Smart City Evaluation Framework (SMACEF): Is a Smart City Solution Beneficial for Your City?

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ABSTRACT

There are currently presented ”smart city” solutions from the biggest worldwide corporations through start-ups up to the universities. It is indisputable that some of them are for sure very interesting and beneficial for citizens and cities themselves. Nevertheless, there are too many provided solutions that make it very hard to evaluate which are really beneficial and which are not. A simple and understandable framework that would allow cities to evaluate a proposed smart city solution is currently missing. The aim of this paper is to provide an approach for evaluation of particular smart city solutions and to determine whether it is suitable and beneficial for the city. Cities are dynamic, non-linear, complex systems and the evaluation cannot be done by a static and deterministic program in most cases, but dynamics and non-linearity of cities must be considered. While modeling is widely used in transportation or energy management, in the field of smart cities, no modeling approach has been used. In this paper, SMACEF (SMArt City Evaluation Framework) is proposed and its contributions are shown on a case study.

Keywords: Modeling, Multi-agent systems, SMACEF, Smart city,

1. INTRODUCTION

A smart city is a phenomenon. Universities, companies, research organizations, entrepreneurs as well as cities themselves have to be involved in this new industry sector if they want to keep up with the latest trends and contribute to improve the quality of life of citizens and the sustainability of cities themselves in the future. There are no doubts that it is very important to increase the quality of life as much as possible in order to create great places for family, cultural, social, and working life as well [1].

However, there are many various solutions livable on the market from different vendors at this time. There are solutions as smart lighting, smart parking, smart grids, smart waste collection, smart energy, and many others [2]. Many of these solutions are definitely very beneficial and useful. On the other hand, the smart city is strongly interdisciplinary field and it might be very difficult for end users (cities and their citizens) to evaluate the benefits of solutions and whether investments will pay off in terms of savings (cost, energy, time, traffic, etc.) [3].
The main goal of this paper is to introduce the SMACEF (SMArt City Evaluation Framework) based on multi-agent systems and try to evaluate and benchmark if any smart city solutions are advantageous for cities. The whole framework is modular and compares actual and proposed future states of a system. The framework is beneficial to cities in order to help them to invest in what is beneficial and suitable for them and not for manufacturers.

2. THE STATE OF THE ART

The smart city is a strongly dynamic, non-deterministic, non-linear and asynchronous system with unpredictable results [4][5]. There is no "big brother", centralized point controlling the whole city. Cities are distributed architectures and we should take the example from the nature all around us. There is no "central brain" that would control our lives, our decisions, every person on the planet is one agent and the same concept should be applied to smart city architectures. People as well as devices should work autonomously and with good balance to achieve their goals and be the most beneficial to their surroundings.

Multi-agent systems (MAS) is a great tool for modeling unpredictable systems and several papers were published about MAS and Smart Grid. Smart Grids are an indisputable part of smart cities. The work [6] proposes modeling of Smart Grids using JADE (Java Agent Development Framework) software based on JAVA. They simulate Smart Grid, where each power station, vehicles and devices are agents and evaluate how the Smart Grid will behave. The whole simulation is based on simulated data and not on real data.

The work [7] discusses the design and implementation of the MAS in the context of Intelligent Distributed Autonomous Smart City (IDASC), a model outlining the subsystems, manufacturing technologies, operating systems, application of multi-agents systems making concrete that the project of the smart city, so as to give a clear overview and user friendly to policy makers. For the implementation of the chosen architecture is used ZEUS, the framework that uses Java based communication ACL (Agent Communication Language).

The work [8] proposes an agent-oriented architecture for a simulation which can help in understanding Smart Grid issues and in identifying ways to improve the electrical grid. They focus primarily on the self-healing problem, which concerns methodologies for activating control solutions to take preventative actions or to handle problems after they occur. They present software design issues that must be considered in producing a system that is flexible, adaptable and scalable. As a design tool is used JADE.

Modeling using MAS is also used for simulating Smart Building Control System as shown in [9]. This paper provides a software system perspective of improving energy efficiency for buildings. It proposes an architecture that allows for phased investments in technologies to capture the returns from energy savings in various use cases. In addition, it addresses the needs and objectives of different stakeholders, including owners, operators, users, and utility providers. A proof-of-concept implementation of the architecture is used to demonstrate the support for building-wide energy conservation policies using real-time energy pricing and individual occupants' locations and preferences.

