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Emergency Department Delays Prior to Admission and In-hospital Health and Economic Outcomes

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ABSTRACT

BACKGROUND: The Emergency Department (ED) plays an important role in the health care safety net, but its ability to deliver care is compromised due to crowding. This is the major issue currently facing emergency care in Canada.

OBJECTIVE: The aim of this study is to determine whether the length of stay (LOS) in the ED affects subsequent hospital outcomes for patients admitted through the ED.

METHODS: This was a retrospective study using London Health Science Centre (LHSC) administrative data from April 2006 to April 2007. Three databases were linked to gather information on patient characteristics, health outcomes, and cost of care. There were 15,959 ED visits that led to subsequent admissions. 13,460 ED visits made by adult patients at either University Hospital or Victoria Hospital were included. The predictor variable was ED LOS. The primary outcomes of interest were hospital LOS in days and total hospital cost. Correlation coefficients were used to characterize the relationship of ED LOS with hospital LOS and costs. We fitted log normal models for each outcome: one with ED LOS expressed as a continuous variable; one using 8 hour ED LOS to define delayed care; and the last model with ED LOS expressed as an ordinal variable using quartiles. Multivariate statistical analyses were performed using SAS (version 9.1.3, SAS Institute, Inc.).

RESULTS: When ED LOS is defined as a binary variable using an 8 hour cutoff, 31% of patients (n=4,198) experienced delayed care. On average, delayed care in the ED is associated with a 7.2% increase in inpatient LOS and a 4.8% increase in inpatient cost. When ED LOS is modeled continuously, each additional hour of ED LOS adds 1.1% to inpatient LOS and 0.86% to inpatient cost. All calculations were adjusted for age, sex,

ED triage urgency, arrival by ambulance, admission to ICU or surgery, site of ED, and case mix group. We estimated that these delays resulted in an additional 3,038 inpatient days and $2,268,014 hospital cost.

CONCLUSION: Delays in the ED are associated with increased inpatient LOS and inpatient cost. As such, improving patient flow through the ED may reduce hospital costs.

Key Words: wait time, emergency hospital services, admission delay, length of stay, economic outcome

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LIST OF ABBREVIATIONS, SYMBOLS & NOMENCLATURE

CADTH	Canadian Agency for Drug and Technology in Health
CAEP	Canadian Association of Emergency Physicians
CCI	Charlson's Comorbidity Index
CI	Confidence Interval
CIHI	Canadian Institute for Health Information
CMG	Case Mix Group
CTAS	Canadian Triage Acuity Scale
DAD	Discharge Abstract Database
ED	Emergency Department
ICU	Intensive Care Unit
IQR	Interquartile Range
IP	Inpatient
LHSC	London Health Sciences Centre
LOS	Length of Stay
LWBS	Left Without Been Seen (by a physician)
MESH	Medical Subject Heading
MIS	Management Information System
NACRS	National Ambulatory Care Reporting System
OCCI	Ontario Case Costing Initiative
OCDM	Ontario Cost Distribution Methodology
OR	Operating Room
PH	Proportional Hazard

RVU	Relative Value Units
SAS	Statistical Analysis Software
SEAM	Simultaneous Equation Allocation Methodology
TTD	Time to Decision
VDL	Variable Direct Labour
VDO	Variable Direct Other
VDS	Variable Direct Supply

CHAPTER ONE

INTRODUCTION

The Emergency Department (ED) plays an important role in the health care safety net in both public and private healthcare systems as it provides assurance that a certain level of care is accessible for all, including marginalized and underserved people [3]. The efficiency of the ED is threatened by both growing demand and resource constraints. Studies of ED efficiency have shown that timeliness of care delivery is compromised during times of crowding, and this is the major issue currently facing emergency care in Canada [1]. Crowding is a broad description of impeded ED function where the number of patients waiting to be seen, undergoing assessment and treatment, or waiting for departure, exceeds the physical or staffing capacity of the ED [4]. Access block is a narrower definition of severe crowding which specifically implies an output bottleneck [1]. That is, access block refers to the situation where patients in the ED requiring inpatient care are unable to gain access to appropriate hospital beds within a reasonable time frame [2]. The breath of this issue has received much attention in both scientific literature and lay media. The effects of overcrowding include inadequate patient care, prolonged delays, pain and suffering, decreased staff and patient dissatisfaction, ambulance diversions, and negative effect on teaching and research [5]. ED delays can be so severe that care is denied as patients divert to other facilities by ambulance or leave without being seen (LWBS) [3]. Problems associated with ED crowding may cause a cascade of problems in the rest of the hospital [2]. For example, increased ED length of stay (LOS) has been shown to cause safety, and quality of care problems, and poor clinical outcomes [4, 6].

Progress has been made in defining the contributing factors of ED crowding. Researchers have moved from patient censuses to examine internal processes as well as systemic determinants of ED access block. Concepts based on operational management, such as the input-throughput-output framework, have been applied to the study of ED crowding [3-5]. With this framework, factors of ED crowding can be classified according to their sites of action: input, affecting the flow of patients into the department; throughput, affecting flow of patients once in the department; and output, affecting the flow of patients after the discharge/admit decision has been made [6]. This framework facilitates a systematic understanding of ED crowding in terms of its component causes, outcomes, interdependencies, as well as potential solutions [7]. Since its introduction in the ED literature in 2003, several reports have adopted the input-throughput-out framework [6, 8, 9].

This thesis has nine chapters. Chapter two focuses on a literature review. We provide a summary of key findings to give an overview research progression in this field, followed by a discussion of methodologies and gaps and finish up the chapter with promising directions for future research. Chapter three outlines the main hypotheses of the effect of ED admission delay on inpatient length of stay, cost and mortality. Chapter four provides background information on the data sources, information available in the dataset, study institution, case costing methodology, defines key variables and summarizes our research question with a conceptual framework. The fifth chapter presents descriptive statistics and univariate analysis. Chapter six details the structure and findings of the multivariate analysis for the outcome hospital length of stay. More specifically, we constructed multivariate models to fit the data using age, sex, location of

ED, ICU admission, arrival by ambulance, and case mix groups to adjust for patient level and hospital level characteristics. In a similar manner, chapter seven details the structure of the multivariate regression models for the outcome total inpatient cost. Chapter eight presents the cumulative effect of ED admission delay on inpatient outcomes on the level of the study population. The ninth chapter discusses implications of the results as well as possible limitations, and the concluding section provides an overview and conclusion.

CHAPTER 2 LITERATURE REVIEW

2.1 METHODS OVERVIEW

A search of published primary research literature on ED crowding using keyword and MeSH searches within the National Library of Science database. This search was completed over a one week period in July 2007. Of the 165 articles found in the database, only 29 were determined to be relevant. Health technology reports by The Canadian Agency for Drug and Technology in Health (CADTH) website are also included. Abstracts were reviewed to determine relevance. In addition, the online search was supplemented by appropriate references identified from the retrieved articles. In total, 53 original research articles were included in the final analysis. We will extend the utility of the input-throughput-output model by conceptualizing each study as a predictive regression equation. The independent variables are classified into the model by their site of effect. For example, a study which examines the effect of reducing acute hospital bed capacity on ED throughput would be considered an output study. This approach allows us to move forward from simply defining the problem of ED crowding to focus on the evidence base of causes and effects. Figure 2.1 illustrates the framework with the main stages input, throughput, and output existing within an overarching system, accompanied by key factors, measures, and interventions.

STAGES	INPUT	SYSTEM THROUGHPUT Initial assessment (triage) → physician evaluation → laboratory work-up, other investigations → disposition decision	OUTPUT
KEY FACTORS	-Increased severity of cases -Managed care problems -Seasonality -Ambulance transfers -Non-urgent visits -Non-medical visits	-Laboratory turnaround -Shortage of on-call specialty consultants -Shortage of staff -High ED bed occupancy -Discharge coordination -Observation units	-Access block -High hospital occupancy -Discharge difficulties (shortage of community beds) -Inpatient admissions from ED -Competition for acute beds with elective surgery -Shortage of ICU beds
MEASURES	-Total patient census -Patients by triage severity -Case-mix groups -Proportion without prior general practitioner visit -Ambulance transfers -Proportion of non-urgent visits -Proportion of non-medical visits	-LWBS rates -ED LOS of LWBS patients -ED bed occupancy rates -Overall ED LOS -Time intervals of treatment stages -ED LOS by triage severity -ED LOS by admit or discharge -Composite crowding scales in real time	-Access block time -Inpatient ward bed occupancy -Ambulance diversion rates -ED bed occupancy -Inpatient LOS -Elective surgery schedule -Inpatient mortality rate -Rate of adverse events
INTER-VENTIONS	-Education/awareness campaigns -Tele-health -After-hour clinics -Adult referral to next day physician visit -Mental health or social worker in the ED	-Improve central laboratory turnaround -Satellite laboratory in ED -Increase staffing -Increase ED bed capacity -Fast track of low severity patients -External consultation on patient flow	-Transitory acute care units -Increase ICU bed capacity -Increase hospital bed capacity -Increase ED bed capacity -Observation Units -Hospital wide patient flow and operations changes

Figure 2.1 The Input-Throughput-Out Model of ED Flow with Key Factors, Measures, and Interventions.

We categorized articles into corresponding stages of the input-throughput-output model based on the authors' research objectives and findings. A major proportion of the articles addressed ED throughput as their primary research objective. The wide variety of methodologies warranted further sub-grouping. An additional category called "Systems Approach" was also created when more than one stage was the model was addressed.

2.2 RESULTS OF LITERATURE REVIEW

2.2.1 Input Approach

We defined input factors as factors that determine patient flow into the ED. This can include patient volume, transfers from other hospitals, case mix, regional demographics, seasonality, as well as the availability of primary health care and supporting community health services [12, 13]. Table 2.1 provides a brief summary of the input studies and their key findings.

Input research focuses on the reasons for the high demand for ED services. A common perception is that ED crowding is due to frequent misuse by non-urgent and even non-medical cases [10]. Some have argued that the ED may be substituting for other branches of healthcare such as primary care and social services [2, 3, 10, 11]. Although this association may be intuitive and has been reported anecdotally, it is not well established in research literature. Part of the difficulty is that non-urgent patients are not easily definable and their demand patterns are not well understood. Afilalo et al. found that non-urgent patients do not have typical profiles but are a highly heterogeneous group [11]. Compared to more urgent patients, they had better health, were less likely to

arrive by ambulance, and cited multiple reasons for not seeking primary care beforehand including distrust or dissatisfaction with their primary care physician. Ruger et al. found that the majority of frequent users of the ED (i.e., those having two to 20 visits annually) were at least as sick as the one time users, and that this was mostly attributed to chronic conditions [2]. In a UK study, ED LOS was divided into wait time (from arrival to assessment) and treatment time (from clinician assessment to disposition). Over the 10 year study period, treatment time interval increased dramatically for major (admitted) patients compared to minor (discharged) patients, and this was attributed to higher volume of elderly patients and the number of patients requiring admission [12].

A second segment of ED input research focused on diverting non-urgent patients away from the ED. Crane and Spark examined the effectiveness of an Emergency Admission Avoidance Team specifically targeting frail elderly and vulnerable younger patients [13]. This intervention successfully prevented inpatient admissions for a few patients through discharge planning. This aims to keep patients in community care to prevent occupancy of already scarce acute care beds. Some researchers suggested that EDs are inefficient places to treat non-urgent patients and recommended diverting patients to offsite clinics [14]. The retrospective chart review conducted by Hauswald concluded that only a small percentage of ED patients would be more efficiently treated in an offsite clinic [15]. It was also emphasized that although the efficiency of existing EDs can be improved, their multifunctional capacity to handle a wide variety of cases makes them advantageous to offsite clinics. Washington et al. conducted a small randomized controlled trial assessing whether the deferral of non acute adult ED visitors

to next day care is a feasible alternative [16]. Their results showed that no adverse outcome was associated with deferred care. The authors concluded that the use of a clinically validated deferral protocol could redirect 12% of total ED visitors to potentially improve ED crowding without compromising clinical outcomes.

2.2.2 Throughput Approach

Throughput refers to the flow of patients from initial triage to disposition decision in the ED. Major steps include initial assessment (triage), physician evaluation, laboratory work-up, various other investigations, and disposition decision [14]. Because of the high number of studies in this category, we subdivided into three further categories: ED LOS, Clinical Efficiency, and Other Outcomes. These are summarized in Table 2.2

2.2.2.1 ED Length of Stay

O'Brien et al. conducted a time study to evaluate a new fast track and concluded the ED LOS for all discharged patients was improved although specialized diagnostic services were identified as an important limiting factor of ED throughput [17]. Jacoby et al. reported that the use of elective synchronized cardioversion in the ED for patients with atrial arrhythmias saved thousands of dollars per patient and significantly reduced ED LOS without compromising clinical outcomes [18]. Two studies, one conducted in Canada and one in Scotland, concluded that triage severity was associated with ED LOS [19, 20]. Moderate-severity patients experienced the longest wait at each stage of

throughput and the longest ED LOS in general. The two studies agreed that admit-status patients experience significant delays waiting for inpatients beds. A study of ED LOS for critically ill patients found that about a quarter of this patient population remained in the ED for more than 24 hours before admission to the ICU [21]. However, prolonged ED LOS was not significantly associated with inhospital mortality or longer lengths of hospital stay. Another study of intubated blunt trauma patients found that longer ED LOS is an independent risk factor of pneumonia, a complication associated with increased ICU stays and hospital stays [22].

2.2.2.2 Clinical Efficiency

Jagminas and Partidge showed that the incorrect diagnosis of chest pain in the ED can lead to inappropriate admission decisions and unnecessary consumption of resources [23]. Forberg et al. found that over-admission of chest pain patients due to diagnostic inaccuracy is a costly inefficiency, since the admission rate was 67% while only 31% of these patients had Acute Coronary Syndromes [24]. Lee-Lewandrowski et al. reported on the benefits of a point-of-care laboratory for common diagnostic tests in the ED [25]. With improved turnaround time of 51.5 minutes on average, shorter ED LOS of 41 minutes per patient, and high clinician satisfaction, their study provided further evidence of clinical accuracy and reliability of this alternative to centralized laboratory testing. Schull et al. used time series analysis to examine multiple factors contributing to ambulance diversion [26]. Of the three ED variables examined, the number of admitted patients boarded in the ED was the most significant predictor of hours of ambulance diversion. Pain management has been identified as an issue for quality of care

improvement in older adults. Hwang et al. concluded that delayed and inappropriate administration of analgesics were the consequences of ED crowding on the assessment and treatment of pain in older adults with hip fracture [27]. In the Netherlands, impaired efficiency in the assessment of chest pain patients due to ED crowding prompted a randomized control trial of specialized emergency nurses dedicated to the assessment of this patient group [28]. Compared to regular ED staff, the specialized nurses provided accurate assessment and reduced delay.

