Service-Oriented Architecture for Automatic Evaluation of Urban Logistical Concepts

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Abstract. With the rapidly increasing availability of logistical concepts new tools are required to provide accurate estimations of concept effectiveness to urban planners. In this paper we describe a service-oriented architecture providing automated concept evaluation through agent-based traffic simulation, combining general traffic models with specialized logistical models into singular simulations. Key focus of the paper is the integration architecture utilized to combine the different tools from a previously developed manual workflow. The architecture is designed to incorporate multiple different tools into a combined workflow, providing non-domain users with a highly specialized tool.

Introduction

Urban logistics is currently changing at a rapid pace. An ever increasing consciousness for environmental factors, new regulatory measures, new services and a pandemic are moving populations from traditional solutions towards utilization of novel logistical concepts [1, 2]. This development confronts urban planners with new challenges as the number of design options for a city logistics system continues to increase, challenging the selection of the most suitable measures to improve the quality of urban mobility and thus environmental, economic, and social effects. New tools are needed to support decision making in municipal planning agencies to increase utilization and effectiveness of logistics solutions [3]. A team consisting of traffic engineers, business IT specialists, computer scientists, and municipal government employees was tasked in the research project *USEfUL* to create a simulation-based decision support tool for urban logistics [4, 5].

An agent-based simulation approach using the multi-agent transport simulation (MATSim) [6] was chosen to evaluate the impacts of logistical concepts on urban traffic patterns within the city of Hannover. For the evaluation, different key performance indicators (KPIs) were defined. Based on these simulation results, the observed impacts on the KPIs were evaluated in order to derive recommendations for urban planners. Consequently a hand-crafted traffic model [7], adapted to the resulting needs and behavioral patterns stemming from logistical concepts was developed, which in turn fed a semi-automated evaluation tool chain. Due to the comparatively long run times of the agent-based simulations and the high computational effort, all scenarios were simulated manually and only the corresponding impacts were stored in the tool. These results are on display on the project's web page [8], where users can gather information about the concepts, the evaluation areas and predicted effects on different KPIs.

However, the workflow with the semi-automatic traffic model generation and the evaluation framework is currently only applicable to the city of Hannover. In particular, the setup of the traffic model is limited by available data sources and therefore not directly transferable to other cities and municipalities. To provide similar assistance to other communities, a completely automated architecture needs to be designed and implemented. The resulting tool has to utilize public and private data sources to create an accurate baseline model of the area of interest, before standardized changes to the model implement novel logistical concepts.

To tackle these issues – and increase the usefulness of the web-based tool – the follow-up project *USEfUL-XT* aims to increase the transferability of the *USEfUL* workflow. In this paper we present the architecture to combine previously manual workflows using a service-oriented approach. A high-level view of the different services is given, as the implementation of the services is still in progress. The result is the concept of an integrated, service-oriented and cloud-based framework capable of automatically collecting and processing the required data, creating a simulation model and performing the resulting simulation runs. As the specified simulation scenario only need to be simulated once, the computation needs are also dynamic and efficient resource usage demands a dynamically scalable solution with adequate storage space to store results.

Section 1 will give an overview of related work. In the following section 2 the current workflow of the project is presented, which is then expanded to an automatic workflow in section 3. Remaining challenges are discussed in section 4 and a conclusion is given in section 5.

1 Related Work

A similar tool to the *USEfUL* web application was provided by [9]. The Urban Transport Roadmap provides statistical evaluations for many regulatory measures and estimates the impacts of technological development on urban traffic. However, the tool focuses on very rough estimates for many different cities and allows in-depth analysis of combinations of measures.

Another theoretical framework for automated evaluation of urban traffic was proposed by [10]. In their proposed system, a user can utilize a partially automated co-creation process to construct simulation models of a city. After model creation, partial changes to the model are proposed to the user, which, when chosen, are in turn simulated within multiple simulation tools. At the same time a rule-based system watches the simulation for inconsistencies and provides input to the user to correct these. The publication focuses on the process of creating the tool, rather than the tool itself. It is unclear if the tool can provide automated model creation for multiple areas and logistical concepts. Furthermore, the proposed system of [10] does not include an expert system to fast-track concept evaluation. The proposed system remains theoretical.