The next important part of this work is also benchmarking. That has the purpose to compare smart cities with each other based on various constructs and factors. There are currently different benchmarking methods aimed at measuring cities from different perspectives, such as sustainability [10], global city performance [11], resilience [12], effectiveness [13], or urban competitiveness [14]. Our framework has the aim to benchmark particular Key Performance Indexes (KPI) that are important for evaluating a particular state. The detailed description of the framework is described in the next section.

3. SMART CITY EVALUATION FRAMEWORK (SMACEF)

The SMACEF is a modular approach that allows in a simple way to model a current state of a particular system(s) as well as a proposed future state(s) of a system(s), and based on scenarios and KPIs to benchmark which proposed solutions are the best one and if it is advantageous for the city to invest into this solution. In other words, the goal of the framework is to evaluate if proposed solutions are beneficial and useful for cities and citizens or not. The SMACEF consists of steps shown in Fig. 1. The core of the framework is modeling highlighted by grey color. First, we need to have a request for a new project followed by the definition of a system (project assignment) which should be evaluated and replaced with a new smart solution.

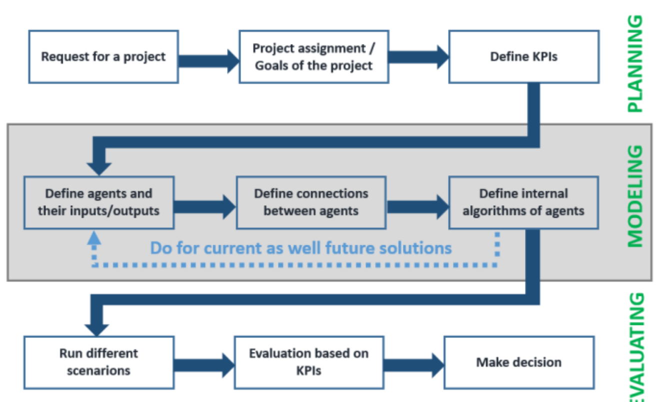

Fig. 1 - Overview of the SMACEF

In order to better understand how the framework is working, a use case related to a city`s public lighting system is discussed below. Let us consider the following case: a city would like to replace a current public lighting system with a new one. The new system should have a motion sensor (dimming of lamps) and should also communicate with a supervisor to enable remote management, control and fault detection. The city needs to select an appropriate system as well as determines energy and cost savings for a certain period, and the return of investments considering changes in energy prices in the future.

Define Keys Performance Indexes

After having the project assignment, the next step of the SMACEF is to define which variables (KPIs) should be measured and benchmarked. As mentioned on the case above, the key performance indexes of any lighting system are definitely energy consumption and costs. It means that energy consumption and costs of the current systems and the future proposed systems should be benchmarked and based on this the return of investments can be easily calculated. The arbitrary number of KPIs can be selected and benchmarked. It is definitely necessary to exactly know which KPIs should be evaluated and benchmarked. The whole framework is fully modular and whatever aspects of benchmarked systems can be taken into account. In case of lighting systems, it might be also important for cities to consider the future maintenance cost, service life, or even modularity and communication with other systems (e.g. through lamps we can collect information from bins if they are full etc.). Systems might not be benchmarked separately, but a model of interconnected systems can be created as a whole, e.g. the cooperation lighting systems, traffic lights, pedestrians can be modeled.

Regardless of project assignments, there are key performance indexes that decide whether it pays to replace the system or not. We need to identify these KPIs and benchmark their changes in the current and the future system.

Define Agents and Connections Between Them

The definition of an agent according to [15]: "An agent is a computer system that is situated in some environment, and that is capable of autonomous action in this environment in order to achieve its delegated objectives." Generally, we can imagine an agent as a software model of a physical object (human, cell phone, car, street lamp, etc.) that based on its perception (sensing) of an environment, where is located, makes certain decision and based on it performed an action affecting the environment [16]. Perception can be seen as inputs into agents and actions as outputs from agents.

