Modelling transport time to trauma centres and 30-day mortality in road accidents in Switzerland: an exploratory study

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Summary

BACKGROUND: Rapid access to a trauma centre for severely injured road accident victims, conceptualised as the Golden Hour, links access time to definitive treatment within 1 hour of trauma with reduced risks of morbidity and mortality. Access times have not been studied in Switzerland. The aim of this work was to model the transport time by ambulance of seriously injured road traffic accident victims to one of the 12 trauma centres in Switzerland and to investigate whether this time influenced mortality.

METHODS: Isochronous travel curves in 10-minute increments were modelled around each of the 12 Swiss trauma centres to assess travel times at the Swiss national level, based on the shortest travel time from the location of a serious road accident to the nearest trauma centre. We used the national database of the Federal Roads Office, which provided the geolocation of these accidents occurring between 2011 and 2017. The association between mortality and transport time to the nearest trauma centre was then analysed.

RESULTS: The current distribution of trauma centres allowed access time within the Golden Hour for accidents occurring on the Swiss plateau, but the time was more prolonged in the Alps or the Jura. An association existed between mortality and prehospital transport time from the site of an accident to the nearest trauma centre. For each additional 10-minute isochrone, an average increase of 0.4% in mortality was observed.

CONCLUSION: This work showed an adequate distribution of trauma centres in Switzerland and suggests a positive relationship between transport time to the nearest trauma centre and mortality. The numerous confounding factors not systematically collected in publicly available databases limit the robustness of our results. This study confirms the importance of having a national trauma registry to allow quality analyses to guide public health decisions.

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Introduction

Road accidents were the seventh leading cause of disability-adjusted life-years in 2019 worldwide, and the leading cause in the age group 10 to 24 years [1]. In 2019 in Switzerland, 17,761 road accidents that caused injuries occurred, including 17,641 minor injuries, 3,639 serious injuries and 187 fatalities [2]. Prompt access to a trauma centre can reduce mortality and trauma-related sequelae for those seriously injured in a road accident [3, 4]. This time dependence has been conceptualised as the Golden Hour, which links access time to definitive treatment in a trauma centre within 1 hour of trauma to reduced risk of morbidity and mortality [5]. The Golden Hour spans the time from the call to the emergency dispatch centre to arrival at the nearest trauma centre.

Although the Golden Hour has been questioned [6, 7], an association exists between transport time or distance and mortality, at least for hypotensive patients or those with penetrating wounds [8]. An English study found a 1% increase in mortality for every additional 10 km from the accident site to the trauma centres [9]. In a more recent Canadian study, a calculated access time of more than 30 minutes from the accident site to the trauma centre was associated with an increased risk of mortality for victims of penetrating trauma or road accidents [10]. In Switzerland, the only study that has explored the relationship between accident mortality and travel time showed no difference in survival between patients who arrived at the emergency department in ≤60 minutes and those who arrived in >60 minutes [6]. However, this single-centre study included only 30 deaths and differentiated survivors from non-survivors by 10 critical factors, a number too large to be adequately adjusted for with such a small sample size. To our knowledge, no study has examined the relationship between transport time to the 12 Swiss trauma centres and mortality. This relationship is worth examining, as the geographical distribution of trauma centres in most countries is based on the location of historical hospitals and not on the frequency of accidents or minimisation of transport time. This may be a relevant issue for remote or mountain-

ous regions that combine a high risk of serious accidents, difficult access and long transport time [11].

The aim of our study was therefore to determine whether the current layout of Swiss trauma centres allowed for homogeneous access time within the Golden Hour in the country, or whether overlapping or uncovered areas exist. A secondary aim was to study the relationship between transport time from the accident site to the nearest trauma centre and mortality in Switzerland.

Methods

As our study included only anonymous and non-medical data, the cantonal human research ethics commission exempted it from the scope of the federal law on human research (CER-VD 2019-00609).

Setting

Switzerland is a country of 41,285 km^2, with just over 8 million inhabitants. Since 2011, severe trauma victims, defined by an Injury Severity Score of ≥20 or a traumatic brain injury with an Abbreviated Injury Scale score of ≥3, have been referred to one of the 12 trauma centres that meet the requirements of highly specialised medicine (Aarau, Basel, Bern, Chur, Geneva, Lausanne, Lugano, Lucerne, Sion, St Gallen, Winterthur and Zurich) [12].

