Quantification of trauma center access using geographical information system-based technology

Dijkink, S.; Winchell, R.J.; Krijnen, P.; Schipper, I.B.

ScienceDirect

Contents lists available at sciencedirect.com
Journal homepage: www.elsevier.com/locate/jval

Health Policy Analysis

Quantification of Trauma Center Access Using Geographical Information System–Based Technology

Suzan Dijkink, MD,* Robert J. Winchell, MD, FACS, Pieta Krijnen, PhD, Inger B. Schipper, MD, PhD, FACS

ABSTRACT

Objectives: There is no generally accepted methodology to assess trauma system access. The goal of this study is to determine the influence of the number and geographical distribution of trauma centers (TCs) on transport times (TT) using geographic information system (GIS)–technology.

Methods: Using ArcGIS-PRO, we calculated differences in TT and population coverage in 7 scenarios with 1, 2, or 3 TCs during rush (R) and low-traffic (L) hours in a densely populated region with 3 TCs in the Netherlands.

Results: In all 7 scenarios, the population that could reach the nearest TC within <45 minutes varied between 96% and 99%. In the 3-TC scenario, roughly 57% of the population could reach the nearest TC <15 minutes both during R and L. The hypothetical geographically well-spread 2-TC scenario showed similar results as the 3-TC scenario. In the 1-TC scenarios, the population reaching the nearest TC <15 minutes decreased to between 19% and 32% in R and L.
In the 3-TC scenario, the average TT increased by about 1.5 minutes to almost 21 minutes during R and 19 minutes during L. Similar results were seen in the scenarios with 2 geographically well-spread TCs. In the 1-TC scenarios and the less well-spread 2-TC scenario, the average TT increased by 5 to 8 minutes (L) and 7 to 9 minutes (R) compared to the 3-TC scenario.

Conclusions: This study shows that a GIS-based model offers a quantifiable and objective method to evaluate trauma system access under different potential trauma system configurations. Transport time from accident to TC would remain acceptable, around 20 minutes, if the current 3-TC situation would be changed to a geographically well-spread 2-center scenario.

Keywords: access, geographical information system technology, traffic flow, transport times, trauma center, trauma system.

VALUE HEALTH. 2020; 23(8):1020–1026

Background

Although the implementation of trauma systems has proven to be effective in reducing mortality rates for injured patients, there are still controversies regarding trauma center (TC) access, and more specifically regarding the optimal number and geographical distribution of TCs.[1–4] According to the principles of the American College of Surgeons Committee on Trauma, TC designation and distribution should be based on the needs of the population served.

The trauma system in The Netherlands resembles the American trauma system and was initially based on the criteria set by the American College of Surgeons Committee on Trauma. Over time, the Dutch Trauma Society has adapted the criteria to the national needs.[5,6] Currently, the Dutch system is organized in 11 trauma regions, each with a coordinating TC, and a catchment area of a minimal 1.2 million inhabitants. All other hospitals within these trauma regions are classified as non-TCs.[7] Trauma centers have multidisciplinary trauma teams available 24/7 that are equipped to manage severely injured patients, including specialties such as neurosurgery and cardiothoracic surgery. The non-TCs are well-equipped trauma hospitals but lack the 24/7 presence of multidisciplinary trauma teams, including neurosurgeons and cardiothoracic surgeons.

Transport times are short in this small and densely populated country with 18 million inhabitants that measures only 300 km from north to south and 200 km from east to west. In the present situation, the numbers of severely injured (polytrauma) patients per TC are relatively low (140-420 per year). Per January 1, 2020, the minimum annual volume requirement was raised from 100 to 240 polytrauma patients per TC.[8] Without further concentration of polytrauma care, only 5 of 11 level-1 TCs fulfill the minimum volume requirements.[7]

In the most densely populated mid-western trauma region of The Netherlands, the TC is organized in a different way than in the other trauma regions. In this trauma region, 3 hospitals act as separate TC locations, together forming 1 TC. The increased

* Address correspondence to: Suzan Dijkink, MD, Department of Trauma Surgery, Leiden University Medical Center, K6-R, P.O. Box 9600, 2300 RC Leiden, The Netherlands. Email: s.dijkink@lumc.nl

volume requirement urges further regional concentration of polytrauma care in 1 or 2 of these 3 hospitals. It is unknown, however, how the quality of trauma care might be affected by further centralization, taking into account the prerequisite that all severely injured patients should be able to reach the nearest TC within 45 minutes after the call for ambulance assistance, with a maximum transport time of 20 minutes in case of high urgency.[6,9]

To solve the ongoing debate about TC accessibility, not only in The Netherlands but also worldwide, there is a need for an objective, generally accepted methodology to assess trauma system access and optimal geographical TC distribution. Geographic information system (GIS)–based technology can facilitate decision making on trauma systems by combining local data from different sources. Geographic information system–based technology was previously used for evaluation of different aspects of trauma systems in various countries, such as the relationship between TC access and outcome, quantification of trauma load, and the relationship between patient volume and TC location.[10–16] To our knowledge, this technology has not been deployed for the Dutch situation.