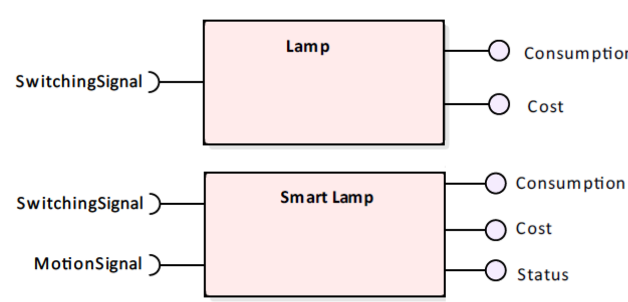

Fig. 2 – The agents with inputs and outputs of the current and the future lamp

How do we start with finding of agents? Let us show it again on the previous example with the public lighting system. We must highlight that firstly the current state of the system should be created and based on that the future proposed states can be designed. We have selected that two KPIs are energy consumption and cost. Both variables are generated by lamps.

The first agent is definitely a lamp itself. The energy consumption of the whole system will be defined as the sum of energy consumption of each lamp. The same approach can be applied to the cost. We can imagine the current lamp as an agent with two outputs - consumption and cost. In case of the future "smart" lamp, we can consider that additional output can be also a status of the lamp because "smart" lamps are able to communicate with other systems. In the Fig. 2, we can see how can be visualized the current and the future lamps as agents. Unified Modeling Language (UML) is used for describing a model system.

In order to be able to define more agents for modeling of the public lighting system, we need to determine inputs into agents. In case of the current lamps, we definitely need a switching signal that is responsible for turning on/off of lamps. In case of the future lamps, there is necessary to have an additional input from a motion sensor in order to be able to control the lamp based on the movement around it.

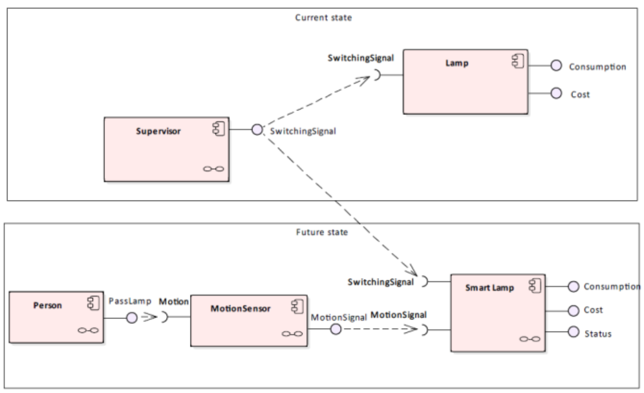

Fig. 3 - Agents with inputs/outputs and connections between them

We define and determine the rest of the agents for the current and the future states in the same way as we show above. The final view on the current and the future states of the systen is shown in the Fig. 3. The supervisor agent is responsible for the switching signal and therefore for turning on/off the lamp. In the future state, there is also necessary to have a motion sensor as an agent that will monitor if any person (or vehicle) is passed the lamp. Person itself is an additional agent that will simulate a person (or vehicle) passing the lamp.

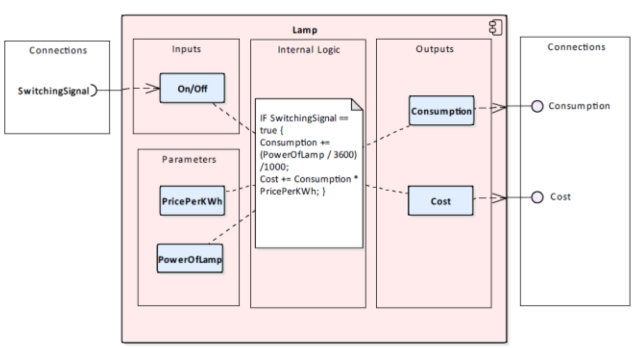

Fig. 4 - The internal logic of the current lamp

The last step is to find the connections between each agents. It means to define the links between inputs and outputs of individual agents. We can see the final result of agents with inter-connected inputs and outputs in the Fig. 4. The output from the supervisor sends a signal that will turn on/off the lamp. The motion sensor will send information into the lamp if any person passes the lamp.

Define Internal Logic and Parameters

After defining the agents, their inputs and outputs, and connections between them, there has to be defined an internal logic and parameters of each agent. Parameters are internal variables that can be changed in order to simulate different scenarios. The internal logic defines relationships between inputs, outputs and parameters. In the Fig. 4, we can see the parameters and internal logic of the agent of the current lamp state.