Transport time modelling

Creation of isochrones around the trauma centres
Transport time represented the time required for the ambulance to travel from the intervention site to the nearest trauma centre (= return travel time). The mission time was the time required for the entire mission (call to 144, time to and from the site, and time at the site). Transport time around each trauma centre was modelled by using the open source Quantum Geographic Information System (QGIS) software [13]. Isochronous curves corresponding to transportation times of 10 minutes were developed based on the shortest distance between the location of a potential road accident site and the nearest trauma centre, following the Swiss road network (OpenStreetMap), with a transport speed set at the maximum legal speed, according to the category of the roads used. A speed of 50 km/h was assigned to roads of unknown category. The road data were uploaded on August 2 2019. The Swiss border layer of Swisstopo (swissBOUNDARIES3D, revision January 2019) was used.

Modelling of travel times from the accident site to the trauma centre
The geospatial data of fatal road accidents (aggregated fatalities on site and within 30 days) in Switzerland between 2011 and 2017 were obtained from the database of the Federal Roads Office (FEDRO) [14] and used to create a point vector layer. The transport time between the accident site and the nearest trauma centre was modelled with the QNEAT3-QGIS Network Analysis Toolbox extension of QGIS [15], which generates the fastest access time via the road network, taking into account the time required to enter this network when the accident site is not directly on a road, with a default speed of 5 km/h.

Validation of the model
The journey times derived from the modelling were tested against a set of real data from priority land missions (with lights and sirens). From 9,579 missions, 1,000 were randomly selected by the random extract function of QGIS, with a median outward journey time of 6.0 minutes (interquartile range [IQR] 3.9—9.6), on-site time of 19.9 minutes (IQR 14.0—27.4), and transportation time to the trauma centre of 12.6 minutes (IQR 7.3—20.1). On GeoDa [16], an alpha factor was calculated for each mission as the ratio between the real mission time and the modelled time. A median alpha for the whole set of modelled transportation times was then calculated and applied as a correction factor to all transport times calculated for accidents in the FEDRO database.

Relationship between travel time and mortality
Each accident was characterised by a modelled transport time from the accident site to the nearest trauma centre, as well as by mortality at 30 days. The total number and percentage of accidents were counted for each 10-minute isochrone. As the starting point of the ambulance for each mission was unknown, the data from the validation set were used to estimate the different mission times [15]. The times required to call and prepare for departure was considered negligible. The median time for on-site management was 19.9 minutes (see Validation of the Model section above), leaving 40 minutes for the cumulative time to travel to and from the nearest trauma centre. As the time to the trauma centre was twice as long as the time to the accident site (12.6 minutes vs 6 minutes), a maximum of two thirds of these 40 minutes, i.e., 27 minutes, was used as a cut-off value for compliance with the Golden Hour rule.

The relation between 10-minute intervals and average mortality was fitted using a non-linear regression line, based on a second order polynomial model.

Results

Weighted transport time modelling through modelling validation (see appendix)
The 10-minute isochrones of simulated return travel are shown in figure 1. Although the travel time to a trauma centre was <30 minutes in the eastern part of the Swiss plateau, it was longer in the Mittelland, the western part of Switzerland, the Alpine valleys and the Jura.

Transport time and mortality
The number and cumulative proportion of fatal accidents per 10-minute isochrone is depicted in figure 2; 45.0% of fatal accidents took less than 27 minutes of transport and 85.8% took less than 54 minutes of transport.

The average proportion of fatal accidents to the total number of serious accidents was 2.8%, and this increased with longer transport times to the trauma centre (fig. 3). Indeed, there was an association between mortality and transport time, which was notably linear up to 80 minutes, with an average increase in mortality of 0.4% per 10-minute isochrone.

The number of fatalities attributed by the modelling to each trauma centre and the proportion of patients admitted after 27 minutes of transportation from the crash site varied

widely (table 1). According to our model, Bern was the centre with the most attributed cases. The trauma centres with the highest percentage of fatal accidents admitted in ≥27 minutes were Bern and Chur at nearly 80%, whereas Geneva, at 10%, was the centre with the lowest rate.

Finally, only Winterthur and Zurich had overlapping territories with a modelling time of ≤27 minutes, with Winterthur being able to rescue 37 (18.2%) of the accidents attributed to Zurich and Zurich being able to rescue 12 (11%) of those attributed to Winterthur.

