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Citation for published version:
Mahdiraji, SA, Holmgren, J, Mihailescu, R-C & Petersson, J 2024, 'Simulation-based Analysis of Co-dispatching in Prehospital Stroke Care', *Procedia Computer Science*, vol. 238, pp. 412-419.
https://doi.org/10.1016/j.procs.2024.06.042

Digital Object Identifier (DOI):
10.1016/j.procs.2024.06.042

Published In:
Procedia Computer Science

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 238 (2024) 412–419

Procedia Computer Science

www.elsevier.com/locate/procedia

The 15th International Conference on Ambient Systems, Networks and Technologies (ANT)
April 23-25, 2024, Hasselt, Belgium

Simulation-based Analysis of Co-dispatching in Prehospital Stroke Care

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Abstract

A mobile stroke unit (MSU) is a specialized ambulance, enabling to shorten the time to diagnosis and treatment for stroke patients. In the current paper, we present a simulation-based approach to study the potential impacts of collaborative use of regular ambulances and MSUs in prehospital transportation for stroke patients, denoted as co-dispatching. We integrated a co-dispatch policy in an existing modeling framework for constructing emergency medical services simulation models. In a case study, we applied the extended framework to southern Sweden to evaluate the effectiveness of using the co-dispatch policy for different types of stroke. The results indicate reduced time to diagnosis and treatment for stroke patients when using the co-dispatch policy compared to the situation where either a regular ambulance or an MSU is assigned for a stroke incident.

Keywords: Co-dispatch, MSU, Simulation, Framework, Stroke, Transportation.

1. Introduction

Stroke is a global leading cause of disability and mortality, resulting from interrupted or reduced blood supply to the brain [1]. There are three common types of stroke: ischemic, hemorrhagic, and transient ischemic attack (TIA), where each type requires specific treatment. Accurate diagnosis of a stroke requires a computed tomography (CT)

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10.1016/j.procs.2024.06.042

scan on the patient's brain, and this technique is typically only accessible at acute hospitals. An ischemic stroke, the most common stroke type, occurs when one or more blood clots reduce the blood flow to the brain, and the patient can be treated through thrombolysis and, in certain cases, through thrombectomy, which is only available in special clinics (SCs). Hemorrhagic strokes happen when a blood vessel in the brain ruptures, requiring an early start of blood pressure-lowering therapy. TIA is a temporary disruption of blood flow to the brain, allowing for complete recovery of brain function. Timely intervention is crucial for the successful recovery of stroke patients, emphasizing the need for rapid and effective prehospital transportation and care [2].

In emergency medical services (EMS), a single dispatch policy refers to assigning only one type of emergency vehicle (EV) for an incident. Fig. 1. A shows a single dispatch policy using a regular ambulance (RA), where the patient can be transported to the closest hospital or an SC. Additionally, the patient sometimes needs to be transported to the secondary hospital (that is, the SC), as shown in Fig. 1. B. The limitations of using RA-dispatch in prehospital stroke care have led to the exploration of alternative policies, such as deploying mobile stroke units (MSUs). MSUs are specialized ambulances equipped with a CT scanner, enabling ambulance personnel to perform diagnosis and intravenous stroke treatment (that is, thrombolysis) inside the MSU. Therefore, the use of MSUs can potentially reduce the time to treatment by eliminating the time required for transporting the patient to the hospital.

Several studies aim to improve prehospital stroke care through simulation and optimization modeling. In particular, some studies use simulation to assess stroke transportation policies, including MSUs [3-5]. For example, Amouzad Mahdiraji et al. [3] present a discrete event simulation (DES) model to assess stroke transportation policies, particularly those involving MSUs. The authors further build a modeling framework applicable to various EMS simulation models for different medical conditions, including stroke [4].

