

Article

Insights from a Decade of Optimizing Emergency Medical Services Across Three Major Regions in Switzerland

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Abstract: Prehospital care, and especially emergency medical services (EMSs), are facing an increasing demand, while experiencing financial pressure. Strategies aimed at improving prehospital care management emphasize the efficient utilization of resources, but often overlook the long-term implications for the prehospital healthcare system, encompassing emergency medical services, emergency departments, and healthcare authorities. This paper draws on almost ten years of improvement in EMS' key performance indicators such as response time or overtime in Switzerland, using Discrete Event Simulation. Three representative simulation studies are used to reflect on the optimization potential of alternative bases and rosters, methodological limitations, and the uptake of the derived recommendations. The results demonstrate that EMSs' efficiency gains in resource utilization increasingly come into conflict with emergency departments' and healthcare authorities' policies, indicating a need to enrich Discrete Event Simulation with a systemic perspective. A new methodology that conceptualizes long-term prehospital care planning as an interdisciplinary and iterative process utilizing a novel combination of System Dynamics and Discrete Event Simulation is proposed.



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1. Introduction

Emergency medical services (EMSs) primarily provide support when urgent medical help is needed. They play a crucial role in prehospital care to prevent life-threatening delays [1,2] as they take severely injured patients to the closest emergency department for appropriate treatment in urgent rescue service operations. In Switzerland, EMSs also handle patient transportation and, in total, Swiss EMSs respond to around 500,000 incidents per year [3], costing approximately CHF one billion [4]. Total healthcare costs in Switzerland have risen to CHF 86.3 billion in 2021, marking an inflation-adjusted increase of 53.7% since 2000. The latest consistent data, which also break down the data to prehospital care, can be found in [4]. Healthcare costs now account for 11.8% of the gross domestic product (GDP) [5], of which 1.2% are due to EMSs.

In Switzerland, the regulation of EMSs and emergency departments occurs at the cantonal (a canton is a political and administrative subdivision of Switzerland with its own government, laws, and cultural characteristics. Switzerland consists of 26 cantons.) level. This means that there is no centralized prehospital healthcare planning at the federal level, which leads to an isolated perspective of prehospital healthcare planning in Switzerland. The means of regulation in most cantons are performance indicators, with response time (i.e., the duration between emergency dispatch and arrival at the scene [6,7]) being the most relevant. Improvements in response time can be primarily achieved through improved resource allocation mechanisms (vehicles, teams, rosters).



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While these performance indicators are set at the cantonal level, municipalities finance EMSs, and EMSs self-organize.

In recent years, financial pressure on Swiss EMSs has steadily increased as healthcare authorities have raised response time targets using the 90-15-rule based on recommendations of the Inter-association for Rescue Services (The “*Interverband für Rettungswesen*”, IVR) directive [6] while funding has been frozen or cut [8]. The 90-15-rule states that 90% of all emergencies (incidents) need to be reached within 15 min for every EMS organization and corresponds to a response time compliance rate of 90% [7]. At the same time, EMSs are responding to more incidents [7], which may be attributed to changes in demography and family support systems. This trend appears in regions such as Germany, Austria, and Switzerland, although the total numbers vary significantly, as shown in Appendix A. The overall situation is further compounded by a shortage of skilled workers in the entire healthcare system, including prehospital care [9].

The challenge of planning and optimizing EMSs (e.g., optimal base locations or deployment schedules, temporary relocation of units) has long attracted the attention of operations researchers, with mathematical optimization playing a prominent role in this domain. Academic research emphasizes computer simulation and optimization methodologies like Integer Linear Programming, while practical applications tend to lean toward Discrete Event Simulation (DES) due to its versatility and adaptability to local nuances [7,10–12].

This article reflects on almost 10 years of optimizing EMSs in Switzerland using DES and discusses its systemic limitations (e.g., misguided incentives), using three representative simulation studies. Finally, we propose an extended methodology for systematic prehospital care planning.

2. Materials and Methods

Figure 1 describes common research designs from a medical perspective. Analytical studies differentiate between observational studies and those that introduce changes to the system (interventions). Computer simulation helps to improve prehospital care planning (i.e., EMSs, emergency departments, and healthcare authorities) [10,13–20] and is less commonly used in medical contexts, but is widely used in the analysis of complex processes (this list is not exhaustive, as computer-aided simulation is also utilized in social science contexts, as demonstrated by the works of [21,22] in the field of societal transitions.). Aringhieri et al. [13] provide a comprehensive review of research on optimized EMS planning, covering static and dynamic ambulance location models, relocation strategies, as well as dispatching and routing policies.

This paper describes the use of computer simulation to improve the operational performance of EMSs, with an explicit focus on simulation studies that apply DES.

