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An agent-based simulation model for assessment of prehospital triage policies concerning destination of stroke patients

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Abstract

Stroke is a life threatening medical condition that is caused either by a blood clot or a bleeding inside the brain. It is generally agreed that immediate treatment of stroke patients is crucial for their ability to recover; however, before treatment can be initiated, the stroke patient has to be diagnosed using, for example, a computed tomography scan of the brain. This, in turn, requires that the patient is transported to a hospital for diagnosis, which is a procedure that consumes valuable time and resources. In the current paper, we present an agent-based simulation model for assessment of logistical stroke patient triage policies. Using a population of stroke patients as input, the model enables to simulate the activities and the main decisions involved in the logistical operations of stroke patients. In an experimental study covering the southernmost part of Sweden, we used the simulation model in order to assess two different policies regarding where to send patients for diagnosis; the nearest hospital policy and the nearest hospital towards the stroke center policy. Our simulation results show that the patients in need of special treatment favor from being transported in direction towards the stroke center, whereas the patients who are not in need of specialist treatment favor from being sent to the closest hospital.

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1. Introduction

Stroke is one of the leading causes of death worldwide. The World Stroke Organization [12] reports that one out of six persons worldwide will suffer a stroke during their lifetime, and as a consequence 5.8 million persons will die each year. The National Swedish Board of Health and Welfare [9] reports that there were approximately 28.300 cases of stroke in Sweden during 2016, affecting approximately 26.500 individuals. The Swedish nationwide mortality rate

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within 28 days was approximately 25%. Even though we see a decrease of both stroke incidents and stroke-related mortality, at least in Sweden, stroke is still considered to be a condition where substantial improvements are needed in order to reduce the suffering for the patients and their relatives, as well as to reduce the societal costs.

Stroke is a medical condition that results in reduced blood flow in the vessels inside the brain. The lack of blood flow causes severe damage on the brain cells, and without immediate treatment, the patient has a low chance to make a satisfactory recovery and more than one in five patients die. However, providing fast treatment of stroke patients is not trivial, which in part is due to logistical challenges, which is described below.

There are mainly two types of stroke, Ischemic stroke and Hemorrhagic stroke, each of which requires different treatment [1]. *Ischemic stroke* refers to the situation where one or more clots reduce the blood flow inside the brain and *Hemorrhagic stroke* refers to when there is a bleeding inside the brain. In order to determine which type of stroke a patient with stroke symptoms is suffering from (if any) it is today necessary to perform a CT (Computed tomography) scan, which in general requires transport of the patient to a hospital. It should be mentioned that there exists CT equipped ambulances; however, they are today used only in few places in the world (e.g., Berlin [3]). It is not until a diagnosis has been made that it is possible to take a decision about which treatment should be given to the patient. For Ischemic stroke, which is the focus of the current paper, there are two types of treatment available, i.e., thrombolysis and thrombectomy. In *thrombolysis*, the patient is given intravenous treatment in the form of an enzyme (Tissue plasminogen activator, tPA) that breaks down the blood clot. In thrombectomy, which is suitable for the larger clots, a specialist interventionalist manually removes the clot by inserting a wired device, e.g., a stent retriever. Due to the need for highly specialized interventionalists to perform thrombectomy, this type of treatment is provided only at a few hospitals, which we refer to as thrombectomy centers, to which patients suffering from large strokes need to be transferred. Thrombolysis is provided at most Swedish hospitals, which means that thrombolysis can be provided immediately after diagnosis has been made.

Before a stroke patient can receive treatment, there are several activities that need to be performed, involving several individuals at different departments. The chain of activities starts with a call to an emergency call center, and is followed by finding an available ambulance, which needs to drive to the patient, transporting the patient to a hospital, diagnosing the patient, redirecting patients with large clots to a thrombectomy center, etc. As all of these activities take time, it is obvious that providing immediate treatment for stroke patients is far from a trivial task.

To some extent, it is possible to reduce the time to treatment by reducing the time of the involved activities, but it is also crucial that the decisions, for example, regarding where patients should be transferred for diagnosis, are made in such a way that they expect to lead to the best outcome for the patients.