In EMS, co-dispatching or a rendezvous approach refers to a situation where two or more EVs are simultaneously dispatched to an emergency incident and collaborate until the patient receives appropriate treatment. For example, involving both an RA and an MSU in the transportation of a suspected stroke patient can provide more timely and effective care [6]. In co-dispatching, upon receiving a stroke-related call, one EV, such as an RA, is dispatched to the patient's location, while the other EV, such as an MSU, is sent directly to a predetermined meeting point. After picking up the stroke patient, the RA travels towards the meeting point, where the two EVs come together to transfer the patient. Then, the MSU transports the patient to an appropriate hospital based on the diagnosis made inside the MSU. Alternatively, the RA may be dispatched to the patient's location, and the MSU to the meeting point, depending on operational considerations. Fig. 1. D illustrates co-dispatching, where both an RA and an MSU are dispatched simultaneously to the patient's location (that is, the meeting point that is assumed in this paper). Then, depending on the diagnosis outcome, the patient is transported to either an acute hospital or an SC using one of the involved EVs (that is, either the RA or the MSU).

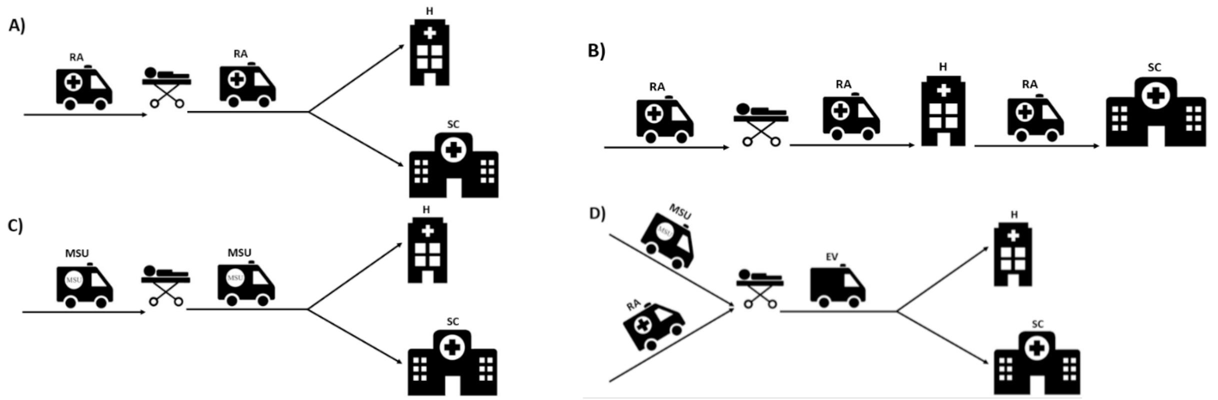

Fig. 1. Different policies made in prehospital stroke care for an acute stroke patient. A) Single dispatch policy using an RA, where the patient is transported to the closest medical center, that is, either the closest hospital or a special clinic (SC); B) Single dispatch policy using an RA, where the patient is transported to the closest hospital and then further transported to the SC; C) Single dispatch policy using an MSU, where the patient is transported to the either the closest hospital or an SC considering the decision made after patient diagnosis inside the MSU or distance to the SC; D) Co-dispatching, where both an RA and an MSU are dispatched simultaneously to the patient's location, and then based on the outcome of patient diagnosis inside the MSU, the patient will be transported to the either closest hospital or an SC using an EV (that is, either an RA or an MSU). Graphs in this figure are inspired by Mathur et al.[6].

Previous research has delved into various aspects of prehospital stroke patient transportation; however, to the best of our knowledge, a simulation-based evaluation of co-dispatching remains unexplored. In the current paper, we present a simulation-based analysis of co-dispatching to investigate the potential advantages associated with the collaborative use of RAs and MSUs in prehospital stroke care for different types of stroke. The contribution of this paper is two-fold: i) an extension of the modeling framework introduced in our companion study [4], by incorporating the co-dispatch policy, and ii) the application of the framework to southern Sweden to study the benefits of using the co-dispatch policy for stroke patients with different types of stroke.

The remainder of the paper is structured as follows. In Section 2, we present how the co-dispatch policy is integrated into the modeling framework proposed in our previous study [4]. Section 3 describes the scenario study, followed by the results and a discussion. Finally, Section 4 concludes the paper.