In another work, [11] present a generalized pipeline for the generation of agent-based transport models in France. This pipeline presents a standardized approach for processing data sources to synthesize a synthetic population and assign mobility behaviour to the agents. The paper also includes a detailed validation of the method. However, the described method is focused entirely on the generation of a model for private traffic omitting commercial traffic and is adapted to the specifically in France available data.

An example for a microscopic modeling approach for commercial traffic is presented in [12]. Therein, the authors then employ land use and structural data to generate businesses and the respective employees and vehicle fleets. By applying the German commercial travel survey, each vehicle is equipped with a daily schedule.

Meanwhile, many other simulation models and studies have been created to identify issues and solutions for urban logistics [13]. However, model creation was not completely automated and often only small areas of urban logistics were modelled. Our proposed system approaches urban logistics from a more abstract point of view, allowing a rough estimation of impacts for many concepts and areas, through automated model creation, simulation and evaluation.

2 Current Solution

The current workflow combines manual data collection, preparation, and model calibration as well as simulation and evaluation. A lightweight, web-based decision support tool was created, not slowed down by long simulation run times, as users want to use the tool at a quick glance. The goal of the process was the easy-to-understand representation of logistic concept impacts on specific KPIs, which are presented to users in a web-based decision support tool. Traffic and logistic simulations are performed using MATSim to benchmark the impact of new logistical concepts. The process can be split into seven parts, as shown in Figure 1.

The first step of the workflow is data collection, as many different sources of information have to be utilized to manually collect the necessary traffic supply and demand information. Several open data sources like OpenStreetMap (OSM) and public transport providers are considered to create a road network with an integrated public transport system for the traffic supply needed in the MATSim model.

To generate a realistic traffic demand, multiple studies and non-public data from companies and municipalities are consolidated into a synthetic population. Furthermore, different input surveys are used to derive the travel or logistic demand from the synthetic population. From the collected data a *basecase* model is created,

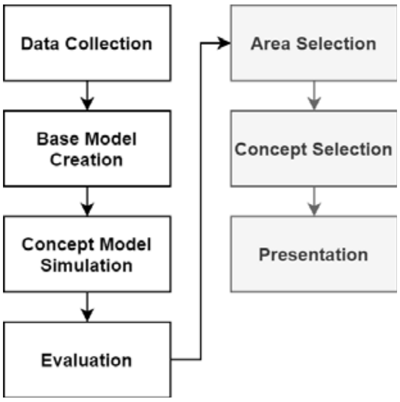

Figure 1: Current manual workflow of the project *USEfUL*. User interactive parts marked in grey.

representing the status quo of traffic within the research area. A manual calibration of the model using traffic counts, as well as a validation against different mobility parameters is performed to achieve a high model accuracy. Building upon the previously created *basecase*, demand changes due to the implementation of novel logistic concepts are replicated in the model and need to be simulated subsequently. Each concept is parameterized in different dimensions (e.g. usage of electric vehicles, total acceptance percentage, etc.), studying concepts more in-depth. A large amount of simulation runs were needed for every area of interest and each parameter combination, since multiple logistical concepts were compared to provide a useful decision support.

Simulation results are in turn evaluated with regards to eight KPIs: acceptance, emissions, area usage, costs, implementation potential, traffic impacts, economic feasibility, ecological break-even-point. For the evaluation, the *basecase* is considered as the starting point and trends on the KPIs through utilization of logistic concepts are derived. After all possible scenarios are simulated, evaluation data is combined in a database queryable through a web-application. Users can now select a research area, a concept (possibly modify it through parameters) and are presented with the evaluated simulation results.

While this workflow produces good results for predefined areas, adaption to new areas is labor intensive and slow, diminishing the usefulness for other parties. Furthermore, since all possible combinations of areas, concepts and parameters need to be simulated a priori, timely simulation requires a large amount of computational resources. A optimized process would allow the users to select the area of interest, a specific concept and then receive the simulation results on-demand (either through a new simulation study or previously performed simulations). Consequently, we designed this concept of an automated simulation framework. This goal-process is shown in Figure 2.