Due to the potential to improve stroke care by using better decision policies, there is a need to be able to assess the performance of different policies. However, this is currently very difficult, partly since it is complicated to perform experiments involving real patients without putting them at further risk. In addition, it takes long time to conduct experiments with real patients, making it impossible to evaluate more than a very small amount of policies in a reasonable amount of time. Due to the difficulties of evaluating decision policies using real patients, we argue that it may be preferable to use computer-supported decision support systems, which enables to quickly assess a large amount of policies, as well as to avoid further risking the health of patients that are already in a vulnerable state.

There are different types of approaches that can be used for the assessment of stroke logistics decision policies, where we find mathematical optimization and simulation most relevant to consider. Mathematical modeling can be used in order to study some types of decision policies; however the detailed modeling that is required in order to capture the complexity of a typical stroke logistics system typically makes it difficult to use optimization other than for rather specific problems. Simulation, on the other hand, enables to study the individual entities of a complex stroke logistics system over time, which is not possible using mathematical optimization. In addition, simulation does not require to mathematically model the system to be studied, which is an advantage as a typical stroke logistic system is rather complex and difficult to model mathematically. Furthermore, it is possible to construct a general simulation model that can be used to model all of the basic activities in the stroke logistics process, and the decision making process can be added on top of this, hence allowing to use the same model to assess different types of policies.

In the current paper, we contribute an agent-based simulation model for assessment of prehospital triage policies for the choice of diagnosis hospital. An agent is often described as a computer system that operates autonomously in some environment in order to reach its design objectives [11]. Furthermore, agents are often used in simulation models

to model intelligent entities, such as humans [2]. A typical stroke logistics system involves several stakeholders, represented by individual, often interacting, decision makers, which is why we constructed our model using agents.

We used the model in an experimental study covering the Southern Swedish hospital region (roughly corresponding to the counties of Skåne, Blekinge, Kronoberg and Halland). In our study, we generate a synthetic population of stroke patients, which we then simulate using two different prehospital triage policies for the choice of diagnosis hospital.

In the next section we give an account to related work. In Section 3 we present our agent-based simulation model followed in Section 4 by a description of our experimental study. Finally, we conclude the paper in Section 5.

2. Related work

In the healthcare domain, agent-based modeling has been used, for example, in order to build effective ambulance diversion policies for hospital emergency departments. Taboada et al. [10] address the effects of patient derivation policies in emergency departments, using an agent-based model. Liu et al. [6] present a generalized agent-based model to simulate emergency departments in order to improve the patients' treatment process. However, none of the existing studies uses agent-based modeling explicitly considering stroke patients and the improvement of stroke transport logistics.

There are several other types of studies focusing on stroke logistics decision policies, for example, Holodinsky et al. [4] and Schlemm et al. [8], who study policies similar to the ones that we consider in our experimental study. Holodinsky et al. [4] study the impact of treatment times on prehospital transport decision-making for ischemic stroke patients, where they compare two different treatment protocols, that is, drip and ship and direct to endovascular thrombectomy. In order to determine the impact of treatment time, they use conditional probability modeling. Schlemm et al. [8] contribute a similar study, where they use prehospital stroke scales in order to predict which patients are expected to be in favor of thrombectomy treatment.

As mentioned above, none of the existing stroke logistics policy assessment models make use of agent-based modeling. However, it is our belief that the use of agent-based modeling will enable improved assessment of stroke logistics policies, in particular if the policies to analyze require modeling of multiple decision-makers that needs to interact in order to decide how to manage the patient.

3. Our agent-based simulation model for assessment of prehospital triage policies

In this section, we present our agent-based model for assessment of prehospital triage policies concerning transport of stroke patients. In particular, the model enables to study different choices regarding where (i.e., which hospital) to transport potential stroke patients for diagnosis. An architectural overview of the model is provided in Fig. 1.

