Proceedings of the 2012 Industrial and Systems Engineering Research Conference
G. Lim and J.W. Herrmann, eds.

Air versus Ground Vehicle Decisions for Interfacility Air Medical Transport

Arsham Fatahi, Birsen Donmez
Department of Mechanical and Industrial Engineering, University of Toronto
Toronto, Canada

Mahvareh Ahghari
Research and Development, Ornge
Toronto, Canada

Russell D. MacDonald
Division of Emergency Medicine, Department of Medicine, University of Toronto
Research and Development, Ornge
Toronto, Canada

Abstract

In emergency medical transport, "time to definite care" is very important. In the setting of a trauma patient, this time interval is referred to as "the golden hour" in recognition that transport to a designated trauma centre positively impacts patient outcome. The same is true for other time-sensitive conditions such as acute myocardial infarction, acute ischemic stroke, and sepsis. Emergency medical services and transport medicine agencies have several possible vehicle options for interfacility transfers. Use of a land vehicle, helicopter, or fixed wing aircraft will be dependent on patient condition, distance between sending and receiving hospitals, crew configuration and capabilities, and other factors such as weather and road conditions. This paper lays out the complex process of patient transfers and highlights the challenges in decision making. It then describes the behaviour of human operators in estimating time to definite care and provides recommendations to improve their estimation. Analysis of a historical dataset on interfacility transfers revealed that time to definite care estimates deviate significantly from observed times. Further, transfers which involve a helicopter appear to be highly underestimated. In fact, 44% of transfers involving a helicopter were underestimated by more than 60 minutes.

Keywords
Air ambulance, emergency medical services, decision support systems, emergency treatment

1. Introduction

Transport medicine is about delivering specialized care in a mobile environment. Patients can be picked up from a trauma scene or transferred from one facility to another due to a lack of resources in the former. The trauma scene responses are generally emergent requiring immediate response, whereas interfacility transfers can be emergent, urgent, or nonurgent. The care delivery model where centres of excellence concentrate expertise in a small number of centres requires patients with potentially time-sensitive or unstable conditions to be transferred from one facility to another in order to access care. The risks versus benefits of interfacility transfers have been reviewed [1], and there is evidence to support the regionalized care model.

Dispatch plays a significant role for medical transport systems: receiving and analyzing transport requests, and assigning proper medical personnel and equipment to these requests [2]. For example, transport medicine agencies may select from multiple vehicle types (i.e., fixed-wing aircraft, helicopter, and land), and a multi-speciality team (e.g., physicians, planners, operation managers) can select from the various vehicles depending on patient and transport factors.

A very important criterion in selecting transportation type is "time to definite care", defined as the time interval from when the call is received in the dispatch centre to the time the patient arrives at the receiving hospital. In the setting of a trauma patient, this time interval is referred to as “the golden hour” in recognition that transport to a designated trauma centre positively impacts patient outcome. The same is true for other time-sensitive conditions such as acute myocardial infarction [3, 4], acute ischemic stroke [5], and sepsis. Time-critical interfacility transfers are often faster when serviced with a helicopter compared to a land ambulance [6], but this is not universally the case. While transport by air may appear to be faster than land transportation, transport by air requires additional steps. These steps include aviation factors such as flight planning, aircraft rollout and startup, and air traffic control limitations. It also includes the potential for multiple patient transfers between vehicles if there is a land ambulance leg required between an airport and a hospital. Each of these factors may offset the faster travel times provided by aircraft. Thus, there is a clear need for evidence-based estimates for time to definite care for different transportation modes, which have to be compared for informed decision making. Given the multiple factors affecting time to definite care, accurate estimation of time to definite care can be a challenge for medical transport decisions makers.