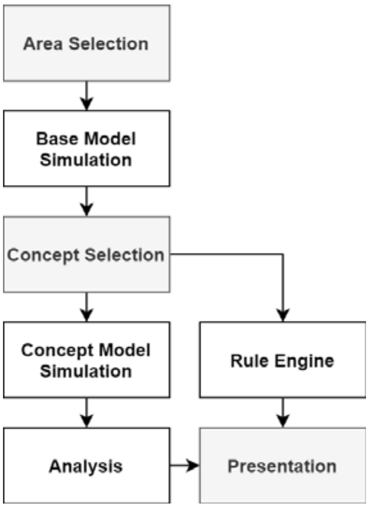

Figure 2: Planned workflow for the *USEfUL*-Application. User interactive parts marked in grey.

The improved workflow also utilizes a rule-based expert-system to give impact estimations almost instantly, as opposed to the simulation, where turnaround times of multiple days, if not weeks are to be expected. To achieve this workflow, major challenges must be solved, most importantly the automatic creation of models based on automatically collected data. While the previous process already uses automated tools at each step in the workflow, data transfer between steps was handled manually, increasing the total time needed. Implementing the new workflow requires a clear definition of software interfaces, processes and deployment into an easily scalable environment.

3 Service-Oriented Cloud-Based Workflow

Service orientation and cloud usage are computing patterns that address multiple issues also encountered in the simulation workflow of *USEfUL*. Service orientation allows the easy integration of quickly evolving tools into combined workflows while providing abstract interfaces, decoupling different steps of software processes [14]. This in turn allows the easy combination

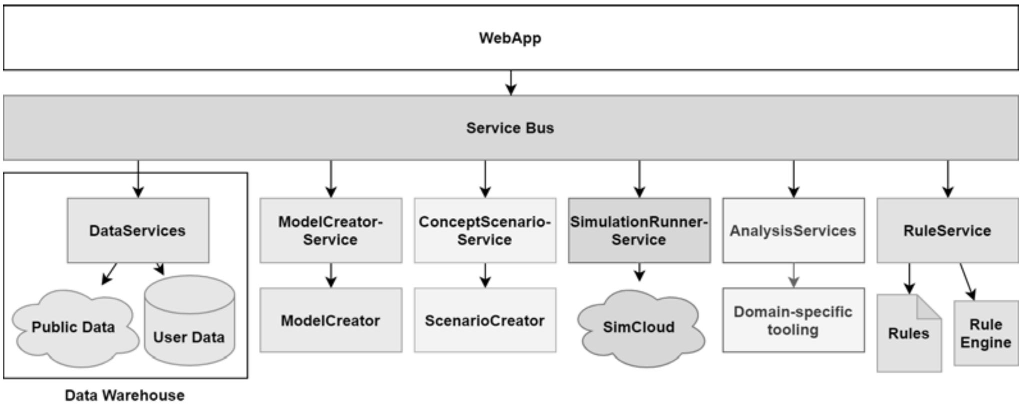

Figure 3: Proposed Architecture for the system. Each step of the previous workflow of the project is encapsulated into a service, which can be invoked in order from the user-accessible web-application

of many different software tools into a combined application. Cloud-based computing provides quickly scalable infrastructure by combining different applications on the same hardware, therefore reducing the cost for hosting of applications.

With a cloud-based simulation service, users can request simulations ad-hoc, paying only for the computational power that is actually needed to run the simulation, instead of investing in expensive simulation hardware. Since primary user groups are located in communal administration and other non-software firms, this approach increases the attractiveness of the solution to the end user. while the architecture is aimed at a cloud deployment, it is not necessary to rely upon an external cloud provider. Through the usage of a private cloud, the entire software can run on-premise, if e.g. data security or privacy requirements dictate it. In general service-orientation is implemented by encapsulating specific tasks of the workflow into independent services that can be recombined for other workflows. Figure 3 shows the proposed service-oriented architecture for the automated solution.

The workflow of the proposed system is controlled by the already existing WEBAPP, providing user interaction and service orchestration. Since only a single workflow – the evaluation of logistic scenarios – is to be expected, a flexible workflow engine is not necessarily needed and implementation complexity can be reduced. In case the workflow changes for the different simulations, an increased workload to implement the changes is to be expected, but does not outweigh the reduction of implementation complexity. As the WEBAPP has already been developed in *USEfUL*, it can easily be adapted to the necessary changes.