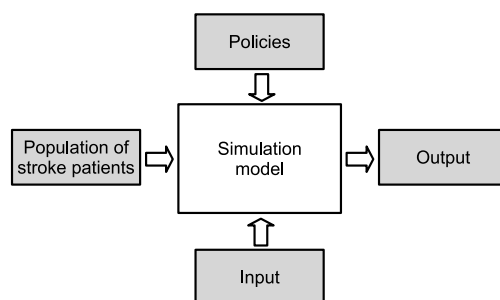


Fig. 1. Architectural overview of our simulation model.

For each of the individuals in a set of stroke patients, our model operates by simulating the main activities and the decision-making that occurs from the time the emergency call center receives a call concerning a potential stroke, until treatment is initiated. We identified the activities and decisions to be included in the model by studying the stroke logistics process within the Southern Swedish hospital region. The typical flow of main activities and decisions for an ischemic stroke patient are:

- The emergency call center is contacted concerning a potential stroke incident.
- An ambulance is ordered and sent to the patient location.
- A decision is made concerning where to transport the patient for diagnosis (depends on which policy is adopted).
- The ambulance arrives at the diagnosis hospital and drops off the patient.
- The patient is examined at the diagnosis hospital and thrombolysis is initiated.
- A decision is made whether thrombectomy should be conducted.
- If thrombectomy will be performed and the patient is located at the thrombectomy center:
 - Transport the patient within the hospital to the thrombectomy room.
 - Start thrombectomy.
- If thrombectomy will be performed and the patient is not located at the thrombectomy center:
 - Order an ambulance to pickup the patient at the diagnosis hospital.
 - Transport the patient using ambulance to the thrombectomy center.
 - At arrival, transport the patient to the thrombectomy room.
 - Start thrombectomy.

The model takes as input a set of stroke patients, a set of available policies, and some additional data, including hospital data. Each patient is described using the following attributes: age, time of stroke (date and time of day), address, and type of stroke. The additional input data includes locations of hospitals, and driving times from each of the patient locations to all of the hospitals in the considered region, and from all of the non-thrombectomy hospitals to the thrombectomy center. The output of the model consists of the times required for each of the activities for each of the simulated patients, hence enabling different types of output analysis.

In order to explicitly capture the decision-making process involved in the handling of stroke patients, we constructed our model using two types of agents representing ambulances and hospitals, respectively. The ambulance agents (one for each ambulance) are responsible for deciding where the patients should be transported for diagnosis once the ambulance has arrived to the patient. The available decisions for an ambulance agent is:

1. Transport the patient to the nearest hospital for diagnosis.
2. Transport the patient to the nearest hospital in direction towards the closest thrombectomy center.
3. Transport the patient to the closest thrombectomy center.

It should be emphasized that it is not possible to determine by certainty in a normal ambulance whether a patient actually suffers from a stroke, and what type of stroke a stroke patient suffers from. Indeed, there are several stroke assessment scales that can be used to indicate if the patient suffers from a stroke, how severe a stroke is, and what type of stroke it is. However, in our model, the ambulance agents make their decisions without assessing the probability of different stroke types, instead considering the expected travel times to different hospitals.

The hospital agents (one for each hospital) are responsible for determining whether patients should be forwarded from the diagnosis hospital to the closest thrombectomy center for thrombectomy. In our model, the decision whether to forward the patient for thrombectomy depends on the size of the clot, and it can be taken as soon as a CT scan has been performed and a neurologist has examined the patient. It should be emphasized that, even though the type of stroke and the preferred treatment is a characteristic of the patients, it is not until the examination, including a CT scan, has been simulated that this information becomes known for the hospital agent.

We implemented our model as a discrete event simulator [5], where each of the activities in the logistical chain are represented by events that are used to advance the simulation clock. Examples of events used in our model are:

- Contact emergency call center
- Ambulance arrives at patient scene
- Ambulance departs from patient scene
- Ambulance arrives at hospital

The events are sorted based on their time in an event list that is implemented as a queue; the next event is always the first event in the queue. Each time a new event occurs, the simulation clock is advanced to the time of that event.