2.2.2.3 Outcomes

Delays in ED throughput have important consequences. These include lost opportunities to treat patients and the potential for poor clinical outcomes. Three sources of opportunity loss have been identified: ambulance diversion to an alternate facility, LWBS patients, and the boarding of admitted patients. Falvo et al. summarized the opportunity cost of throughput congestion in two reports. In the first report, missed service opportunities due to ambulance diversion and LWBS patients were determined by matching characteristics (mode of arrival, Emergency Severity Index-based acuity level, payer status, and disposition) with similar patients from historical data [29]. In the second report, Falvo et al. determined the total hours of lost treatment bed capacity based on a predetermined benchmark of 2 hours boarding time. The 3% opportunity loss in total ED treatment capacity was estimated at US$3.9 million in potential patient revenues [29, 30].

To examine the effect of ED crowding on quality of care, several studies examined care processes for time sensitive conditions when high acuity trauma patients are competing for ED resources. Fishman et al. found an association between concurrent trauma activation, impaired treatment and worse outcomes for patients with potential acute coronary syndrome. Longer wait for initial ECG and initial cardiac marker results as well as a small increase in adverse cardiovascular events within 30 days of presentation were reported [31]. In a similar study, chest pain patients presenting to the ED immediately after a major trauma victim experienced longer ED LOS and potentially impaired quality of care indicated by lower guideline adherence scores [32]. On the contrary, Chen et al did not find a statistically significant delay for CT diagnostics or compromised outcomes for suspected stroke patients while the ED was caring for trauma patients [33]. For patients who were admitted to hospital wards from the ED, Richardson found that hospital mortality rates were significantly higher for patients presenting during overcrowded ED conditions [34]. Relative risk of death at 10 days was 1.34 comparing patients presenting during ED crowding versus normal ED volume, which is equivalent to additional 13 deaths per year.

An analysis of LWBS patients by the Canadian Institute for Health Information showed that on average, these patients wait much longer prior to leaving than patients who stayed. Both patient and healthcare facility characteristics were related to an increased incidence of LWBS, including younger age, less urgent presentations, time of visit, visiting teaching and high-volume EDs. Although the LWBS patients account for a small percentage of total ED visitors, approximately 1,370 of these patients made a

second ED visit within 72 hours of the first [35]. A US study of LWBS patients found similar patient characteristics. Potentially alarming, however, is the finding that LWBS patients include a small number triaged as the most urgent as well as elderly patients, both groups may be at higher risks for adverse outcomes [36]. The analysis by Ding et al found that previous ED utilization is predictive of future ED utilizations such that patients who LWBS are more likely to have uncompleted treatments in the future [37].

2.2.3 Output Approach

The output stage encompasses the time from discharge or admission decision to the time at which the patient actually leaves the ED. Table 2.3 summarizes the relevant ED crowding research articles with an output focus.

Access block is commonly attributed to problematic output which in turn worsens ED overcrowding [12, 23, 38, 39]. Fatovich et al. found a linear correlation between total ED occupancy and the proportion of cubicles occupied by ED patients experiencing access block [40]. Kyriacou et al. found that ED LOS varied widely depending on inpatient bed availability for admit-status patients [41]. Litvak concluded that the ED's supporting hospital units and their associated operational difficulties are the cause of access block [42]. Specifically, competing demand for inpatient beds from elective surgery patients was noted as a major barrier. The US Accounting Office concluded that the single most important capacity variable is the availability of inpatient beds [43]. Similarly the Canadian Association of Emergency Physicians(CAEP) stated that shortage of beds in hospital wards and intensive care units is the principle cause [44]. Elaborating

on this conclusion, Foster et al. concluded that a 10% increase in hospital bed occupancy translated to an 18 minutes increase in ED wait time per admitted patient [38]. Richardson found that on average access block adds 0.8 days to inpatient LOS [45]. Sprivulis et al. hypothesized that hospital occupancy and access block interact with each other with modifying effects and developed the Overcrowding Hazard Scale [46]. The authors found that a high Overcrowding Hazard Scale score resulting from high hospital occupancy (>90%) and/or severe access block (>10% of ED census) was associated with higher mortality on days 2, 7, and 30 of hospital stay.

The rapid development of access block in South Australian hospitals from 1998-2002 prompted an analysis of the existing urgency and disposition group (UDG) model to capture ED activity and costs [47]. Using a new model (AWOOS) which incorporates increased LOS and economic factors, Stuart's comparison of the two models showed that the existing model severely underestimate the cost associated with access block.

Three studies reported on the effect of access block on the clinical outcomes of ICU patients. Chalfin et al. found that critically ill patients admitted to ICU from the ED experiencing access block have increased hospital LOS, as well as increased ICU and hospital mortality [48]. On the contrary, another study of ED admission delay to the ICU did not find negative outcomes in terms of hospital LOS and quality of life at six month comparing ED admissions to those admitted from other sources [49]. Nguyen et al. examined morbidity and mortality of ICU patients admitted through the ED using three established physiologic assessments. They concluded that initial care delivery in the ED

significantly impacts total in-hospital LOS as well as progression of organ failure and mortality for ICU patients [50].

Some hospitals expanded bed capacity hoping to improve output and to better accommodate demand fluctuations. Han et al. showed that ED bed expansion did not relieve access block and ED LOS actually increased post expansion [51]. The authors noted that the absence of any change in ambulance diversion and longer ED LOS post expansion were likely driven by competition for inpatient beds from elective surgery during the study period. McConnell et al. examined the impact of a 40% increase in ICU bed capacity on ED performance in terms of ambulance diversion and ED LOS. The ICU expansion helped a small portion of admitted ICU patients who were very ill but did not reduce access block for the ED as a whole [39]. Kelen et al. reported that a 14 bed acute care unit, managed by ED staff, in a segregated section of the hospital was successful in reducing access block. The unit acted as an intermediary bridge between the ED and hospital wards by promptly removing admitted patients from the ED, thereby freeing up ED beds for incoming patients [52].

2.2.4 Systems Approach

The systems approach to ED performance takes into account multiple stages of the input-throughput-output model and considers influences external to the ED itself. Table 2.4 summarizes the research in this area that used an observation design, either conducted at the narrow system level of the hospital or broad system level taking into

account more than one hospital. Table 2.5 summarizes system interventions implemented to improve ED crowding.

Three recent studies undertook systemic examinations of ED processes and outcomes within the hospital. All concluded that hospital level factors controlling patient output were important determinants of ED performance [3, 53, 54]. Rathlev et al. focused on daily mean length of stay as the key outcome of interest [54]. Time series analysis confirmed that hospital occupancy and inpatient admissions from the ED were strong predictors of ED crowding. In addition, the authors emphasized the impact of elective surgery on ED operations, adding as much as 35.2 hours for ED patients awaiting an inpatient bed every week. Researchers at CADTH examined measurements of ED crowding using the input-throughput-output model. Using the Delphi method, the CADTH report generated a list of 10 clinically important indicators of ED crowding, among which the percent of inpatient boarding the most important and staffing related measures the least important [55]. Krochmal et al. found that ED LOS of greater than one day is associated with longer inpatient LOS. The opportunity loss for this inefficiency was estimated at US$6.8 million over the three year study period [56]. Bayley et al. examined if ED crowding was due to a shortage of specific bed type focusing on the ED LOS of chest pain patients awaiting monitoring beds. They concluded that ED LOS for these patients was not associated with hospital LOS, or costs and revenues in the ED and the hospital. However, the researchers estimated US$168,300 annual opportunity cost in hospital revenue for prolonged (>3 hours) wait in the ED [57].

The ED is highly susceptible to external changes in the hospital and the wider health care system [58]. When hospital ICU bed capacity suddenly decreases or primary care services in the community are reduced, EDs are at risk of becoming overburdened with patients who have nowhere else to go [59]. This was demonstrated by one study of ambulance diversion hours and hospital closures in Los Angeles. Although only nine out of 80 hospitals were closed, average monthly ambulance diversion increased from 57 hours to 190 hours in just five years [60]. Schull et al. conducted a similar longitudinal study of ED crowding during system-wide reconstruction of Toronto hospitals from 1991 to 2001. Using ambulance diversion as the indicator of ED overcrowding, the study reported increases in both severe and moderate monthly incidences of ED overcrowding. A contributing factor is the existing high acute care bed occupancy, which suggested that the system was already operating at capacity [58]. In terms of hospital performance measures, Schull et al conducted an analysis of the effect of network crowding on time to thrombolysis in Acute Myocardial Infarction patients. It was concluded that both severe and moderate network crowding are associated with a longer time to thrombolytic delivery, which could have serious consequences given the time sensitive nature of this therapy [61]. Liew et al. examined the association between ED LOS and inpatient LOS in three hospitals in Melbourne Australia, using the state-defined average LOS for diagnosis related groups as benchmark. After adjusting for common confounding factors, excess inpatient LOS increased from 0.39 to 2.35 days as ED LOS lengthened from 8 hours to greater than 12 hours [62]. Anecdotal evidence of transfer difficulties due to the lack of inpatient beds, ambulance diversion and long ED delays were noted at Houston

hospitals. Begley et al examined mortality rates for trauma patients who were transferred during ambulance diversion versus non-diversion days in these hospitals and did not find a statistically significant difference in mortality rates [63].

Several researchers summarized system interventions addressing ED crowding. Spaite et al. reported on an effort by hospital administrators and clinicians in redesigning ED processing [64]. Five major areas were targeted with the aim of improving ED LOS for discharged patients, as they make up 80-85% of all ED visitors. ED LOS for admitted patients also decreased, as they also benefited from both faster laboratory turnaround and faster triage to ED bed placement. Although the individual contributions made by each process factor were not measured, Spaite et al. ranked the relative importance of changes implemented in order to improve generalizability to other EDs. Cardin et al. investigated quality of care related outcomes 10 years after system wide changes were made and concluded that the standards were maintained while ED LOS dramatically improved [65]. At a hospital in Maryland, systems improvements implemented include division of the ED into functional zones, matched staffing to daily volume patterns, improving radiology turnaround, and flagging patient charts to expedite disposition or discharge decisions. The benefits include record low ambulance diversions, prompt placement of patients in ED beds, and a shortened time interval to physician assessment [66]. Moloney et al. found that a 59 bed acute care unit decreased ED wait times and inpatient LOS [67]. Although cost per bed-day increased with this alternate arrangement, the saving of 4,039 bed-days yielded a total cost benefit of 1.7 million Euros in 2003. Timely discharge coordinated by a designated discharge manager and prioritization of patients who

required ancillary services such as radiology and endoscopy were key. In Australia, Melbourne Health dedicated $10 million to a clinician-led task force with the aim of improving ED access block while maintaining elective throughput. Over three months, 50 changes were implemented hospital wide, effectively reducing ambulance diversion and ED LOS [1].

2.2.5 Economic Cost of Waiting

Although there are scarce data demonstrating the economic consequence of waiting in emergent care, the cost of waiting has been captured in other health care areas, such as elective surgery, diagnostic tests, and organ transplantations. Generally, it was found that the longer the wait time, the higher the costs during the entire period of waiting [23]. In addition, health deterioration, either partly or completely irreversible, during the waiting period can have substantial impact on the cost-effectiveness of treatments [23, 24].

Analysis of health-related quality of life and costs in patients with osteoarthritis on wait list for total knee replacement in Spain concluded that costs due to functional limitations and loss of autonomy was ten times higher than the direct medical costs of waiting [68]. A study conducted in New Zealand on waiting for hip arthroplasty concluded that significant extra medical, personal and societal were incurred by patient who waited more than 6 months while their post-operative outcomes were also poorer due to deterioration while waiting [69]. Higher pre-surgery inpatient costs and increased patient discomfort were the costs of queuing for hip fracture surgery in Canada [70]. An

economic decision tree simulation modeling immediate verses wait list total hip arthroplasty concluded that substantial savings in resources and improved patient outcomes can be gained through immediate care [71].

Opportunity costs associated with screening tests were analyzed for cervical cancer screening in young women in Kansas, based on self reported wages. Time costs associated with waiting and travel were noted as important barriers to screening adherence [72]. A similar study on cervical cancer screening in the UK concluded that associated time and travel costs amounts to 26-33% of direct health service cost of providing the tests, and as such, the cost-effectiveness ratio of screening from the patients perspective may be lower [73].

Stenevi et al. estimated the cost to the community for hospital stay and home help care for 1458 cataract patients waiting for surgery as $868,031.25 [74]. Cataract patients have a significantly increased risk of injury and also bear a heavier burden of illness [75] Bishai and Lang used a willingness-to-pay model for cataract patients in Manitoba Canada, Barcelona Spain and Denmark. It was estimated that individuals are willing to pay between $24 and $107 for a one month reduction in wait time In addition, they estimated that the average lost consumer surplus/patient due to the cataract surgery queue was 4128, $160, and $243, respectively [76]. Sach et al conduced an economic evaluation of first cataract surgery compared to no surgery, and estimated savings from earlier cataract surgery as 4390 British Pounds per fall prevented [77]. A systematic review was conducted for cataract surgery wait times and the authors concluded that

despite the lack of a precise consensus benchmark wait time, timely access to surgery is advocated as visual deterioration occurs after 6 months of waiting [78].

High cost of organ transplantation has been well documented. However, the "hidden costs" of waiting, such as management of complications requiring hospitalization, outpatient visits, and post-transplant medications account for 41% of total organ transplant costs [79]. Lung transplant patients incur $670 US dollars per week while waiting [80].

Recently, the Centre for Spatial Economics analyzed four of the five priority areas identified by the 2003 First Ministers' Accord on Health Care Renewal: total joint replacement surgery, cataract surgery, coronary artery bypass graft (CABG) and MRI scans. This analysis defined wait time as the period from when a specialist requests a course of treatment to the time that treatment occurs and considered three cost types: patient costs, caregiver costs, and medical system costs. Comparing current wait time data to the wait time benchmarks developed by the Wait Time Alliance for Timely Access to Health Care, the total economic cost of waiting is estimated at $14.8 billion in Canada [81].

2.3 CRITICAL APPRAISAL OF PREVIOUS RESEARCH

Studies focusing on input factors have concluded that numerous challenges lie in achieving effective control of patient demand for ED services. As such, efforts to relieve

ED crowding targeting patient demand may not be the most effective. Granted that although patient demand is highly variable, seasonal patterns are predictable and some control can be gained through strategies such as fast track and preparatory staffing for expected high volume times [42]. In addition, disease prevention and improved chronic disease management in the community could both reduce ED usage, although this should be approached as a continuous commitment and not the immediate solution to ED crowding [3].