2. A Co-dispatch Policy in the Modeling Framework

In a prior study [4], we proposed a modeling framework to simplify the construction of EMS simulation models. The framework includes model construction and execution phases. During the construction phase, the framework uses various input, including geographical data, patient data, ambulance data, hospital data, and a care chain specification, to build a DES model for a specific EMS scenario. In the execution phase, the created model is executed using the input data, and the given care chain specification is applied to each simulated patient. The framework utilizes building blocks to construct care chains of EMS activities as flowcharts, where each block represents a generic activity, either a decision-making activity or a pure task activity (see Fig. 2-4). The original version of the framework supports only a single dispatch policy, assigning either an RA or an MSU for a stroke incident. In the current paper, we extend the framework to include the co-dispatch policy.

In Fig. 2-4, we illustrate the chain of EMS activities for a suspected stroke patient, starting from when the emergency center receives a call concerning an incident until the patient receives treatment. As shown in Fig. 2, following the execution of the *select ambulance* activity, the care chain advances to either the single dispatch or the co-dispatch policy. In the co-dispatching branch, the *co-dispatch type* activity is split into two branches: *RA_first_arrival* (Fig. 3) and *MSU_first_arrival* (Fig. 4), implying the situations where the RA arrives before the MSU at the patient's location and the MSU arrives before the RA at the patient's location, respectively. The activities for the co-dispatch policy are split into two distinct branches as the sequence of activities are different depending on whether an RA or an MSU arrives first at the patient's location. A detailed presentation of the EMS care chain activities for the single dispatch policy is provided in our prior study [4].

The key decisions modeled in the framework, and which are included in the care chain example in Fig. 2-4 are choosing 1) the type of EV to be dispatched towards the patient, 2) the dispatch type between single dispatch and co-dispatch, 3) the destination hospital. To reflect these decisions, we included a range of policies for the selection of ambulances, dispatch types, and hospitals, described in the following.

The ambulance selection policies aim to choose one or two EVs and their corresponding types by minimizing either the expected time to 1) the patient, 2) the diagnosis, or 3) the initiation of treatment. The user decides which of these

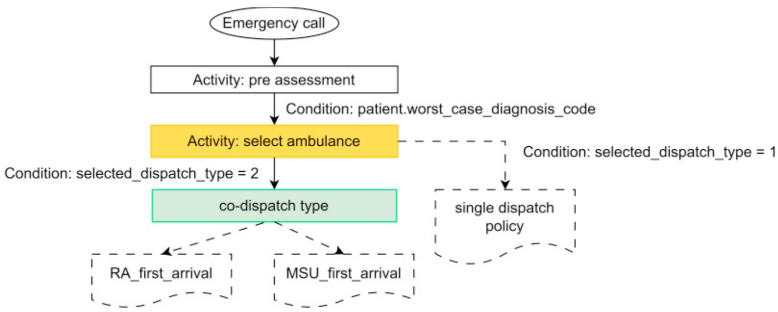

Fig. 2. Overview of the proposed EMS care chain activities, including co-dispatch policy, from *emergency call* until the *co-dispatch type* activity. The proposed chain of EMS activities for the single dispatch policy is presented in our prior study [4]. The continuation of the two branches of the *co-dispatch type* activity, RA_first_arrival and MSU_first_arrival, are illustrated in Fig. 3 and Fig. 4, respectively.

policies should be chosen for the ambulance selection process. The values of the time to diagnosis and time to treatment are estimated based on the identified patient's symptoms over the phone during the preassessment activity.

Dispatch policies have a tied link with ambulance selection policies, where we decide whether a single dispatch policy (dispatching either an RA or an MSU) or a co-dispatch policy should be chosen for a suspected stroke incident.

