# Creating Cloud Simulations for Urban Logistics

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**Abstract.** In the project USEfUL, simulations are used for the evaluation of novel logistics concepts, since real-world evaluations are very cost intensive. However, no simulation tool can provide a holistic solution to high-detail small-scale solution and low-detail large-scale simulation at the same time. To increase simulation capabilities, we enhanced two simulation tools, AnyLogic and MATSim, to run in lock step. This provides a single solution for different simulation needs. Furthermore, a job-based simulation cloud was designed to reduce simulation costs while preserving data security.

## Simulation for urban logistics

Currently urban logistics are changing, novel concepts taking hold in cities to reduce emissions and improve efficiency. At the University of Applied Sciences and Arts Hannover, we are working with the city of Hannover and other institutions to explore the effects of novel logistics concepts on the current urban mobility. Within the project USEfUL [1], the project team evaluates multiple novel logistics concepts and presents the results in an easily understandable way to support decision making. Simulation models are used to reduce costs and avoid investing in concepts with adverse effects on the environment or the quality of life of residents. Two tools are used for the simulations, AnyLogic [2, 3] and MATSim [4], to simulate microscopic and macroscopic behavior respectively.

AnyLogic is a commercially available multi-method simulation tool using a graphical modeling language in combination with snippets of java code. While allowing fine-grained modeling of individual agents, AnyLogic does not scale easily to city-scale populations.

MATSim is a simulation framework purpose built for the simulation of large logistical scenarios, supporting a large amount of agents traversing a predefined road network. Published as an open-source Java library, MATSim can be easily extended with new modules, providing modeling support for e.g. trains. Within MATSim, agent behaviour is modeled through agent plans, containing a sequence of activities at certain locations and the routes the agents use to move from activity to activity.

For the evaluation, research areas within the city of Hannover were defined. The research areas coincide with four districts of Hannover, which were selected as representation of the city as a whole. Selecting smaller parts of the city allows fine-grained simulation within the research area and reduces administrative burden if a certain concept is to be tested in practice.

Within the project the following workflow has been established: First a baseline simulation is created, modeling the current state of traffic within Hannover. The baseline provides a current standard against which new logistics concepts can be evaluated. In the next step, changes in agent behaviour deriving from the logistical concept (e.g. online grocery shopping) are modeled within AnyLogic and simulated to evaluate the effects on activities and routes within the small-scale research areas [5]. Changes in activities and routes are then fed back into MATSim to evaluate the effects of the logistical concept on the entire city. Finally, all data is collected and evaluated to estimate the ecological and economic benefits and disadvantages of the concept.

The simulations are run on office laptops and other consumer-grade hardware, as mobile working is often necessary in a cooperative project without a centralized office location. A cost-efficient service is therefore needed to provide easily usable computational resources for simulation.

In the following we present our work on combining MATSim and AnyLogic into a joint simulation tool and constructing an automated platform to run simulations in a cost-efficient, privacy-conserving way. Section 1 will provide an overview of related works concerning the combination of AnyLogic and MATSim as well as cloud-based simulation solutions. In Section 2 we will describe the designed solution to run AnyLogic and MATSim in lock step, while Section 3 presents the

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job-based simulation cloud. A conclusion is provided in Section 4.

## 1 Related Work

Co-simulation and bringing simulation to the cloud have been extensively researched in the past.

Gütlein et al. [6] present a co-simulation framework for MATSim and SUMO, both traffic-oriented simulation tools. In a similar setup, the authors use SUMO as microscopic traffic simulation tool and embed the SUMO-based microscopic simulation into a macroscopic simulation run in MATSim. However, SUMO does not support multiple simulation modeling principles and is not as accessible as AnyLogic.

Further work on co-simulation between traffic-oriented simulation tools was done by Kaths et al. [7]. In the publication the authors describe the combination of SUMO and DYNA4's virtual vehicle as test bed for certification of automated and connected driving. The proposed system concentrates on the fine-grained simulation of a single car's systems on small-scale traffic scenarios instead of the simulation of whole cities.