Excess wait in the ED could mean that patients do not receive care within the optimum time frame. For the very ill and critical patients, this is rarely an issue. However, Liu et al. and Yoon et al. both reported that moderately-urgent patients experienced the longest wait to initial physician assessment and longest ED LOS overall [19, 20]. One explanation of the long ED LOS for this group may be that patients presented vague clinical presentations which warranted further clinical investigation and extensive testing [19]. However, it is possible that during the long ED wait symptoms exacerbate. Consequently, these patients are admitted to the hospital sicker than they would have been had they received more timely care after arriving in the ED. This in turn may result in longer inpatient LOS at higher levels of care. Spruvilis et al. speculated that ED crowding could lead to compromised patient outcomes through "outlying", where inpatients are transferred to an incorrect ward or corridor locations inappropriate for their care. In these situations, although patients are cleared from the ED, they are still at risk of compromised outcomes [46]. Therefore, in addition to

decreased patient satisfaction and opportunity loss, higher inpatient costs and worse clinical outcomes may also add to the high price of access block.

Much of ED performance is dependent on hospital inpatient bed availability, laboratory turnaround and elective surgery schedules [26, 42, 82]. Hospital occupancy at levels above 90% is known to affect ED function [46]. However, the performance of the hospital may also depend on the ED. Since ED admissions account for a notable portion of admissions to inpatient wards, the initial quality of care provided by the ED may be a significant predictor of inpatient health outcomes [62]. This important association was recognized by Sprivulis et al., who concluded that outcomes of access block such as prolonged inpatient LOS and increased mortality may act as proxies for delay in time-critical care in the ED [46]. Trzeciak and Rivers warned that boarding critically ill patients in non-ICU settings could cause treatment delays at a pivotal point in the hospital course, potentially resulting in poor outcomes [83]. Several studies addressed this issue for ICU patients, but to date, few studies have attempted to draw the link between excess delay in the ED and clinical outcomes following admission to other hospital wards [84].

The financial burden of access block has been estimated in several studies. However, cost derivations differ widely. One study arrived at the daily cost of $800.00 per patient by dividing total hospital funding into the total number of patient-days during the 3-year study period [56]. This method, although simple, is not patient specific and omits information on where and how costs are incurred. Another study predicted average cost of bed days per patient using multivariate modeling taking into consideration general

versus specialist level of care and case mix [67]. Alternatively, in another study historical case-mix data was used to estimate admission probability and expected inpatient utilization [30]. In order for cost estimations to be informative and relevant to resource decision making, they must be as precise and accurate as possible. Differentiating cost types and refining granularity using patient-specific itemization can improve cost precision.

2.3.1 Limitations of Methods

The numerous ED outcome measures, institutional specific definitions, accounting costs and performance standards may limit the applicability of findings at one hospital to other hospital types across different health care systems. This is largely due to inconsistencies in definitions and measurements of performance. Similar inconsistencies were the focus of the CADTH study on measures of ED overcrowding. The authors concluded that the current bank of definitions, indicators, and measures of ED overcrowding was a "contradictory research base", and must be detangled [55]. Recently, four quantitative scales of ED crowding have been presented in literature: the National ED Overcrowding Scale(NEDOCS), the ED Work Index(EDWIN), the Real-time Emergency Analysis of Demand Indicators (READI), and the Emergency Department Crowding Scale (EDCS) [85-87]. The feasibility of these measures is currently being independently evaluated with the aim that using these scores adjusted for hospital factors would facilitate unbiased comparisons between different institutions and across health care systems. Though promising, their uptake and use is uncertain at this point.

The framework of the input-throughput-output model allows us to focus on the interdependent relationships between key causal factors and key outcome measures. However, a weakness of the throughput model is that it does not separate the relative importance of the various contributors to ED crowding. As a result it would be difficult for a policy maker to narrow down problematic areas and their contributing factors sufficiently in the model, in order to be able to decide where to invest scarce healthcare resources for maximum improvement in the ED.

2.3.2 Directions for Future Research

It should be emphasized that not all EDs have the same inefficiency problems and that the implementation of effective solutions will require careful analysis of where and how delays occur [12, 88]. Although systemic efforts to alleviate ED crowding problems are encouraged, considerations for input of valuable resources should be guided by institution specific outcomes data to ensure maximum benefit [9]. Systematic examinations of ED performance can employ a combination of interdisciplinary tools such as time series analysis, activity-based costing, as well as operations and economic analysis. For example, linear programming models have been used for labour cost minimization and stochastic simulation models have been used to draw the link between high hospital occupancy rates and bed shortages [82, 89].

Surprisingly, many delivery systems are implementing operational changes much faster than the research agenda on ED crowding is unfolding, driven by the perspective

that change must take place faster than at the pace of research. It needs to be emphasized that a large gap remains in our understanding of the adverse effects of ED crowding, as well as the nature and frequency of these effects [9]. Therefore, identifying the health and economic consequences of excessive delays in the ED, such as the impact on patient safety and quality of care, as well as the financial implications, must be measured to pave the way for implantation of strategies [42, 90]. Several studies conducted in the US have begun to fill in the void in this area of ED crowding research [29, 30, 56, 57]. However, the total costs of waiting in publicly funded EDs are not known. Furthermore, economic outcomes of access block in US studies were reported in terms of potential loss in patient revenue. For public health care systems, alternative cost estimation methodology maybe needed that would generate cost information in the perspective of loss opportunity to provide service and lessen disease burden. Most importantly, research findings in this area would be valuable in making an urgent case for strategies to relieve access block and improve overall institutional efficiency [26].

2.3.3 CONCLUSION

Recent ED crowding research has made much progress in identifying where delays occur in patient flow as well as important factors impeding efficient ED throughput. However, the clinical and economic outcomes of inefficient ED service are still not well known. Although outcome-focused studies have begun to emerge in the United States, there is a gap in this knowledge base for public healthcare systems. The

highly clinically relevant results from such research area could provide the necessary push for ED crowding to top the list of health policy agenda.

Table 2.1: A summary of recent ED crowding research addressing input issues.

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
Afilalo et al. (2004) [10]	Canada	Secondary analysis from prospective observational study data	1,783 patients October 1999 to May 2000	The non-urgent ED patient group was found to be highly heterogeneous. Although 42% were referred to ED care by another health professional or felt their condition warranted ED attention, only 4% were admitted. Distrust with primary care physician, lack of alternatives, and accessibility were other reasons cited for seeking ED care.
Crane and Sparks (1999) [13]	UK	Prospective descriptive study	1,254 patients Nine weeks	An admission avoidance team was implemented to enable safe discharge and to prevent re-attendance to the ED, the frail elderly or 'vulnerable' younger patients with physical, psychological or social needs. In nine weeks, 15 unnecessary admissions were prevented.
Hauswald (2004) [15]	USA	Retrospective cohort	650 patient representing 1 in 10 patients from hospital records within one month period	85% of the patient sample met the definition for efficient treatment in the ED compared to an offsite clinic. Since few patients presented non acute problems, diversion of patients to clinics would not improve efficiency.
Locker et al. (2005) [12]	UK	Retrospective analysis of routinely collected data	252,156 patients April 6 to July 5 of each year from 1993 to 2003	ED LOS increased for both major (admitted) and minor (discharged) patients over the 10 year study period. In 1993, median wait time for major patients and minor patients were 19 minutes and 24 respectively. In 2003, these numbers increased to 58 minutes and 40 minutes. Median treatment time (clinician assessment to ED exit) for major patients worsened dramatically, increasing from 55 minutes to 203 minutes.
Ruger et al. (2004) [1]	USA	Retrospective cross-sectional study	80,209 visits 12 months (2001)	Frequent users of the ED (two to 20 annual visits) have serious illnesses associated with chronic conditions and contributed to half of annual ED volume. High frequency users (>20 annual visits) accounted for only 2% of total visits. Targeting high frequency users would not improve ED crowding or save costs.
Washington et al. (2002) [16]	USA	Prospective randomized controlled trial	156 patients March 1997 to May 1998	Patients identified as suitable for deferred next day primary care by clinically detailed standardized screening criteria did not report clinically worse outcomes at 1 week follow up.

Table 2.2: A summary of recent ED crowding research addressing throughput issues. These are sub-categorized further by methodology.

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
ED LOS				
Carr et al. (2007) [22]	USA	Retrospective case-control study	509 patients 2003	ED LOS of the 33 trauma patients who developed pneumonia and trauma patients without this complication was 281 minutes versus 214 minutes, which is significantly longer (p<0.005). Each additional hour in the ED increased the risk of developing pneumonia by approximately 20%.
Jacoby et al (2005) [18]	USA	Retrospective cohort study	30 patients in each cohort Convenience sampling from past year data	Using synchronized cardioversion in the ED, mean hospital LOS was 22.8 hours compared to 55.6 hours in the control group who received usual care. This alternate technology is estimated to reduce median hospital charge from $4,271 to $1,598 per patient.
Liu et al. (2003) [20]	USA	Retrospective matched cohort	118 patients July 2001	ED flow pattern analysis comparing periods of normal patient volume and acute overcrowding showed that moderate-acuity patients wait longer in every interval, especially for physician assessment. The most significant delay occurs while awaiting placement in the ED bed.
O'Brien et al. (2006) [17]	USA	Prospective time series analysis	1,482 patients 12 weeks	30% of ED patients benefited from a newly implemented fast-track. The average LOS decreased by 18% for non-admission patients compared to previous year. ED LOS of admitted patients was not affected.
Tilluckdharry et al. [21]	USA	Retrospective cohort study	555 patients 2001 to 2002	Critically ill patients who stayed less or greater than 24 hours in the ED prior to ICU admission did not differ significantly with respect to mortality rate (27%) or hospital LOS (10 days), controlling for patient demographics and APACHE II scores.
Yoon et al. (2003) [19]	Canada	Retroactive time interval study	1,047 patients A continuous seven-day period in 1999	Moderate severity patients (triage level III) experienced the longest wait to initial physician assessment and longest total ED LOS. Triage level, investigations and consultations were determined as independent factors which influence ED LOS.
Clinical Efficiency				
Derksen et al. (2006) [28]	The Netherlands	Randomized controlled trial	512 patients June 2004 to March 2005	Comparison of specialized emergency nurses to the stand care provided by regular nursing staff for foot and ankle injury showed that diagnostic accuracy was comparable and median ED wait time was reduced.
Forberg et al. (2006) [24]	Sweden	Retrospective analysis	1,000 consecutive patients five months	Analysis of total hospital costs for admitted chest pain patients of the ED showed that inpatient admission days accounted for 73% of costs while diagnostics accounted for only 13%. The cost per life-year saved from admission versus a discharge-only policy was estimated at 38,000 EU. Cost-

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
				effective but efforts to decrease costs for suspected ACS patients should be aimed at improving ED diagnostics and reducing length of hospital stay.
Hwang et al. (2006) [27]	USA	Secondary analysis of prospective cohort data	158 patients August 1997 to July 1998	During ED crowding, mean delay to treatment of pain in older adults with hip fracture was 122 minutes. ED crowding at 120% of bed capacity was significantly associated with a lower likelihood of pain assessment as well as longer to times to pain assessment.
Jagminas and Partridge (2005) [23]	USA	Retrospective cohort study	440 and 973 in each of the two cohorts five months	In comparing ED observation unit (OU) and in-hospital OU, fewer chest pain patients were admitted as inpatient from the ED OU with lower associated costs. As such, the ED OU is concluded as more cost effective than the alternate of in-hospital OU for chest pain patients.
Lee-Lewandrowski et al. (2003) [25]	USA	Pre-post descriptive study	369 patients	A satellite laboratory for four routinely completed tests was implemented in the ED staffed by dedicated personnel. Laboratory turnaround for urinalysis, pregnancy testing, glucose, cardiac markers improved from 40 minutes, 78 minutes, 10 minutes, 110 minutes pre-implementation to 4 minutes, 5 minutes, 6 minutes, 17 minutes, respectively post-implementation . Overall ED LOS also decreased by 41 minutes on average.
Schull et al. (2003) [26]	Canada	Prospective time series analysis	37,999 patients January to December 1999	The number of admitted patients boarded in the ED was an important predictor of ambulance diversion. An average of 3.2 patients was boarded in the ED every 8 hour period and each was associated with 9 additional minutes of ambulance diversion.
Outcomes				
Baibergenova et al (2006) [35]	Canada	Retrospective analysis	4.3 million patients visits to 163 Ontario EDs April 2003 to March 2004	On average, LWBS patients wait 103 minutes before leaving while patients who stay wait 54 minutes before they were assessed. LWBS patients accounted for 0.1% to 12% of all annual visits, averaging at 3.1%. 5.5% of LWBS returned to an ED later and 21% of the second visit occurred within 72 hours of the first. Facility specific median ED LOS is most strongly correlated with percentage of LWBS patients (r=0.62).
Boutros et al. (2000) [32]	Canada	Retrospective cohort study	210 patients April 1 1995 to April 1 1997	Simultaneous management of trauma patient cases was associated with an average of 81 minute increase in ED LOS and lower adherence of guideline appropriate care for chest pain patients.
Chen et al. (2006) [33]	USA	Secondary analysis of prospectively collected data	171 patients January 1 2004 to November 30 2004	Competition for a single CT scanner from concurrent trauma evaluation in the ED did not delay the time to head CT, suggesting that specialty diagnostics may not be the most responsible bottleneck for ED efficiency.
Ding et al. (2006) [37]	USA	Retrospective matched cohort	2,952 patients July 12004 to December	17% of LWBS patients had a LWBS episode in the previous year, compared to only 5% in the patients who stayed. LWBS patients are younger, more

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
		study	31 2004	likely to be uninsured or Medicaid and also more likely to have an uncompleted visit in the previous year compared to patients who completed treatment in the ED.
Fishman et al. (2006) [31]	USA	Prospective cohort study	1,610 patients July 2003 to July 2004	Concurrent trauma activation was independently associated with increased risk of 30-day cardiovascular adverse complications, after adjustment for patient acuity, OR = 1.72.
Falvo et al. (2007) [29]	USA	Retrospective descriptive analysis	62,588 patient records July 1 2004 to June 30 2005	Over the 12 months period, 648 patients were diverted by ambulance and 1,332 patients LWBS. Since ambulance arrival patients are typically sicker and more likely to be admitted, the total lost revenue for this group was estimated at $3,150,079. The LWBS patients could have generated another $731,427. In total, the opportunity loss in revenue was $3,881,506.
Falvo et al. (2007) [30]	USA	Retrospective descriptive analysis	62,588 patient records July 1 2004 to June 30 2005	29% of admitted patients experienced access block longer than the set benchmark of 2 hours. Associated opportunity loss was 10,397 treatment hours, 3,175 patient encounters and forgone revenue was estimated at $3,960,264.
Richardson (2006) [34]	Australia	Retrospective stratified cohort analysis	66,608 patients 144 weeks from 2002 to 2004	Presentation to the ED during high occupancy is associated with higher mortality at 10 days (0.42% versus 0.31%, p=0.025) following admission to the hospital, stratified for shift, day, season, and year, and matched for age and sex.
Vieth and Rhodes (2006) [36]	USA	Prospective multi-method analyses	11,743 patients 13 weeks in 2003	Of the 11% of patients who LWBS during the study period, six were triaged as emergent, 87 triaged as unstable. 21 patients over the age of 80 LWBS even though they are 3.3 more likely to be triaged as higher severity/priority. Furthermore, patients LWBS 1.4 times Monday to Wednesday and 2.4 times more likely to LWBS between 6pm and 6am.