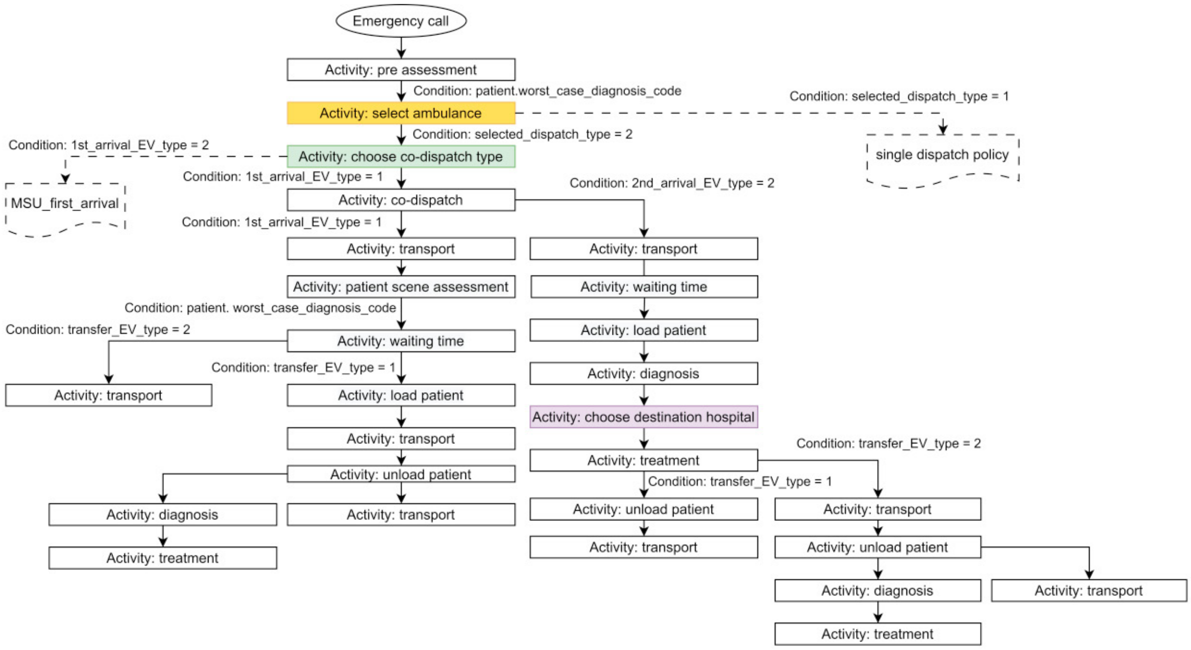

Fig. 3. Continuation of Fig. 2; proposed care chain activities of the co-dispatch policy for a suspected stroke patient, where an RA arrives earlier than an MSU at the patient's location. The colored boxes demonstrate the decision-making activities.