While all these works provide some guidelines and follow similar approaches, the combination of MATSim and AnyLogic has not be extensively researched. However exhaustive works have been published on the combination of different modeling and simulation approaches [8].

A flexible simulation framework for cloud computing is presented by Filho et al. in [9]. The presented framework CloudSim Plus is an improvement over an existing cloud simulation framework. The authors focus on the usage of software engineering principles to create a flexible, extensible framework, instead of an concrete application to execute simulations.

Fujimoto et al. [10] view cloud computing as a chance to provide non-computer-science users an easy access to efficient resource usage on distributed computer hardware. The authors present Aurora, a cloud platform that uses a master/worker system to divide the work needed to execute a parallel discrete event simulation. While the described system is of similar intent to our design, the authors concentrate on the technical execution of the simulation instead of a broader view. Security and privacy are not the focus of the design.

Another shift of simulations into the cloud to reduces simulation costs is presented by Wang et al. in [11]. The authors describe a very low-level approach to the distributed execution of Monte-Carlo simulations within a cloud environment. While the work shares the goal of reducing simulation cost, neither privacy nor traffic-simulation is considered.

Zehe et al. [12] present a cloud-based simulation service for large-scale urban systems. Instead of importing off-the-shelf simulation tools, the authors construct SEMSim as a purely cloud-based alternative providing fine-grained agent based simulation for urban traffic. This however results in researchers having to learn another tool instead of continuing the usage of known tools, which also often provide extensive libraries.

Within the different cloud-systems for simulation, privacy is often mentioned but not design-centric. The reduction of cost and decreasing simulation runtime are often main goals. Our approach focuses on cost-savings and privacy, as the data used in the simulations is partially non-public.

## 2 Combining MATSim and AnyLogic

As previously described the project USEfUL uses MATSim for macroscopic traffic simulation and AnyLogic for the fine-grained microscopic simulation of inhabitants behaviour when exposed to novel logistics concepts.

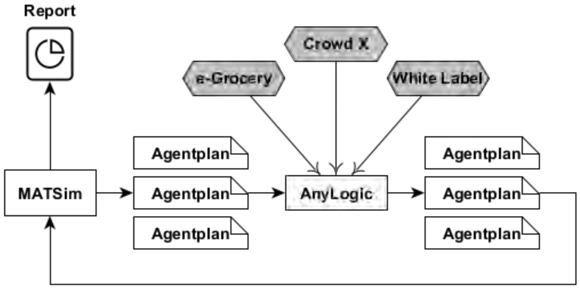

**Figure 1:** Workflow utilizing MATSim and AnyLogic.

Currently, simulation data is exchanged between AnyLogic and MATSim twice as shown in Fig. 1. First, MATSim simulates the current behaviour of the population of Hannover, creating plans for each agent to follow. Then, the plans are fed into the small-scale simulation of a logistical concept within a research area. This results in changes within the agent plans, which are in turn integrated into the city-scale simulation in MATSim. A second simulation of the city is run to study the city-wide effects of introducing a concept into a research area.

This process does not allow for interactions between city-scale and research area-scale simulation, neglecting feedback between the different areas. The task thus is to combine both tools to work in tandem, running both simulations at the same time.

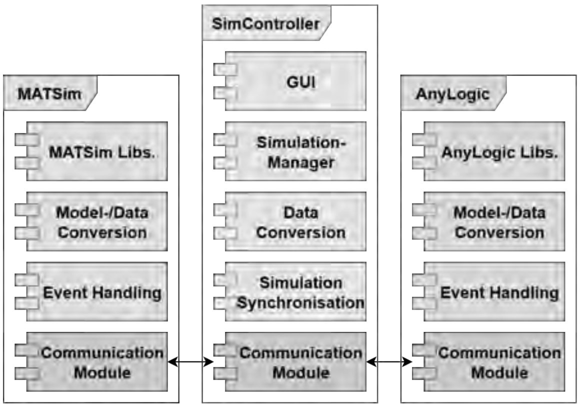

**Figure 2:** Architecture of the combined simulation.

Figure 2 shows the architecture of the combined simulation solution. MATSim and AnyLogic have been extended to accommodate inter-tool-communication by introducing special communication modules interacting with a third component. The SimController has been introduced to coordinate the simulation between MATSim and AnyLogic. This controller provides a graphical user interface to start and stop the combined simulation, controls the simulation execution by providing a single synchronizing point for both tools, and converts data between tool-specific formats.