The model is initiated by creating a “contact emergency call center” event for each of the patients in the population. During the simulation, new events are continuously created and sorted into the event list. For example, when the “contact emergency call center” event is handled, the model estimates the time when an ambulance is able to arrive at the patient scene, creates an “ambulance arrives at patient scene” event, and sorts the new event in the event list.

4. Experimental study

In an experimental study, we used our agent-based simulation model in order to compare two prehospital triage policies concerning the choice of hospital to transport patients for diagnosis. In our study, we considered the Southern Swedish hospital region, which roughly corresponds to the counties of Skåne, Blekinge, Kronoberg, and Halland. See Fig. 2 for an illustration of the Southern Swedish hospital region, where the yellow bullets represent the non thrombectomy hospitals and the red bullet represents the thrombectomy center in the considered region.

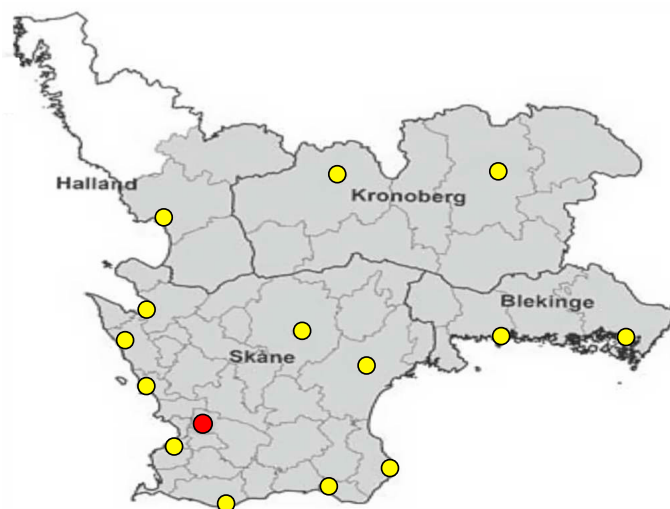


Fig. 2. Southern Swedish hospital region, where the yellow bullets represent normal hospitals and the red bullet represents the thrombectomy center.

We refer to the two considered policies as the *nearest hospital* policy and the *way to thrombectomy center* policy. In the nearest hospital policy, which is the policy currently used in the Southern Swedish hospital region, the patient is transported to the hospital closest to the patient’s location. In the way to thrombectomy center policy, the patient is instead transported to the nearest hospital on the way to the closest thrombectomy center; however, if the stroke incident occurs within 10 minutes from a hospital, the patient will be transferred to the nearest hospital. The reason for considering the way to thrombectomy center policy is to reduce the time it takes to receive thrombectomy treatment, which is of particular importance for those patients that are located far away from the thrombectomy center.

From the Regional Council of Skåne, we obtained aggregate data including 5684 stroke incidents that occurred in the Southern Swedish hospital region during year 2016. In particular, the received data set specifies the:

- Number of stroke patients per municipality (Fig. 2 shows how the counties are divided into municipalities).
- Number of stroke incidents per age group.
- Number of patients for each type of stroke diagnosis.
- Number of stroke incidents for each of the 24 hours of the day.

As discussed in Section 3, our simulation model takes a population of stroke patients as input, and we used a patient population corresponding to one year, where we simulated the main activities and decisions for each of the patients and each of the considered policies. However, a general obstacle with this type of privacy sensitive research is that it is typically not possible to access information about the real patients, including their age, address, diagnosis, time of getting sick, etc. Instead we used the received aggregate data in order to generate a synthetic population of stroke

patients with the necessary attributes, including age, patient address, time of getting a stroke, and type of stroke. We provide a brief description of our synthetic population generation approach in Section 4.1.

As will be described in Section 4.1, we generated an address for each of the patients in the synthetic population. Since the decision-making of the ambulance agents are based on the traveling times between the patient's locations and the hospitals (including the thrombectomy center) in the region, we also estimated traveling times that we provided as input in our model. In particular, we used Google maps in order to estimate the driving times from each of the patient locations in our synthetic population to each of the hospitals in the region, and from each of the hospitals to the thrombectomy center.