2.1. Simulation Study Design

In Switzerland, the Institute for Modeling and Simulation has been using DES for 10 years for the analysis and optimization of EMSs [7,12]. This article’s study design is a retrospective analysis of the regional background, optimization potential, and further observations (see Section 3) of three simulation studies. Each of these studies is structured as follows:

1. Description of study background
Regional context and specific objectives of each simulation study, defining the decision variables, are presented.
2. DES process
Rule-based DES offers maximum flexibility to account for cantonal conditions and contains the following four steps:
 - (a) Import, validation, and analysis of historical data
Historical EMS data of incidents (the “where”, “when”, and “what” happened) and the teams’ availability (rosters for paramedics, emergency doctors, ...) for the period under consideration are imported. A standardized import routine

ensures a consistent technical validation of historical data provided by EMSs across cantons (e.g., non-negative travel times, missing team labels, missing coordinates, completion of incident) and correct calculation of response time in line with IVR regulations [6]. The result of this process is a validated and accepted dataset called *historical scenario*, which serves as input for simulation and contains all relevant historical incidents and available teams.

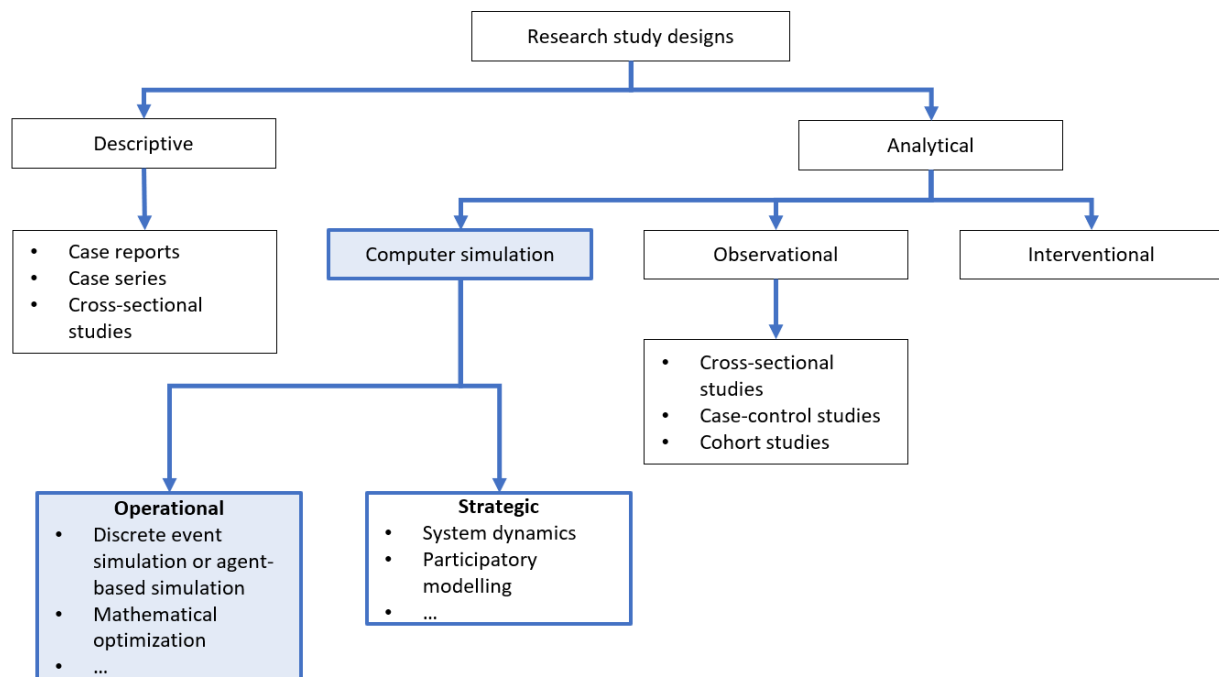


Figure 1. Research methodology based on medical standards summarized by Ranganathan and Aggarwal [23]. Our article is located in the area of operational computer simulations which is highlighted in blue.

(b) Simulation

A rule-based DES processes the *historical scenario* to create a *simulated historical scenario*. Any disparities between the *historical scenario* and *simulated historical scenario* generally stem from model simplifications, which are discussed with all involved stakeholders. The initial analysis compares the *simulated historical scenario* against the *historical scenario*, and uses predefined key performance indicators such as the response time quantiles, a histogram of response time, and the spatial distribution of response time [7]. This is an iterative process with the respective EMS to ensure the simulation's validity [7].

The validated DES uses individual dispatching strategies that take into account the characteristics of incidents and available teams (in most cases, the closest-idle strategy based on incident priority). Simulations may also test individual destination strategies to influence transportation behavior after the initial treatment has been carried out on site (in most cases, the historical destination). The simulation uses the OpenStreetMap routing machine (OSRM) to calculate driving times. A more detailed description of the simulation workflow can be found in Appendix B.

(c) Optimization

During optimization, a set of scenarios is generated from the *historical scenario*, with the option of manipulating the historical composition of incidents (i.e., increase/reduce the number of incidents by sampling) or teams (i.e., add/remove teams or bases). Each of these scenarios will then be simulated

with the option of using different dispatch strategies or different destination strategies. The resulting *simulated scenarios* are ranked and compared with the *simulated historical scenario*. A visualization of this optimization process can be found in Appendix C.