The goal of this study was to determine the effect of a reduced number of TCs in the mid-western trauma region in The Netherlands, in combination with traffic flow variation, on transport time from accident scene to the closest TC in different scenarios, using GIS-based technology.

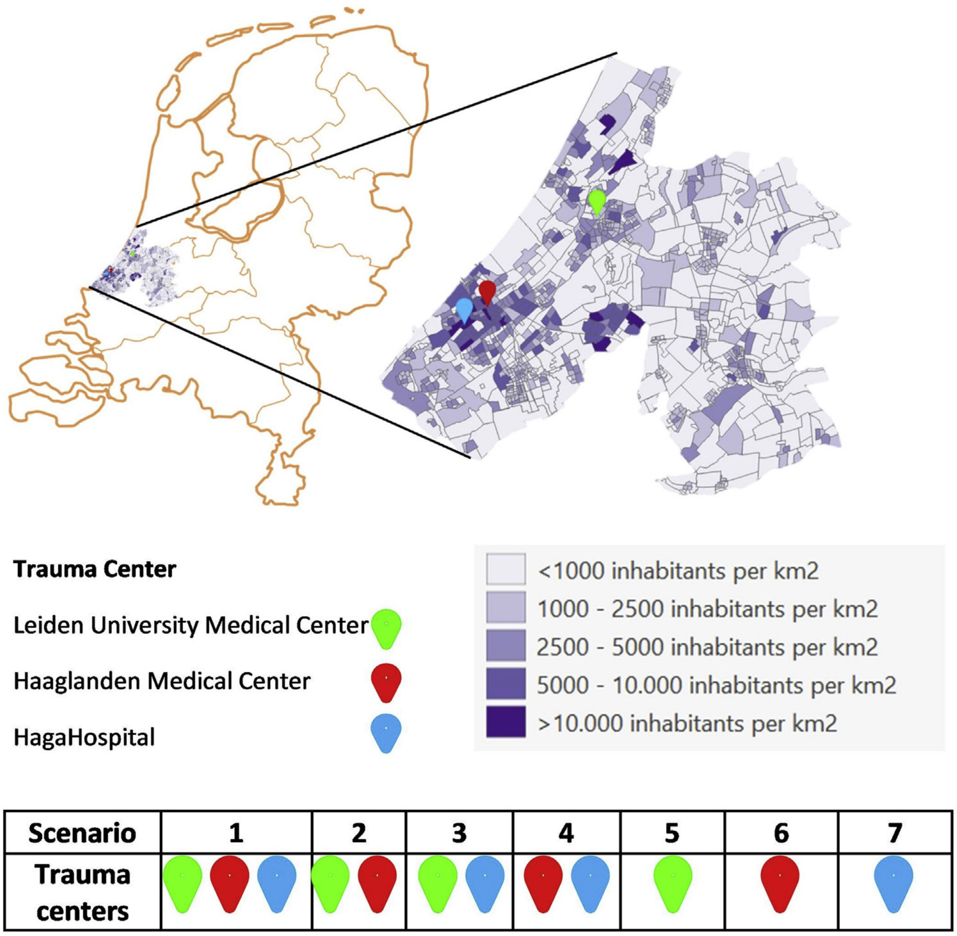
Materials and Methods

Setting

Trauma Center West Netherlands (TCWN) is located in the midwestern trauma region of The Netherlands. This TC has 3 locations: Leiden University Medical Center in Leiden and Haaglanden Medical Center Westeinde and Haga Hospital, both in The Hague (Fig. 1).[7] These TCs are located in one of the most densely populated areas in The Netherlands, with roughly 1.86 million inhabitants in an area of 3403 km^2. According to the national guidelines, severely injured patients (defined as having an injury severity score ≥ 16) should be transported to a TC. Each year, approximately 500 severely injured patients are transported by the ambulance services in the TCWN region. According to national guidelines, which state that at least 90% of the severely injured patients primarily should be brought to a TC, patients classified as severely injured should be directly transported to the nearest TC in the region.[9]

Although Helicopter Emergency Medical Services are available 24/7 throughout in The Netherlands, only 3% of the polytrauma patients are transported by helicopter.[7] Most patients in the TCWN are brought to the TC by 2 regional ambulance services (RASs). RAS Mid-Netherlands mainly covers the area around the Leiden University Medical Center, whereas RAS Haaglanden mainly covers The Hague.