4.1. Synthetic population generation

As mentioned above, we generated a synthetic population of stroke patients based on the aggregate patient data we received from the Regional Council of Skåne. The reason for generating a synthetic population of patients is that our agent-based simulation model requires detailed information about patients as input, but no individual level patient data could be accessed due to privacy reasons. Our synthetic population generation approach was based on the principles of statistical sampling from our aggregate data, similar to the approach suggested by Moeckel et al. [7].

From the number of patients in the received data set (i.e., 5684 patients), we generated the number of patients in our synthetic stroke population using a 95% confidence level. That is, we multiplied the number of patients with a random number in the interval [0.95, 1.05]. This gave us a synthetic population size of 5902 patients.

We then generated the number of patients per day by dividing the number of patients with the number of days, i.e. $\lfloor \frac{5902}{365} \rfloor = 16$. We distributed the remaining $5902 - (365 \cdot 16) = 62$ patients randomly to the 365 days of the year. We then generated the time of the day for each of the patients through sampling from the time distribution included in the received data set. For each patient, we also sampled a municipality, age, and stroke diagnosis (ischemic or hemorrhagic) according to the aggregate statistics. For example, if $x\%$ of the stroke incidents occurred in a particular municipality, the probability of each patient belonging to that municipality is $\frac{x}{100}$. For each ischemic stroke patient, we also determined whether it is a thrombectomy patient so that the expected number of thrombectomy patients was 10% of the ischemic stroke patients, and the remaining ischemic stroke patients required only thrombolysis treatment.

As part of the synthetic population generation, we collected all addresses in the Southern Swedish hospital region from the Swedish leading postal company, which is responsible for delivering the address lookup service in Sweden. After determining the municipality belonging of each patient, we randomly chose an address from the set of collected addresses within the municipality of the patient.

4.2. Computational results

As mentioned above, the model outputs the times of the included activities for each of the simulated patients. We here present the time to treatment for each of our two groups of ischemic stroke patients, i.e., 1) thrombectomy patients and 2) non thrombectomy patients, in the form of histograms that we generated based on the times to treatment that were recorded for the simulated patients.

For the non thrombectomy patient group consisting of 5311 patients, we present in Fig. 3 a histogram over the times to reach the diagnosis hospital. These results clearly indicate that the nearest hospital policy gives shorter time to diagnosis than the way to thrombectomy center policy. For the nearest hospital policy, the average time to reach the diagnosis hospital was 59 minutes, and the average time in the way to thrombectomy center policy was 67.2 minutes. In the nearest hospital policy, 80.6% of the non thrombectomy patients reached the diagnosis hospital within 40-70 minutes, whereas in the way to thrombectomy center policy only 65.3% of the patients reached the diagnosis hospital within the same amount of time.

For our 591 thrombectomy patients, we present in Fig. 4 a histogram over the times to reach the diagnosis hospital. For the nearest hospital policy, the average time to reach the diagnosis hospital was 59.3 minutes for the thrombectomy patients and the average time in the way to thrombectomy center policy was 67.3 minutes.

As mentioned above, thrombolysis is given to both groups of ischemic stroke patients (thrombectomy and non thrombectomy patients); however for the thrombectomy patients, it is also relevant to compare the time until thrombectomy treatment is initiated. In Fig. 5 we provide a histogram showing the time to thrombectomy. It can be seen in the diagram that the thrombectomy patient group is in favor of the way to thrombectomy center policy. The average time

to thrombectomy is 200.6 minutes for the nearest hospital policy and 197.6 minutes for the way to thrombectomy policy.