Table 2.3: A summary of recent ED crowding research addressing output issues.

Author (year)	**Country**	**Methods**	**Sample Size and Time Frame of Study**	**Key Findings**
Chalfin et al. (2007) [48]	USA	Retrospective cross-sectional analysis	50,322 patients 2000 to 2003	1,036 critically ill patients experienced access block delay (>6 hour ED LOS) in their transfer to the ICU from the ED. Compared to non-access blocked patients, inpatient hospital length of stay was longer (7 days versus 6 days), and both ICU mortality and hospital mortality were higher (10.7% versus 8.4%, and 17.4% versus 12.9%, respectively).
Fatovich et al. (2005) [40]	Australia	Retrospective descriptive analysis.	259,580 patients from three hospitals 2001 to 2002	Total ED occupancy was shown to have linear relationship with proportion of patients experiencing access block. The authors estimated that one access blocked patient impaired the assessment for 24 low acuity patients (20 minutes per assessment). A strong relationship was also demonstrated between access block with both ambulance diversion and long ED waits.
Han et al. (2007) [51]	USA	Pre-post descriptive design	40,978 patient records Five months pre-expansion (November 2004 to March 2005) and post-expansion (June 2005 to October 2005)	Total and admission hold LOS significantly increased even though ED occupancy levels fell 9%. Ambulance diversion rates were unaffected. ED expansion concluded as ineffective in reducing ambulance diversion or ED crowding.
Kelen et al. (2001) [52]	USA	Descriptive observational study with prospectively collected data.	1,589 patients Eight weeks	Acute care unit outside ED decreased number of LWBS patients by 40% and ambulance diversion by 30%. Inpatient admission was avoided for 12% of admit-status patients after further diagnosis, suggesting cost saving.
Kyriacou et al. (1999) [41]	USA	Prospective analysis of patient flow time studies	862 patients Seven one-week sample periods from September 1993 to July 1998	Median time interval of disposition decision to ED discharge for admitted patients ranged from 95 minutes to 220 minutes at the worst access block. Availability of inpatient beds was a major factor. Administrative interventions were beneficial, though their independent effects could not be evaluated.
McConnell et al. (2005) [39]	USA	Retrospective review of routine ED data.	7,519 admitted patients and 43,125 discharged patients August 1 to August 6 2003	Increasing ICU capacity by 20 beds decreased daily ambulance diversion hours from 3.8 hours to 1.4 hours (66% decrease) but minimally benefited other admitted patients and discharged patients, who were the majority of ED visitors.
Richardson (2002) [45]	Australia	Retrospective cohort study.	11,906 patient records 12 months	7.7% of patients experienced access block, stayed an additional 6.5 hours in the ED and 0.8 days longer as inpatients. Annually, this accumulated to over 700 bed-days. Access block was also found to

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
				associate strongly with arrival time outside of office hours.
Saukkonen et al. (2006) [49]	Finland	Prospective cohort study	1,675 patients July 2002 to June 2004	64% of ICU patients were admitted from the ED with a mean ED LOS of 6.2 hours. Comparison of outcomes with non-ED admitted patients at 6months did not show higher mortality (20% versus 33%) or worse quality of life.
Sprivulis et al. (2006) [46]	Australia	Retrospective analysis; Overcrowding Hazard Scale	62,495 patients from three urban hospitals July 2000 to June 2003	Analysis using the Overcrowding Hazard Scale showed 30% increase in relative mortality of admitted patients due to hospital and ED overcrowding by Day 2 and Day 7, adjusted for seasonality and admission selection.
Stuart (2004) [47]	Australia	Retroactive case costing comparison between AWOOS and urgency and disposition group (UDG) models	172,000 patients per year 1998 to 2002	Mean length of stay of admitted patients from the ED increased 93% within study period. A wide variation was observed in the proportions of patients experiencing access block, ranging from 15% to 63%. The AWOOS model was strongly correlated to the degree of access block as demonstrated by high r values (0.84-0.99) while the UDG did not consistently capture the correlations.

Table 2.4: Summary of observational findings examining ED performance from a systemic perspective

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
Asaro and Boxerman (2007) [3]	USA	Retrospective descriptive study	166,854 patient records January 2004 to March 2006	Of all input and output measures considered, daily inpatient bed utilization and boarded ED admits were statistically significant predictor of ED LOS.
Bayley et al. (2005) [57]	USA	Prospective cohort study	817 patients two months	Prolonged ED LOS was not associated with worse clinical outcomes or increased costs for chest pain patients. However, potential opportunity cost of prolonged (>3 hours) wait in ED was estimated at $168,300 per year or $204 per patient.
Begley et al. (2004) [63]	USA	Retrospective analysis	18,888 trauma patients July 1999 to October 2001	For the most severely ill patients admitted through transfer on diversion versus non-diversion days, the difference in mortality rate was 25% versus 14%, although not statistically significant due to small sample size. This suggests a harmful delay in treatment for trauma patients may be the consequence of access blocked hospitals forced to go on ambulance diversion.
Downey and Zun (2007) [53]	USA	Retrospective study	3,300 to 4,440 patients per month Data collected monthly for four years	Of the 15 statistically significant factors affecting ED throughput, the author noted the number of patients requiring inpatient admission and the ability of the hospital's auxiliary departments as key determinants.
Krochmal et al. (1994) [56]	USA	Retrospective analysis of routinely collected data	26,020 admissions Three years	Those who spend >1 day in ED has at least 10% increase in total hospital LOS. Associated costs of this inefficiency are estimated to be 8,455 excess bed days, which at $800 per patient day, cumulated to US$6,788,144 over the study period.
Liew et al. (2003) [62]	Australia	Retrospective descriptive analysis.	17,954 admissions in three hospitals July 1 2000 to June 30 2001	Prolonged ED LOS was associated with excess inpatient LOS in a "dose-dependent" relationship. Odds ratios show that compared to patients whose ED LOS was shorter than 8 hours, those who stay 8-12 hours are 20% more likely to have longer inpatient LOS, and as ED LOS increase to above 12 hours, this probability increases to 50%.
Ospina et al. (2006) [55]	Canada	Delphi method	38 Canadian experts in ED-related issues	Experts concluded that percent of boarded inpatients is the most important measure. The next top five key measurements, in order of importance, were: total ED patients, ED LOS, percentage of time ED is at or above capacity, and overall bed occupancy.
Rathlev et al. (2007) [54]	USA	Retrospective time series analysis	93,274 patient visits April 15 2002 to December 31 2003	Three output factors independently associate with daily mean ED LOS: elective surgical admissions, ED admissions and hospital occupancy. Autocorrelation was also found between the daily mean length of stay of the

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
				current day and the previous day
Schull et al. (2001) [58]	Canada	Retrospective time series analysis	47,098 visits per month 120 months	Decreasing acute care bed capacity in Toronto hospital system restructuring over a 10 year period correlated with an increase of moderate ED crowding and severe levels of overcrowding in the ED. Moderate ED overcrowding increased from 0.5% to 3% while severe overcrowding increased from 9% to 14% per month.
Scull et al. (2004) [61]	Canada	Retrospective data analysis	3,452 patients 1998 to 2000	Network crowding is associated with poorer hospital performance measures such as time-to-thrombolysis delays for patients with suspected acute myocardial infarctions. In adjusted analyses, high network crowding was associated with a 40% increase in the odds of a major door-to-needle time delay and a 5.8-minute increase in the median door-to-needle time compared with conditions of no network crowding. Moderate network crowding was associated with an increase of 3.0 minutes in median door-to-needle time compared with no crowding.
Sun et al. (2006) [60]	USA	Retrospective multiple interrupted time series with control group	350,000 average ambulance transports in 80 hospitals in Los Angeles 1998 to 2004	Nine hospital closures during the study period resulted in a network crowding effect, increasing average monthly ambulance diversion hours from 57 hours to 190 hours. Temporal effect of hospital closure on the closest ED closest in terms of increased ambulance diversion lasted about 4 months.

Table 2.5: Summary of interventions to reduce ED crowding implemented at the systems level

Author (year)	Country	Methods	Sample Size and Time Frame of Study	Key Findings
Cameron et al. (2002) [1]	Australia	Observational study (prospective)	Average 3,000 patients per month January 1999 to October 2001	Clinician-led taskforce dramatically improved access block in three months to achieve 40% decrease in 12-hour waits in the ED and brought ambulance diversion to a minimum.
Cardin et al. (2003) [65]	Canada	Retrospective comparison analysis of outcomes.	1,935 ED patients and 2,766 hospital ward patients 28 sample days from the year before and after intervention	After hospital-wide implementation of structure and process of care measures, ED LOS improved from 21 hours to 9 hours and ED stretcher occupancy decreased from by 35%. Evaluation of this intervention did not reveal decreased quality of care in terms of return visits.
Moloney et al. (2005) [67]	Ireland	Retrospective analysis of routinely collected data	10,566 episodes among 7,857 patients January 1 2002 to December 31 2003	The implementation of an efficiency unit lowered inpatient LOS for general admissions from six to five days. Number of patients waiting for ED went down by 30%. Total cost benefit estimated at €1,714,152.
Spaite et al. (2002) [64]	USA	Retrospective descriptive study	January 1998 to December 1998	Hospital wide efforts at reducing ED crowding led to the redesign of five key processes, thereby decreasing wait time intervals for discharged patients by 31% and admitted patients by 27%. Patient satisfaction improved and ambulance diversion decreased by 98%.
Twanmoh and Cunningham (2006) [66]	USA	Retrospective descriptive study	32,577 patient visits December 2003 to August 2004	Over 24 process flow barriers were recognized in ED input, throughput and output. System wide streaming maximized the use of previously "untapped capacity". Improvements resulted in record low ambulance diversions, prompt placement of patients in ED beds and assessment as well significant reduction in ED overcrowding

CHAPTER THREE

OBJECTIVES & HYPOTHESES

3.1 Start/End period

Our data was based on the 2006 fiscal year and captured ED visits made between April 1st 2006 and March 30th 2007. The definition of "first visit" is based on the start date of the study period and may not denote the first visit to an ED or disease episode in their life time.

3.2 Time Line

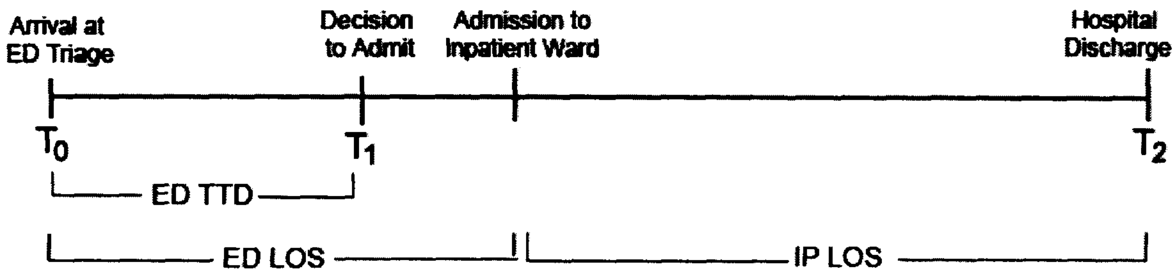

Figure 3.1: Timeline of Treatment Episodes.

There are three important time points defining an ED encounter and subsequent IP admission. Figure 3.1 shows a representation of the timeline. The first time point, arrival at the ED is recorded at triage and denoted as T_0. The second time point, decision to admit to an IP service, is denoted as T_1. The time between T_0 and T_1 defines "ED Time to Decision" (ED TTD). The remaining segment of ED LOS was not accurately captured in our data, shown as "Decision to admit" and "Admit to Ward" in Figure 3.1. This is because when a patient is placed on a wait list for a ward bed, IP admission time is

recorded and the data system simultaneously discharged the patient from the ED, although the patient may wait much longer for the actual transfer to take place. The third time point is end of IP treatment, recorded as IP discharge time.

3.3 Aims and Hypothesis

The aim of this study is to determine whether the ED length of stay (LOS) is associated with subsequent inpatient LOS and costs in the hospital for patients admitted from the ED.

There are three hypotheses in this study:

H1: Prolonged stay in the ED prior to IP admission is associated with longer inpatient length of stay.

H2: Prolonged stay in the ED prior to IP admission is associated with higher inpatient costs.

H3: Prolonged stay in the ED prior to IP admission is associated with worse patient outcomes in terms of in hospital mortality.

CHAPTER FOUR:

4.1 DESCRIPTION OF STUDY SETTING

4.1.1 Study Institution

The London Health Sciences Centre (LHSC) is one of Canada's largest acute-care teaching hospitals. It encompasses three sites, South Street Hospital, University Hospital and Victoria Hospital, as well as two family medical centres. In the year of the study LHSC recorded 139,612 Emergency visits, 795,697 outpatient visits and 39,126 inpatient admissions [40].

4.2 Case Costing Methodology

Patient costs are derived via the Ontario Case Costing Initiative (OCCI) methodology [43]. This methodology aims to capture the context within which a particular hospital produces patient services and allows comparability between hospitals.

The case costing methodology is based on CIHI's Management Information System (MIS) standards, and draws from it two unique features: Functional Centre Framework and the Chart of Accounts. The OCCI first characterizes the mixture of services provided by various departments of the hospital, called functional centres, to derive direct and indirect costs. Then it translates the costs to per patient values based on their individual consumption of these services [43].

Cost derivation is as follows: Hospital services are first divided into Functional Centres according to the type of service provided. The functional centre framework incorporates Markov modeling and a system of linear equations to define hospital departments as transient or absorbing centres of care. In most cases, Functional Centre

division is the same as existing department definitions. The total cost incurred by each centre is determined as a sum of two components: direct costs from its own services, as tracked by Charter of Accounts, as well as indirect costs, derived by Simultaneous Equation Allocation Methodology (SEAM). Next, Relative Value Units (RVUs) are used to determine appropriate proportions of costs from each functional centre distributed to each patient [91]. The case costing methodology provides itemized patient specific costs grouped into a number of broad cost types, a detailed table is provided in the Appendix.

4.3 Case Costing Data Quality

Cost data completeness is periodically assessed with case cost figures provided by the Ontario Cost Distribution Methodology (OCDM). Analysis of LHSC case cost data using this methodology has shown the total inpatient case costs, at 102% of the OCDM value, due to the greater precision in LHSC costing methodology. As such, cost data from LHSC is the most complete of any Ontario hospital [92].

In addition, it is possible that in some hospitals a portion of cost records are "orphans" that cannot be linked to a valid patient encounter and may result in underestimation of total hospital costs. At LHSC, "orphan" cost records constitute less than 0.1% of the total nine million annual cost-item records. Audits of these cost-items are routinely conducted by LHSC to ensure data integrity [93].