The mode of transport is a time-critical decision itself, posing further challenge to decision-makers. Time-pressure reduces the quality of decision making when humans have to acquire and process information from multiple sources [7]. In terms of information acquisition, research has shown that humans tend to cope with time-pressed situations in different ways [8]. Humans may use acceleration, which is attending to all information sources at a faster rate, which in turn may cause errors due to temporary overload of working memory and/or processing capacity. Another strategy is filtration, i.e., gathering only the subjectively important information. Earlier studies on decision making and judgment under time pressure indicates increased importance given to negative evidence [9]. Overall, time pressure makes individuals switch to simpler decision-making strategies [10].

Although transport mode decisions have significant implications for patient care, supporting these decisions has not received much attention from the research community. For example, [11] has developed simple decision rules for trauma scene responses based on averages obtained from historical data. However, these decision rules did not incorporate various factors (e.g., weather, traffic) that can have a significant impact on transfer times. Thus, the ultimate goal of this research is to develop a more comprehensive tool to support air versus land decisions in emergent inter-facility patient transfers.

In this paper, we will present an analysis of the domain to lay out the complex process of patient transfers and highlight the challenges in decision making. We will then describe the behaviour of human operators in estimating time to definite care and provide preliminary recommendations to improve these estimates.

2. Characterizing the Domain

This section briefly describes the transport decisions made at the air and land critical care transport medicine service in the Province of Ontario, Canada. There is a focus on the decision making process for selecting transportation mode. The information presented here was obtained from domain experts and through field observations, interviews, and ride outs with paramedics.

2.1 Transport Medicine Services

As the sole provider for air and land critical care transport medicine services in Ontario, this service performed approximately 81,000 interfacility patient transfers and 7,000 on-scene responses in the five-year interval between 2007 and 2011. Interfacility patient transfers and on-scene responses were the most common medical transport services provided.

Interfacility transfers typically occur when the patients require a higher level of care that is not available at the sending hospital. Such transfers can be divided into emergent (time-sensitive, immediate threat to life – 42%), urgent (stable but risk for deterioration or threat to life or limb – 21%), or non-urgent (acute but non-urgent, where transfer can safely be delayed – 37%). For this type of transfers, the service utilizes one or more of the following vehicle types: helicopters, fixed-wing aircraft, and land vehicles.

The service also responds to on-scene calls. The goal of on-scene responses is to quickly transport trauma patients from an accident scene to a provincial trauma centre or patients suffering from time-sensitive or potentially life-threatening conditions to a centre of excellence where air transport decreases the time to definite care.

This research focuses on emergent and urgent interfacility transfers, where time-sensitive conditions require prompt transport mode decisions.

2.2 Transport Medicine Team

The transport medicine service consists of two active divisions: a communications centre (or dispatch) and the ambulance bases (air and/or ground). A team of medical and transport experts operate the communications centre where the transport requests are received (by phone, fax, or online), analyzed, and assigned to the proper medical personnel and equipment. The communications centre includes an operations manager (physically present), a transport medicine physician (can work remotely), travel planners (physically present), and medical analysts (physically present). A team of paramedics and pilots/drivers operate the ambulance bases. Usually two paramedics are assigned for each call. For air ambulances, they are accompanied by two pilots. Some paramedics have expertise in a wider variety of medical care (primary care < advanced care < critical care), which means that the paramedics are only semi-exchangeable. For example, a primary-care-level paramedic cannot go on a call requiring critical care, whereas the opposite is permitted.

2.3 Dispatch Process for Emergent/Urgent Interfacility Transfers

The dispatch process (Figure 1) begins when the communications centre receives a request from a sending facility. A medical analyst receives the request, acquires the relevant patient information, and forwards a request to a planner. The planner reviews the call details, and contacts the appropriate air or land critical care transfer vehicle to determine if it can service the call. If the vehicle chosen is a land vehicle, it departs on the response within minutes. If the vehicle is an aircraft, the pilot must check the weather and determine if the aircraft can do the flight safely. The pilots will inform the planner within ten minutes with regards to flight acceptance. If there are several vehicle options, the planner manually estimates the total time to definite care for different transportation modes and forwards these estimates to the transport medicine physician. The transport medicine physician considers these estimates, patient acuity, and resource availability in deciding which vehicle to allocate to the request.