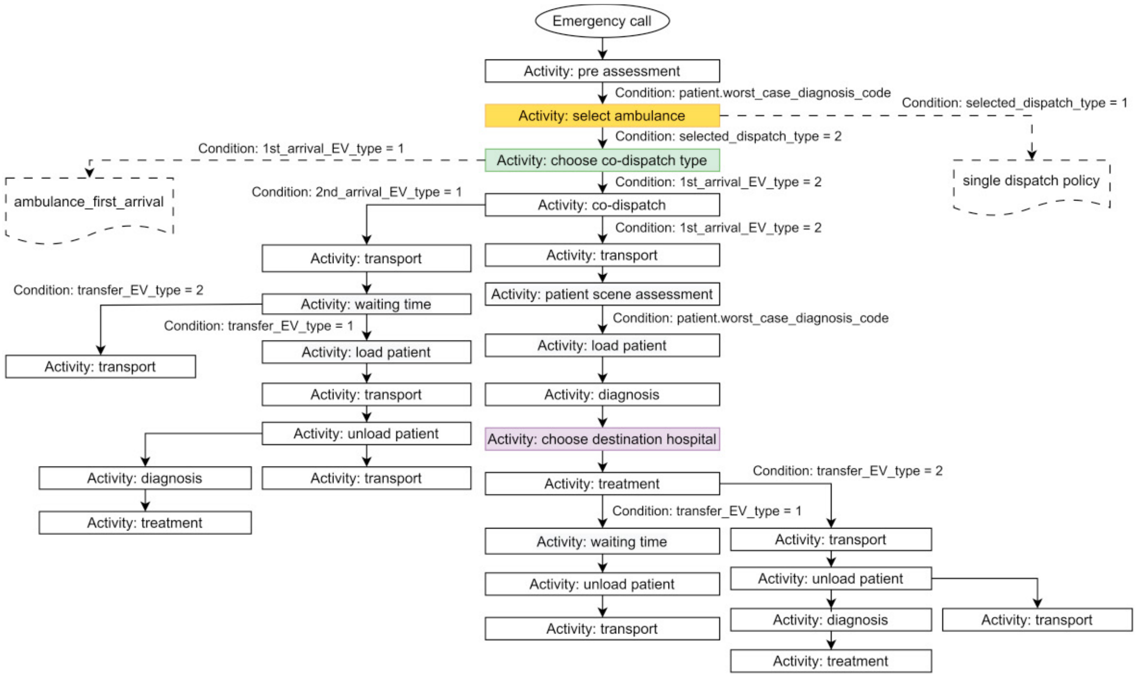

Fig. 4. Continuation of Fig. 2; proposed care chain activities of the co-dispatch policy for a suspected stroke patient, where an MSU arrives earlier than an RA at the patient's location. The colored boxes demonstrate the decision-making activities.

The dispatch policy is designed to choose the dispatch type (either single dispatch or co-dispatch) that minimizes the expected time according to the chosen ambulance selection policy (that is, either *time to patient*, *time to diagnosis*, or *time to treatment*). The supported policies are:

- **Single dispatch**: Either an RA or an MSU is assigned for a stroke incident (see Fig. 1. A to Fig. 1. C).
- **Co-dispatch**: Two EVs collaborate in prehospital stroke care and transportation (see Fig. 1. D). In this policy, when a stroke incident occurs and both an RA and an MSU are dispatched to the meeting point, that is, the patient's location, two situations may occur:
  - **Ambulance_first_arrival**: (see Fig. 3) If the RA arrives earlier than the MSU at the patient's location, the RA staff performs patient scene assessment (and waits) until the MSU arrives. When the MSU arrives at the patient's location, the patient is loaded into the MSU, and the MSU staff performs diagnosis and treatment. After the diagnosis procedure and choosing a destination hospital, the patient is transported either by the MSU or the RA to the destination hospital. When the transferring EV starts to drive to the chosen hospital, the other EV is dismissed and returns to its station. Once the transferring EV has unloaded the patient at the hospital, it returns to its station.
  - **MSU_first_arrival**: (see Fig. 4) If the MSU arrives earlier than the RA to the patient's location, the MSU staff performs patient scene assessment, loads the patient to the MSU, performs diagnosis and treatment, and chooses a destination hospital. Upon the arrival of the RA at the patient's location, the patient is transported either by the MSU or the RA to the destination hospital. Simultaneously, the other EV is released and heads back to its station. Once the transferring EV has unloaded the patient at the hospital, it returns to its station.

The use of co-dispatching, including an RA and an MSU, in prehospital stroke care offers several advantages for stroke patients. For example, in the ambulance_first_arrival situation, once the RA arrives at the patient's location, its staff can perform the patient scene assessment, enabling the patient to be diagnosed inside the MSU upon arrival. Additionally, in the MSU_first_arrival situation, if the RA transports the patient to the chosen hospital, the MSU becomes available immediately for subsequent emergency operations.

In the co-dispatch policy, we define two distinct policies, referred to as transferring to hospital policies, to decide which of the assigned EVs in co-dispathcing should transport a stroke patient to the hospital. The choice of the EV for the patient transfer is based on the user preference between the following two transferring to hospital policies:

- **Faster vehicle**: The EV that can transfer the patient fastest to the destination hospital is chosen.
- **Two vehicles collaboration**: Refers to the collaboration of both assigned EVs, meaning that if one EV arrives earlier at the patient's location, the other EV will be assigned to transfer the patient to the chosen hospital.

Hospital selection policies determine to which hospital the patient should be transported: 1) directly to the closest hospital, 2) directly to the SC, or 3) to either the closest hospital or the SC depending on the patient scene assessment (and diagnosis) and how far the SC is from the patient's location, phrased as fusion. As an illustration of the fusion policy, following the diagnosis of the patient inside the MSU, if specific treatment is deemed necessary, the patient is transported to the SC; otherwise, the patient is transported to the nearest hospital. Using RA-dispatch, if the patient requires specific treatment, yet the SC is far away, the patient is first transported to the closest hospital; then, if it is needed, the patient will be transported to the SC using the same RA (see Fig. 1. B).