Figure 1. The region of Trauma Center West Netherlands with its population density and the location of the 3 trauma centers. The 7 scenarios for trauma center distribution are presented at the bottom.



The high population density and mobility in the TCWN region are cause for constant traffic jams during rush hour. Also, ambulances are only allowed to go 40 km/h faster than the actual traffic, so they often cannot drive full speed. The high traffic flow and the speed limit could potentially contribute to longer transport times to the closest TC during rush hour.

Study Design

We assessed average high-urgency ambulance ride transport times to the nearest TC in 7 scenarios (Fig. 1); 1 scenario reflected the current situation with 3 trauma centers (3-TC scenario, 1), 3 hypothetical scenarios with 2 trauma centers (2-TC scenarios, 2-4), and 3 hypothetical scenarios with 1 trauma center (1-TC scenarios, 5-7). Each scenario was evaluated for situations with low and high traffic flow. Based on information of the Dutch Traffic Information Service, the traffic situation on an average Tuesday morning at 8 AM was used as proxy for rush hour, and on an average Saturday morning at noon was used as a proxy for low traffic hours to calculate average transport times to the nearest TC.[17] Ambulance rides are classified as high-urgency if the emergency medical dispatch center classifies the patient's situation as potentially life-threatening or as associated with a high risk of immediate deterioration. In these cases, the ambulance is authorized to drive at high speed with lights and sirens.

GIS-Based Model and Data Sources

The ambulance transport times in the 7 scenarios were assessed using a geospatial approach. Over the past decade, the GIS-based technology has been increasingly used in population health and has become a distinct research area.[18,19] In our GIS-based model, different layers of information from independent sources were combined.

The first layer of information about the Dutch road network and traffic flow was obtained via Esri Netherlands Content.[20] This map is continuously updated to give the most up-to-date information about the road network and average traffic flow in The Netherlands, taking the average speed, speed limits, and traffic volume into account. The second layer of population density data was obtained from The Netherlands Statistics. A total of 27 municipalities within the trauma region were included, with 1023 neighborhoods and 1 866 160 inhabitants.[21] The third layer included the GPS locations of the TCs in the Trauma Center West Region. The fourth layer consists of assumed accident scene locations, being the accident location zip codes.

Analysis

All GIS-based analyses were performed using ArcGIS Pro 2.3 (Esri, Redlands, CA). All descriptive analyses were performed using IBM Statistics for Windows, version 23 (IBM Corp., Armonk, NY).

First, we validated the GIS-based model. The patient location GPS codes of the high-urgency rides provided by RAS Hollands Midden were uploaded in ArcGIS-Pro. These included all high-urgency rides with an indication to go to one of the TCs in the region, including but not limited to trauma patients. The transport times generated by the GIS-based model (calculated) were compared with factual transport times obtained from the RAS Hollands Midden (observed). The observed data were divided in 2 groups: (1) ambulance rides during rush hour (between 6:00AM and 9:00AM and 4:00PM and 7:00PM during weekdays), and (2) ambulance rides during low traffic (12:00AM – 6:00AM, 9:00AM – 4:00PM, 7:00PM – 12:00AM on weekdays and on the weekend).[17]

The fastest transport time from the accident scene to hospital was calculated using the "Network Analyst Find Closest Facility" function in the ArcGIS-Pro system. Data about accident scene location and actual transport time from accident scene to the TC for high-urgency rides were obtained from the Regional Ambulance Service Mid-Netherlands and were imported in the model. Observed and calculated transport times were reported as median and interquartile range (IQR). To evaluate the agreement between the observed (factual) and calculated (model) transport times, the median difference between observed and expected transport times with IQR during low-traffic hours and during rush hours was reported and tested using a related-samples Wilcoxon signed rank test. Also, the intraclass correlation coefficient (ICC) between the observed and calculated transport times during low-traffic hours and during rush hours was calculated with the corresponding 95% confidence interval (CI).

To assess the effect of TC distribution in the 7 scenarios (Fig. 1), central data points ("centroids") in the 1023 neighborhoods in the TCWN region were created and used as accident scenes in the "network analyst" function in ArcGIS-Pro to assess transport times to the nearest TC in each scenario in rush hour as well as in low-traffic hours. Population coverage was calculated by combining the centroids layer with the drive time layer by summing the population from all the centroids within the transport time bands, 0 to 15, 15 to 30, 30 to 45, and 45 to 60 minutes.

Results

Validation of GIS-Based Transport Time Model

Between January 1, 2018 and December 31, 2018, a total of 28 556 patients were transported by ambulance. In total, 4963 patients, including but not limited to trauma patients, were transported by RAS Mid-Netherlands with high urgency to the emergency department of 1 of the 3 regional TCs. After excluding ambulance rides with missing zip code of the patient location or recorded transport time, 4487 were included in the analysis (n = 3689 during low-traffic hours and n = 798 during rush hour).