To combine both simulations, a geographical split was utilized. The research area, simulated in fine detail with AnyLogic, was cut out from MATSim, as shown in Fig. 3. Agents that cross into the area are transferred with their plans (including a route to follow on the shared network) from MATSim to AnyLogic and vice versa. Furthermore, the simulations are sliced into fixed time units used as synchronization points. This allows for both tools to run in lock step as a single combined simulation.

For the communication between components remote procedure calls are utilized, which enables the distributed execution of simulation tools and coordinating components. By enabling a distributed execution, the optimal hardware for the simulation can be chosen to fine-tune performance. Existing hardware in different geographical locations can be combined, reducing the cost of integrating the new system into existing projects.

The system has been shown to work with small-scale examples just including agent movement between the areas. Further work now focuses on building complex scenarios containing an entire city and complex behaviour, to test if the strengths of both tools have been successfully combined. Especially the performance of the combined solution will be evaluated. Simulations within the larger project have already shown run times of multiple days and a moderate (within a server context) usage of resources (e.g. 8 threads using 12 GB RAM), which prohibits running the simulations on standard office laptops normally used by researchers.

## 3 Creating a job-based simulation cloud

When large amounts of computing resources are needed, execution of software is usually shifted to server hardware. Often institutes have special simulation servers or a shared access to large server infrastructure. This however requires a lot of resources in the form of space and server administrators, restricting research budgets.

To circumvent acquisition and maintenance of large server infrastructures cloud computing has become increasingly popular. Therefore, a job-based simulation cloud was considered. This solution follows the idea of a mainframe, allowing users to submit jobs which are then executed on powerful hardware. Instead of executing different kinds of programs, only user-configurable predefined simulation models are executed.

### 3.1 Requirements

The goal of the job-based simulation cloud is however not exclusively saving costs. The system should also provide an easy-to-use interface to enable non-computer-science researchers to utilize the tool in their day to day research. Therefore, all of the tools functionalities should be accessible via a graphical user interface, which allows a user to create, edit, save and run simulation configurations.

The tool needs to provide configurable simulations that use standardized inputs, so researchers can configure scenarios (e.g. the usage of online grocery shop-

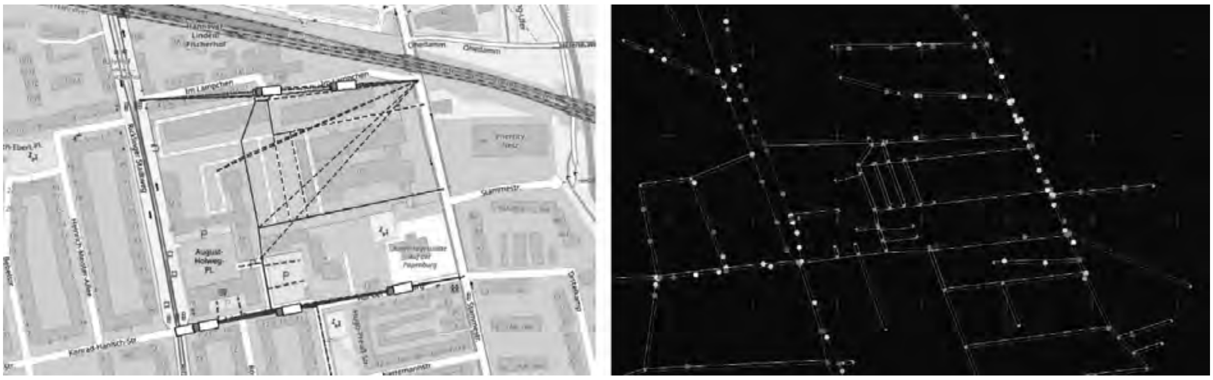

**Figure 3:** Left: Simulated area in AnyLogic. Right: Simulated area shown MATSim.

ping) for their specific needs. Depending on the simulation tool, this can be achieved via configuration files or an online value editor.