4.4 The Dataset

This is a retrospective study at LHSC using three sources of administrative data: National Ambulatory Care Reporting System (NACRS), Discharge Abstract Database (DAD) and the T2 Case Costing system, all collected by the Canadian Institute for Health Information (CIHI) and available from the LHSC database. The NACRS database

captures all Emergency Department visits, while the DAD stores information on inhospital stays, and the T2 Case Costing system tracks patient specific costs incurred for services completed. Information for each patient's ED episode and subsequent inpatient stay was first combined from NACRS and DAD using a personal identification number. The identified encounter number was then linked with the T2 Case Costing database to arrive at the final dataset.

4.5 Variables and Measures

In this section, we describe key dependent variables and independent variables, as well as covariates in our study.

Outcome Variables:

1. ***Inpatient LOS***

   In the analyses, inpatient LOS was calculated as the number of days of hospital stay, and modeled as a continuous variable. In order to ensure data consistency and accuracy this variable was reconciled with a LOS calculated by subtracting inpatient admission date and time from inpatient discharge date and time. .

2. ***Cost of Inpatient Stay***

   Actual costs were extracted from the LHSC Case Costing Initiative data. All costs are in 2006 Canadian dollars. The total cost of each inpatient stay is the sum of variable and fixed costs as well as direct and indirect costs.

Three types of variable direct costs were analyzed:

1. Variable Direct Labour (VDL): This captured higher levels of care provided by inpatient department staff.

2. Variable Direct Other (VDO): This encompassed referred out expenses, such as consultations by specialists from other hospital departments and care provided by rehabilitation services.
3. Variable Direct Supplies (VDS): This captured extra diagnostic and laboratory tests, interventions, and pharmacological agents consumed by patients.

Independent Variable:

ED TTD

ED TTD is ED LOS until a physician's decision to admit the patient to IP services, shown as T_0 to T_1 in Figure 4.1. In our data, this was calculated as the difference between the recorded ED arrival time and ED discharge time. The patient classification tool allows this time interval to be captured in minutes. In the analysis, we defined ED TTD as ED LOS > 8 hrs as an admission delay.

Covariates:

ED LOS is affected by individual disease characteristics as well as system-level factors. In addition to the common patient characteristics age and sex, we included ambulance use and ICU admission as surrogate markers for degree of patient acuity and severity of disease. Additional patient information is provided by variable "Admission Source". It captured whether the ED visit was a first visit, and whether or not previous medical advice had been sought. The categories "planned return" and "unplanned return" indicate follow up visits to either an inpatient or outpatient clinic, or to any other areas of

the hospital for a follow up on findings from the ED visit. Our data includes patient visits from two LHSC hospitals: University Hospital and Victoria Hospital. These two sites differ with regard to some services and medical specialties, as such the site of an ED visit was included as a covariate in this model to adjust for hospital level characteristics that may affect IP outcomes. Most importantly, Case Mix Groups(CMG) were included to provide further information on severity of illness and case complexity.

4.6 Conceptual Model of the Effect of ED Admission Delay

We constructed a conceptual framework to delineate the relationship between the dependent variables (IP outcomes) and independent variables (ED Admission Delay and Covariates), shown in Figure 4.2. To reiterate our hypotheses from Chapter three, we proposed that ED admission delay results in longer IP LOS, higher IP cost and higher IP mortality. In Figure 4.2, our main association of interest is shown by a bold arrow. The dashed box in the arrow shows the mediating pathway for the proposed association: patients deteriorate in health during the wait to be admitted and thus require more resource intensive care during their IP stay, thereby increasing the cost of care; recovery time after interventions also lengthens, leading to longer overall IP LOS. In addition, we included both patient level and hospital level factors in Figure 4.2. In the top half of the diagram, light grey boxes are used for patient level covariates. These include disease condition (CMG), ICU admission, new or repeat visit, sex, and age. In the bottom half of the diagram, dark grey boxes have been used for location of ED (University or Victoria Hospital), as a proxy for hospital level characteristics that may affect IP outcomes.

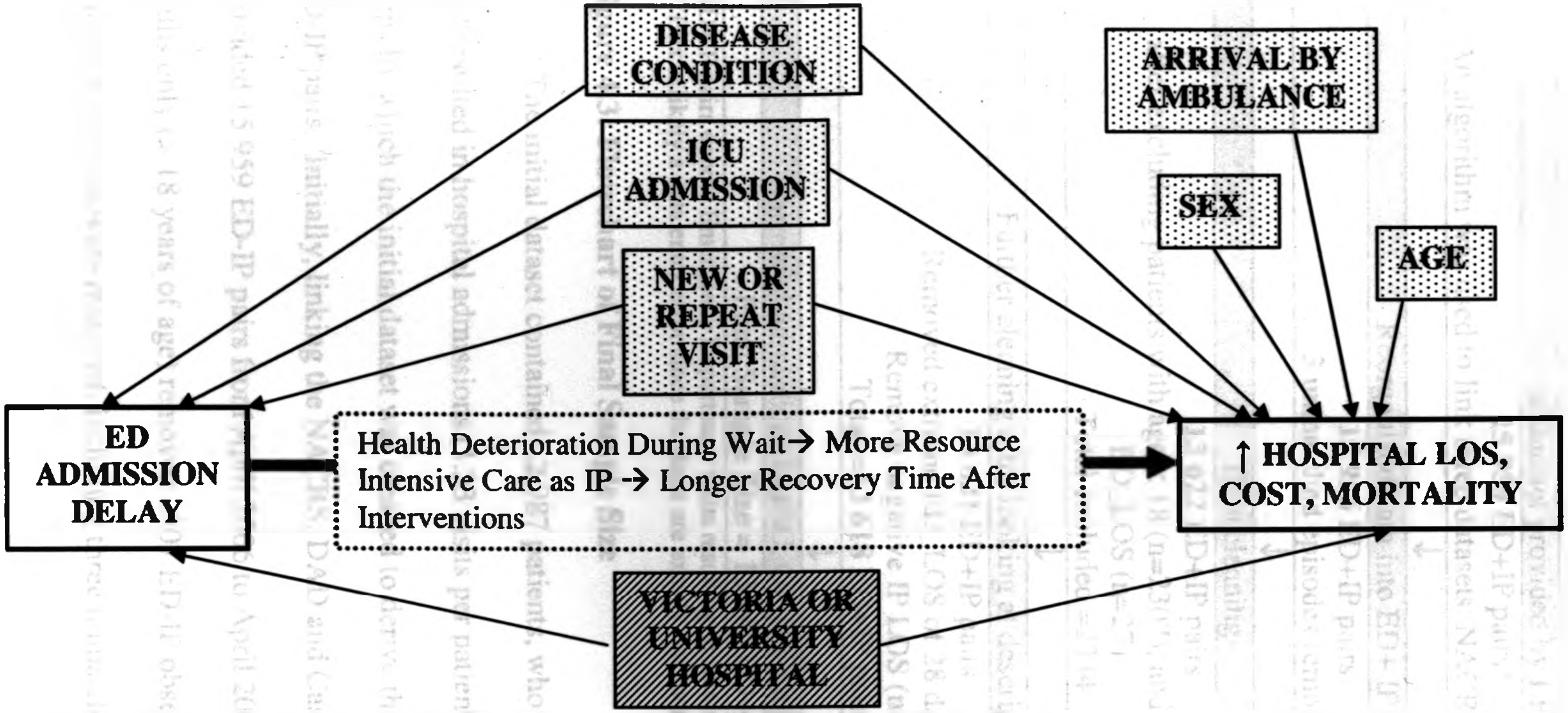

Figure 4.2 Conceptual Framework of the Association between Independent Variable (ED Admission Delay) and Dependent Variable (Hospital LOS, cost and mortality) and Covariates

4.7 Sample Size

Flowchart of Final Sample Size Derivation:

Initial dataset provided by LHSC

15 959 ED+IP pairs*
An algorithm was used to link three datasets: NACRS, DAD, and Case Costing

↓

Reorganized data into ED+ IP pairs

15 956 ED+IP pairs
3 unmatched episodes removed

↓

Data cleaning

13 622 ED+IP pairs
after excluding patients with age < 18 (n=2307), and observations with negative ED_LOS (n=27)
Total excluded =2334

↓

Further cleaning after looking at descriptive statistics

13 621 ED+IP pairs
Removed extreme ED_LOS of 28 days** (n=1)
Remove negative IP LOS (n=2)
Total =**13 618** ED+IP pairs

↓

Narrowed admissions to ICU, OR and inpatient wards only

Final Sample Size = **13 460** ED+IP pairs

*ED+IP pairs denote Emergency Department visits resulting in admissions to inpatient wards.
** This is likely a data entry error since the dates are exactly one month apart.

Figure 4.3: Flowchart of Final Sample Size

The initial dataset contained 12,987 patients, who made 15,959 visits to the ED that resulted in hospital admissions (1.23 visits per patient). Figure 4.3 illustrates the steps by which the initial dataset was cleaned to derive the final sample size of 13460 ED-IP pairs. Initially, linking the NACRS, DAD and Case Costing datasets for LHSC provided 15 959 ED-IP pairs from April 2006 to April 2007. Restricting this dataset to adults only (> 18 years of age) removed 2307 ED-IP observations. Errors caused by the linking algorithm were removed, including three unmatched ED episodes and 27 episodes

with negative time values. Two extreme observations that were likely due to data entry errors were also eliminated: one had ED LOS of 28 days and the other had a negative hospital LOS. In terms of discharge disposition from the ED, the DAD codes for more than ten categories. These are detailed in Appendix C. Patients who left without being seen by a physician (LWBS) or who were seen but left without treatment, or who left against medical advice) were excluded (n=28). While many destinations are possible as IP admission destinations, only patients admitted to an Operating Room (OR), ICU or inpatient ward, were included in the analysis. In addition, patients in the following ambiguous categories were removed: “discharged to ED”, “discharged to clinic”, “signed out”, “treatment within facility”, “transfer to clinic” “transfer to long term care facility”, “transfer to ED”. This last step removed another 111 observations and the final sample size of 13 460 ED-IP episode pairs were patients who were admitted to the ICU, an OR, or other IP wards.

4.8 Data Analysis

Statistical analyses were conducted using SAS version 9.1.3 and SAS Enterprise Guide 4.0 (SAS Institute, Cary, NC). The data was first explored to provide descriptive profiles of admitted patients from the ED. We then examined the relationships between outcome variables and several variables that were proxies for potential risk factors. Independence of predictors was verified using multicollinearlity tests such as variance inflation factor and tolerance. These variables are then included in the final regression models.

CHAPTER FIVE: DESCRIPTIVE STATISTICS AND UNIVARIATE ANALYSIS

5.1 Description of Patient Population

There were 10,847 patients, who made 13,460 visits to the ED that resulted in hospital admissions (1.24 visits per patient). Table 5.1 summarizes the demographic and clinical characteristics of study patients. Males accounted for 50% of the study population and the mean age was 62.6 years. 31% of patients had LOS of more than 8 hours in the ED. The overall mean ED TTD was 419 minutes (approximately 7 hours) and the maximum ED TTD was 3254 minutes or just over 54 hours.

The variable "ED triage urgency" is based on the five level CTAS scale. The most common ED triage category was CTAS level 3, semi-urgent (n=7613, 57%) and very few CTAS level five or non-urgent patients were admitted to the hospital after ED treatment. More than half of the patient population arrived by some form of ambulance, ground ambulance being common at 54% (n=7202). The use of air ambulance was infrequent (n=51 or 0.4%) and some patients used both air and land ambulances (n=57 or 0.4%). The mode of arrival was not available for 78 patient encounters.

After receiving initial care in the ED, patients needing urgent or intensive care were either admitted into the ICU or OR (n=1936 or 14%), or to other hospital inpatient wards (n=11524 or 86%). After completion of hospital treatment, 7598 (56.5%) of patients were discharged home. Of the remaining 5862 patients, 2488 were discharged to

destinations with some level of additional care: transferred to another acute care facility (n=372, 2.8%), long term care facility (n=1780, 13.2%) or nursing home (n=14, 0.1%), and 1169 died, corresponding to a hospital mortality rate of 8.7%.

Table 5.1: Demographic and Clinical Characteristics of Patients

VARIABLES	FREQUENCY (%)
Total visits	13460
Unique patients	10846
Male (n, %)	5390 (50)
Mean Age yrs ± SD	62.6 ± 20
ED Triage Urgency	
1 – Resuscitation	623 (5)
2 – Emergent	3898 (29)
3 – Urgent	7613 (57)
4 – Less Urgent (Semi-Urgent)	1307 (10)
5 – Non-Urgent	19 (0.14)
Mode of arrival	
Ground Ambulance	7202 (54)
Air Ambulance	51 (0.4)
Both	57 (0.4)
Neither	6067 (45)
Not Available	78
Destination after ED stay	
ICU/OR	1936 (14)
Ward	11524 (86)
Mode of Discharge from IP unit	
Transfer to Inpatient Facility	372 (3)
Transfer to Long Term Care	1780 (13)
Transfer to Other Facility (nursing home)	14 (0.10)
Discharged Home with Support	2385 (18)
Discharged Home	7598 (56)
Left Against Medical Advice (Signed Out)	142 (1)
Died	1169 (9)

Table 5.2: Descriptives of the Main Outcome Variables of Interest

Variables	Mean (SD)	Median (Inter-quartile Range)	Skewness	Kurtosis
ED total cost	1,027 (761)	842 (754)	2.05	6.2
ED TTD minutes	419 (307)	359 (320)	2.07	7.4
IP LOS days	8.8 (15)	4.6 (7.1)	6.1	60.3
IP total cost	11,064 (13,917)	5,256 (8,661)	7.5	87.8

From Table 5.2 it is evident that the distributions of the four main outcome variables of interest as well as the independent variable are skewed. As such, both the mean and standard deviation as well as the median and inter-quartile ranges (IQR) are reported.

5.2 Disease Characteristics

CMGs are commonly used to adjust for differences in disease condition and severity when looking at health care outcomes. Of the 470 possible CMGs defined by CIHI, 342 were present in our dataset, indicating a diverse mix of patients. Similar to the two primary outcomes of interest, the distribution by CMG was skewed. 169 CMGs categories had 10 or fewer patients, of which 120 CMG categories had 5 or fewer patients. More detailed CMG frequencies are included in Appendix D.

5.3 UNIVARIATE ANALYSIS

5.3.1 Modeling the Key Independent Variable

While ED TTD is recorded as a continuous variable in minutes, we considered other ways to model ED TTD. As 8 hours is commonly used to define reasonable ED TTD for patients designated for hospital ward admission [40, 46], we defined ED TTD

longer than 8 hours as an admission delay to inpatient wards. By this definition 4,198 of our patients experienced some period of admission delay while the remaining 9,262 patients were not delayed. This is displayed in Table 5.3. Liew et al. used alternate groupings of 0-4 hours, 4-8 hours, 8-12 hours and greater than 12 hours to categorize ED TTD [62]. Using the same cut points for our data, the most frequent ED TTD category was 4-8 hours, this is shown in Table 5.4. In addition to categorizations used by previous research, ED TTD minutes were divided into quartiles. This ensures that the number of patients in each quartile category is approximately equal. Frequencies are shown in Table 5.5.