There are selected two parameters - price per kWh of energy and power of lamp. Price per kWh enables to simulate changing costs of energy during a time. The power of lamp determines the consumption when the lamp is switched on. As we can see also from the Fig. 4, when the time comes, the switching signal is sent and the lamp is switched on. Once the lamp is switched on, the consumption [kWh] is calculated according to the following equation:

$$Consumption \mathrel{+}= (PowerOfLamp/3600) / 1000 \qquad (1)$$

When the lamp is switched on, the cost is then calculated accordingly:

$$Cost \mathrel{+}= (Consumption/PricePerKWh) \qquad (2)$$

This is simplified model of the current public lighting system, but it contains all what is needed to determine the cost. The supervisor agent can be internally created as is shown in the Fig. 5.

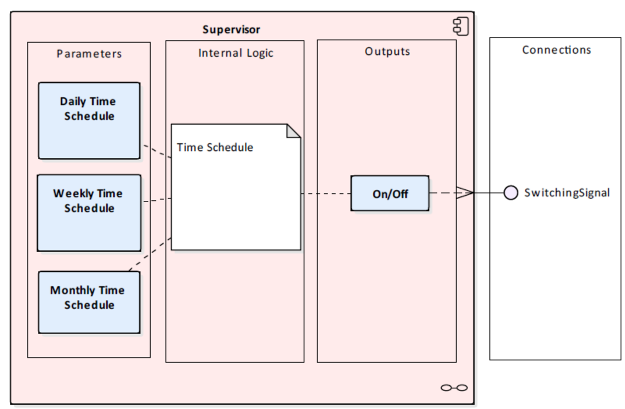

Fig. 5 - The internal view on the supervisor

The future smart lamp has two inputs – the switching signal and the motion signal from the motion sensor and unlike the current lamp has three parameters - price per kWh, power of lamp in case of no movement (*PowerOfLampLow*), and power of lamp in case of a movement (*PowerOfLampHigh*). The internal logic is a bit more complex and there are three different scenarios:

- Both the switching signal and the motion signal are activated, the brightness of the smart lamp is fully switched on. The smart lamp checks its status and send it to the appropriate supervisor.
- Only the switching signal is activated, the brightness of the smart lamp is partially dimmed. It means that the smart lamp consumes only certain percentage of its maximum power. The

smart lamp also checks its status and send it to the appropriate supervisor.

- The switching signal is not activated, the smart lamp is switched off and checks its status and send it to the appropriate supervisor.

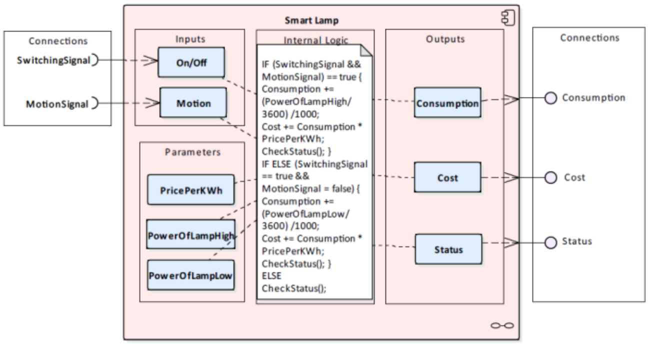

Fig. 6 - The internal view on the smart lamp

We can see the whole internal structure of the smart lamp including the internal logic and parameters in the Fig. 6. The outputs are the energy consumption and the cost. These two key outputs can be compared with the current state of the system. The motion sensor agent and the person agent are shown in the Fig. 7.

The motion sensor has only one input that is received from the person agent (can be created more agents, e.g. vehicle) and the active/inactive signal is sent to the smart lamp based on a movement presence. The person agent internally contains only the generate function that simulates the movement of person. It must be mentioned that many different scenarios can be prepared in order to verify and benchmark proposed future solutions related to the current state of the system.