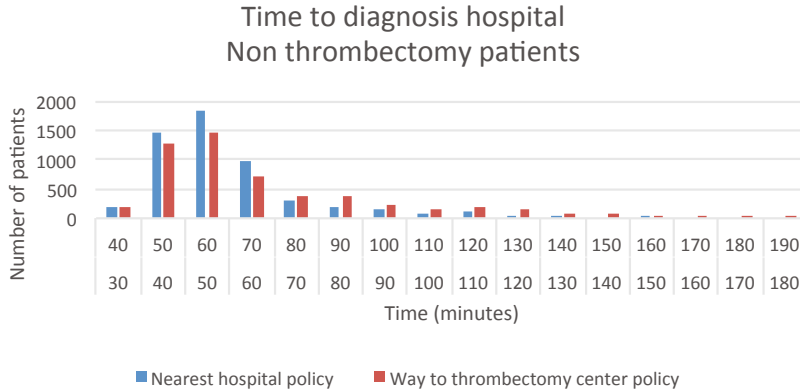


Fig. 3. Histogram over the time it takes for the non thrombectomy patients to reach the diagnosis hospital for both of the two considered policies.

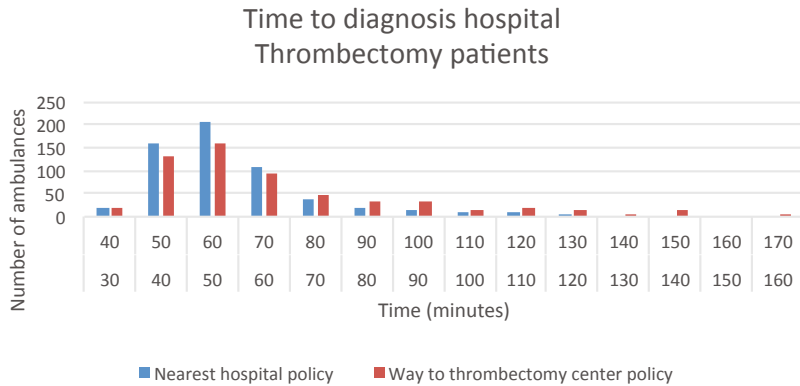


Fig. 4. Histogram over the time it takes for the thrombectomy patients to reach the diagnosis hospital for both of the two considered policies.

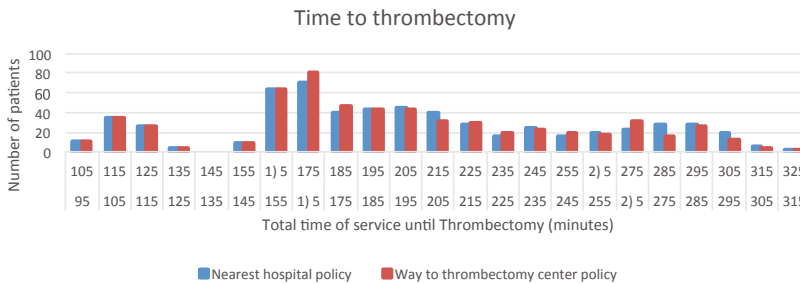


Fig. 5. Histogram over the time it takes for the thrombectomy patients to receive thrombectomy treatment for both of the two considered policies.

5. Conclusions and future work

We have presented an agent-based simulation model for assessment of logistical stroke patient triage policies. Using a population of stroke patients, the model enables to simulate the activities and the main decisions involved in the logistical operations of stroke patients. In particular, the model enables to study the effects of transporting the

patients to different hospitals for diagnosis. We refer to the two considered policies as the *nearest hospital* policy and the *way to thrombectomy center* policy.

In an experimental study covering the southernmost part of Sweden, we used our model in order to assess whether it is most beneficial to transport the patients to the nearest hospital or to the nearest hospital in direction towards the closest thrombectomy center for diagnosis. As we could not access individual level patient data, we created a synthetic stroke population consisting of 591 thrombectomy patients, whose final destination is the thrombectomy center, and 5311 non thrombectomy patients, which can be transported to any hospital in the region.

For the non thrombectomy patients, the average time to reach the diagnosis hospital is 59 minutes for the nearest hospital policy and 67.2 minutes for the way to thrombectomy center policy. For the thrombectomy patients, our computational results suggest that the time to reach the diagnosis hospital in average is 59.3 minutes for the nearest hospital policy and 67.3 minutes for the way to thrombectomy center policy. The average time to initiate thrombectomy is 200.6 minutes for the nearest hospital policy and 197.6 minutes for the way to thrombectomy policy.