Table 5.3: The Number of ED Stays with Less Than or More Than 8 hours ED TTD

ED TTD (hours)	ED TTD (minutes)	Number of Visits (%)
< 8	< 480	9262 (69)
> 8	> 480	4198 (31)

Table 5.4: The Number of ED Visits Experiencing 0-4 Hours, 4-8 Hours, 8-12 Hours, and Greater than 12 Hours of ED TTD.

ED TTD (hours)	ED TTD (minutes)	Number of ED Visits (%)
0 – 4	0 – 240	3888 (29)
4 – 8	240 – 480	5374 (40)
8 – 12	480 – 720	2640 (20)
>12	> 720	1558 (11)

Table 5.5: Frequency by Quartiles of ED TTD minutes

ED TTD Categories	Time Range (hours)	Time Range (minutes)	Number of ED Visits (%)
1st quartile	0 – 3.6	0 – 215	3372 (25)
2nd quartile	3.6 – 6.0	215 – 359.5	3358 (25)
3rd quartile	6.0 – 8.9	395.5 – 535	3356 (25)
4th quartile	8.9 – 54	535 – 3254	3374 (25)

5.3.1 Univariate Analysis by Delayed Group

Using our definition of ED TTD > 8 hours for admission delay, we conducted univariate comparisons to assess the characteristics of delayed versus non-delayed patients. This is summarized in Table 5.6.

We used t-test comparisons for continuous variables comparing delayed patients to non-delayed patients. A statistically significant difference in age was found between the two groups ($p<.0001$), with the delayed group being slightly older on average. We used chi-square tests for categorical variables. Comparison of sex between the two groups showed a statistically significant difference, with a slightly lower proportion of men in the delayed group ($p<.0001$). For "arrival by ambulance", air ambulance, land ambulance and combined types are lower in the delayed group compared to the non-delayed group, and this difference is also statistically significant ($p<.0001$). The overall chi-square test show that the proportion of admission delay visits differed by triage category ($p<.0001$). A higher proportion of "resuscitation" and "emergent" category patients did not experience admission delay. ICU admission (ref=no) was used as a proxy measure of initial acuity. A higher proportion of non-delayed patients was admitted into the ICU (n=1610, 17%) compared to 7.8% (n=326) in the delayed group ($p=<.0001$).

Table 5.6: Comparison of ED Visits by Presence or Absence of Admission Delay, defined as ED TTD greater than or less than 8 hours

Variables	MEAN No Delay N=9262	Delay N=4198	P Value
Mean Age yrs ± SD	61.5 ± 20	65 ± 19.5	p<.0001±
Male n (%)	4824 (52)	1942 (46)	p<.0001*
ED EPISODE			
Mode of arrival (n, %)			
Ground Ambulance	5042 (55)	2165 (52)	
Air Ambulance	46 (0.50)	5 (0.12)	p<.0001*
Combined	48 (0.52)	9 (0.22)	
Neither	4068 (44)	1999 (48)	
ED Triage Urgency (n, %)			
1 – Resuscitation	581 (6.3)	42 (1.0)	
2 – Emergent	2929 (32)	969 (23)	
3 – Urgent	4998 (54)	2615 (62)	p<.0001*
4 – Less Urgent (Semi-Urgent)	740 (8.0)	567 (13.5)	
5 – Non-Urgent	14 (0.15)	5 (0.12)	
ICU Admission (n, %)	1610 (17)	326 (7.7)	p<.0001*
ED Total Cost (Cdn $)	862	1,392	p<.0001±
ED TTD (mean minutes, SD)	265 (123)	759 (318)	p<.0001±
INPATIENT(IP) EPISODE			
IP Length of Stay days ± SD	8.3 ± 12.8	10 ± 18.5	p<.0001±
IP Total Cost (Cdn $)	11,023	11,154	p=0.73±
IP Variable Costs	7,342	7,330	p=0.96±
Labour	5,766	6,041	p=0.20±
Supply	1,529	1,241	p=0.64±
Other	47	46	p<.0001±
IP Mortality (n, %)	822 (8.8)	347(8.3)	p=0.25*

± Student's t-test
* Pearson's chi-square

For our first hypothesis H1, we proposed that ED admission delay is associated with longer IP LOS. Univariate analysis shows that delayed patients stayed two days longer on average compared to non-delayed patients (p<.0001). As such, there is sufficient statistical evidence from univariate analysis to suggest our first hypothesis holds. Further analysis on risk-adjusted IP LOS is presented in Chapter six.

For our second hypothesis H2, we proposed that ED admission delay is associated with higher IP costs. From the univariate analysis shown in Table 5.6, we found the distribution of total IP cost and total IP variable cost was similar; the mean difference in total IP cost was only $131 between delayed and non-delayed groups (p=0.73). Total variable cost, a proxy for the level of service provided, was minimally different between the two groups. In fact, total variable cost of IP stay was $13 higher for those who did not experience delay (p=0.96). Given the insufficient evidence of an association between ED admission delay and variable cost of IP stay from the univariate analysis, we did pursue further analysis on variable cost. To further test hypothesis H2 we focused on total IP cost with multivariate analytic models in Chapter seven.

For our last hypothesis H3, we proposed that ED admission delay is associated with higher inhospital mortality. Our univariate analysis shows that the proportion of patients who died in hospital in the two groups are also similar, 8.9% (n=822) in the non-delay group, and 8.3% (n=347) in the delayed group. This difference was not statistically significant (p=0.25). It is possible that disease condition confounded the true association between admission and inhospital mortality. This may explain the lack of a statistically significant association from our univariate analysis. After adjusting for CMGs in the multivariate analysis, the association still failed to show statistical significance. We discuss possible reasons in Chapter nine.

In section 5.3 we explored alternate ways to model the independent variable ED TTD by categorizing minutes of ED stay into quartiles and clinically substantive groupings of 0-4 hours, 4-8 hour, 8-12 hours and greater than 12 hours. In this section we show the results of univariate analysis using these same groupings for ED TTD. The results are summarized in Tables 5.7 and 5.8. Using ANOVAs we found that the overall differences in means for IP LOS, IP cost, and IP mortality were statistically significant across ED TTD groups ($p<.001$). Pair-wise comparisons using the shortest ED TTD category as the reference group showed a trend of increasing ED total cost, mean patient age, and IP LOS with longer ED TTD. However, there did not appear to be such a trend with IP cost or in hospital mortality. In fact, mortality appears to decrease across categories of increasing ED TTD, which is the opposite of hypothesis H3, although this trend was not statistically significant from the pair-wise tests. ED TTD categorization using quartiles showed similar results.

Table 5.7: Clinical Characteristics and Outcomes of Interest by ED TTD Groups

ED TTD Groups (hours)	N	Mean minutes	Mean Age	Mean IP LOS Days	Mean ED cost	Mean IP cost	Avg Total Cost (ED+IP)	Mortality (n, %)
0-4	3888	142	58	8.1	740	12,767	13,507	381 (9.8%)
4-8	5374	354	63*	8.4*	949*	9,762*	10,711*	441 (8.2%)
8-12	2640	582	65*	9.3*	1,252*	10,474*	11,726*	233 (8.8%)
>12	1558	1059	64*	11.3*	1,631*	12,307	13,938	114 (7.3%)

* denotes statistically significant ($p<0.05$) differences of means in pairwise comparison with 0-4 hrs group using the Tukey procedure

Table 5.8: Clinical Characteristics and Outcomes of Interest by Quartiles of ED TTD Minutes

ED TTD Quartiles (minutes)	N	Mean minutes	Mean Age	Avg IP LOS Days	Avg ED cost	Avg IP cost	Avg Total Cost (ED+IP)	Mortality (n, %)
0-215	3372	129	57	8.1	727	12,960	13,687	338 (10%)
215- 359.5	3358	287	63*	7.9	864*	10,032*	10,897*	292 (8.7%)
359.5- 535	3356	438	65*	8.8	1,067*	9,782*	10,849*	266 (7.9%)
535- 3254	3374	821	65*	10.4*	1,448*	11,473*	12,922	273 (8.1%)

* denotes statistically significant ($p<0.05$) differences of means in pairwise comparison with 1st quartile using the Tukey procedure

CHAPTER SIX: MULTIVARIATE MODELS FOR IP LOS

6.1 Model L1: Linear Multiple Regression Model

In addition to univariate analysis to test hypothesis H1, we constructed multivariate models to isolate the effect of ED admission delay on IP LOS from other determinants of IP LOS. Model L1 is a multivariate linear regression with IP LOS as the dependent variable and ED TTD as the independent variable. Covariates included were age, sex, ED triage urgency, ambulance, ICU admission, site of ED, and CMG. The five levels of ED triage urgency was combined into three categories of low, moderate, and high urgency in the analysis. The adjusted R2 value was 0.21 and the overall relationship was significant ($F_{349,13110}=11.7$, $p<.0001$). ED TTD is statistically significantly associated with IP LOS, such that each additional minute of stay in the ED increased IP LOS by 0.38% or 5.5 minutes on average ($p<.0001$). Following the same logic, one additional hour spent in the ED would increase total IP LOS by 5.5 hours and for 8 additional hours spent in the ED, total IP LOS would increase by 44 hours.

$$\text{IP LOS} = \text{intercept} + \beta_1(\text{ED TTD minutes}) + \Sigma_i\beta_i(\text{Covariates}_i) \qquad \textbf{(1)}$$

Table 6.1: Results of the Multiple Regression Model, with the Outcome Variable Total Inpatient Length of Stay Modeled and Exposure Variable ED TTD Modeled as Continuous, with Covariate Age, ED Triage Urgency, Ambulance Arrival, ICU Admission, Site of ED, and CMG

Predictor	Coefficients	Confidence Interval	p value
ED TTD minutes	0.0038	0.0031 – 0.0046	<.0001
Triaged most urgent*	-0.72	-1.60 – 0.17	0.11
Triage moderately urgent*	-0.68	-1.48 – 0.11	0.09
Ambulance (ref = no)	1.10	0.59 – 1.61	<.0001
Sex (ref = male)	-0.40	-0.87 – 0.066	0.09
ICU (ref = no)	-0.36	-1.08 – 0.37	0.24
Age (year)	0.09	0.077 – 0.10	<.0001
Site of ED** (University vs Victoria)	0.25	-0.21 – 0.73	0.27
CMGs 001-901	Included in model to adjust for the effects of disease conditions, individual values are not shown		

* Triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group
** Victoria hospital is the reference group

Regression Diagnostics on Model L1

Due to the skewed distribution of IP LOS, an assessment of model assumption and fit of residuals of Model L1 showed heteroskedasticity, as explained in detail in Appendix A.5. Skewed distributions are particularly common when mean values are low, variances large, and values cannot be negative, and are typical of LOS and cost data. Figure 6.1a shows the distribution of IP LOS. This affects the standard errors and demonstrates the need for a transformation of the dependent variable. Log models are typically used in the study of these outcomes in health economics [94]. The connection between additive effects and the normal distribution parallels that of multiplicative effects and the log-normal distribution [95]. As such, we transformed IP LOS on the

natural logarithmic scale to better fit the skewed distribution. Symmetry moved to the multiplicative level, as shown in Figure 6.1b.

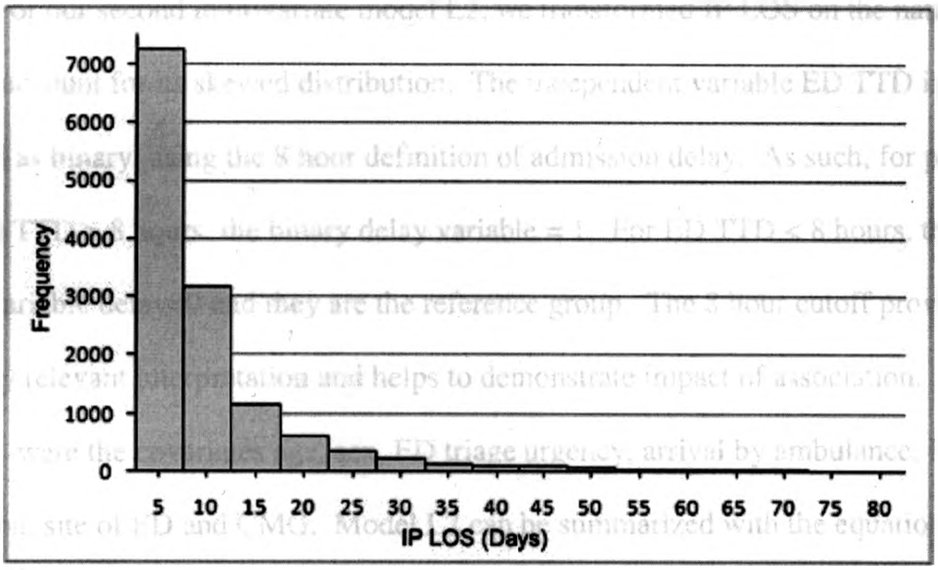

Figure 6.1a: Frequency distribution of IP LOS in days observed in our study. This distribution is right skewed.

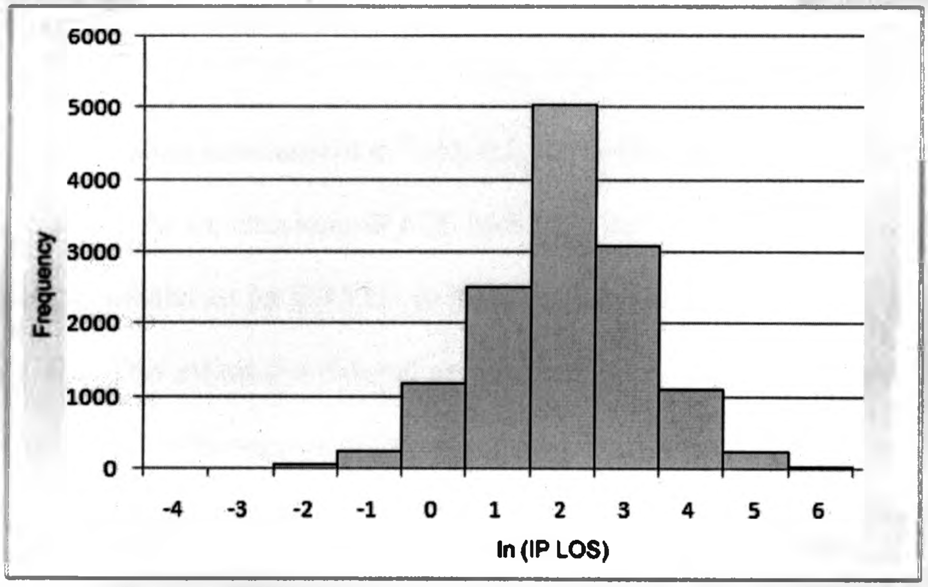

Figure 6.1b: Frequency distribution of IP LOS in days transformed on the natural logarithemic scale. The transformed distribution is approximately normal.