By conducting a series of simulation runs, it is possible to compare different decision policies to observe from which policy the patients are expected to benefit most. It is worth noting that in the MSU-dispatch or co-dispatch policy, the framework settings allow us to exclude diagnosis and treatment inside the MSU depending on the patient's symptoms, diagnosis inside the MSU, and preferred treatment.

In Fig. 2-4, the decision to select dispatch policy and select EV(s) and their type are made in the *select ambulance* activity, shown in orange. In the co-dispatch policy, the type of EV that should transfer the patient to the hospital (transferring to hospital policy) is determined in the *choose co-dispatch type* activity, shown in green. Moreover, the decision for choosing the destination hospital is made in the *choose destination hospital* activity, colored by purple, using the predefined hospital selection policy.

3. Scenario Study

We evaluated our approach using Sweden's Southern Healthcare Region (SHR), which is depicted in Fig. 5, where the ambulance sites and acute hospitals are shown by green triangles and purple circles, respectively, and each ambulance site has its unique ID. Currently, no MSU operates in the SHR. Lund SUS is the only SC for thrombectomy treatment, located near ambulance site ID: 24. According to the Swedish Stroke Register (Riksstroke) [7], Sweden recorded over 20,000 annual stroke incidents in 2022, with 3,900 cases reported in the SHR. Of the registered stroke cases in Sweden, 87% were diagnosed with ischemic stroke, and 13% with hemorrhagic stroke. Among the ischemic stroke cases, 81% did not receive treatment, while the remaining 19% underwent recanalization therapy, including thrombolysis alone (11%), thrombolysis combined with thrombectomy (3%), and thrombectomy alone (5%).

We built a model for the EMS care chain of stroke patients in the SHR and carried out a series of simulation runs. In the simulation runs, we considered all decision policies described in Section 2. We used the same input data, MSU locations, and assumptions as we did in our companion study [4]. The geographic region, that is, the SHR, is divided into disjoint 1×1 km^2 subregions, which are used to locate patients, hospitals, and ambulance sites. The stroke patient data, created using a Poisson distribution, is a synthetic population distributed over SHR (details in a previous study [3]). Each patient in the population has specific attributes such as incident time, location, age, symptoms, diagnoses, and preferred treatment. We assumed that all generated patients were acute stroke patients who require diagnosis, and potentially, treatment either inside the MSU or at a hospital. The TIA cases were not considered. We also assumed ischemic stroke cases can receive both diagnosis and treatment (thrombolysis) at the patient's location. However, the patient will be transported to the hospital for (further) diagnosis and treatment (see Fig. 1. C). In all situations, the time to diagnosis/treatment is the expected time from when a stroke occurs until the patient receives diagnosis/treatment either inside the MSU or at the hospital.

We considered three scenarios aligned with the defined dispatch policies: 1) single dispatch using RA only (current situation in the SHR), 2) single dispatch using MSU only, and 3) co-dispatch. We evaluated these scenarios concerning the other mentioned decision policies, namely ambulance selection, hospital selection, and transferring to hospital policies. In the experiments, the MSU locations in the SHR correspond to the findings from our previous paper [8], where we presented an optimization model for the MSU placement problem to make a balance between maximizing population coverage and ensuring equitable service. Thus, we conducted experiments by placing one MSU in Alvesta (ID: 3) or three MSUs in Ängelholm (ID: 2), Alvesta (ID: 3), and Malmö (ID: 38).

In the co-dispatch policy, the *waiting time* activity determines how long each EV waits at the patient's location considering each of the mentioned co-dispatch types, which corresponds to one of the following situations:

- For the ambulance_first_arrival situation (RA arrives earlier, MSU arrives later):