Furthermore, the simulations need to be organized and executed by the tool. Each simulation run can be seen as a single job, which is added to a queue and then executed when processing resources are available.

After the simulation run has concluded, the user needs to be able to view the results and compare them to other simulation runs of the same scenario. In case the simulation run has to be executed a second time, the complete configuration needs to be saved by the system. This ensures the ability to replicate simulations by other researchers, as configurations can easily be shared.

To provide this functionality, the system needs to manage user accounts, providing functionality to create, delete and change user details. The users need to be authenticated by password an grouped by research projects, to facilitate sharing of results within a project. Users should be able to use the system on all devices, allowing them to check the status and results of their simulations while on travel.

While cost-savings are a main driver of the system development, the systems stability and performance are paramount. If the tool can not reliably execute simulations in a timely manner, acceptance of the system will be very low. Furthermore, scalability is an issue, since multiple users can quickly demand large amounts of resources when parameter studies are needed.

Within the context of urban simulation, privacy is a major concern. The utilized simulation models are often based on non-public data (as shown in [15]), requiring a higher degree of security, often only provided by self-hosted solutions.

### 3.2 Cloud computing models

When switching from classic server based based computing to a cloud service, first the appropriate cloud computing model needs to be chosen. Within cloud computing multiple different models have evolved. Most commonly known are the public cloud, the private cloud and the hybrid cloud [13], shown in Fig. 4. Each cloud model has advantages and disadvantages that need to be considered.

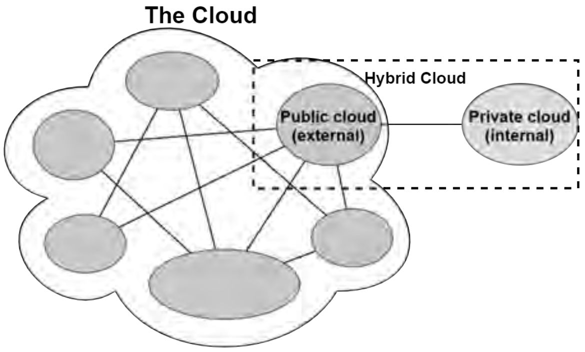

**Figure 4:** Overview of different cloud models [14].

Within a public cloud, all computation is done on shared hardware, owned by a service provider. This model often has large cost-saving potential for the clients, as no own hardware or support team is necessary. Furthermore, only utilized hardware is billed by the provider, reducing the cost of less computation intensive periods. However, a public cloud is also a very attractive target for an attacker, as access to the system also provides access to the client's system. With multiple users configuring their own systems in the cloud, the likelihood of insecure configuration rises, potentially compromising the security of other users within the same cloud environment.

In a private cloud however, only a single client has access to the cloud infrastructure. This solution is comparable to a company owned mainframe or an institute's simulation server and is often the most expensive cloud model. However, a private cloud also provides the highest level of security, since only a single client's applications are executed on the hardware.

As a compromise between the public and the private cloud, the hybrid cloud was created. Within a hybrid cloud, some applications are run on private cloud-like infrastructure, while other applications are executed within the public cloud environment. By limiting the connections between public and private parts, security engineering becomes easier.

For the job-based simulation cloud a hybrid cloud approach was chosen to reduce costs and provide a secure platform. Long-term data storage is provided by the private part of the cloud, accessible only through clearly defined interfaces as to minimize the attack surface. User interface and computation power are provided by the public cloud, where data is only temporarily stored in memory while simulations are executed. By encrypting all communications between the public and the private part of the solution, confidentiality is assured while data is in transit. This split provides the best trade off between cost, security and usability.

### 3.3 Architecture

Figure 5 shows the proposed architecture of the job-based simulation cloud. Clients can access the Frontend through the internet and are authenticated via password based login. After configuring a simulation scenario through the parameter control, the user's simulation request is added to the simulation queue. The simulations are then automatically executed and the results logged in a database for later access and analysis. Users can access their results through the result analysis.