Discussion

This work is the first, to our knowledge, to show that the current distribution of trauma centres allows adequate coverage of the Swiss plateau, with travel times for the transport of road accident victims within the time limits compatible with the Golden hour principle. In addition, our data support a link between return transportation time and mortality.

Figure 1: Isochrones of 10 minutes around the trauma centres in Switzerland after validation.
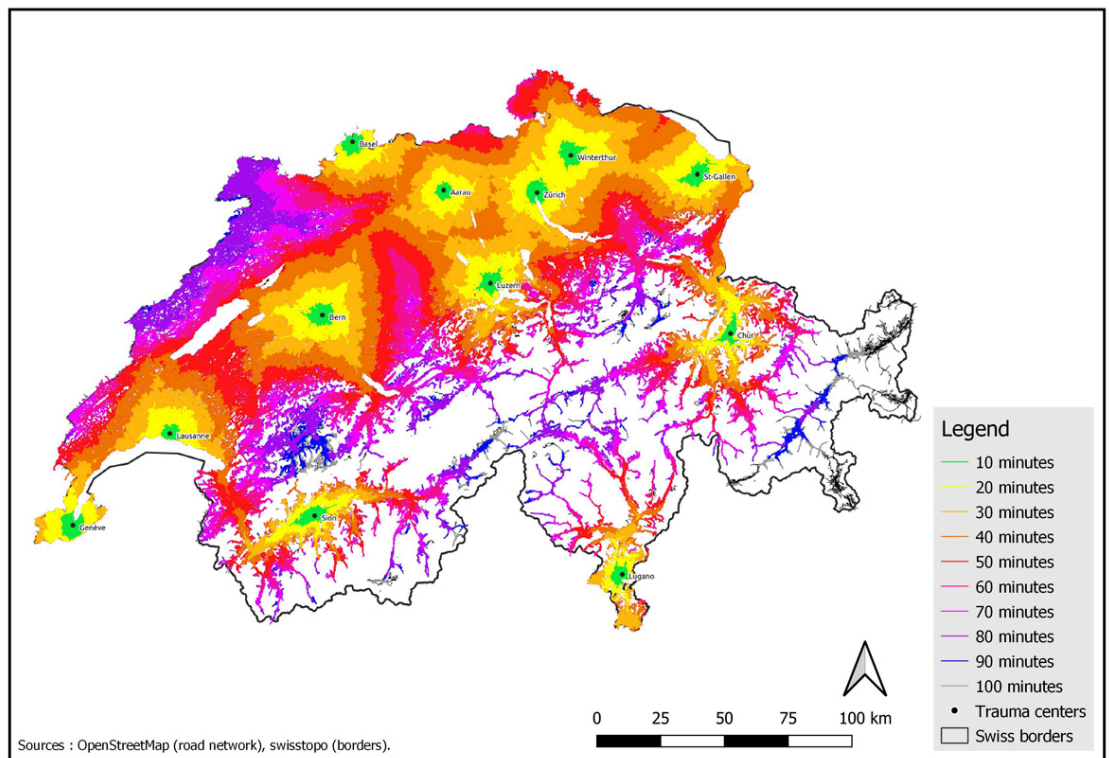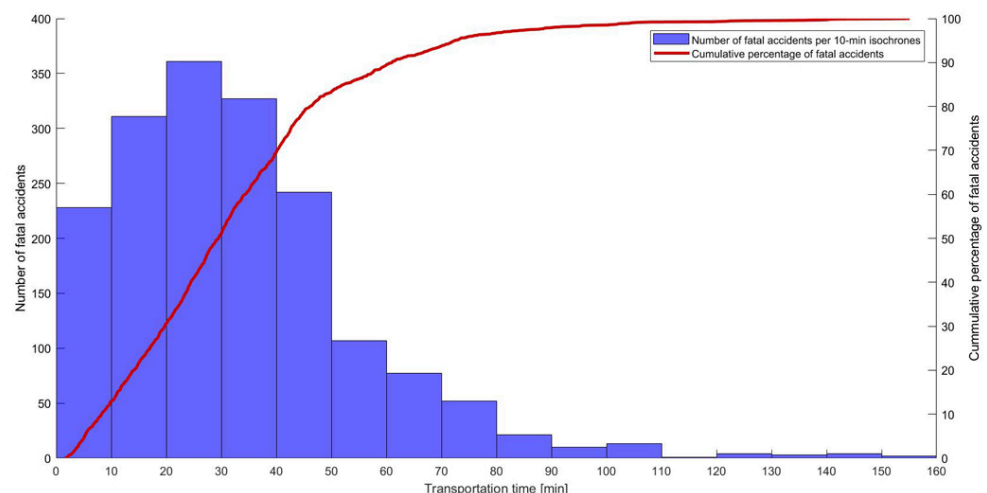

Figure 2: Relationship between the number of fatal accidents and transportation time to the trauma centre (Switzerland 2011—2017).