The median observed and expected transport times during low-traffic hours were, respectively, 11.4 minutes (IQR 7.8-16.3) and 11.1 minutes (IQR 7.9-16.0). The median difference between the observed transport and calculated transport times from patient location to the nearest TC in low-traffic hours was 0.3 minutes (IQR -1.8 to 2.1, Wilcoxon signed rank test $P<.0001$). The median observed and expected transport times during rush hour were, respectively, 12.1 minutes (IQR 8.5-17.5) and 12.0 (IQR 8.4-17.0). The median difference between the observed transport and calculated transport times from patient location to the nearest TC in rush hour was 0.1 minutes (IQR -2.4 to 2.4, Wilcoxon signed rank test $P=.20$). The ICC for the transport times in low-traffic hours was 0.82 (95% CI 0.81-0.83) and for transport times in rush hour was 0.77 (95% CI 0.74-0.80).

Effect of Number of TCs and Geographical Distribution During Rush Hour and Low Traffic

In the 7 scenarios, the population that could reach the nearest TC location within 45 minutes varied from 97% to 99% among all models during low traffic, and 96% to 98% during rush hour (Figs. 2 and 3).

In scenario 1, roughly 57% of the population reached the nearest TC within 15 minutes in both rush hour and low-traffic hours (Fig. 3). The hypothetical scenarios with 2 geographically well-spread TC locations (2 and 3) showed similar results as the current 3-TC location scenario, with a population coverage within 15 minutes of about 53% in scenario 2 and 51% in scenario 3 in both traffic circumstances (Fig. 3).

This decrease in population coverage < 15 minutes was the largest in the 1-TC scenarios (5-7). In scenario 5, 19% of the

Figure 2. Seven scenarios in which the geographic coverage within 15, 30, 45, and 60 minutes of closest trauma center for all models in rush hour (R) and low-traffic hours (L) is shown.