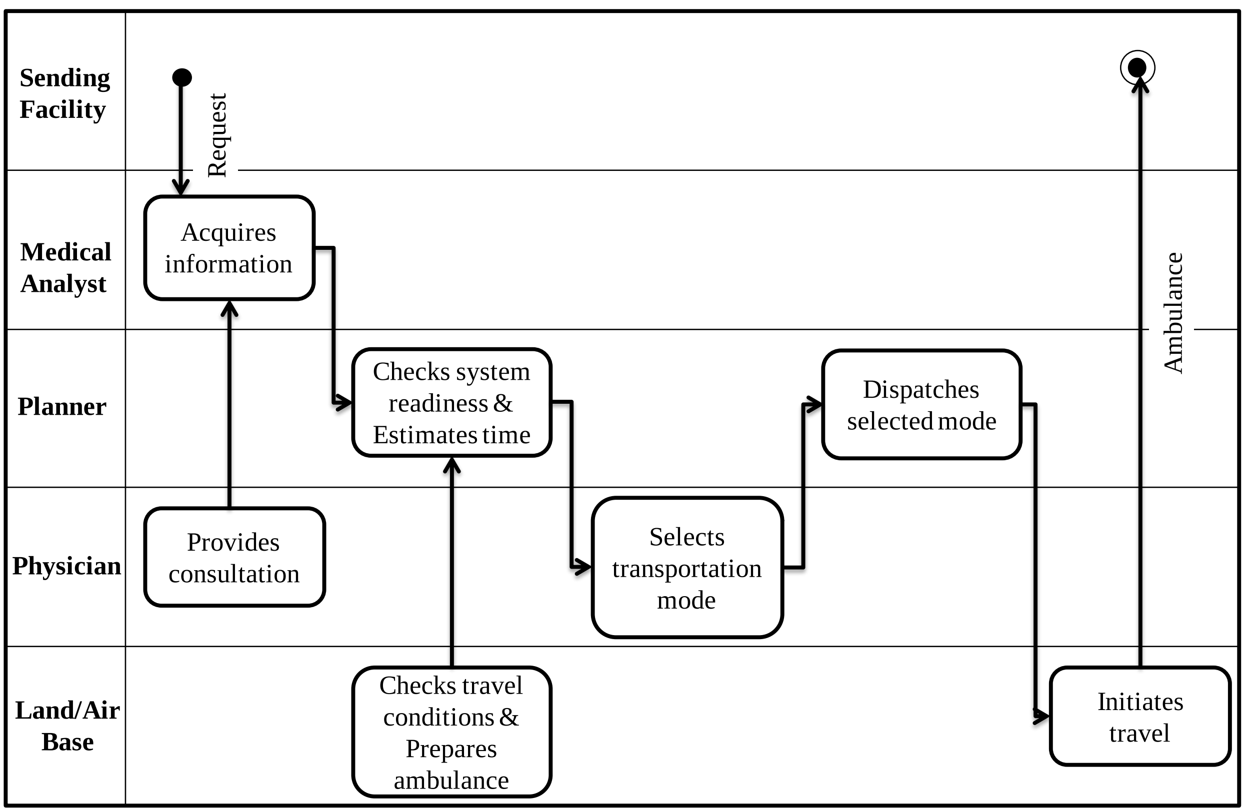

Figure1: Dispatch process for interfacility patient transfers involving different vehicle options

2.4 Field Operations during Emergent/Urgent Interfacility Transfers

Once the planner in the communications centre selects the mode of transport, the major steps performed in the field are as follows: 1) vehicle departs base, 2) vehicle arrives at pick-up site (for land vehicles: sending hospital; for aircrafts: can be an airport, a helipad at the sending hospital, or a helipad at a nearby location), 3) paramedics arrive at the patient site, 4) paramedics depart with the patient, 5) vehicle departs pick-up site, 6) vehicle arrives at the destination site (for land vehicles: receiving hospital; for air vehicles: can be an airport, a helipad at the receiving hospital, or a helipad at a nearby location), 7) transfer of care (or delivery of the patient). For air vehicles, if the receiving and/or sending hospitals do not have a helipad (for helicopter) or the landing site is an airport (for helicopter or fixed wing), there are additional local land ambulance transfers to deliver paramedics to the patient site and/or to deliver the patient to the vehicle or to the receiving hospital.

