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DYNAMIC URBAN POPULATION SIMULATOR

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Abstract: Releases of hazardous substances are often investigated using a full chain of models which includes source models followed by atmospheric dispersion models and finally toxicological models that provide the injury outcome for the population in the risk area. A vital component in this chain, that is often neglected or treated on a naïve level, is the exposure model that could be categorized as a part of the toxicological models or positioned after the atmospheric dispersion process. The purpose of an exposure model is to provide the, possible time-dependent, acquired dose for the population. In this work we present an exposure model that treats the synthetic population as dynamically moving individuals in the risk area. A case study is considered where the injury outcome is compared between scenarios utilizing static or dynamic population descriptions.

Keywords: *Micro model, Behaviour analysis, Simulation, Modelling, Dispersion, Toxicology***.**

INTRODUCTION

In today's society it is of high priority to be prepared for unexpected and sudden events regarding both prevention and ability to handle an ongoing emergency and its aftermath. One situation with possible disastrous result is a release of a hazardous substance in aerosol or gaseous form that is dispersed over a large area in a city. In such a case, the behavior of the population in the area of interest is of most importance to the overall injury outcome. Traditionally, injury assessments in models have been conducted using a static population with a geographical distribution to calculate the exposure dose and thereafter the possible injuries. This method does result in a correct estimate of the total exposure dose of the population but with a distorted exposure distribution on an individual scale. Since the injury outcome for a person often is a highly nonlinear function of the received dose, the total injury outcome of a population is dependent on the exposure distribution and not only the total collective dose.

To improve upon existing scenario tools, we have developed a micro model that allows for simulation of individual movement of the population. The model is called *Dynamic Urban Population Simulator* (DUPS) and is based on a network description of the city. The network captures the geometry, infrastructure, and demography quantitatively which also serve as input data into behavior algorithms that calculate likely paths the population will use depending on the current scenario. The spatial distribution and connectivity of the nodes in the network is a direct reflection of the structure of the city determined from such features as streets, bridges, parks and so on. The citizens, referred to as *agents*, will follow possible paths on this network on an individual level in such a way that the aggregated spatial distribution of the population as well as the distribution over the included types of activities follow user predefined statistics. The idea and mechanisms of DUPS is briefly covered here.

Finally, we present a case study of the Swedish city Norrköping, hosting 23 Seveso-classified companies, using a scenario where a chemical accident causes a hazardous cloud of sulphur dioxide to be transported over the central parts of the city. A comparison over the injury outcome between cases with static or dynamic population models was conducted and is here presented.

DUPS - AN OVERVIEW

DUPS provides synthetic movement paths for the population in an urban area. The citizens are allocated individual activities that involve being outdoor for a long enough time to possible be exposed to a hazardous dose of a released substance.

Purpose and limitations

The task for DUPS is to provide a quantative description of the movements of the population within an urban area that will serve as a tool for exposure modelling in a scenario including atmospheric dispersion of hazardous substances. This problem is normally restricted to scenarios with distinct spatial and temporal domains. The time span of interest includes the exposure phase of an incident which is assumed to be restricted to a maximum of three hours. The geographical domain is set by the size of a risk area which implies a size of approximately a few hundred square kilometers.

Specifically, DUPS is designed to answer to the following demands and is allowed to hold the following limitations:

- Provide a representative exposure of the population on an individual level after a sudden event.
- Provide the opportunity for agents to interact.
- Provide the opportunity for dynamic behavior alterations of the agents.

- Limited to scenario of maximum 3 hours.
- Limited to a geographical domain of a few hundred square kilometers.
- Does not include indoor exposure.

Starting with these demands and limitations, the model DUPS was developed. Structurally, DUPS can be described as a *Time Limited Open Domain Agent Synthesizer*. There are two specifically parts of this description of interest, *Time Limited* and *Open Domain*. The limitation in time refer to the restriction that the model is not expected to be able to handle the population movement for more than three hours which implies that a person that leaves the geographical domain for a time period that is expected to last longer than three hours can be regarded to have left the simulation domain forever. The fact that DUPS is defined using an open domain means that there is no geographical restrictions for the agents. They may enter and leave the resolved region during the simulation.