Location of trauma centres

The location of the trauma centres in Switzerland is adequate, since there is little overlap in their coverages. Our data therefore support the report evaluating the 12 Swiss trauma centres that stated that their distribution was judicious, taking into account geographical peculiarities and favouring optimal access of patients to definitive treatment without long travel, regardless of weather conditions [17].

However, the plateau and large cities were better covered than were the mountainous areas. A new trauma centre in a remote area would, however, have insufficient activity to maintain the required skill level, not to mention the excessive costs. In the United States, a Level I trauma centre must receive at least 1,200 patients per year or have 240 admissions with an Injury Severity Score greater than 15 [18], a requirement that most Swiss trauma centres do not currently meet.

Our work has shown an association between prehospital transport time and the proportion of deaths, with a 0.4% increase in mortality for every 10 minutes. Our results are

Figure 3: Proportion of fatalities as a function of time for 10-minute isochrones; dashed lines indicate the 95% confidence interval.

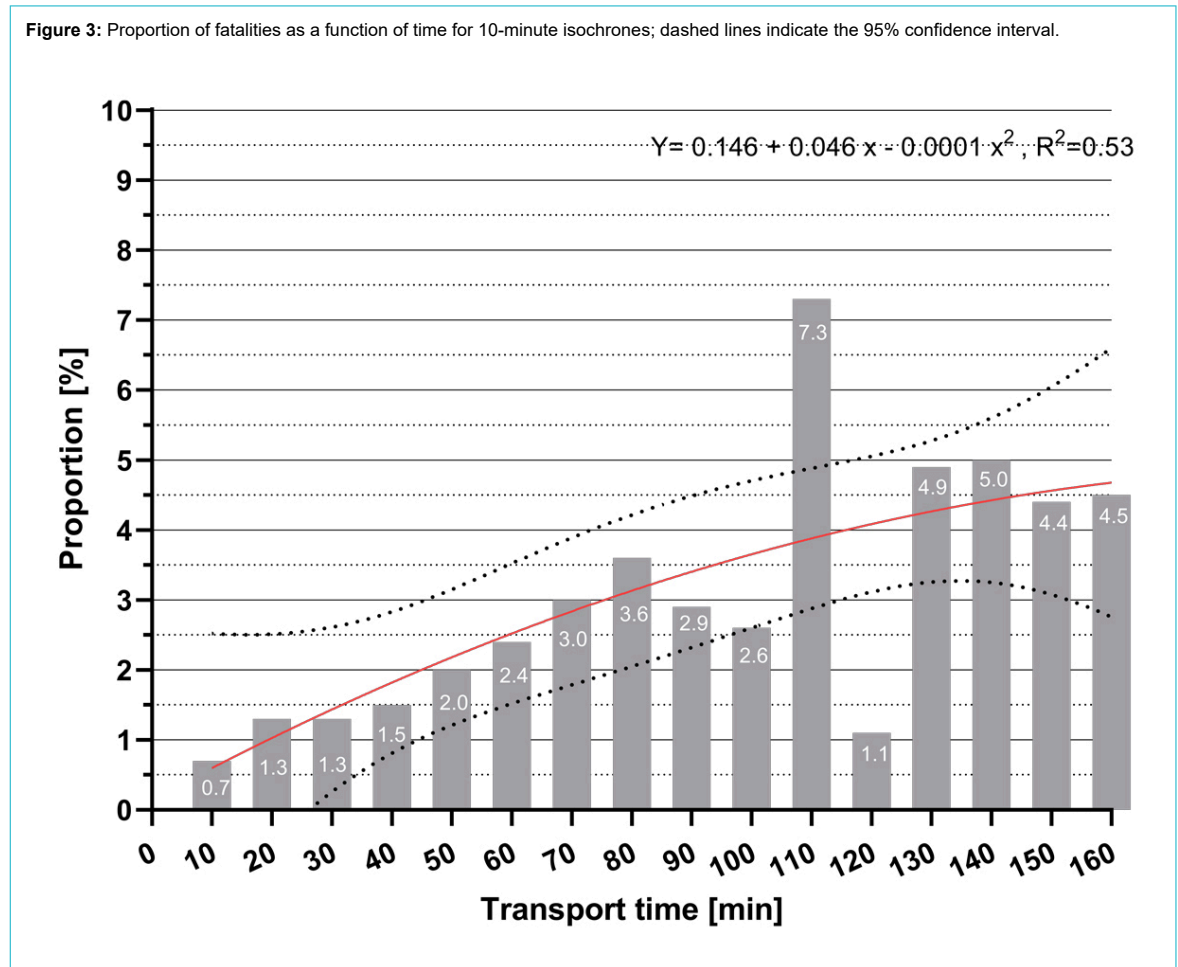$$Y = 0.146 + 0.046 \cdot x - 0.0001 \cdot x^2; \ R^2 = 0.53$$