2.5 Time to Definite Care Estimation

Currently the planners estimate time to definite care through experience, subjective judgments, and consultations with pilots and physicians. The planners appear to adopt varying strategies to estimate time to definite care. For example, some planners use a web mapping service to estimate land vehicle travel times, whereas others may depend on their own knowledge of the region. In general, the planners break down the transfer process into components and estimate a time for each component. For example, in most cases, time spent in the sending facility is assigned 45 minutes regardless of transportation mode. Vehicle preparation on the other hand is longer for an air vehicle compared to a land vehicle and standard estimates are again used for this component. However, in bad weather conditions, when a helicopter has to fly under instrument flight rules (IFR) an additional 20-30 minutes is required to obtain IFR approvals from air traffic control.

3. Challenge in Decision Making

3.1 Historical Time to Definite Care Estimates

A stratified random sample of 182 interfacility transfers performed by the above-mentioned transport medicine service in 2010-11 were examined. Eighty seven (47.8%) cases utilized a helicopter, and 95 (52.2%) utilized only a land transfer vehicle.

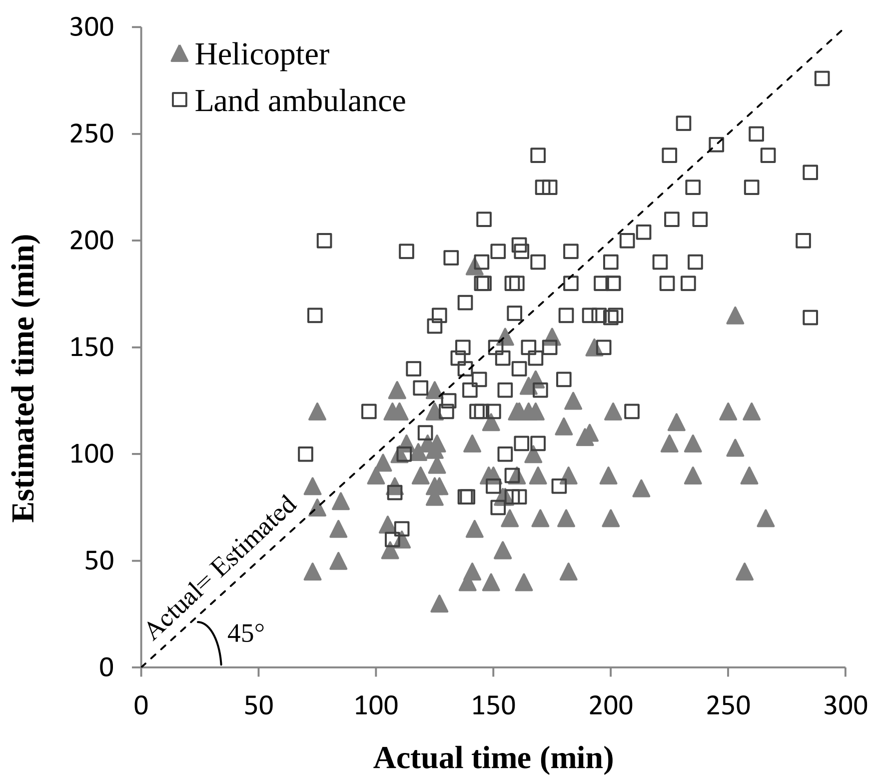

Figure 2: Time to definite care: actual times vs. planner estimates

Figure 2 shows the actual total time to definite care versus the times estimated by the planners. The 45-degree line represents the ideal situation where the estimated time equals to actual time. Points below this line are underestimates and points above the line are overestimates. Overall, 77% of cases were underestimated, and 23% were overestimated.