The SERVICE BUS provides stable service endpoints for usage through the WEBAPP (or other applications) and connects them to the service implementations. This effectively decouples declaration and definition of different tasks, allowing easy redevelopment of different parts of the overall workflow without leading to widespread changes. Many different existing solutions can be adapted for this particular purpose. Communication between the SERVICE BUS and other components is technology-dependent and can be implemented in multiple different ways. As the chosen simulation tool MATSim utilizes xml-files for configuration and modelling, data transfers will also utilize the xml-standard to achieve design homogeneity.

The SERVICES implement the steps of the workflow and utilize technologies independent of the rest of the application. This allows technology selection according to the domain-specific needs, as well as flexibility when services are updated to new methods. A description of the services is given in the following sections.

Some cross-cutting concerns are life cycle management and security, as these are needed at all levels of the application. While life-cycle management needs to be decentralized due to the technical nature of the domain, security can be handled at the SERVICE BUS and deployment environment. E.g. access to services from external sources can be blocked by a firewall and internal compartmentalization is achieved by extending the existing role-based-access-control to service bus level.

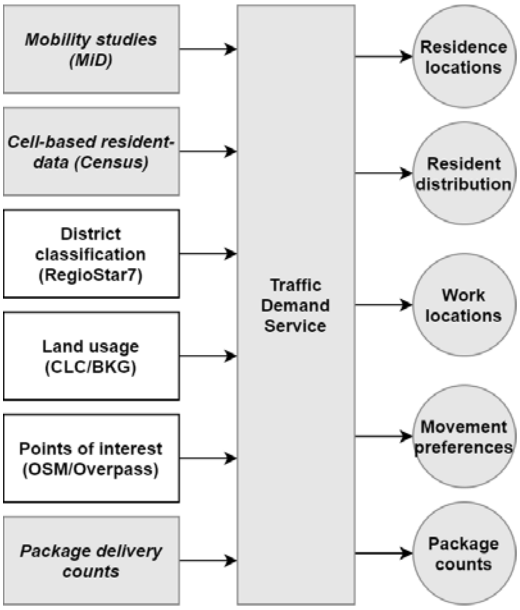

Figure 4: High-level view of the Demand data service. White background marks machine readable sources, slanted writing marks manually interpreted Data.

3.1 DataServices

The data services, are responsible of adapting different sources of data into the system. To create simulation models for urban logistics, different information sources are summarized to create the traffic supply as well as the traffic demand.

As these data sets are built from many different sources, the services are responsible for aggregating this data and providing the necessary information in a standardized format. The data services consolidate the processed data in a data warehouse and allocate it to the associated services for further processing. While some data might be pulled from standardized web services, other need to be manually interpreted, prepared and provided in a suitable format. Consequently most of the technical and logical complexity of handling different data is localized in these services.

Figure 4 shows a high-level view of one of the main data services, the TRAFFIC DEMAND SERVICE. This Service is responsible for providing information about traffic demand and population behavior, which in turn is used to generate traffic demand within the MODELCREATORSERVICE. Information for this service is gathered from public APIs like OSM/Overpass, public statistical data, manually extracted from documents, and non-public studies. Data pulled from public APIs can easily be converted into the necessary XML structure, utilized by consuming services. Other Data, like the aforementioned public statistical data, needs manual conversion and own storage infrastructure, as document structures vary vastly between different sources or iterations of the same studies. For example, the study *Mobility in Germany 2017* added a new excel-based tool for data exploration, which was not available for the studies predecessor, created in 2008 [15]. While automatic extraction of the study is possible, the created tool would only work for this iteration of the study. The resulting effort/effect-balance is not favourable for automation. To make manually extracted data available for the automatic workflow, it is entered into a database, which provides a machine readable data format. Since the TRAFFIC DEMAND SERVICE collects data from different sources and provides a unified interface for consumers, it can be viewed as a data warehouse.

As part of the modelling process, the traffic demand service also provides data for the automated model calibration service. Thus, mode share information of the simulation area as well as other mobility parameters must be specified and provided by the user. An essential element for the quality of the model is the availability of real traffic data from the simulation area particularly consisting of vehicle count data of different sections of the network. While this detector data can be accessed online for specific network connections, it is often not directly available. Therefore, this missing component must be provided by the user.

3.2 ModelCreatorService

After all necessary input data is collected and processed into the data warehouse, the MODELCREATORSERVICE is executed. This service contains three consecutive modeling steps that gradually generate an agent-based transport model for individual traffic along with a service-based model for commercial traffic (Figure 5).