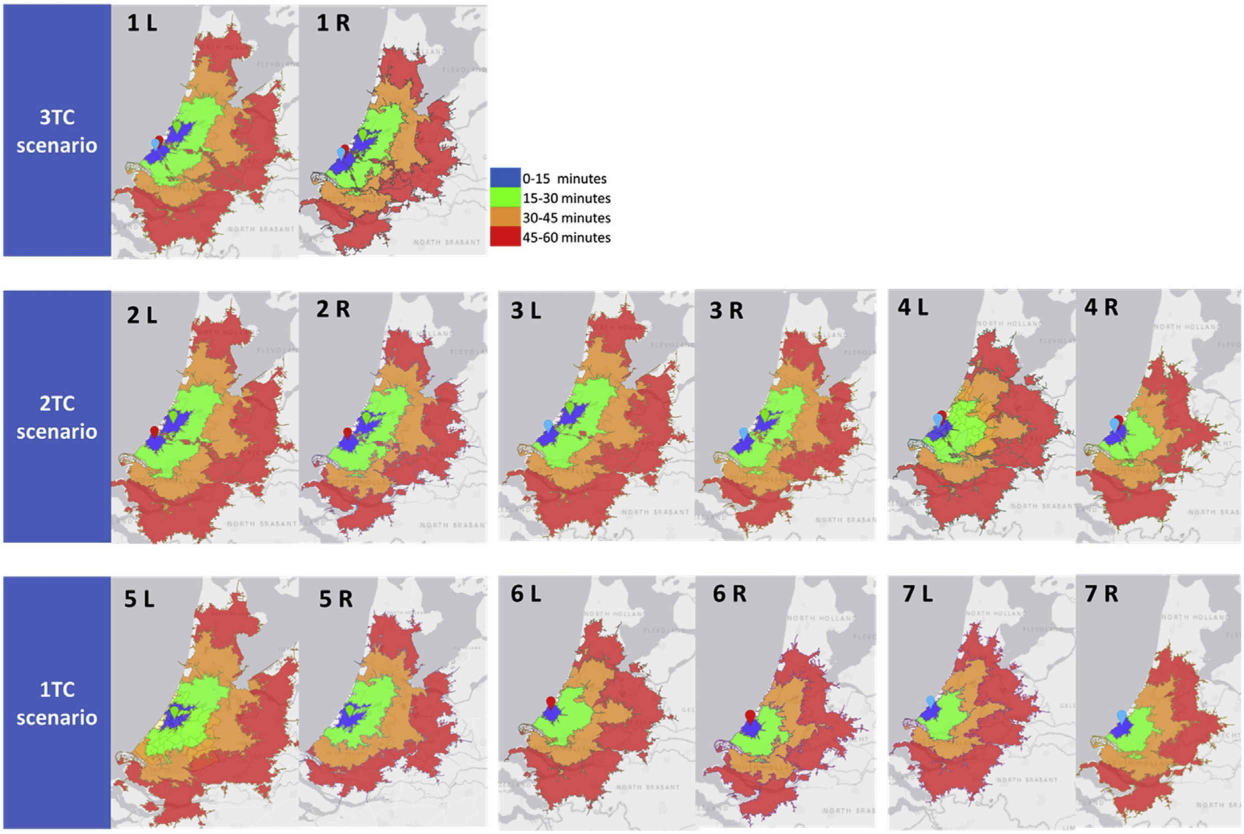
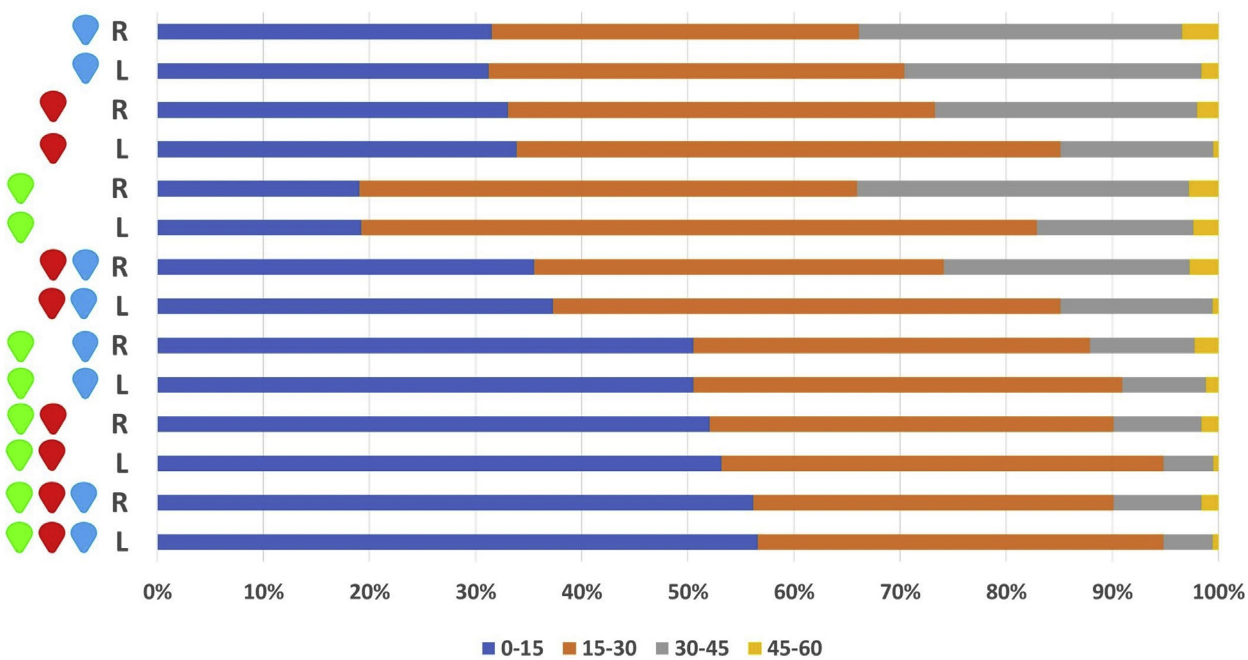


Figure 3. Percentage of TCWN population that can be brought to the closest trauma center in the 7 scenarios during rush hour (R) and low-traffic hours (L) within 15, 30, 45, and 60 minutes. TCWN indicates Trauma Center West Netherlands.



population could reach the nearest TC within 15 minutes in both rush and low-traffic hours, and 31% to 34% of the population was able to reach the nearest TC within 15 minutes in scenario 6 and 7 in both rush hour and low-traffic circumstances. Scenario 4 showed a decrease to 36% of the population that could reach the nearest TC within <15 minutes (Fig. 3).

In scenario 1, the current situation (1), the average transport time of 19 minutes during low-traffic hours increased by about 1.5 minutes to almost 21 minutes in rush hour (Fig. 4). Transport times in both scenarios 2 and 3 were comparable to scenario 1 with a transport time of 20 minutes in low traffic and 22 minutes during rush hour. The 1-TC-location scenarios (5-7) and the geographically less well-spread 2-TC scenario (4) showed an increase of 5 to 8 minutes to the average transport time during low traffic, and an increase of 7 to 9 minutes during rush hours compared to the current 3-TC scenario (1) (Fig. 4).