For questions regarding the reserve capacity of teams, an automated optimization process is used to find a minimum set of teams that meet the response time compliance rate. During this process, additional scenarios are iteratively created as long as less than 90% of incidents have been reached within 15 min. In each iteration, a greedy search [24] is used to find the team that can serve the most incidents in the system, thereby improving the total response time. The process stops when (i) 90% is reached or if (ii) the improvement is below a certain threshold [7]. A visualization of this automated optimization process can be found in Appendix D.

(d) Communication of results

In each of the preceding steps, results are summarized in reports that are iteratively discussed with all stakeholders involved. Most reports use response time and the response time compliance rate as the main key performance indicator of interest (an example for spatial patterns in response time and response time compliance rate is shown in Figures 2 and A1). The iterative procedure aims to assert consistency and correct the integration of respective cantonal contexts. The provided reports then support decision-making processes of EMSs and healthcare authorities (HAs).

3. Further observations

A critical reflection on political constraints and decisions is presented for each simulation study. The role of simulation-based optimization in the respective decision-making processes of prehospital care planning is discussed.

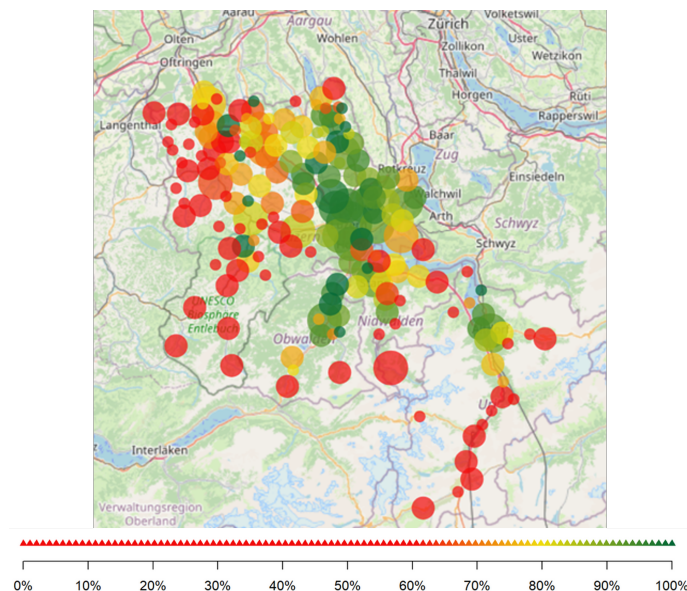


Figure 2. Response time compliance rate. The circles' size indicates the magnitude of the "number of incidents". The smallest circles correspond to 1–9; the next size to 10–99; the largest circles to 100–999. The clustering corresponds to communities, i.e., more or less a postal code.

Section 3 is structured according to the study design.

2.2. Ethical Approval

The present study was classified as a quality evaluation study by the local institutional ethical review board (BASEC Nr. Req-2023-001476, EKOS 23/233, approved 21 December 2023), and the need for informed consent was waived.

3. Results

This section describes the process' outcome for three different regions in Switzerland (region Zurich, Central Switzerland, and canton St. Gallen).

3.1. Simulation Study 1—Region Zurich

3.1.1. Background

The region Zurich covers an area of 3200 km² and 1.9 million inhabitants (2019) with an annual total of 130,000 incidents. As outlined in the Explication of canton Zurich [25], “(. . .) the government council has determined to optimize the quality and efficiency of the Zurich rescue system. The Healthcare Department tasked the Institute for Modeling and Simulation with analyzing the rescue system and identifying opportunities for improvement (. . .)”. The central key performance indicator was response time and reserve capacity, i.e., the number of rescue resources, including emergency doctors, that an EMS organization must deploy to ensure that the area can be covered within the IVR specifications [6]. The dispatch strategy in Zurich before 2018 was mainly area succession, i.e., the rescue vehicle was sent to an incident because it was responsible for the area—in most cases, a well-defined set of communities finance their respective EMSs.

3.1.2. Simulation-Based Findings

The DES was used to estimate the resources needed to comply with the 90-15 rule [7]. One significant finding was that only one out of 14 EMS organizations showed resource-neutral optimization potential when viewed as an isolated system. The identified optimization potential of the response time compliance rate was about one percent. The other 13 EMS organizations' performance improved only when adding additional resources. Furthermore, the issue of territorial coverage remains unresolved in numerous rural areas. Regions with a low response time compliance rate demonstrate the trade-off between delivering quality care in low-density regions and managing costs. The additional teams required to achieve the response time compliance rate demand disproportionately higher financial resources. Further results can be found in Appendix E.

3.1.3. Further Observations

At first, the results of the simulation were accepted. However, approximately one year after completion of the simulation process, the dispatching strategy was changed by healthcare authorities from area succession to closest-idle. This means that, instead of dispatching teams based on areas of responsibility, the closest available team is dispatched to a call, while the communities continued to finance the EMSs. This means that any team from any EMS can be dispatched to an incident because it can be on site the fastest, rather than dispatching teams based on areas of responsibility. Without the ability to use the closest-idle strategy to decide the routing of their teams, EMSs lost a means to influence the response time compliance rate.