In the first step, a synthetic population consisting of households with corresponding agents is generated based on the grid cells that are deposited in the data warehouse. Grid cells are selected according to the area of interest included in the execution request. Each of the agents in the population represents one person living in the specific cell and is assigned with certain socio-demographic attributes, such as gender or age, as well as attributes that impact the mobility, such as the possession of a driving licence or public transport ticket. In addition to these agents, companies are synthesized as

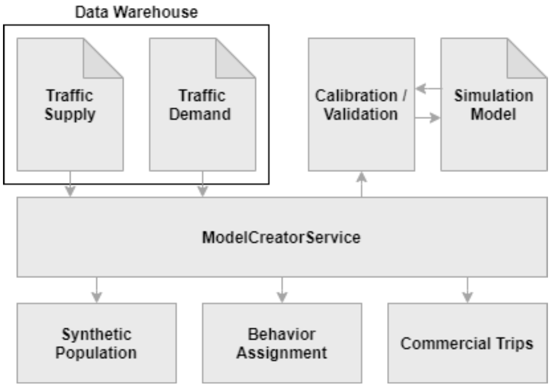

Figure 5: Architecture of the ModelCreatorService

location for work activities and as instances that generate commercial or logistic traffic. The companies are differentiated by industry sectors and also obtain attributes such as the number of vehicles and the number of agents working at that location.

In the second step of the model creation, each agent is assigned a mobility behavior corresponding to the predefined attributes. The behavior is defined by a sequence of activities the agent performs during a day and the necessary trips that the agent must perform to reach those activities. These patterns are provided by the data services and also contain additional information such as the transportation modes used and the travel distance for the trips. The location choice for the activities is then carried out on the basis of these information along with land-use data.

The last element of the MODELCREATORSERVICE is the generation of commercial trips. In this process, the defined vehicles for each company are assigned with a sequence of services they have to operate on the simulated day. The services act in a similar way to the activities of the agents and are linked to the population and other companies. For example, if a craftsman performs a service for an agent, the agent has to be at home. A special focus is laid on logistical aspects of the model. Specifically, the parcel demand is used to generate service sequences for parcel delivery vehicles of multiple delivery services. The resulting vehicle routing problem is solved using a ruin-and-recreate-algorithm and resulting trips are assigned to the vehicles [16]. The output of the MODELCREATORSERVICE consists of several independent XML-files, representing the model in its entirety. This model then has to be calibrated and validated using additional data sources from the warehouse that were not used for the model creation.

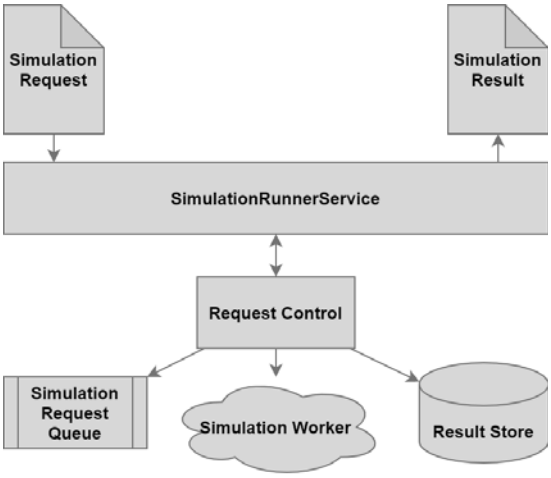

Figure 6: Simulation Runner Service responsible for asynchronous execution of simulation requests.

3.3 ConceptScenarioService

After the *basecase* has been created, further changes to the model are necessary to inspect different logistical concepts. In the CONCEPTSCENARIOSERVICE subcomponents make changes to the model according to the concepts. For example, some of the traffic resulting from grocery runs is replaced by a centralized grocery distribution system. To add a new concept, new components can easily be added to the service, without changing other parts of the system. Since the logistical concepts are not in service at the research area, validation of the changed model proves difficult.

3.4 SimulationRunnerService

The simulation service is responsible for scheduling and executing the simulations. A detailed analysis through simulations can be provided by utilizing a worker cloud where simulation tasks can be asynchronously executed.