DUPS includes some additional features that are not discussed in this paper such as walking speeds, breathing frequency, and interactions between agents. For more detailed information regarding DUPS in general as well as the case study the reader is referred to (Björnham, 2013) and (Björnham, 2014).

PATHBUILDER

DUPS relies on spatial paths on which the agents are dynamically transferred during simulations. A custom made program called *PathBuilder* was constructed to allow the user to set up a spatial network and to insert all other necessary input data.

Graph theory

A key feature of DUPS is the network (or graph) that describes the urban area. In general, nodes are placed at cross-roads and edges connects the nodes. The idea with this structure is that agents may move between two different nodes following any series of edges that connects the nodes. Any such series of nodes (or edges) is called a *path*. The graph constructed for Norrköping is shown in Figure 1.

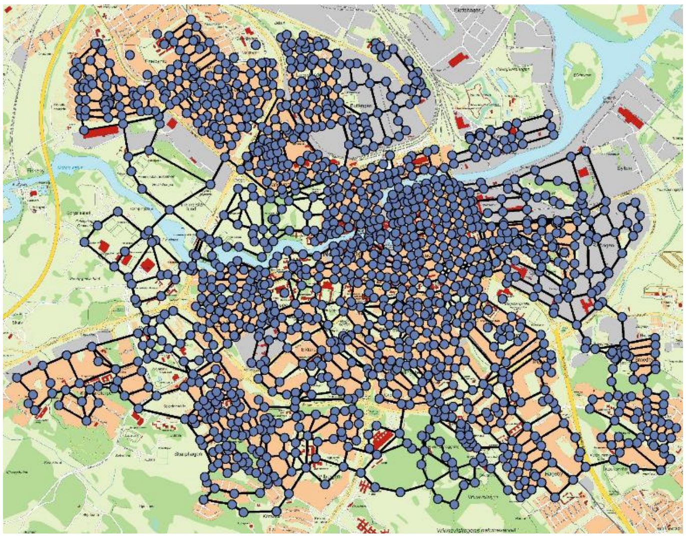

Figure 1. The graph over Norrköping contains 1425 nodes (blue circles) and 2110 edges (black lines).

In general there are many possible paths between any two nodes in the graph. It is assumed that people tend to choose one of the shortest paths. There is a commonly used algorithm called A* to find the shortest path between two nodes in a network. The algorithm uses a distance-plus-cost heuristic function to compare different choices of paths. This is how the algorithm finds the shortest path between a start node and a goal node. All nodes with edges that are directly connected to the start node are compared. The distance to a certain node is the total distance from the start node to that node which in the first step only is the length of the edge. To this distance is a *heuristic estimate* added. This estimate serves as a guide to speed up the search. For this kind of search, the Euclidean distance between the node and the goal node is commonly used as estimate. This implies that edges that geographically leads further away from the goal node are punished. The edge with the smallest distance plus estimate is chosen to be included in the continuing search. In step 2 the same procedure is conducted with the expansion that all nodes connected to the start node or the chosen node are included. For every step the number of chosen nodes grows. This procedure is then repeated until the goal node is reached whereby the shortest path is found. A more detailed description is given by (Hart, Nilsson, & Raphael, 1968). Further on, it is judged unlikely that all people would always choose the exact same path between two nodes if there are several options that only differs marginally in length. To account for this a stochastic element is included in the search algorithm which results in a spread in the distribution of picked paths where the shortest is still the most likely.

Activities

There are six defined types of activities for the citizens that together span the vast majority of everyday outdoor activities in an urban region, see Table 1.

Table 1. There are six different activities in DUPS.