3.2. Simulation Study 2—Central Switzerland

3.2.1. Background

The region Central Switzerland covers an area of 3300 km² and has 0.5 million inhabitants (2019) with an annual total of 29,000 incidents. The city of Lucerne is urban, whilst most of the area in Central Switzerland is rural and has a low population density. It is therefore difficult for the various EMSs in the four cantons of Lucerne, Uri, Nidwalden, and Obwalden to comply with the 90-15 rule, as can be seen from Figure 2. In order to solve the problems of poor coverage combined with a shortage of skilled workers, a cross-cantonal

project was launched. One part of this project focused on using simulation to investigate how area coverage could be improved and to identify measures that may mitigate the shortage of skilled workers.

3.2.2. Simulation-Based Findings

Planning the teams across cantons offered advantages for operational reasons: the DES predicted resource-neutral optimization potential for Central Switzerland of 0.9 percentage points (from 80.4% to 81.3%) with respect to overall response time compliance rate. This improvement was not fully realized in the following year with a real increase of 0.5 percentage points (from 79.6% to 80.1%). In addition, the DES showed a decrease in overtime by 300 h per year by improving dispatching strategies and shift times through, e.g., avoidance of the dispatch of teams close to the end of a shift. This was implemented and improvements were confirmed one year later. The DES revealed further benefits concerning employee satisfaction: joint planning made it possible for employees to choose between different deployment areas (urban–rural). The clustering in Figure 2 corresponds to communities, i.e., more or less a postal code. The area with a high response time compliance rates (green circles) includes the city of Lucerne, whereas the rural area is difficult to cover.

3.2.3. Further Observations

This project also faced an unexpected systemic limitation: although it was very difficult to find improvements in the EMSs' locations or the rosters, air rescue was not included in the simulation process because smaller hospitals feared that it would drive more patients to the large hospitals, meaning that small hospitals would lose patients and thus revenue. This highlights the interconnection of EMSs, emergency departments, and HAs.

3.3. Simulation Study 3—Canton St. Gallen

3.3.1. Background

The canton St. Gallen covers an area of 2000 km² and has 0.5 million inhabitants (2019) with an annual total of 31,000 incidents. Over the past 10 years, healthcare authorities have raised *response time* targets while financial budgets have been frozen [26]. On the other hand, the number of incidents has risen continuously, as Table 1 shows [7,26].

Table 1. Response time compliance rate for canton St. Gallen versus growth of number of incidents. Apart from 2022, only data for every second year are shown to highlight the overall trend.

	2013	2015	2017	2019	2021	2022
Response time compliance rate [%]	88	93	92	92	93	93
Incidents (total)	20,283	24,001	26,510	26,045	28,768	30,979

The improved performance from 88% to 93% occurred along a simulation supported large-scale change process where several EMS organizations merged. While this did not increase the available resources, it allowed for a central coordination. In addition to the increasing number of incidents, EMSs were concerned about an HA plan regarding the closure of two hospitals. To assess the potential implication on EMSs, a DES was conducted as follows.

3.3.2. Simulation-Based Findings

The *simulated scenarios* indicated that EMSs are currently operating at their capacity limits, as a perfect implementation of the closest-idle strategy in the simulation did not lead to any further improvement in response time compared to the *simulated historical scenario*. The closure of two hospitals was simulated by dispatching EMSs to different destination hospitals. The simulation showed that fewer ambulances were available due to prolonged mission duration, resulting in a reduction in response time compliance rate.

As these closures "only" affected smaller hospitals, the impact was marginal, i.e., within typical statistical uncertainties of less than 0.5 percentage points.

3.3.3. Further Observations

Two hospitals were closed in St. Gallen, resulting in changes to the conditions under which EMSs plan and operate. At an early stage in the HAs' decision-making process, quantitative data from DES could have confirmed the HAs' assumptions and improved the basis for discussion.

4. Discussion and Future Work

As described in the results, DES is able to replicate historical behavior across different regions of Switzerland and find improved resource allocation strategies. The outcomes of the three simulation studies indicate that alternate strategies can improve response time in terms of response time compliance rate, but also highlight that resource-neutral improvements are marginal in all presented cases. The simulation studies point at the complexity of servicing relatively small, yet geographically challenging regions where governance is shared across federal, cantonal, and municipal instances. By reflecting upon the results, we find that data-driven decision support processes for EMSs in Switzerland face two challenges.

- Resource-neutral performance saturation: Regional gains through optimization of routing, base locations, and scheduling are marginal without increasing resources (e.g., additional teams, bases, or modes of transport). In each case (Zurich, Central Switzerland, and St. Gallen), optimizing the *simulated historical scenario* indicated that resource neutral strategies only led to improvements of up to 1 percentage point at most. The performance could only be significantly improved through additional resources. This demonstrates how individual resource allocation improvements saturate within planning processes due to the conflict between financial pressure and performance targets. This conflict could be mitigated using mathematical optimization, but requires a fundamental discussion among stakeholders regarding objectives.
- Systemic coordination and collaboration: Besides the conflict between financial and performance perspectives, we identify governance structures as highly relevant. The cases of Zurich, Central Switzerland, and St. Gallen are examples of top-down governance wherein planning processes were adjusted without involving all affected actors (e.g., EMSs).