Figure 3 presents the histograms for the difference between the actual time to definite care and the planner estimate. Figures 2 and 3 illustrate that the planners appeared to underestimate time to definite care involving a helicopter, whereas land transfers had a more symmetric distribution of over- and under-estimation. In fact, 44% of air transfers were underestimated by more than 60 minutes.

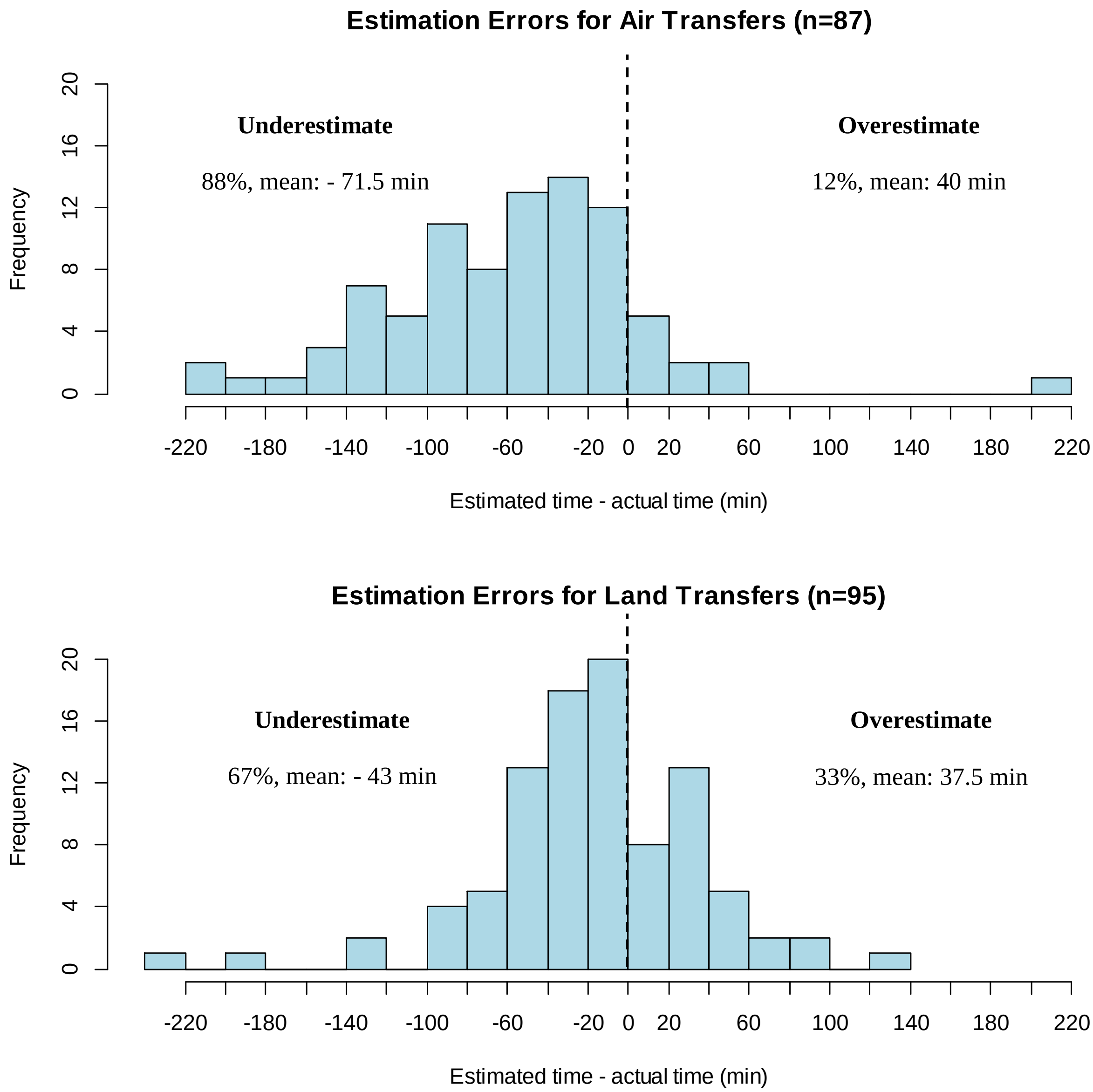

Figure 3: Histograms of estimation errors for air (top) and land (bottom) transfers

Further, the sample standard deviation of actual transfer times was larger than the sample standard deviation of planner estimates for both air and land transfers (Table 1). However, the variance of actual times was significantly greater than the variance of estimated times for air transfers (F(1, 172)=7.67, p=.006), whereas no significant differences were found for land transfers (F(1, 188)=0.41, p=.52). This suggests that planners' estimates do not accurately capture the variability in the air transfer process.

Table 1: Standard deviations of actual and estimated time to definite care values

	Standard deviation	
	Helicopter	**Land ambulance**
Actual time to definite care	51 min	61.5 min
Estimated time to definite care	39 min	50 min

3.2 Factors Potentially Introducing Variability to Actual Time to Definite Care

Table 2 shows a list of factors that potentially introduce variability to different components of interfacility transfers. These factors have been so far identified through field observations, personnel interviews, and ride outs with transfer vehicle crews. Our future research will apply statistical analysis on historical transfer data from 2007 to 2010 to verify the effects of these factors and identify if and how these effects differ given different transportation modes. For example, one would expect that traffic would have a significant impact on land transfers and no impact for air transfers that involve only an air vehicle.

Table 2: Key steps in patient transfer and factors that might introduce temporal variability

	Factors that might introduce temporal variability	
Call received	- Weather (might affect time to organize travel, e.g., weather checks)	- Patient acuity (might affect time to acquire patient information)