6.2.1 Model L2: ED TTD as a Binary Variable by the 8 Hour Definition of Delay

For our second multivariate model L2, we transformed IP LOS on the natural log scale to account for its skewed distribution. The independent variable ED TTD is modeled as binary, using the 8 hour definition of admission delay. As such, for patients with ED TTD > 8 hours, the binary delay variable = 1. For ED TTD < 8 hours, the binary variable delay=0 and they are the reference group. The 8 hour cutoff provides a clinically relevant interpretation and helps to demonstrate impact of association. Included were the covariates age, sex, ED triage urgency, arrival by ambulance, ICU admission, site of ED and CMG. Model L2 can be summarized with the equation:

$$\ln(\text{IP LOS}) = \text{intercept} + \beta_1(\text{Delayed or not}) + \Sigma_i\beta_i(\text{Covariates}_i) \qquad \textbf{(2)}$$

Table 6.2: Results of the multiple regression model L2, with the outcome variable total inpatient length of stay modeled on the natural logarithmic scale, and the exposure variable ED TTD dichotomized as less or more than 8 hours ($R_{adj}^2=0.32$, $F_{349,13110}=19.3$, p=<.0001). Covariates included were ED triage urgency, arrival by ambulance, sex, ICU admission, age, site of ED, and CMG.

Predictor	Coefficient	Impact of Factor (Natural Units)	Confidence Interval	p value
Admission Delay (ref = no)	0.069	1.07	0.031 – 0.11	0.0003
Triaged most urgent*	0.041	1.04	-0.025 – 0.11	0.22
Triage moderately urgent*	0.039	1.04	-0.021 – 0.098	0.20
Ambulance (ref = no)	0.12	1.13	0.087 – 0.16	<.0001
Sex (ref = male)	-0.073	0.93	-0.11 – -0.037	<.0001
ICU (ref = no)	-0.16	0.86	-0.21 – -0.10	<.0001
Age (years)	0.01	1.01	0.010 – 0.012	<.0001
Site of ED** (University vs Victoria)	0.04	1.04	0.0061 – 0.077	0.02
CMGs 001-901	Included in model to adjust for the effects of disease conditions, individual values are not shown			

* triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group
** Victoria hospital is the reference group

From the values summarized in Table 6.2, the coefficient for delayed patients was 0.069 (p=0.0003). As we transform IP LOS back from the natural log scale, we take the exponent of the coefficient for ED TTD on the other side of the equation (2), exp (0.069) to obtain 1.072. This means that delayed patients have on average 7.2% longer IP LOS compared to patients who were not delayed, adjusted for age, sex, ED triage urgency, ambulance, ICU admission, site of ED, and CMGs. We transformed coefficients for covariates in Model L2 for interpretation in the same manner. Patients triaged as high urgency in the ED on average stay 4% longer in the hospital compared to patients triaged as low urgency, although this is not statistically significant (p=0.22). Similarly, patients

triaged as moderately urgent on average also have 4% longer hospital stays compared to low ED triage urgency patients, and this association also did not reach statistical significance (p=0.20). Patients who arrived by ambulance also have 12% longer IP LOS on average compared to those who relied on self transportation to the ED (p<.0001). Male patients on average have 7% longer IP LOS compared to female patients (p<.0001). Patients admitted to the ICU on average have 14% decrease in IP LOS compared to patients admitted to all other hospital wards (p<0.0001). Age is positively associated with IP LOS such that older patients are more likely to stay longer, with one additional year adding 1% to IP LOS (p<.0001). The site of ED visit may also affect IP LOS such that University Hospital patients on average have 4% longer IP LOS compared to Victoria Hospital patients (p=0.02). CMGs were included in model to adjust for the effects of disease conditions, individual values are not shown in Table 6.2. In brief summary, 169 of the total 340 CMGs categories meet the common criterion for statistically significance with p<.05, of which 67 CMGs were highly statistically significant, with p values <.0001. The beta coefficients for CMG categories ranged from -3.3 to 2.9, which suggest that some disease conditions were associated with long IP LOS while others are associated with shorter IP LOS.

6.2.2 Log-Normal Model L3: ED TTD Quartiles

Additionally, we constructed model **L3**, with ED TTD categorized into quartiles. The key advantage of this alternate grouping of ED TTD is that it provides more information than the binary categorization of delayed/not-delayed in Model L2. With quartiles, we can compared the impact of short, moderate and long ED admission delay on IP LOS, using the lowest quartile ED TTD as the reference group. From a statistical perspective, quartile categorization also ensures that the number of patients per group is approximately equal. Again, we transformed IP LOS on the natural log scale and the relationship to the exposure variable ED TTD can be summarized as

ln (IP LOS) = intercept + β_1(2nd ED TTD Quartile) + β_2(3rd ED TTD Quartile) + β_3(4th ED TTD Quartile) + Σ_i(β_iCovariates$_i$) **(3)**

Table 6.3: Results of the multiple regression model, with the outcome variable total inpatient length of stay in days modeled on the natural logarithmic scale, and the exposure variable ED TTD categorized by quartiles, with the first quartile as the comparison group (R^2_{adj}=0.32, $F_{351,13108}$=19.3, p=<.0001). Covariates included were ED triage urgency, arrival by ambulance, sex, ICU admission, age, site of ED, and CMG.

Predictor	Coefficient	Impact of Factor (Natural Units)	Confidence Intervals	p value
2nd quartile ED TTD (215 min - 359.5 min)	0.053	1.05	0.00296 – 0.102	0.038
3rd quartile ED TTD (359.5 min – 535 min)	0.125	1.13	0.074 – 0.18	<.0001
4th quartile ED TTD (535 min - 3254 min)	0.145	1.15	0.094 – 0.20	<.0001
Triaged most urgent*	0.052	1.05	-0.015 – 0.12	0.13
Triage moderately urgent*	0.040	1.04	-0.019 – 0.10	0.18
Ambulance (ref = no)	0.13	1.14	0.094 – 0.17	<.0001
Sex (ref = Male)	-0.071	0.93	-0.11 – -0.036	<.0001
ICU Admission(ref = no)	-0.14	0.87	-0.20 – -0.093	<.0001
Age (years)	0.011	1.01	0.010 – 0.12	<.0001
Site of ED* (University vs Victoria)	0.041	1.04	0.006 – 0.077	0.024
CMGs 001-901	Included in model to adjust for the effects of disease condition, individual values are not shown			
* Triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group ** Victoria hospital is the reference group				

As in the previous case, to transform In (IP LOS) back to IP LOS we take the exponents of the right hand side of the equation:

IP LOS= exp [intercept + β_1(2nd ED TTD Quartile) + β_2(3rd ED TTD Quartile) + β_3(4th ED TTD Quartile) + $\Sigma_i(\beta_i \text{Covariates}_i)$]

IP LOS=e ^intercept * e^β_1(2nd ED TTD Quartile) * e^β_2(3rd ED TTD Quartile) * e^β_3(4th ED TTD Quartile) * e^ $\Sigma_i(\beta_i \text{Covariates}_i)$

Results are shown in Table 6.3. The coefficient for the 2nd quartile of ED TTD was 0.053. As we transform the dependent variable IP LOS back from the natural log scale, we take the exponent of the coefficient on the other side of equation (3) for ED TTD, exp(0.053) to obtain 1.05. This means on average 2nd quartile ED TTD patients have 5% longer IP LOS compared to patients in the lowest quartile of ED TTD, adjusted for age, sex, ED triage urgency, ambulance arrival, ICU admission, site of ED and CMG ($p=0.038$). Similarly, for 3rd quartile ED TTD patients, we take exponent of the coefficient in the model exp(0.125) to obtain 1.13, which means on average 3rd quartile ED TTD patients have 13% longer IP LOS compared to 1st quartile ED TTD patients ($p<.0001$). For 4th quartile ED TTD patients, we take exp(0.145) to obtain 1.15, which means on average 4th quartile ED TTD patients have 15% longer IP LOS compared to 1st quartile ED TTD patients ($p<.0001$). Coefficients for other covariates in Model L3 were transformed for interpretation in the same manner. Patients triaged as high urgency in the ED on average stay 5% longer in the hospital compared to patients triaged as low urgency, although this is not statistically significant ($p=0.13$). Similarly, patients triaged as moderately urgent on average also have 4% longer hospital stays compared to low ED triage urgency patients, and this association also did not reach statistical significance ($p=0.18$). Patients who arrived by ambulance also have 14% longer IP LOS on average compared to those who relied on self transportation to the ED ($p<.0001$). Male patients on average have 7% shorter IP LOS compared to female patients ($p<.0001$). Patients admitted to the ICU on average have 14% decrease in IP LOS compared to patients admitted to all other hospital wards ($p<.0001$). Age is positively associated with IP LOS such that older patients are more likely to stay longer, with one additional year adding on

average 1% to total IP LOS ($p<.0001$). The site of ED visit may also affect IP LOS such that University Hospital patients on average have 4% longer IP LOS compared to Victoria Hospital patients ($p=0.022$). CMGs were included in model to adjust for the effects of disease conditions, individual values are not shown in Table 6.3. In brief summary, 65 of the total 340 CMG categories were highly statistically significant, with p values <.001; 166 CMG categories have $p<.05$. The beta coefficients for CMG categories ranged from -3.3 to 3.0, which means that CMG as a proxy for disease condition influence IP LOS both ways; that is, disease condition is important in determining whether a patient's IP stay is long or short.

6.2.3 Model L4: ED TTD as Continuous Variable

For the last log normal model, we kept ED TTD as a continuous variable. Essentially, Model L4 is Model L1 with IP LOS transformed on the natural log scale. From a statistical perspective it is beneficial to keeping ED TTD as a continuous variable. As with previous models, we included the covariates age, sex, ED triage urgency, ambulance arrival, ICU admission, site of ED and CMG. This model can be summarized with the equation

$$\ln(\text{IP LOS}) = \text{intercept} + \beta_1(\text{ED LOS minutes}) + \Sigma_i(\beta_i \text{Covariates}_i) \quad (4)$$

Results are summarized in Table 6.4.

Table 6.4: Results of the Multiple Regression Model, with the Outcome Variable Total Inpatient Length of Stay Modeled on the Natural Logarithmic Scale and Exposure Variable ED TTD Modeled as Continuous, with Covariate Age, ED Triage Urgency, Ambulance Arrival, ICU Admission, Site of ED, and CMG (R_{adj}^2=0.32, $F_{349,13110}$=19.45, p<.0001).

Predictor	Coefficient	Impact of Factor (Natural Units)	Confidence Interval	p value
ED TTD minutes	0.00019	1.00019	0.00013 – 0.00024	<.0001
Triaged most urgent*	0.047	1.05	-0.019 – 0.11	0.17
Triage moderately urgent*	0.04	1.04	-0.020 – 0.10	0.19
Ambulance (ref = no)	0.13	1.14	0.093 – 0.17	<.0001
Sex (ref = male)	-0.070	0.93	-0.11 – -0.035	<.0001
ICU (ref = no)	-0.15	0.86	-0.20 – -0.098	<.0001
Age (years)	0.011	1.01	0.010 – 0.012	<.0001
Site of ED** (University vs Victoria)	0.041	1.04	0.006 – 0.077	0.024
CMGs 001-901	Included in model to adjust for the effects of disease condition, individual values are not shown			

* Triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group
** Victoria hospital is the reference group

The regression had an adjusted R square value of 0.32 and the overall relationship was significant ($F_{349,13110}$=19.45., p<.0001). The coefficient for the ED TTD in minutes was 0.00019. As we transform IP LOS back from the natural log scale, we take the exponent of the ED LOS coefficient, exp (0.00019) to obtain 1.00019. This means on average each additional minute of ED TTD adds 0.019% to the total IP LOS, adjusted for age, sex, ED triage urgency, ambulance arrival, ICU admission, site of ED and CMG (p<.0001). Coefficients for other covariates in Model L4 were transformed for interpretation in the same manner. Patients triaged as high urgency in the ED on average

stay 5% longer in the hospital compared to patients triaged as low urgency, although this is not statistically significant (p=0.17). Similarly, patients triaged as moderately urgent on average also have 4% longer hospital stays compared to low ED triage urgency patients, and this association also did not reach statistical significance (p=0.19). Patients who arrived by ambulance also have 14% longer IP LOS on average compared to those who relied on self transportation to the ED (p<.0001). Male patients on average have 7% shorter IP LOS compared to female patients (p<.0001). Patients admitted to the ICU on average have 13% decrease in IP LOS compared to patients admitted to all other hospital wards (p<.0001). Age is positively associated with IP LOS such that older patients are more likely to stay longer, with one additional year adding 1% to total IP LOS (p<.0001). The site of ED visit may also affect IP LOS such that University Hospital patients on average have 1% longer IP LOS compared to Victoria Hospital patients (p=0.02). CMGs were included in model to adjust for the effects of disease conditions, individual values are not shown in Table 6.4. In brief summary, 167 out of the total 340 CMGs categories have p<.05, of which 67 CMGs have p values <.0001. The beta coefficients for CMG categories ranged from -3.2 to 3.0, which means that CMG as a proxy for disease condition influence IP LOS in either direction.

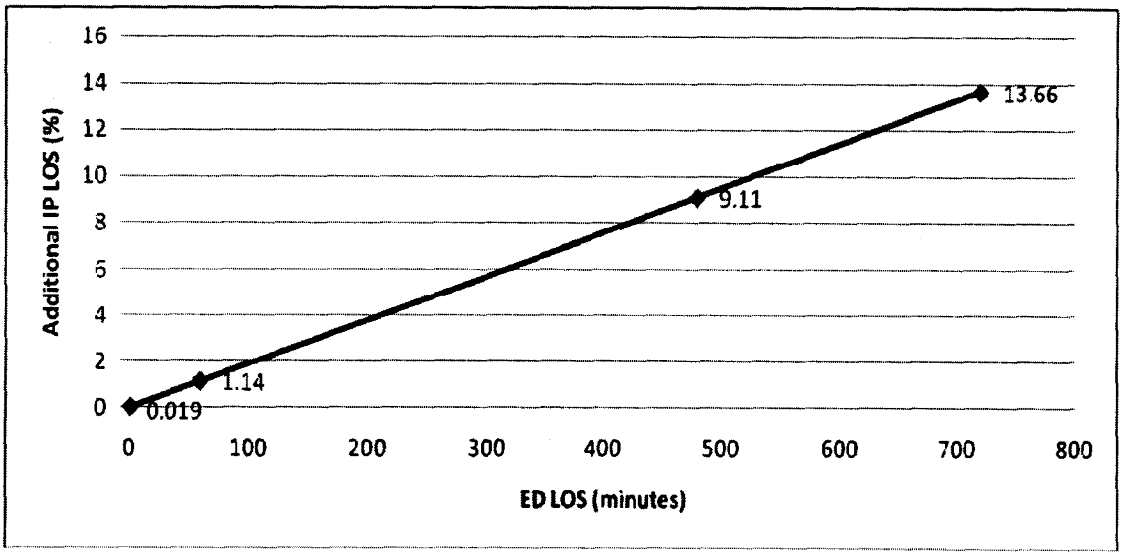

Figure 6.2: Additional IP LOS in Days as ED LOS Increases.