Discussion

This model allows for the assessment of different potential changes in the number and location of TCs in the midwest trauma region in The Netherlands, and predicts that a suboptimal approach to centralization of trauma care (scenario 4-7) could result in increased transport times to the closest TC, especially during rush hour. The influence of high traffic density on transport times was substantial in the 1-TC scenarios (5-7) and in the 2-TC scenario with 2 TCs that are geographically near to each other (scenario 4), compared with the current situation with 3 TCs in the region (scenario 1) and the situation with 2 geographically well-spread TCs (scenarios 2 and 3). As mentioned before, the Dutch government set a time limit of approximately 20 minutes for transporting severely injured patients to the nearest TC. This study showed that the transport time in the geographically less well spread 2-TC scenario (scenario 4) and in the 1-TC scenarios (scenario 5-7) exceeds the maximum time with 4 to 10 minutes. Although in all scenarios roughly 98% of the population could reach the hospital within 45 minutes in both rush hour and low traffic, the transport time for the population living in the region's periphery did increase substantially. The transport times for these patients would, in fact, be shorter if they were to be brought to the nearest TC in an adjacent region.

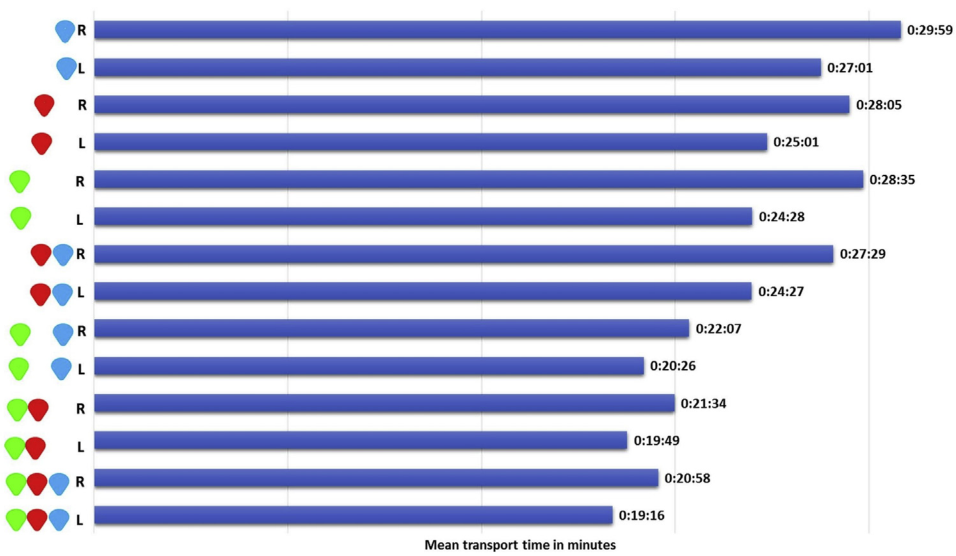
Although the GIS-based approach has been used earlier to evaluate geographical TC distribution in other countries,[10,12,16,22–24] this study is, to our knowledge, the first that used the GIS-based technology to assess access to TCs in The Netherlands and validated the model. There was only a 0.3-minute difference between observed and expected transport times during low-traffic hours and 0.1-minute difference during rush hour. Although the difference in transport time was statistically significant owing to the large number of ambulance rides, this was not deemed clinically relevant. In combination with the good agreement between the calculated transport times and the observed transport times (ICC $>$ 0.75),[25] this model can be considered a valid tool for evaluating the access to TCs in different geographic settings.

The GIS-based results may be useful to help guide policy decisions regarding trauma system organization. Although the importance of well-developed trauma systems is internationally recognized, there is still no consensus about their optimal organization. In almost all cases, trauma systems have developed organically, with TCs arising in existing hospitals based on historical practice patterns, instead of strategically locating the TCs geographically in the most efficient way, taking access and population coverage into account.[23]

The trade-off between centralization of care with sufficient hospital volumes on the one hand and better TC access in transport times and population coverage achieved by a distributed system of smaller centers on the other hand is a difficult one. Several studies have shown that reduced TC access led to differences in outcomes, such as higher mortality rates.[26–29] Nevertheless, providing 24/7 highly specialized trauma care comes at a cost. Year-round TC readiness costs around $2.7 million per TC annually in the Unites States.[30] Efficient planning of distribution of TCs could therefore not only lead to better outcomes in patients, but also to more efficient distribution of resources and potentially lower healthcare costs.

