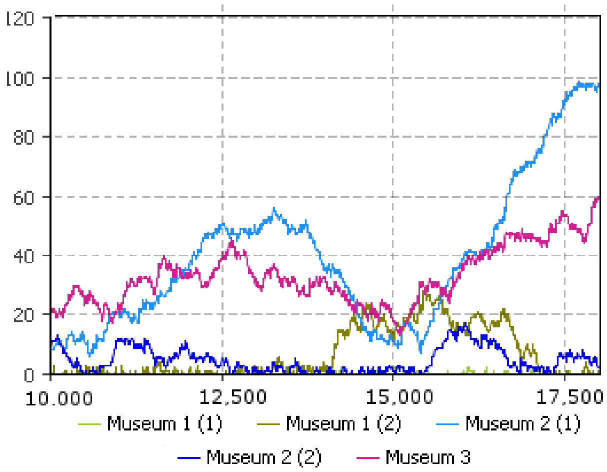

Figure 5: Queue Lengths (50% of tourists use applications)

In the case where relative numbers of advanced tourists are fairly high, the queues are still formed. This is due to a time lag. In the current logic of the model, tourists are suggested to go to the next attraction when they leave the previous one. While they are moving, the attraction can be occupied by other tourists. Thus, logic of the applications is supposed to be adjusted to deal with this time lag.

A regression metamodel is built to measure the sensitivity of queue lengths from a relative number r of tourists with the proposed application. In the model, the total queue length L is calculated as a sum of all tourists waiting in the queues to indoor attractions at the end of the simulation period and $r \in \{0, 0.2, 0.4, 0.6, 0.8, 1.0\}$. In each experiment, 200 simulation replications have been performed to obtain the mean value with the 95% confidence interval (Figure 6).

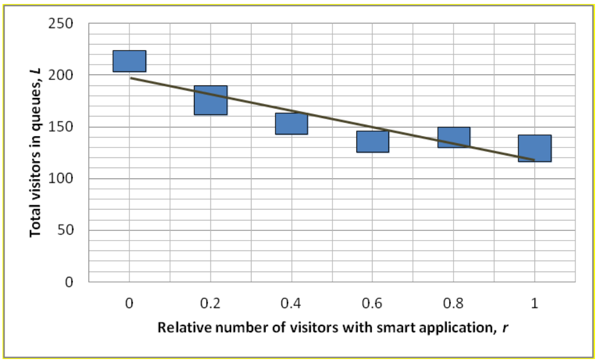

Figure 6: Confidence Intervals for Total Queue Lengths

As a result, the simulation metamodel is approximated by a linear function, i.e., $L \approx 197.9 - 78.1r$. So, an increase in the number of tourists which would use such applications can significantly reduce a number of visitors waiting in queues while managing tourist flows and overloading of heritage sites, thereby reducing their negative impacts on the heritage buildings.

7. CONCLUSIONS

Smart mobile applications with embedded simulation capabilities can significantly improve intelligence of managerial decisions and quality of customer services.

The proposed concept of an intelligent touristic mobile application which integrates agent-based simulation has shown its sustainability and allowed partially unload overcrowded heritage sites. It may be advanced by a more sophisticated processing logic and decision making procedures.

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