The case of Zurich highlights how a change in dispatch strategy, such as moving from area succession to closest-idle, removed the EMSs' ability to plan and optimize their own fleet operations. The case of St. Gallen shows how top-down decision processes, such as closing two hospitals, did not consider the trade-off between quality improvements and increasing costs for EMSs. As further hospital closures are possible in the future, this case suggests to systematically involve all stakeholders in prehospital care planning at an early stage. The case of Central Switzerland presents a conflict of interest between capacity utilization of regional hospitals (a political decision) and response time compliance rate (an operational consequence). In all three cases, there are behaviors indicating a lack of awareness of system complexity, resulting in insufficient collaboration.

To summarize both challenges, we highlight the complex and dynamic governance of the planning process in prehospital care, which encompasses HAs, emergency departments, and EMSs, as shown in Figure 3.

Our examples indicate that simulation has its limitations and fails to explain or even predict systemic failures when not connected properly to all stakeholders. Such considerations are outside the system boundaries of DES, presenting a methodological limitation. We therefore argue that such a complex system can only be significantly and sustainably improved if computer simulation goes hand in hand with a systemic analysis. Taking a more systemic perspective would go beyond the mere optimization of performance, but

requires a more integrated role in the entire planning process of prehospital care. Any methodological advance needs to (i) lead to improved planning processes across multiple political levels, (ii) increase collaboration between diverse actors, and (iii) understand feedback and mitigate unintended consequences.

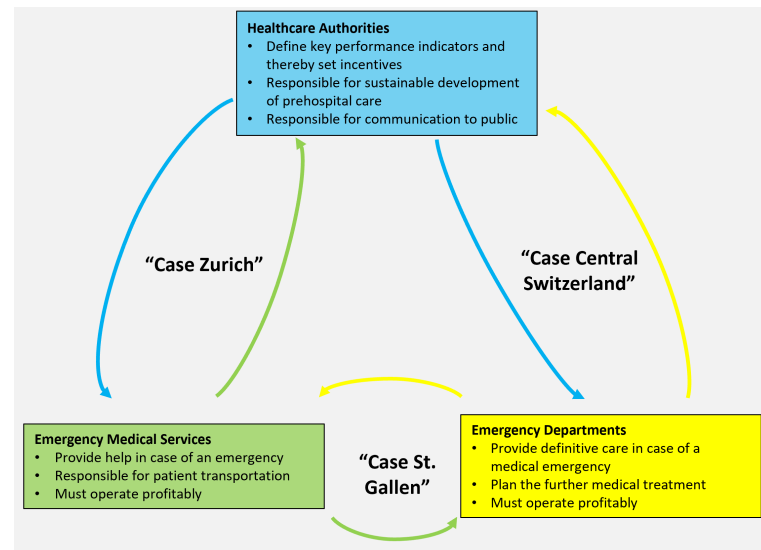


Figure 3. Stakeholders and their interactions. The three simulation studies are assigned to the respective interaction which, according to the “further observations” of each study, lies at the core of political constraints and decisions.

Our proposition is to complement operational optimization (see branch “Operational” in Figure 1) with a “strategic” approach (see branch Strategic in Figure 1). Thereby, our aim is to develop a standardized prehospital healthcare planning process that utilizes a hybrid simulation model adopting DES and “System Dynamics”. We suggest System Dynamics because it applies to complex and dynamic systems characterized by interdependence, the presence of interactions, information feedback, and circular causality [27]. The use of System Dynamics focuses on strategic management decisions on the systems level, whereas DES focuses on tactical and operational decision-making of isolated subsystems. Typical strategic questions in health systems seek to identify misguided incentives or the appropriate intervention lever in the system causing policy resistance (Rodwin and Couturier showed that conflicts of interest in healthcare are often related to financial disincentives [28,29]).

System Dynamics applications focusing on decisions in healthcare and emergency management have a long tradition [30–33]. Hybrid modeling approaches of System Dynamics and DES focus on the feedback loops and long-term impacts of decisions within healthcare systems [34], provide a comprehensive framework for healthcare modeling [35], and offer significant benefits for healthcare modeling by balancing long-term strategy insights and result accuracy [36].

The complexity of developing and validating hybrid models necessitates collaboration among stakeholders to fully realize their potential in EMS planning [36–39]. Our simulation studies highlight the locally diverse challenges in Switzerland and support the argument that further improvement in prehospital healthcare planning requires collaboration among stakeholders. Since no centralized prehospital healthcare planning exists in the federalist setting of Switzerland, we observe fragmented bottom-up research silos which hinder significant systemic improvements. Therefore, we highlight the need for an institutionalized prehospital healthcare planning process using hybrid models from a practical perspective. This process could potentially identify further optimization potential in planning processes, reduce unintended consequences, and increase the acceptability and implementation due to stakeholder involvement. Based on our practical experience, we conclude that, for

this process to be successfully adopted in Switzerland or elsewhere, it must be: (i) based on common standards regarding language and data-handling (including rigorous data-validation, see [35]), (ii) adapted to local conditions, and (iii) accepted and implemented by EMSs, emergency departments, and HAs nationwide.