Table 1:

Number of fatal accidents attributed to each trauma center in Switzerland and the number of fatal accidents above the 27-minute cutoff for compliance with the Golden Hour rule.

Trauma centre	Fatal accidents (n)	Transport time from site to trauma centre ≥27 minutes	
		n	% (95% CI)
Geneva	89	9	10.1 (4.7—18.3)
Zurich	203	65	32.0 (25.7–38.9)
Winterthur	108	45	41.7 (32.3–51.5)
Sion	106	48	45.3 (35.6–55.2)
Basel	110	50	45.5 (35.9–55.2)
Aarau	127	58	45.7 (36.8–54.7)
St Gallen	100	47	47.0 (36.9–57.2)
Lausanne	187	111	59.4 (51.9–66.5)
Lucerne	184	112	60.1 (53.4–68.0)
Lugano	90	59	65.6 (54.8–75.3)
Bern	325	258	79.9 (74.6–83.7)
Chur	134	108	80.6 (72.9–86.9)
Total	**1763**	**793**	**45.0 (42.6–47.3)**

95% CI: 95% confidence interval

therefore similar to those of a Canadian study, in which a transport time of more than 30 minutes was associated with a 66% increase in the risk of mortality for road accidents [10]. However, this association disappeared if deaths on site were excluded, which we cannot do with the FE-DRO database. This correlation between prehospital time and mortality is, however, debatable. In a recent study, a longer prehospital time was associated with lower mortality [19], as it reflected essential actions for patient survival, such as medication administration, ventilation or patient retrieval. However, the study did not specify whether patients who died during transport were included in their survival calculations. If excluded, this would lead to a biased optimistic estimate of the effect of time, a phenomenon known as "healthy worker survivor bias" [19–21]. The debate between a "scoop and run" vs a "stay and play" strategy is still unresolved. "Scoop and run" may be superior in urban areas with short transport times, whereas "stay and play" would benefit patients in rural areas, allowing for interventions required for stabilisation prior to a longer transport [22]. Outside the field of trauma, out-of-hospital cardiac arrest patients cared for in prehospital systems with a "scoop and run" strategy had a lower probability of survival to hospital discharge [23]. However, the strategy applied by rescuers in our study is unknown.

Limitations of our study

Our study is an attempt to model the system of care for serious road traffic injuries in Switzerland on the basis of publicly available data. Our modelling suffers from limitations related to the quality of the national data necessary for researchers who are attempting to establish scientifically robust findings. First, although geolocalisation of accidents is accessible, data on patient status and outcomes are lacking. For example, the presence of hypotension and the type of injury (blunt vs penetrating) are not available, but these variables would help to better stratify patients' short-term prognosis. In addition, mortality on site or in the first 30 days is aggregated in the public database. However, deaths — on site, in the hours following the accident or within 30 days — have very different causes, from injuries that are immediately fatal to infections or organ failure in the event of late death [24, 25]. These different causes require different solutions, for which our work cannot provide any insight. A second limitation is the impossibility of obtaining the real timing of the different components of the overall rescue mission, for several reasons. The first is the inability to identify the vehicle type used for transport. The use of a rescue helicopter is frequent in Switzerland, with the REGA Company, the main actor in Switzerland, capable of reaching any point of the territory in 15 minutes at the most from one of its 12 bases. However, it intervened in only 862 road accidents in 2019, a small fraction of the total number [26], but possibly a higher percentage of those with a fatal outcome. Nonetheless, the duration of helicopter transport is not much shorter than that of land ambulance, mainly because of the time required to prepare the helicopter [27]. Other US studies suggest that helicopter transport is slightly shorter, mainly in rural areas [28, 29]. Since distances are much shorter in Switzerland, the impact of helicopter transport on the time between the accident and the arrival at a Swiss trauma centre is unknown. A study in nearby Germany shows an increased