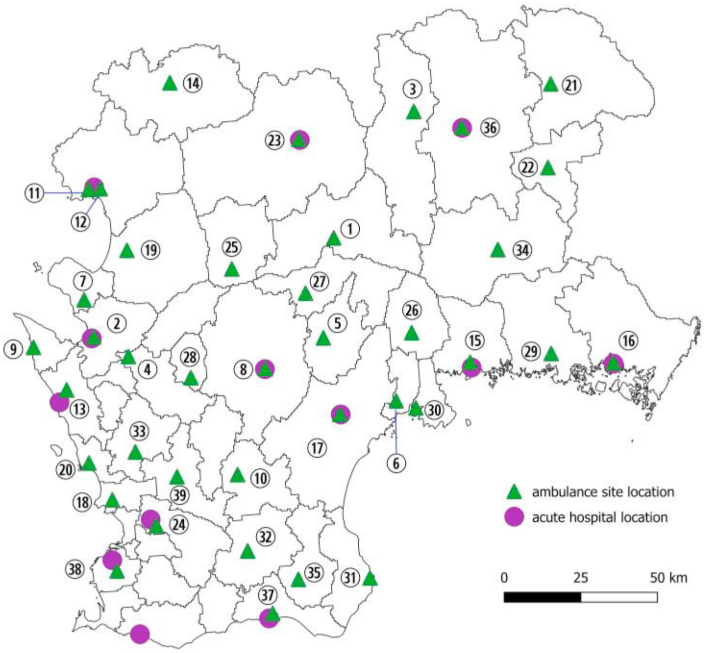

Fig. 5. Overview of Sweden's southern healthcare Sweden region (SHR), reproduced from [8]. The purple circles and green triangles show the locations of acute hospitals and ambulance sites, respectively. The circled numbers indicate the corresponding ambulance site IDs.

- When the RA arrives earlier at the patient's location and its paramedics have done the patient scene assessment, the RA should either wait until the MSU arrives to load the patient to the MSU or wait until the end of diagnosis and treatment inside the MSU to transfer the patient to the chosen hospital.
- When the MSU arrives at the patient's location, it should wait until the RA's paramedics perform the patient scene assessment. Then, the patient is loaded into the MSU for diagnosis and treatment.

- For the MSU_first_arrival situation (MSU arrives earlier, RA arrives later):
  - When the MSU arrives at the patient's location, after performing assessment, diagnosis, and treatment procedure, it should wait until the RA arrives to transport the patient to the chosen hospital.
  - When the RA arrives at the patient's location, it should wait until the patient receives diagnosis and treatment inside the MSU before transporting the patient to the chosen hospital.

3.1. Experimental Results

In the experiments, we employed various policies including time to diagnosis, single dispatch, co-dispatch, faster vehicle, two vehicles collaboration, and fusion. In Table 1, we present the simulation results concerning the average time to diagnosis and time to treatment for the described scenarios and the current situation in the SHR, where no MSU is used. Please note that the transferring to hospital policy is only applicable to the co-dispatch policy.

As shown in Table 1, by placing one MSU in ambulance site ID {3} and using co-dispatching, the average time to diagnosis decreases compared to the single dispatch policy (either RA-dispatch or MSU-dispatch) for the patients receiving thrombolysis, hemorrhagic treatment, or no treatment. Also, by using co-dispatching, the average time to treatment decreases compared to the single dispatch policy (either RA-dispatch or MSU-dispatch) for ischemic stroke patients who undergo at least one treatment. The results in Table 1 also demonstrate that the co-dispatch policy is used for 9.34% of all operations, and in the MSU-dispatch, the share of MSU operations is 6.86%.

When three MSUs are placed in the ambulance sites {2, 3, 38}, by using the co-dispatch policy, the average time to diagnosis decreases compared to the single dispatch policy (either RA-dispatch or MSU-dispatch) for all stroke patients except those treated with thrombectomy. Also, by using co-dispatching, the average time to treatment decreases compared to the single dispatch policy (either RA-dispatch or MSU-dispatch) for all patients. The results indicate that the co-dispatch policy is used for 61.40% of all operations, and the MSU-dispatch for 52.40%.

The outcomes in Table 1 indicate that while placing only one MSU in the SHR has a positive impact on patients' conditions compared to the current situation, the most favorable results for the average time to treatment among patients undergoing different treatments are achieved when three MSUs are placed in the specified locations within SHR. As shown in Table 1, by using co-dispatching, the RA arrives before the MSU at the patient's location in both MSU settings, leading to a longer average waiting time for the RA compared to the MSU. Furthermore, both transferring to hospital policies, that is, faster vehicle and two vehicles collaboration, yield the same results.