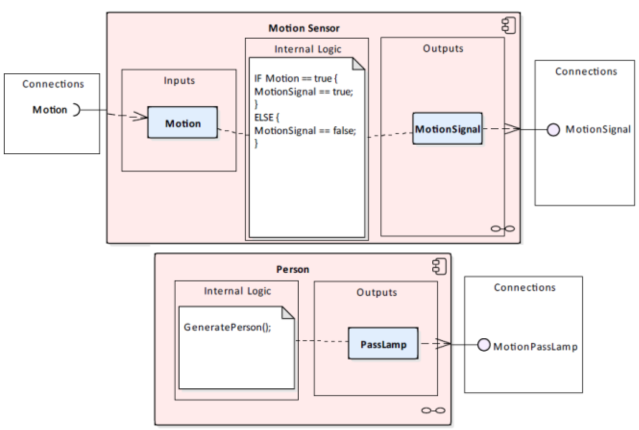

Fig. 7 - The internal view on the motion sensor and person

4. THE BENEFITS OF SMACEF

The goal of the SMACEF is to provide the simple approach for cities to model and evaluate if a particular solution is beneficial and suitable for them. It means to benchmark the benefits of a new proposed system compared to an existing system. This is achieved by means of selecting any KPIs that are important to the individual city. The SMACEF is fully modular and can be very easily extended. System(s) can be modeled and if it is found necessary to make some changes during the tests or based on the results, it is very simple to add, e.g. some parameters or agents, change the internal logic any of them or make some new connections. The smart city concept is also based on an interconnection of various systems. The SMACEF enables this interconnection of different systems in the same procedure as shown in this paper.

In contrast with static computer programs (e.g Excel), SMACEF enables to create any model whether static or dynamic. We expect that the biggest benefit of the framework is precisely the creation of dynamic systems and simple evaluating (see Fig. 1) through running tests and compares the KPIs of the current system with the future ones. We show it on the specific use case study in the next section.

5. SMACEF IN PRACTICE

The previous section is related to the theoretical background and also shows how to easy create such the multi-agents model on the use case with the public lighting system. In this section, we show the implementation of that use case. Models were created using AnyLogic software [17].

We consider two different models - the current and the future state. For a simulating purpose, we assume a street with five street lamps. In the current state (see Fig. 8), the lamps are switched on/off by the supervisor represented by a time schedule and the lamps are turned on/off according to the specific times. The internal logic of the current lamp is shown in the Fig. 4. The internal logic of the supervisor is shown in the Fig. 5.

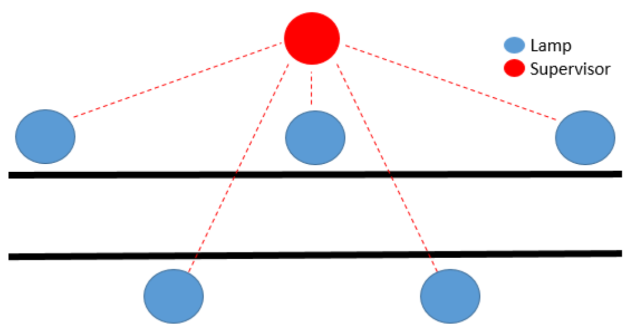

Fig. 8 - The current simulated scenario

In the future state (see Fig. 9), each lamp should be equipped by a motion sensor and the lamps should be controlled not only according to the time schedule but also according to the motion sensor`s signal.

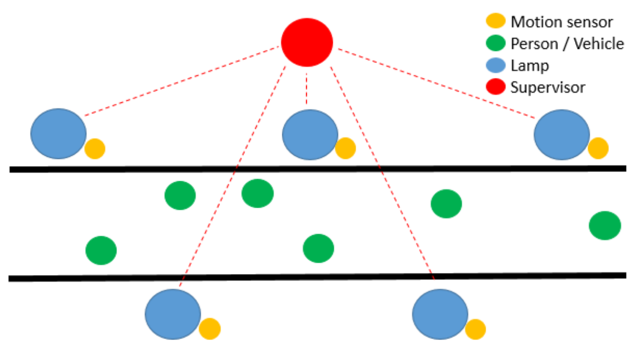

Fig. 9 - The future simulated scenario

The lamps are also able to communicate with the supervisor in order to send their actual status (especially for maintenance purpose). The internal logic of the future lamp is shown in the Fig. 6. The internal logics of the supervisor, the motion sensor and the person are shown in the Fig. 5 and Fig. 7.

First, we need to get the results from the current state of the public lighting system. We compare the energy consumption and costs within the one whole week (168 hours). The supervisor is represented by the time schedule in the Table 1. The power consumption of one current lamp is 400 W and price per kWh of electricity is 20 cents.