Although concentration of complex trauma care in fewer TCs could potentially increase the expertise of the trauma teams in the resulting higher-volume centers, and also may have

Figure 4. Mean transport times to closest trauma center in different models during rush hour (R) and low-traffic hours (L).



organizational and process advantages, it would also have consequences for system access. Our results suggest that hospital volume is not the only objective aspect of trauma care that can be modeled and taken into account in trauma system planning. Research has shown that especially time is of the essence for the hemodynamically unstable trauma patients and that rapid transport to a TC can improve outcomes.[31,32] The GIS-based model offers an objective way to evaluate the effects of proposed changes in trauma systems for specific regions or countries with their specific geography and demography.[10,12,16,22–24]

Strengths and Limitations

A major strength of this study is that the outcomes of the model were validated, using factual data of a large number of high-urgency cases, largely publicly available data, and commercially available GIS-based technology. There are also some limitations. Although we validated the model, we must emphasize that the results are based on a mathematical model, which is of course a simplification of the real world. For example, instead of using the exact geographic coordinates of the accident scenes, the zip codes were used as a proxy. In our opinion, these 4-digit, 2-letter zip codes are an acceptable proxy because these codes cover areas of a few streets at most, meaning that the actual accident scene is in close proximity. Another limitation is that the data used to validate the model outcomes may have contained erroneous transport times that could not be corrected, which is illustrated by some extremely short or very long transport times in the database provided by the RAS. Because it is not possible to determine which of the extreme data points were errors and which were actual outliers, we included all available data in the validation to not manipulate the data. Unfortunately, owing to strict privacy regulations, we were unable to include patient characteristics in this study. This prevented us from a more detailed investigating of the types and severity of the injuries of the included patients.

Third, as mentioned before, ambulances in The Netherlands are allowed to drive 40 km/h faster than the speed of the surrounding traffic for high-urgency transports. Unfortunately, we were not able to correct for the effect of the increased speed of the ambulance in the model. Nevertheless, the GIS-model transport times did not differ significantly from the actual RAS Hollands Midden data, despite the assumed speed differences.

Last, only a specific part of the trauma system (ie, transport time from accident scene to TC) was evaluated in this study. Other components that influence TC access, such as shifts in volumes as a consequence of changes in TC distribution, were not analyzed. Although we do feel that maximum capacity and shifts in patient volume should be an important part of strategic TC planning, this could not be analyzed using the currently available data. We therefore want to emphasize that decisions about the organization of trauma care, both prehospital and in-hospital, should be based on more factors than only transport times. Nevertheless, despite this limitation, we do think that this type of objective data can help to guide policy decisions such as those involving potential centralization of trauma care resources.

Conclusions

This study shows that a GIS-based model offers a quantifiable and objective method to evaluate trauma system access under different potential trauma system configurations. Applying this technology to one of the most densely populated areas in The Netherlands shows that the transport time from accident to TC would remain acceptable if the current situation with 3 TCs were changed to a scenario with 2 geographically well-spread centers; it also shows that a single-center configuration, or one with 2 poorly located centers, could have an adverse effect on patient access to care. This type of objective data can support strategical and political decisions, such as those involving potential centralization of resources.

Article and Author Information

Accepted for Publication: May 12, 2020

Published Online: July 4, 2020

doi: https://doi.org/10.1016/j.jval.2020.05.005

Author Affiliations: Department of Trauma Surgery, Leiden University Medical Center, Leiden, The Netherlands (Dijkink, Krijnen, Schipper); Division of Trauma, Burns, Acute and Critical Care, Department of Surgery, Weill Cornell Medicine, New York, NY, USA (Winchell)

Author Contributions: *Concept and design:* Dijkink, Winchell, Krijnen, Schipper
Acquisition of data: Dijkink
Analysis and interpretation of data: Dijkink, Winchell, Krijnen, Schipper
Drafting of the manuscript: Dijkink, Winchell, Krijnen, Schipper
Critical revision of the paper for important intellectual content: Dijkink, Winchell, Krijnen, Schipper
Statistical analysis: Dijkink
Administrative, technical, or logistic support: Dijkink
Supervision: Winchell, Krijnen, Schipper

Conflict of Interest Disclosures: None reported.

Funding/Support: None.