Depart base	- Weather (might slow down land vehicles and might lead to instrument flight for air vehicles) - Traffic	- Road types to the sending facility - Geographic location of sending facility (e.g., larger distances might require fuel stops)
Vehicle arrives at pick-up site	- Distance from the pick-up to the patient site (may require a local land ambulance for paramedics) - Traffic	- Local land ambulance resources (might induce delays) - Weather (might slow down land vehicles)
Paramedics arrive at patient site	- Patient acuity (some patients may need response from paramedics before being transported)	- Hospital efficiency in emergency patient transfer procedures
Paramedics depart with the patient	- Distance from the patient site to the pick-up site (may require a local land ambulance transfer which would require extra patient loads/unloads)	- Local land ambulance resources (might induce delays) - Traffic - Weather
Vehicle departs pick-up site	- Weather (might slow down land vehicles and might lead to instrument flight for air vehicles) - Road types to the receiving facility	- Geographic location of sending and receiving facilities (e.g., larger distances might require fuel stops) - Traffic
Vehicle arrives at destination site	- Distance from the destination site to the transfer of care point (may require a local land ambulance transfer) - Weather (might slow down land vehicles)	- Traffic - Local land ambulance resources (might induce delays) - Hospital efficiency in emergency patient transfer procedures
Transfer of care		
time		

4. Recommendations and Conclusion

There are various factors that can affect time to definite care in emergent/urgent interfacility patient transfers. Given the uncertainties associated with these factors and the time-critical nature of patient transfers, accurate estimation of time to definite care can be a challenge for medical transport decisions makers. In fact, analysis of historical data revealed that time to definite care estimates deviate significantly from observed times. Further, planners appear to highly underestimate transfers which involve a helicopter. The underestimations may result from the neglect of some steps taken during the transfer (e.g., multiple patient load/unloads if the helicopter cannot land at the patient site). Our future research will analyze the dataset presented in this paper to identify the factors that lead to significant under estimation in air transfers.