Considering that the time until the patients reach a hospital for diagnosis in our experimental study is higher for the way to thrombectomy center policy than for the nearest hospital, we find it difficult to justify an implementation of the way to thrombectomy center policy in the Southern Swedish hospital region. The fact that thrombolysis in general is given to both thrombectomy and non thrombectomy patients, our results indicate that the nearest hospital is a better option than the way to thrombectomy center policy.

Future work includes refining the agent system included in our simulation model, hence allowing to study the logistical system in further detail. As part of future work, we also aim to add support in our simulation model to study other types of policies than prehospital triage, for example, the use of mobile stroke units, i.e., stroke ambulances, which allow to diagnose patients already in the ambulance.

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References

- [1] American stroke association, 2018. About stroke. https://www.strokeassociation.org/STROKEORG/AboutStroke/About-Stroke_UCM_308529_SubHomePage.jsp. Accessed: 2018-09-06.
- [2] Davidsson, P., 2001. Multi agent based simulation: Beyond social simulation, in: Lecture Notes in Computer Science: Vol. 1979. Multi-Agent-Based Simulation, Springer, pp. 97–107.
- [3] Ebinger, M., Winter, B., Wendt, M., Weber, J., Waldschmidt, C., Rozanski, M., Kunz, A., Koch, P., Kellner, P., Gierhake, D., Villringer, K., Fiebich, J., Grittner, U., Hartmann, A., Mackert, B., Endres, M., Audebert, H., 2014. Effect of the use of ambulance-based thrombolysis on time to thrombolysis in acute ischemic stroke. A randomized clinical trial. *JAMA* 311, 1622–1631.
- [4] Holodinsky, J.K., Patel, A.B., Thornton, J., Kamal, N., Jewett, L.R., Kelly, P.J., Murphy, S., Collins, R., Walsh, T., Cronin, S., Power, S., Brennan, P., O'hare, A., McCabe, D.J., Moynihan, B., Looby, S., Wyse, G., McCormack, J., Marsden, P., Harbison, J., Hill, M.D., Williams, D., 2018. Drip and ship versus direct to endovascular thrombectomy: The impact of treatment times on transport decision-making. *European Stroke Journal* 3, 126–135.
- [5] Law, A.M., Kelton, W.D., 2000. Simulation Modelling and Analysis. 3rd ed., McGraw-Hill, Singapore.
- [6] Liu, Z., Cabrera, E., Rexachs, D., Luque, E., 2014. A generalized agent-based model to simulate emergency departments, in: Proceedings of the Sixth International Conference on Advances in System Simulation, pp. 65–70.
- [7] Moeckel, R., Spiekermann, K., Wegener, M., 2003. Creating a synthetic population, in: Proceedings of the 8th International Conference on Computers in Urban Planning and Urban Management, pp. 1–18.
- [8] Schlemm, L., Ebinger, M., Nolte, C.H., Endres, M., 2018. Impact of prehospital triage scales to detect large vessel occlusion on resource utilization and time to treatment. *Stroke* 49, 439–446.
- [9] Swedish National Board of Health and Welfare, 2017. Statistik om stroke 2016 (Statistics about stroke 2016).
- [10] Taboada, M., Cabrera, E., Epelde, F., Iglesias, M.L., Luque, E., 2013. Using an agent-based simulation for predicting the effects of patients derivation policies in emergency departments. *Procedia Computer Science* 18, 641–650. 2013 International Conference on Computational Science.
- [11] Wooldridge, M.J., Jennings, N.R., 1995. Intelligent agents: theory and practice. *The Knowledge Engineering Review* 10, 115–152.
- [12] World Stroke Organization, 2018. Facts and Figures about Stroke. <https://www.world-stroke.org/component/content/article/16-forpatients/84-facts-and-figures-about-stroke>. Accessed: 2018-06-28.