REFERENCES

1. MacKenzie EJ, Rivara FP, Jurkovich GJ, et al. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006;354(4):366–378.
2. Lansink KW, Leenen LP. Do designated trauma systems improve outcome? *Curr Opin Crit Care*. 2007;13(6):686–690.
3. Celso B, Tepas J, Langland-Orban B, et al. A systematic review and meta-analysis comparing outcome of severely injured patients treated in trauma centers following the establishment of trauma systems. *J Trauma*. 2006;60(2):371–378. discussion 378.
4. Statement on trauma center designation based upon system need. *Bull Am Coll Surg*. 2015;100(1):51–52.
5. Committee on Trauma. *Resources for Optimal Care of the Injured Patients*. Chicago, IL: American College of Surgeons; 1999.
6. Ministry of Health Welfare and Sport. *Beleidsvisie Traumazorg 2006–2010*. Den Haag: Dutch Government; 2006.
7. Landelijk Netwerk Acute Zorg. *Traumazorg in Beeld -Landelijke Traumaregistratie 2013 - 2017 -Rapportage Nederland*. Utrecht; 2018.
8. Nederlandse Vereniging voor Traumachirurgie. *Visiedocument 2016-2020*. Utrecht; 2016.
9. Bos N, Hendriks M, de Booys M, Wets M. *Spoed Moet Goed: Indicatoren en Normen Voor zes Spoedzorgindicaties*. Diemen: Zorginstituut Nederland; 2015.
10. Tansley G, Schuurman N, Amram O, Yanchar N. Spatial access to emergency services in low- and middle-income countries: a GIS-based analysis. *PLoS One*. 2015;10(11):e0141113.
11. Gomez D, Larsen K, Burns BJ, Dinh M, Hsu J. Optimizing access and configuration of trauma centre care in New South Wales. *Injury*. 2019;50(5):1105–1110.
12. Winchell RJ, Xu P, Mount LE, Huegerich R. Development of a geospatial approach for the quantitative analysis of trauma center access. *J Trauma Acute Care Surg*. 2019;86(3):397–405.
13. Lawson FL, Schuurman N, Oliver L, Nathens AB. Evaluating potential spatial access to trauma center care by severely injured patients. *Health Place*. 2013;19:131–137.
14. Hardcastle TC, Samuels C, Muckart DJ. An assessment of the hospital disease burden and the facilities for the in-hospital care of trauma in KwaZulu-Natal, South Africa. *World J Surg*. 2013;37(7):1550–1561.
15. Hu W, Dong Q, Dong C, Yang J, Huang B. Access to trauma centers for road crashes in the United States. *J Safety Res*. 2018;65:21–27.
16. Tansley G, Schuurman N, Erdogan M, et al. Development of a model to quantify the accessibility of a Canadian trauma system. *CJEM*. 2017;19(4):285–292.
17. Ministry of Infrastructure and Water Management. *Publieksrapportage Rijkswegennet*. Den Haag: Rijkswaterstaat Water Verkeer en Leefomgeving; 2016.
18. Rushton G. Public health, GIS, and spatial analytic tools. *Annu Rev Public Health*. 2003;24:43–56.

19. Bell N, Schuurman N. GIS and injury prevention and control: history, challenges, and opportunities. *Int J Environ Res Public Health*. 2010;7(3):1002–1017.
20. ESRI. Stratenkaart Nederland. https://services.arcgisonline.nl/arcgis/rest/services/Basiskaarten/Stratenkaart/MapServer. Accessed August 6, 2019.
21. Statistiek CBvd. Kerncijfers wijken en buurten 2017. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83765ned/table?fromstatweb. Accessed August 6, 2019.
22. Horst MA, Gross BW, Cook AD, Osler TM, Bradburn EH, Rogers FB. A novel approach to optimal placement of new trauma centers within an existing trauma system using geospatial mapping. *J Trauma Acute Care Surg*. 2017;83(4):705–710.
23. Jansen JO, Moore EE, Wang H, et al. Maximizing geographical efficiency: an analysis of the configuration of Colorado's trauma system. *J Trauma Acute Care Surg*. 2018;84(5):762–770.
24. Jansen JO, Campbell MK. The GEOS study: designing a geospatially optimised trauma system for Scotland. *Surgeon*. 2014;12(2):61–63.
25. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155–163.
26. Brown JB, Rosengart MR, Billiar TR, Peitzman AB, Sperry JL. Geographic distribution of trauma centers and injury-related mortality in the United States. *J Trauma Acute Care Surg*. 2016;80(1):42–49. discussion 49-50.
27. Hsia RY, Srebotnjak T, Maselli J, Crandall M, McCulloch C, Kellermann AL. The association of trauma center closures with increased inpatient mortality for injured patients. *J Trauma Acute Care Surg*. 2014;76(4):1048–1054.
28. Sampalis JS, Denis R, Lavoie A, et al. Trauma care regionalization: a process-outcome evaluation. *J Trauma Acute Care Surg*. 1999;46(4):565–581.
29. Branas CC, MacKenzie EJ, Williams JC, et al. Access to trauma centers in the United States. *JAMA*. 2005;293(21):2626–2633.
30. Taheri PA, Butz DA, Lottenberg L, Clawson A, Flint LM. The cost of trauma center readiness. *Am J Surg*. 2004;187(1):7–13.
31. Harmsen AMK, Giannakopoulos GF, Moerbeek PR, Jansma EP, Bonjer HJ, Bloemers FW. The influence of prehospital time on trauma patients outcome: a systematic review. *Injury*. 2015;46(4):602–609.
32. Mills EHA, Aasbjerg K, Hansen SM, et al. Prehospital time and mortality in patients requiring a highest priority emergency medical response: a Danish registry-based cohort study. *BMJ Open*. 2019;9(11):e023049.