These insights are subject to methodological limitations, as well as limitations that are inherent to the concept of applied research. Our simulation-based findings can be reproduced because the simulation framework does not use any stochasticity. A limitation of this deterministic approach is that, without stochasticity, no sensitivity analysis is conducted to increase the robustness of the simulation results. A limitation of this applied research is that there is no systematic monitoring over time to assess whether any observed improvements can be attributed to simulation-based recommendations or exogenous system changes. The added value of this research, beyond the simulation findings, is conveyed through the further observations in each case study. These simulation studies are representative of the presented applied research process, consistently conducted in 31 simulation studies during 15 years. Yet, through the retrospective research design, the insights may be influenced by the implicit knowledge of the researchers from the 28 additional simulation studies outside of this study. As all simulation studies take a very practical approach, driven by real-world optimization goals, they do not question current definitions of quality of care or engage in relevant academic discourses.

5. Conclusions

Discrete Event Simulation adds value to the quantitative planning of individual EMS organizations by identifying fundamental operational limits. Nevertheless, its application is limited without data, simulation, and evaluation standardization across cantonal and national borders. In case of conflicting interests between stakeholders, an alternative methodological approach is required. Hence, further investigations are necessary to enhance optimization and systematically explore the interactions among EMSs, emergency departments, and healthcare authorities. The discussion indicates that combining DES with System Dynamics in an *institutionalized* process is a critical step to overcoming limitations of isolated disciplinary, organizational, and regional perspectives in prehospital healthcare planning.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the local institutional ethical review board (BASEC Nr. Req-2023-001476, EKOS 23/233, approved 21 December 2023).

Informed Consent Statement: Not applicable.

Data Availability Statement: The data provided by EMS and dispatch centers are subjected to ethical, legal, and privacy issues. Concepts to comply with data protection law and regulations including appropriate IT structure and safety precautions are mandatory.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

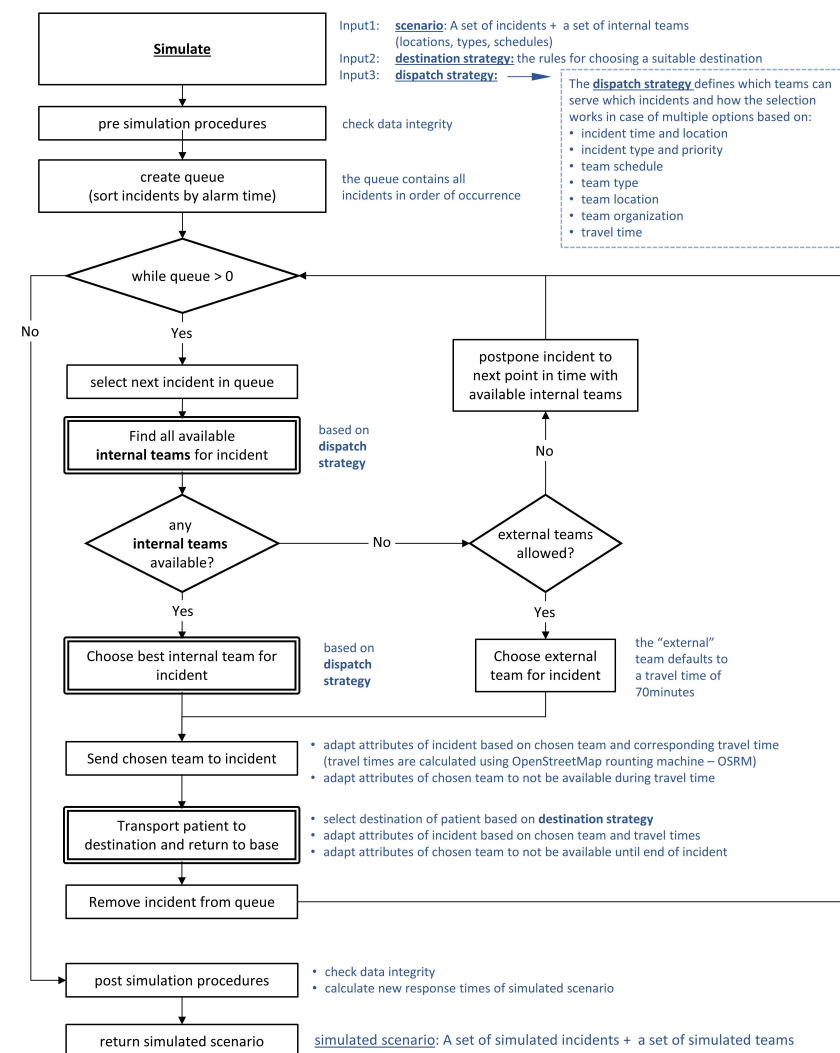
EMSs	Emergency medical services
HA	healthcare authorities
IVR	Inter-association for Rescue Services (“Interverband für Rettungswesen”)
RTCR	Response time compliance rate
DES	Discrete Event Simulation
OSRM	Open Streetmap Routing Machine