mission time by helicopter compared with that of land ambulance because of a greater number of actions performed on site [30]. The third limitation is the inability to know the exact starting point of the ambulance for each mission, since several bases are likely to provide an ambulance for a given accident. Moreover, no official national register exists about their location and whether they operate year-round. Fourth, it is possible that some patients may have been transported to a local hospital before their secondary transfer to a trauma centre. Finally, our model shows a shorter travel time compared with real data. The road data used were from the year 2019. It is therefore possible that road conditions have changed and thus contributed to some inaccuracy. In addition, the traffic conditions at the time of the accident could not be taken into consideration. The use of a correction constant improved the overall accuracy of the modelling, but it remains an approximation.

Conclusions

Management and referral of trauma patients to a trauma centre in a minimal amount of time is a challenge for any healthcare system. In this modelling work, we show that the current layout of trauma centres allows adequate coverage of the Swiss plateau and that a longer transportation time to the nearest trauma centre is potentially associated with a greater probability of death within 30 days. However, our conclusions need to be confirmed by real-world data because of the assumptions required to circumvent the limitations of currently available public data. This work confirms the importance of a nationwide trauma registry, with homogeneous procedures for data collection, in order to improve public health safety. The Swiss trauma registry was created in 2015 (http://www.swisstraumaboard.ch/index.php) and will eventually be an essential tool for benchmarking and improving practices in the care of severe trauma victims in our country.

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Appendix

Modeling validation

The validation of the transport time was performed with an extension of the open source Quantum Geographic Information System (QGIS) software (QNEAT3-QGIS Network Analysis Toolbox). It proposes the calculation of origin-destination matrices from a layer of origin points (the priority missions) to a layer of destination points (the 12 trauma centers). The calculation is similar to that of the Service Area function: for each origin-destination combination, the algorithm produces the fastest access time via the road network; in addition, the cost of entering and leaving the network is taken into account (e.g., the mission to be rescued is not directly on the road network, but a few meters away). These costs are calculated with a default speed of 5 km/h. Then, for each mission, only the fastest time in the network for the 12 trauma centers tested was retained by processing the information via MATLAB32 (MATLAB version 7.10.0 (R2010a). Natick, Massachusetts: The MathWorks Inc). At this stage, 15 erroneous models were removed (the same time was indicated to go to each trauma center). The modeled times are joined to the priority missions layer by using the QGIS join attributes by field value function, which uses an identical key to characterize the missions in the original layer and in the layer created via MATLAB.

On GeoDa (Anselin L, S I, Youngihn KGA, 5-22. GeoDa: An Introduction to Spatial Data Analysis. Geogr Anal. 2006; 38(1):5-22), the correlation between mission times and modeled times is calculated. A correlation close to 1 indicates a model evolving linearly with reality. In a second step, the ratio between mission time and model time is calculated according to the ratio

$$\alpha = \frac{t_{missions}}{t_{modeling}},$$

with $t_{missions}$ being the time measured during priority missions and $t_{modeling}$ the time obtained by modeling for these same missions.

An alpha greater than 1 indicates a modeling time less than the time measured during the mission. Very different alphas indicate whether the modeling values are close to real time. They provide additional information to the correlation, which indicates only a link in the variation between the values, but does not indicate anything about the absolute difference of the values.

By averaging the alphas, one can correct a modeling time that is too fast or too slow according to the following equation:

$$d_{mission} = v_{mission} * t_{mission} = v_{modeling} * t_{modeling} = \alpha * v_{mission} * t_{modeling},$$

$$t_{mission} = \alpha * t_{modeling},$$

$$\alpha = \frac{t_{mission}}{t_{modeling}},$$

$d_{mission}$ = distance from the place where the mission is carried out to the trauma center;
$v_{mission}$ = average speed during the mission's journey;
$t_{mission}$ = mission travel time;
$v_{modeling}$ = average speed during the modeling process;
$t_{modeling}$ = modeling travel time;
α = linear proportionality factor between $v_{mission}$ and $v_{modeling}$.