Activity	Description
Walk	A walk with no particular purpose other than the walk itself.
Jogging	A jogging tour.
Shopping	An activity with the purpose of conducting shopping by foot. This activity will mainly be performed in the centrum of the city where most of the shops are located.
To Sink	This activity implies that the agent starts at one node and ends up at another node where it is removed from the simulation. This can typically be the case when the agent are walking from its home to a working place or vice versa.
To Com	The agent is walking to a communication node followed by a certain waiting time to, e.g., enter a bus.
Still	During this activity the agent stays at the same place the entire time. This may typically be used for pupils at a school that are outside for a break.

To conduct an activity equals following a path that has been compiled to represent a likely choice of spatial movement for that particular activity. This means that an agent that is shopping is likely to walk around in the centrum of the city while a person that is out for a walk is most likely to actively choose areas that are generally considered attractive such as parks or riverbanks.

Creating paths

When an agent is assigned an activity it will follow a representative path that has been constructed for that type of activity. Different nodes are not equally probable to be picked for each type of activity. To take this phenomena into account each node is assigned nine different property values that describe the demography of the region surrounding the node. These properties are *Residences*, *Parks*, *Markets*, *Shops*, *Bicycle Parkings*, *Car Parkings*, *Communications*, *Workplaces*, and *Schools*.

Activities may not be well represented by the shortest path between two nodes. For instance, a walk normally starts and ends at the same node. This is handled by creating a series of subpaths where subpath #2 starts with the same node as subpath #1 ended with. An A*-search is used to find each subpath and the series of subpaths can thereafter constitute any arbitrary path and still end up at the same node as it started at. A large number of paths was pre-constructed for each activity, see Figure 2. To obtain a likely distribution of path lengths many of them were then discarded and finally six representative sets of paths was stored in a database to be used in simulations.

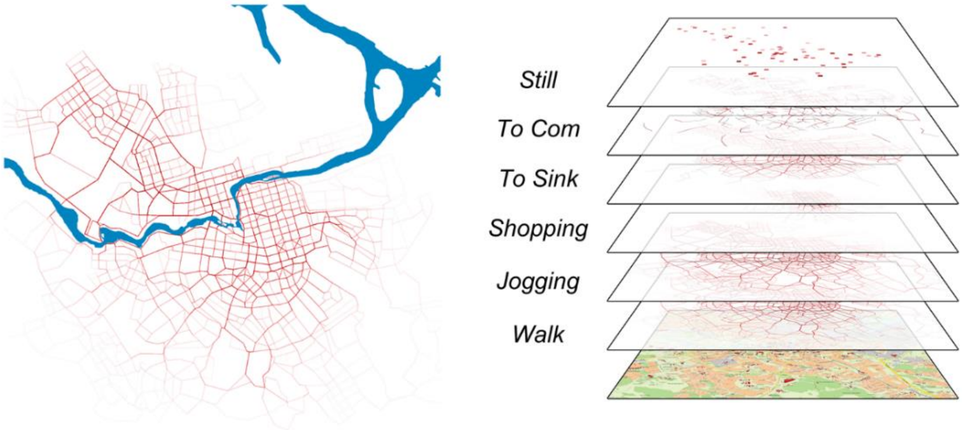

Figure 2. A large number of paths for each activity were constructed that together serve as a representation of likely movements for the agents. The paths for the activity Walk is depicted in the left panel where the grade of red represent how commonly the edges are used for this type of activity. The river running through the city is kept in the image to preserve a measure of perspective. The right panel shows the concept that all sets of paths are superimposed on the map to obtain a complete database of possible paths for the simulation.