Appendix A. Annual Growth of Incidents in Germany, Austria, and Switzerland

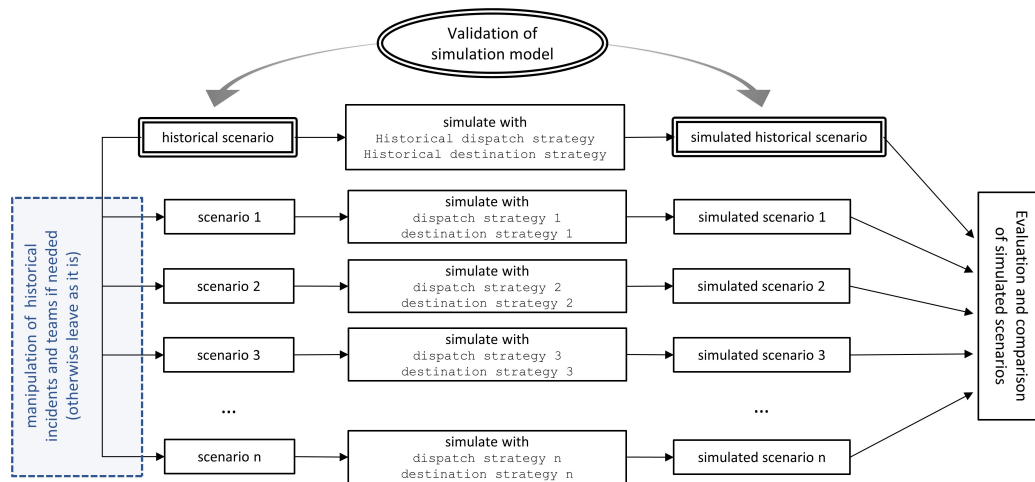
Table A1. Incidents. The density is given in units of “incidents per 100’000 inhabitant and year”. The meaning of annual growth (Column “Growth”) is as follows. Switzerland: estimate based on data of canton St. Gallen for 2013–2022 [7,26]. Bavaria: Average number of incidents over the period 2012–2021 [40]. Baden-Württemberg: Value for 2021–2022 [41]. Vorarlberg: Value for 2021–2022 [42].

Country (Region)	Incidents	Inhabitants	Density	Growth
Switzerland [3]	460,000	8,000,000	5700	5%
Germany (Bavaria) [40]	1,900,000	13,000,000	14,600	3.5%
Germany (Baden-Württemberg) [41]	2,200,000	11,000,000	20,000	7.7%
Austria (Vorarlberg) [42]	120,000	400,000	30,000	10.7%