Table 1 - Time Schedule of the Supervisor

From	To	State
6:00 AM	6:00 PM	OFF
6:00 PM	6:00 AM	ON

The lamps are switched on every day on 6:00 PM and switch off on 6:00 AM. Since the current state of the system is completely linear, it can be easily calculated how much the current system will consume and what they will cost. The result of the simulation of the current state is shown in the Table 2. The current system consumes 168 kWh and costs 33.6 \$ every weeks.

Table 2 - The consumption of the current system

5 Lamps	Runtime [hour]	Consumption [kWh]	Cost [$]
ON	84	168	33.6
OFF	84	0	0

We want to replace such solution by the new proposed solution (see Fig. 9). There are two different power consumptions - if no motion is presented (50 W) and if motion is presented (90 W). The supervisor uses the same time schedule (see Table 1). The lamps are switched on into the high consumption mode using the movement that is simulated by the rate per hour according to the Table 3. It means that the lamp no. 1 is switched into the high consumption mode 0.2 times (12 minutes) per hour.

Table 3 - The rate of the high consumption mode

Lamp No.	Rate per hour
1	0.2
2	0.5
3	0.7
4	0.1
5	0.5

The lamps are switched on from 6:00 PM till 6:00 AM in the low consumption mode (50 W). Only in case of the movement presents around the lamp, the lamp is switched into the high consumption mode (90 W). In the Table 4, we can see the results of the new proposed system. There are 80 % savings compared to the current system if we take into account the same price per kWh.

Table 4 - The consumption of the proposed system

Lamp No.	Runtime [hour]	Consumption [kWh]	Cost [$]
1 ON low	67.2	3.36	0.67
1 ON high	16.8	1.51	0.30
1 OFF	84	0	0
2 ON low	42	2.10	0.42
2 ON high	42	3.78	0.76
2 OFF	84	0	0
3 ON low	25.2	1.26	0.25
3 ON high	58.8	5.29	1.06
3 OFF	84	0	0
4 ON low	75.6	3.78	0.76
4 ON high	8.4	0.76	0.15
4 OFF	84	0	0
5 ON low	42	2.10	0.42
5 ON high	42	3.78	0.76
5 OFF	84	0	0
SUM	-	27.72	5.54

The last step of the SMACEF is to evaluate the results and make a final decision based on the results from the different scenarios. It is clear that energy and cost savings are key for cities and decision-making. On the other hand, the initial costs and the return on investment will be no less important. The authors want to show the basic principles and possibilities of the SMACEF on this simple example. We assume that the SMACEF is especially beneficial in the dynamic and non-linear systems. Any parameters, agents, inputs, outputs or connections can be modified, added or deleted, and the whole model can be simply adapted. For example, we can add parking system depends on traffic, waste bin collection system depends on the fullness of trash cans, smart grids model and simulate the future state of the systems in terms of costs, time, energy savings and any other variables that are important for the evaluation of the system. The next important benefit is that the interconnection of different systems between themselves can be modeled in the same way as is shown in this paper.

6. CONCLUSIONS

In this paper, we discuss the necessity in providing a framework to help cities with the evaluation and benchmark of different smart city solutions provided from various manufacturers. The SMArt City Evaluation Framework (SMACEF) is introduced and described. To better introduce the SMACEF, the use case with the replacement of the lighting system is presented and the procedure is shown. The main advantages of the SMACEF are modularity, extensibility, individual adaptation of models, focus on key outputs influencing the system the most and ignore unimportant, and the possibility to model linear and non-linear systems as well as static or dynamic.

The SMACEF is based on Multi-agent systems and consists of the three basic parts - planning, modeling and evaluation (see Fig. 1). The project assignment, goals of the project and key performance indexes are defined during the planning phase. Models of the current state and future proposed solutions are created and the model of the current system is compared with the future states based on the key performance indexes defined in the first phase. The models are created during the second modeling phase. The agents with their inputs and outputs as well as connections between agents and their internal algorithms are defined. The last step is to run the designed models with different scenarios, compare the results based on measured variables, and make a decision. It can be assumed that many new smart solutions will be presented in the future. The SMACEF should help to end users to better understand and eveluate which solutions are beneficial for them and not only for manufacturers.

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