Thus, in the continuation of the analysis, the accidents can be characterized by times that are likely to occur by correcting the modeled times by the alpha coefficient ($\alpha * m_{odeling}$), a median alpha being defined for all the models.

The validation of this modeling, using GeoDa, delivers the following results. A correlation of 0.390 is obtained between modeling and reality for 967 missions. This rather low correlation is due to very fast missions that are modeled with very long times and fast modeling that took a lot of time in reality (points A and B in Figure S1). However, a point cloud showing a linear structure is visible in region C of Figure S1.
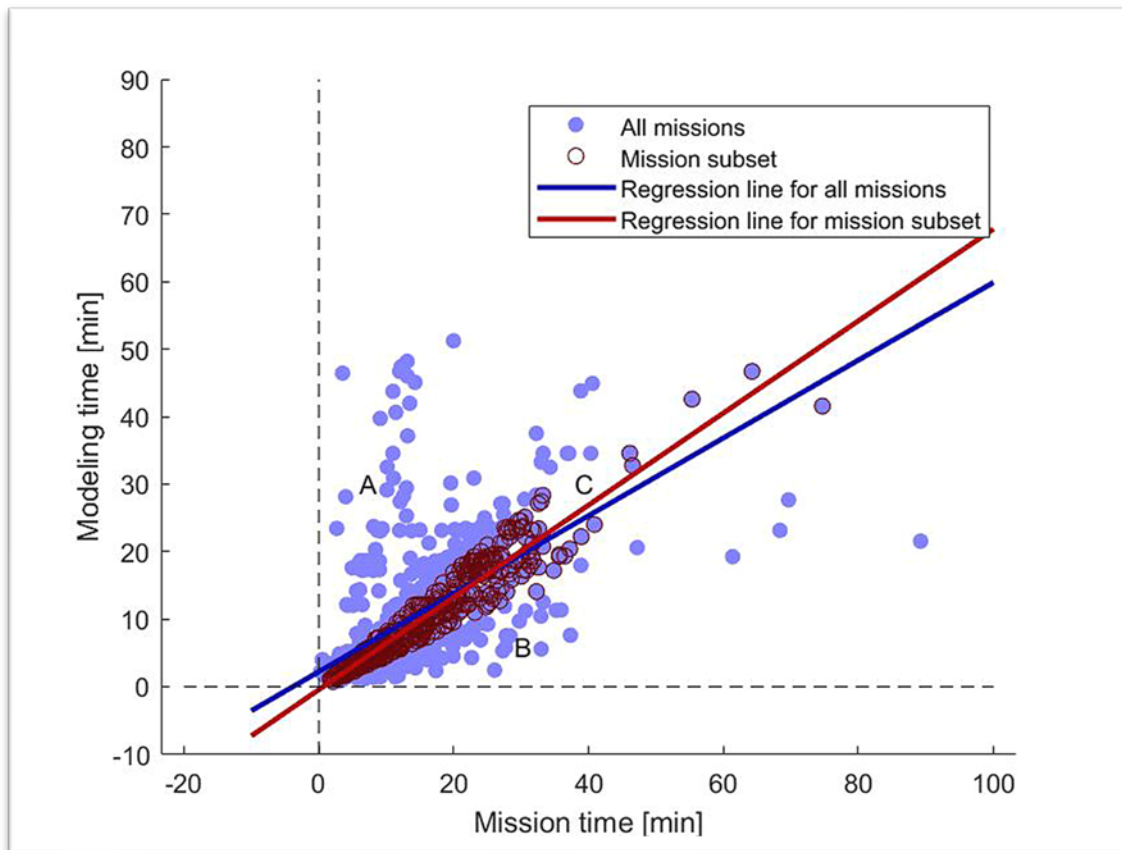
Of these missions, 833 have an alpha greater than or equal to 1. Thus, in general, modeling is faster than reality. Indeed, the distribution of alphas is such that 50% are between 1.1585 and 2.1385. By selecting only these alphas, a correlation coefficient of 0.916 is obtained. The selected points seem to follow a clearer linear trend (see Figure 4). The median alpha of the selection is the median alpha of the alpha distribution and is 1.5220. It is used to convert the modeled times into those consistent with the measured times of the priority missions (cf. Methods).