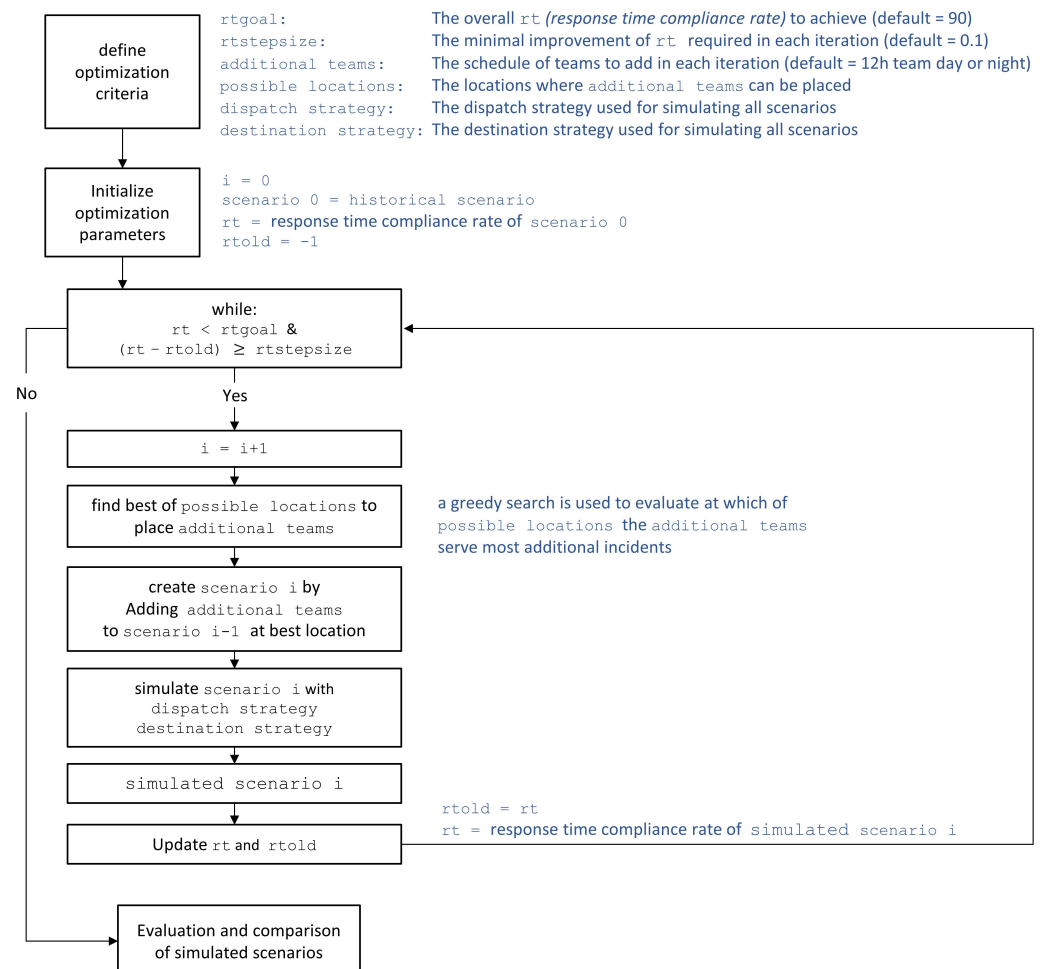
Appendix B. Simulation Process



Appendix C. Overall Optimization Process



Appendix D. Automated Optimization Process



Appendix E. Further Observations for Simulation Study 1—Zurich

One of the main results from the analysis using simulation are visible in Figure A1 right-hand side, showing the *response time compliance rate* at the community level. On the one hand, these maps are used to detect under-served areas to further optimize the system for better quality everywhere. On the other hand, the 90-15 rule is a threshold value, and therefore says nothing about absolute numbers: 90% of 1000 incidents corresponds to 100 unattended events within time, whereas rural areas typically show about 50 incidents or less, corresponding to only five unattended incidents when the 90-15 rule is applied.

About 5 years ago, this analysis using response time compliance rate on the community level was adopted by healthcare authorities for the regular monitoring of EMSs. Although useful for analysis of optimization results, this evaluation was no longer in line with the defined standards from the Interverband für Rettungswesen [6]. The only promising measure to increase the coverage of rural areas available to the EMSs was to deploy more teams, which increases costs and is difficult to be implemented due to the current shortage of skilled workers.

Therefore, we switched from evaluating response time compliance rate to the response times' 90% quantile and changed the color code significantly, as shown in Figure A1, left-hand side: In many cases, a red circle to the right represents only few incidents (about 10) and, in many cases, the 15 min are exceeded only by a few minutes when considering the 90% quantile.

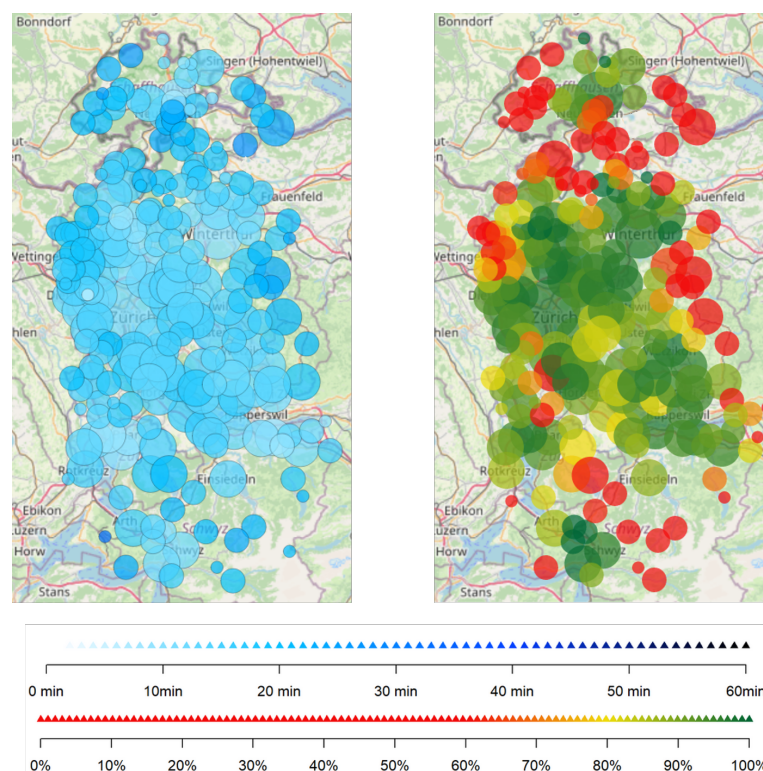


Figure A1. Map of 90% quantiles and response time. The circles' size indicates the magnitude of the number of incidents. The smallest circles correspond to 1–9; the next size to 10–99; the largest circles to 100–999. The clustering corresponds to communities, i.e., more or less a postal code. Left: the response time's 90% quantile (white to blue color bar). Right: the principle of response time compliance rate (red to green color bar).

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