Table 1. Comparison of the average time to diagnosis and treatment (in hours) for each stroke treatment for the considered dispatch policies and transferring to hospital policies. SD: single dispatch, CD: co-dispatch, THS: thrombolysis, THY: thrombectomy, THSY: thrombolysis + thrombectomy, HT: hemorrhagic treatment, NT: no treatment, TrHP: transferring to hospital policy, TrF: faster vehicle, TrT: two_vehicles_collaboration, WEV1: waiting time for the first arrival EV in hours, WEV2: waiting time for the second arrival EV in hours, and SH: share of the co-dispatch/MSU operations out of all operations. The numbers within the curly brackets show the ambulance site IDs (see Fig. 5).

MSU locations	Dispatch policy	TrHP	Average time to diagnosis (h)					Average time to treatment (h)					WEV1 (h)	WEV2 (h)	SH (%)
			THS	THY	THSY	HT	NT	THS	THY	THSY	HT	NT			
-	SD (RA)	-	0.97	1.07	1.06	0.98	0.99	1.56	2.19	2.11	1.57	1.57	-	-	-
{3}	SD (MSU)	-	0.96	1.14	1.10	0.97	0.97	1.53	1.96	2.01	1.59	1.58	-	-	6.86
{3}	CD	TrT/ TrF	0.95	1.13	1.09	0.96	0.96	1.51	1.86	1.99	1.58	1.58	0.18	0.07	9.34
{2,3,38}	SD (MSU)	-	0.78	1.28	1.10	0.78	0.78	1.23	1.84	1.75	1.43	1.44	-	-	52.4
{2,3,38}	CD	TrT/ TrF	0.70	1.27	1.05	0.71	0.72	1.14	1.66	1.70	1.36	1.38	0.15	0.1	61.4

The CT scanner in the MSU is employed to distinguish between ischemic and hemorrhagic stroke types. However, it does not specify the patient's specific need for thrombolysis and thrombectomy or thrombectomy alone. As a result, we assumed that ischemic stroke patients potentially requiring thrombectomy should be transported to a hospital for further diagnosis, even if they have been initially diagnosed inside the MSU. The time to diagnosis for these patients is from when the emergency center receives a call until the patient is delivered to the hospital (either the closest hospital or SC). This justifies the reason that the obtained time to diagnosis for these patients using the co-dispatch policy in both MSU settings is longer than in the single-dispatch policy. The other reason is that we assumed that an RA drives faster than an MSU, thus, an RA transports the patient faster to the chosen hospital.

The results in Table 1 demonstrate the considerable waiting times for the involved EVs in the co-dispatch policy, particularly for the RA, the EV that arrives earlier at the meeting point in our scenario. Our framework currently uses precalculated travel times, limiting us to consider the patient's location as the meeting point for the two involved EVs in the co-dispatch policy in prehospital stroke care. To minimize the waiting time, we plan to develop the framework by dynamically calculating travel times between any two locations within the region under study. This enables us to dynamically determine optimal meeting points based on the current locations of the patient, RA, and MSU, leading to a faster and more efficient service for the patient.

4. Conclusions

In this paper, we presented a simulation-based analysis to study the potential impacts of using a co-dispatch policy involving both RAs and MSUs in the prehospital transportation of stroke patients. We included the co-dispatch policy and different types of stroke to a modeling framework, introduced in our previous study [4]. The proposed framework is sufficiently general for application in any region, allowing end-users to adapt it to the region of interest by providing the appropriate inputs. In the scenario study, we applied the extended framework to southern Sweden to assess the benefits of using the co-dispatch policy for stroke patients. Our study, including different stroke types and scenarios, provided a comprehensive insight into how a co-dispatch policy might affect transporting stroke patients before they reach the hospital. The simulation results demonstrated the advantages of using the co-dispatch policy by indicating reductions in time to both diagnosis and treatment for stroke patients receiving different types of treatment.

In future work, we plan to incorporate real-time conditions such as traffic and weather phenomena into the model, enabling more realistic modeling of prehospital stroke transportation and care.

Acknowledgments

This work is partially funded by Sweden's Southern Regional Health Care Committee and The Kamprad Family Foundation for Entrepreneurship, Research & Charity.

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