The planners' air transfer estimates had a smaller variance than the observed times, suggesting that the humans do not accurately capture the variability in the air transfer process. Planners may not be accounting for the changes in the transfer process such as additional fuel stops or extraneous factors such as weather. Given the time-critical and complex nature of patient transfers and various factors that can affect time to definite care, it is expected that humans would not make accurate estimations. Some estimation errors are inevitable due to unpredictable factors. Other estimation errors can be decreased by providing consistent guidelines and/or feedback to the planners. Feedback on the accuracy of past estimates as well as sample scenarios can provide valuable training. Another strategy is to provide more accurate time estimates to the planners, which can be identified through historical data analysis rather than utilizing humans' experience.

In the next step of this research, we will develop a decision support tool for emergent and urgent inter-facility patient transfers that will provide the decision makers with evidence-based time estimates for different transfer scenarios (e.g., land vehicle, winter, rush hour traffic). These estimates (potentially means and variances) will be derived from historical transfer data through statistical analysis. A usability study will be conducted to identify how best to present decision support to the decision makers.

Acknowledgements

The funding for this research effort was provided by Ornge. Thanks to Dr. Nathan Lau for his insightful comments on an earlier version of this manuscript.

References

1. Singh, J.M. and R.D. MacDonald, *Pro/con debate: Do the benefits of regionalized critical care delivery outweigh the risks of interfacility patient transport?* Critical Care, 2009. **13**(4): p. 219.
2. Forsman, D. *Introduction to Emergency Medical Care*. Educational Subcommittee – Paramedic Association of Manitoba August 2009 [cited 2012 Jan 16]; Available from: http://www.paramedicsofmanitoba.ca/storage/09-10ARML/Intro%20to%20EMS.pdf.
3. Manari, A., P. Ortolani, P. Guastaroba, G. Casella, L. Vignali, E. Varani, G. Piovaccari, V. Guiducci, G. Percoco, S. Tondi, F. Passerini, A. Santarelli, and A. Marzocchi, *Clinical impact of an inter-hospital transfer strategy in patients with ST-elevation myocardial infarction undergoing primary angioplasty: the Emilia-Romagna ST-segment elevation acute myocardial infarction network.* European Heart Journal, 2008. **29**(15): p. 1834-42.
4. De Luca, G., G. Biondi-Zoccai, and P. Marino, *Transferring patients with ST-segment elevation myocardial infarction for mechanical reperfusion: a meta-regression analysis of randomized trials.* Annals of Emergency Medicine, 2008. **52**(6): p. 665-76.
5. Wardlaw, J.M., G. Zoppo, T. Yamaguchi, and E. Berge, *Thrombolysis for acute ischaemic stroke.* Cochrane database of systematic reviews, 2003. **3**: p. CD000213.
6. Svenson, J.E., J.E. O'Connor, and M.B. Lindsay, *Is air transport faster?A comparison of air versus ground transport times for interfacility transfers in a regional referral system.* Air Medical Journal, 2006. **24**(5): p. 170-172.
7. Payne, J.W., J.R. Bettman, and E.J. Johnson, *The adaptive decision maker.* Cambridge: Cambridge University Press., 1993.
8. Miller, J.G., *Information input overload and psychopathology.* American Journal of Psychiatry, 1960. **116**(8): p. 695-704.

9. Wright, P., *The harassed decision maker: Time pressures, distractions, and the use of evidence.* Journal of Applied Psychology, 1974. **59**(5): p. 555-561.
10. Edland, A. and O. Svenson, *Judgment and decision making under time pressure: Studies and findings*, in *Time Pressure and Stress in Human Judgment and Decision Making*, O. Svenson and A.J. Maule, Editors. 1993, Plenum: New York.
11. Smith, J.S., B.J. Smith, S.E. Pletcher, G.E. Swope, and D. Kunst, *When is air medical service faster than ground transportation?* Air Medical Journal, 1993. **12**(8): p. 258-261.