As shown in Figure 6, SIMULATION REQUESTS are accepted by the SIMULATIONRUNNERSERVICE, where they can be stored in a queue until resources are available for execution. The SIMULATION REQUEST contains XML-Files which were generated in the MODELCREATORSERVICE along with configuration parameters for the simulation, which have to be provided by the user. Data is then fed into the SIMULATION WORKERS, which execute MATSim simulations on dynamically scaling infrastructure e.g. through the use of Docker containers. After the simulation runs are finished, data is pushed into a RESULT STORE for subsequent requests to prevent repeated simulation of the same model/parameter-combination.

3.5 AnalysisServices

The final step before presenting concept impacts to the user is the analysis of simulation results. The analysis is carried out by applying models for different KPIs to parts of the simulation output (e.g. additional traffic caused by the given concept). As models are created by domain experts, an integration for widely used tools like Microsoft Excel is required. The different models compare information from the simulation of the modified models to the *basecase* and derive trends for KPIs. This allows the easy-to-understand representation in the final visualization for the user.

One example of ANALYSISSERVICES is the AREA MODEL, which gives an estimation on the expected change of area needed for the implementation of a given logistical concepts. The AREA MODEL uses information like the amount and type of delivery vehicle used to implement a given concepts and then calculates additional area needs for e.g. construction of micro hubs. This is in turn compared to the reduction of e.g. parking spaces to calculate the net difference. Since the effects of concepts are also interconnected, the AREA MODEL feeds its result directly into the COST MODEL, which predicts cost changes.

3.6 RuleService

As an alternative to the time-consuming simulation path (shown in Figure 2), a rule-based expert system can be utilized to estimate the impacts KPIs. The RULESERVICE uses the JSONRULESENGINE and multiple sets of Rules to estimate Results, as each concept reacts differently to structural and behavioural peculiarities of different concepts. While not providing the accuracy achieved by the simulations, the RULESERVICE allows the preliminary study of concepts effects on non-simulated areas to identify promising combinations for further study.

The rules are built upon previous simulation results for each logistical concept and model the connection between concept effects and structural attributes of areas. As no high accuracy is expected until a large amount of simulations have been carried out, the first iteration of the rules engine only predicts three categories of change, instead of a numerical scale. As more and more simulations are carried out, new results are incorporated into the rules, thus improving model prediction. However, the rule engine cannot predict changes in radically new areas or for unknown logistical concepts.

3.7 WebApp

After the impacts of the concept have been evaluated, a web-based decision support tool presents the results to the user. This WEBAPP is built upon Laravel [17], using a modern design to attract users. It uses a rule-based expert system [18]. Functionalities for selecting areas and concepts as well as dynamical presentation of results are already implemented, therefore only additions to existing components are necessary.

4 Remaining Challenges

While the technical integration of all existing tools can easily be achieved through the use of available software solutions, some procedural issues remain. First and foremost the validation of the simulation models remains problematic, as multiple data sources for similar information are required. Data has proven to be relatively scarce, as privacy of residents or workers needs to be protected and some data are simply not collected. Furthermore, validation is currently a time-consuming, manual process, that has not been fully automated yet.

Another challenge is the calibration of the simulation models, as this is again a manual process, requiring a human-in-the-loop approach to properly interpret information and adapt parameters accordingly. An automated process could involve a meta-optimization approach such as evolutionary algorithms, but would in turn increase resource demand and runtime. Since open data projects are utilized, data quality is inconsistent, as data tends to be biased. One of the main reasons for this are the inhomogeneous contribution patterns of its contributors [19]. This issue is not fixable through the proposed system, as automatic data quality improvement is out of scope for its requirements.

5 Conclusion

In this paper an architecture for the automation of simulation and decision support has been presented. Built upon a previously developed workflow, the system aims to allow users to evaluate novel logistical concepts in specific research areas. The system shall provide rough estimates on effects on key performance indicators of traffic like emissions and population behaviour. This allows users to evaluate logistical concepts in theory and aids in preliminary selection, reducing the need for cost-intensive prototype-projects in the real world.

While the technical aspects of the proposed system do not pose show-stopping challenges, domain specific workflows, like simulation validation need to be developed further to implement the system. In future work a prototypical implementation as well as the definition and evaluation of automated processes for simulation validation and calibration are planned.

Acknowledgement

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