SCENARIO

A case study for DUPS was conducted involving a serious accident that lead to the rapid release of one ton of sulphur dioxide. These are the input to the scenario:

- A release of sulphur dioxide takes place in the urban district Sylten southeast of the bridge Hamnbron which is frequently used for transports of dangerous substances in Norrköping.
- The event took place a weekday afternoon at 15.00. It was spring with no extreme weather conditions and no unusual events taking place until the accident.
- Weather: 3 m/s, 12 °C, northeast wind, Pasquill stability class E.
- Release: A 1 cm in radius hole in a tank which creates a leakage that goes on for 4 minutes. The total release amounts to 1000 kg.

When setting up DUPS the user should take into account some scenario input data such as the day of the year, the time of the day and special issues such as possible major events taking place. For instance, people are in general moving from their homes to their workplaces in the mornings and the other way around at the afternoons. A database consisting of 41.429 paths was constructed for this scenario using the PathBuilder according to the description above. Demographic and infrastructural data were mainly collected from Statistics Sweden and the municipality of Norrköping (Centralbyrån, 2013a, b, c; Quester & Billsjö, 2011). The atmospheric dispersion was treated using the model *LillPello* which is a Lagrangian particle model developed by the Swedish Defence Research Agency.

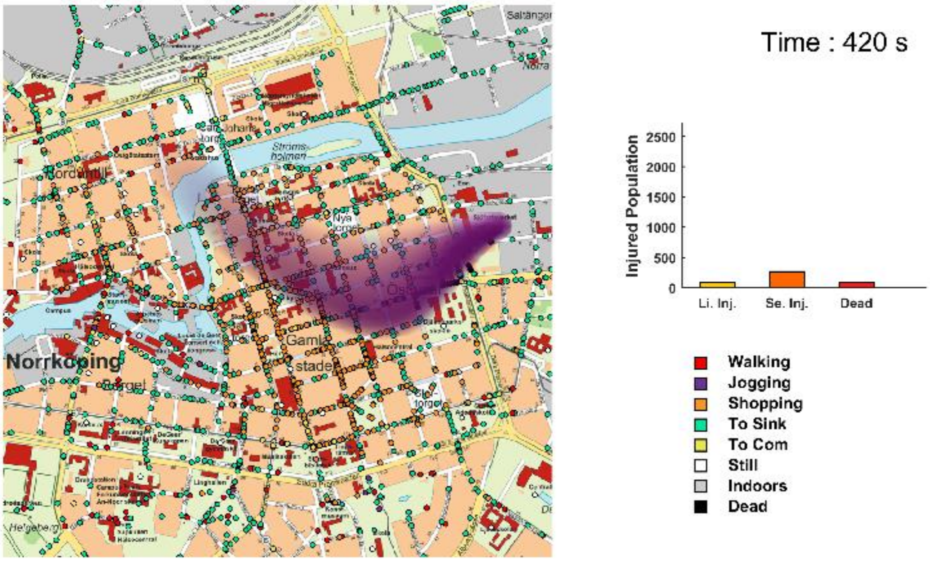

Figure 3. Scenario status 420 seconds into the simulation. On the left all agents are depicted as circles that are colour coded according to their activities. The toxic plume is shown as a semitransparent purple cloud. The release has ended at this point in time and the plume is moving along with the wind over the city. As it has passed by some agents has been so heavily exposed that they have died which is shown with a black color on their circles on the map.

Since the time scale of the passing time of the toxic cloud and the movement of the agents are in the same order of magnitude there will be dynamic effects from both on the exposure distribution. There were significantly more injuries with a dynamic population which is explained by the fact that people are moving in and out of the cloud during the scenario, see Table 2.

Table 2. The injury outcome of the scenario when static or dynamic population is used.

Injury level	Static	Dynamic
Light injury	283 (29%)	865 (30%)
Serious injury	691 (70%)	2021 (69%)
Dead	11 (1.1%)	24 (0.8%)

This case study showed that DUPS may be implemented in a full chain model and that it has impact on the results. The strong discrepancy between the injury outcomes for two exposure models highlights that the choice of exposure models may be of high importance to the result in these kind of simulations. However, further studies are required before general conclusions may be drawn.

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