Utilizing the hybrid cloud approach, Frontend and Simulation components are executed within the public part of the cloud, User and Simulation Storage are secured within the private part. The communication between the different components is secured by encryption and authentication of the participating servers. The developed architecture is currently designed for the manual process of executing simulations one after another, feeding the results of the tools into each other. As a proof of concept, the next step will be a first implementation and deployment to explore the performance of the solution.

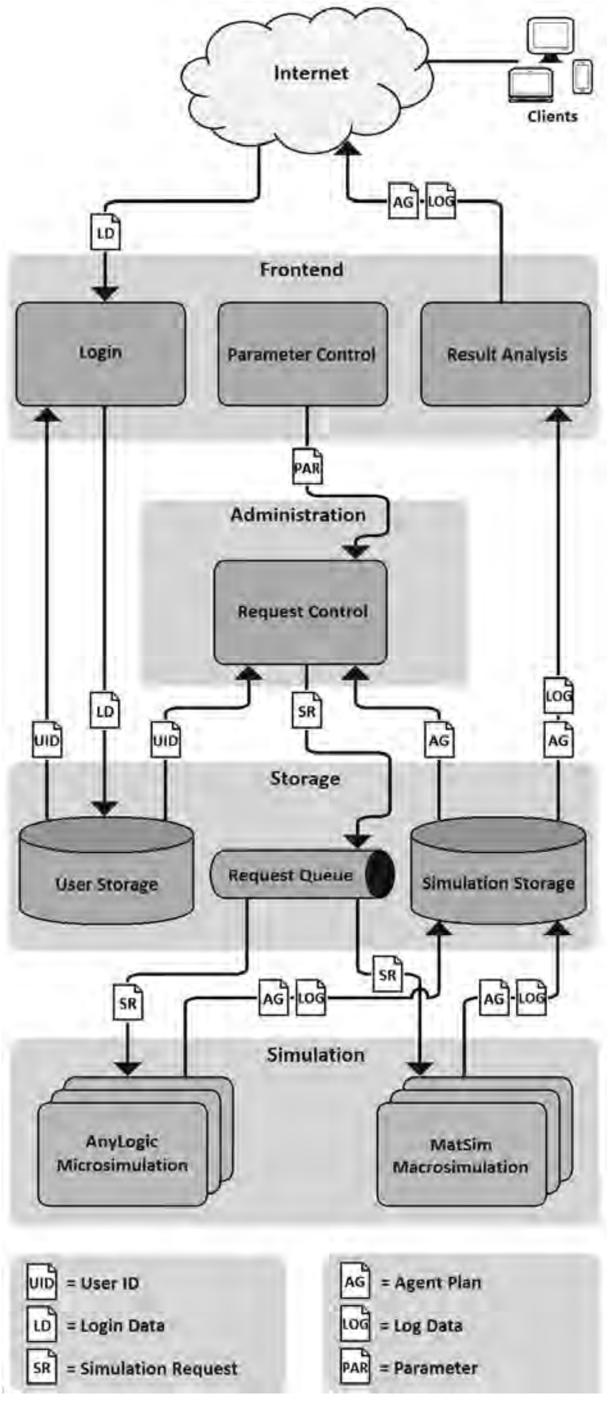

**Figure 5:** Design of the job-based simulation cloud.

## 4 Conclusion

In this paper we gave an excerpt of two subprojects within the context of the research project USEfUL, which aim to increase productivity in research concerning urban logistic simulation.

By combining the two simulation tools used within the research project, we increase the flexibility in modeling urban traffic and population behaviour. The tools are run in lock step by embedding a highly detailed, small-scale simulation within a low-detail, large-scale simulation, exchanging agents on predefined points in the network.

The second project aims to provide an easy-to-use platform for non-computer-science researchers. By utilizing a hybrid cloud approach, security requirements can be met while reducing the client's costs. The developed architecture reduces the technical burden for domain experts.

In further work, we plan to adapt the combined simulation to the developed job-based simulation cloud and create an all-in-one solution for the usage in projects building on the tools and workflows created in the project USEfUL.

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