In Model L4, each additional minute of ED LOS on average adds 0.019% to the total IP LOS (p<.0001). As illustrated in Figure 6.2, the longer the ED LOS the progressively larger the corresponding increase in IP LOS. Additional 60 minutes would translate to e^(0.00019*60) = e^.0114 = 1.01147, or roughly a little over 1% increase in overall IP LOS. Using the same calculation, additional 8 hours (480 minutes) ED LOS translates to e^(0.00019*480) = e^0.0912 = 1.091, or 9.1% increase in overall IP LOS. Additional 12 hours (720 minutes) ED LOS translates to e^(0.00019*720) = e^0.137 = 1.147, or 14.7% increase in overall IP LOS. Additional 24 hours (1440 minutes) ED LOS translates to e^(0.00019*1440) = e^0.274 = 1.315, or 31.5% increase in overall IP LOS. Longer delays have a progressively bigger impact. For the mean IP LOS of 10 days in our study, 60 minute delay in the ED would add 2.75 hours to the 10 days, while 8 hours of delay in the ED would add almost 22 hours to the 10 day IP LOS.

6.3 Proportional Hazard Models for IP LOS

The proportional hazard (PH) model is commonly used to analyze time to event data. As such, in addition to multivariate regression models L1-L4 we used the PH model to assess the relationship between ED TTD and IP LOS. In our case, IP LOS is equivalent to "survival time in hospital" and the event is defined as end of hospital treatment, via discharge or death. The measure of effect is the hazard rate or relative risk of event and we assume it is constant over time. While the PH model typically considers censoring we do not have this issue since the discharge times of hospital stays are known for all patients.

6.3.1 Model PH1: ED TTD as Binary Variable of Admission Delay

We constructed a multivariate PH model using IP LOS as the dependent variable and ED TTD was included as a binary variable, using the 8 hour definition of admission delay. To visually assess IP LOS between the two ED TTD groups, the Kaplan-Meier survival curve was constructed and shown in Figure 6.3. It is evident that delayed patients in general have longer IP LOS overall, as the upper tail extends beyond that of the non-delayed group. Comparison of the area under the curve shows that delayed patients are more likely to remain in hospital compared to the non-delayed group.

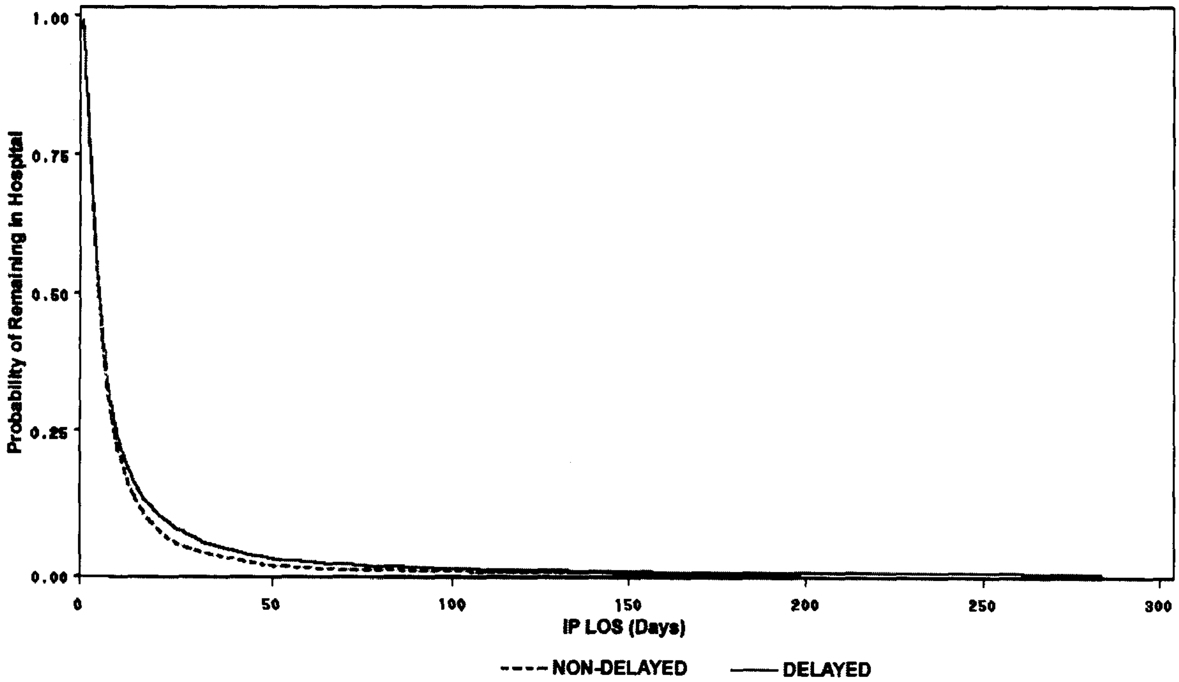

Figure 6.3: Kaplan-Meier Survival Curve Comparing IP LOS of Delayed versus Non-delayed Groups

As with previous models, we included the covariates age, sex, ED triage urgency, arrival by ambulance, ICU admission, site of ED and CMG. We refer to this model as PH1 and the results are shown in Table 6.5.

Table 6.5: Hazard ratios for variables used in the proportional hazards model of IP LOS

Predictor	Hazard Ratio (95% CI)	p value
Admission Delay (ref=no)	**0.901 (0.87 - 0.94)**	<.0001
Age (years)	**0.987 (0.986 - 0.988)**	<.0001
ICU (ref = no)	**1.09 (1.03 - 1.15)**	0.0051
ED location* (University or Victoria)	**0.95 (0.92 - 0.98)**	0.0005
Triaged most urgent**	**0.95 (0.89 – 1.02)**	0.13
Triaged moderately urgent**	**0.98 (0.93 – 1.05)**	0.59
Sex (ref = male)	**1.06 (1.02 - 1.10)**	0.0012
Ambulance (ref = no)	**0.83 (0.80 - 0.87)**	<.0001
CMGs 001-901	Included in model to adjust for the effects of disease condition, individual values are not shown	

*Victoria hospital is the reference group
** Triaged most urgent = CTAS level 1-2, triaged moderately urgent = CTAS level 3, the least urgent triage group (CTAS level 4-5) is the reference group

The overall comparison of survival was significant ($\chi2$=5618, p<.0001). The hazard ratio is the ratio of mean likelihood of hospital discharge comparing patients in the delayed group to that of patients in the non-delayed group. A hazard ratio of 0.905 comparing delayed to non-delayed patients means that hospital discharge is less likely for delayed patients. To put it another way, delayed patients are more likely to remain in hospital, adjusted for age, sex, ED triage urgency, arrival by ambulance, ICU admission, site of ED and CMG (p<.0001). Coefficients for other covariates in Model PH1 can be interpreted in the same manner. A hazard ratio of 0.987 for age indicates that increasing age is associated with decreasing likelihood of hospital discharge (p<.0001). With a hazard ratio of 1.08, admission to ICU or surgery increases the likelihood of ending hospital treatment (p=0.00051). The location of the ED also affects IP LOS such that patients at University Hospital are less likely to be discharged compared to Victoria Hospital patients (p=0.0005). When compared to patients with low ED triage urgency, the hazard ratio show that patients triaged as high urgency and moderately urgent are less

likely to be discharged, although these associations were not statistically significant (p=0.14, p=0.58). A hazard ratio of 1.06 indicates that female patients are more likely to be discharged compared to male patients (p=0.0012). Arrival by ambulance decreased the likelihood of hospital discharge (p<.0001). In terms of CMGs, 108 categories meet statistical significance, while 68 CMGs had p values of <.0001.

6.3.2 Model PH2: ED TTD AS CONTINOUS VARIABLE

For the second multivariate PH model, we kept ED TTD as a continuous variable. The unit of the coefficient for ED TTD is in minutes and for more meaningful interpretation we report the impact in 60 minute increments. The results are shown in Table 6.6.

Table 6.6: Hazard ratios for variables used in the multivariate proportional Hazards Model for IP LOS, with ED TTD modeled continuously

Predictor	**Hazard Ratio (95% CI)**	**P value**
ED TTD (60 minutes)	**0.986 (0.982 – 0.99)**	<.0001
Age (years)	**0.987 (0.986 – 0.988)**	<.0001
ICU (ref = no)	**1.07 (1.01 – 1.13)**	0.013
ED location* (University or Victoria)	**0.95 (0.91 – 0.98)**	0.0035
Triaged most urgent**	**0.95 (0.89 – 1.01)**	0.11
Triage moderately urgent**	**0.99 (0.93 – 1.05)**	0.63
Sex (ref = male)	**1.06 (1.02 – 1.10)**	0.0013
Ambulance (ref = no)	**0.832 (0.80 – 0.87)**	<.0001
CMGs 001-901	Included in model to adjust for the effects of disease condition, individual values are not shown	

*Victoria hospital is the reference group
** Triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group

The overall association was statistically significant ($\chi2=5650$, $p<.0001$). A hazard ratio of 0.9865 for ED TTD means an additional 60 minutes in the ED decrease the likelihood of that hospital discharge by about 2%, adjusted for age, sex, ED triage urgency, ambulance arrival, ICU admission, site of ED and CMG ($p<.0001$). We interpret coefficients for covariates in model PH2 in the same manner. A hazard ratio of 0.987 for age indicates that increasing age is associated with decreasing likelihood of hospital discharge ($p<.0001$). With a hazard ratio of 1.07, ICU admission increases the likelihood of ending hospital treatment ($p=0.014$). The location of the ED also affects IP LOS such that patients at University Hospital are less likely to be discharged compared to Victoria Hospital patients ($p=0.0035$). Patients triaged as high urgency in the ED on average have decreased likelihood of discharge, compared to patients triaged as low urgency, although this association is not statistically significant ($p=0.11$). Similarly, patients triaged as moderately urgent on average have decreased likelihood of discharge with a hazard ratio of 0.99 compared to low ED triage urgency patients, this also failed to show statistical significance ($p=0.63$). A hazard ratio of 1.06 indicates that female patients are more likely to be discharged compared to male patients ($p=0.0013$). Arrival by ambulance decreased the likelihood of hospital discharge ($p<.0001$).

CHAPTER SEVEN: MULTIVARIATE MODELS FOR IP COST

7.1 Model C1: Linear Multiple Regression Model

The second outcome of interest to our study was total IP cost. In addition to univariate analysis to test hypothesis H2, we constructed multivariate linear regression model using IP cost as the dependent variable and ED TTD as the independent or exposure variable. We refer to this model as C1.

$$\text{IP cost} = \text{intercept} + \beta_1(\text{ED TTD minutes}) + \Sigma_i\beta_i(\text{Covariates}_i) \qquad \textbf{(5)}$$

Covariates included were age, sex, ED triage urgency, ambulance, ICU admission, site of ED, and CMGs. The regression had a R^2_{adj} of 0.31 and the overall relationship was significant ($F_{349,13110}$=18.63, p<.0001). Each additional minute spent in the ED adds on average $3.66 to the total cost of IP stay, adjusted for age, sex, mode of arrival, ED triage urgency, location of ED and CMG. This means that for 1 additional hour spend in the ED, total IP cost increases by $220 and for 8 additional hours spend in the ED, total IP cost increases by $1,757. In terms of the covariates included in C1, arrival by ambulance adds $1,589 to the total cost, patients triaged as the most urgent costs $1,720 more than other triage category patients, and those admitted to the ICU versus other hospital wards costs on average $3,095 more for their IP stay (p<.0001).

Table 7.1: Results of the Multiple Linear Regression Model, with the Outcome Variable Total Inpatient Cost and Exposure Variable ED TTD Modeled as Continuous, with Covariate Age, ED Triage Urgency, Arrival by Ambulance, ICU Admission, Site of ED, and CMG

Predictor	**Coefficients**	**Confidence Interval**	**p value**
ED TTD minutes	3.66	2.67 – 4.66	<.0001
Triaged most urgent*	1720	574 – 2867	0.0003
Triage moderately urgent*	340	-689 – 1370	0.52
Ambulance (ref = no)	1589	934 – 2243	<.0001
Sex (ref = male)	-198	-804 – 407	0.52
ICU or surgery (ref = no)	3095	2150 – 4040	<.0001
Age (years)	62	44 – 80	<.0001
Site of ED** (University vs Victoria)	118	-495 – 731	0.71
CMGs 001-901	Included in model to adjust for the effects of disease conditions, individual values are not shown		
* Triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group ** Victoria hospital is the reference group			

Similar to the multivariate linear regression model for IP LOS, the distribution of IP cost was right skewed and fit of the residuals for C1 was heteroskedastistic. More model fit and residual analysis is discussed in Appendix E. Figure 7.1a displays the distribution of IP cost. After transformation of IP cost onto the natural logarithmic scale, the distribution approximated normality, shown in Figure 7.1b. As such, alternate log-transformed models are presented below.

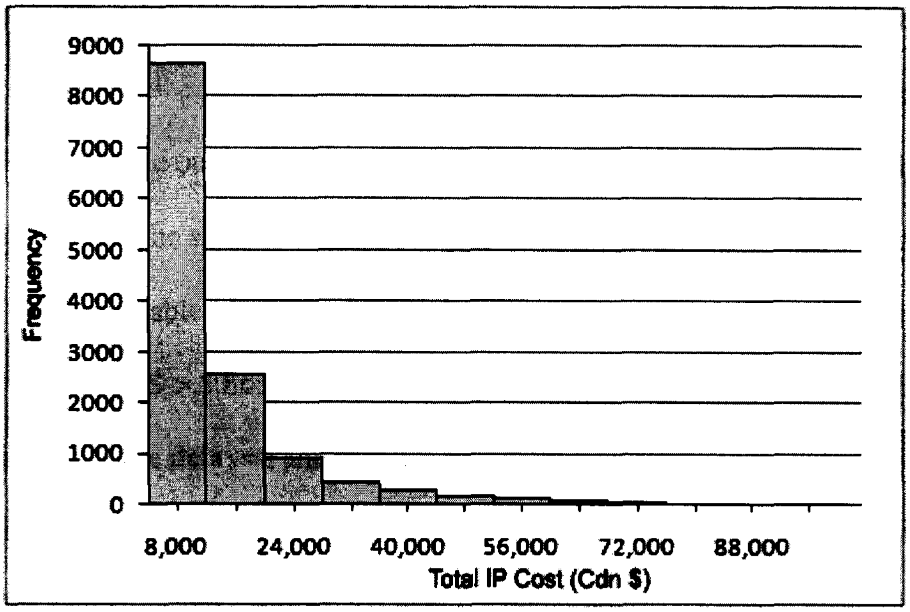

Figure 7.1a: Frequency distribution of total IP cost. It is skewed.

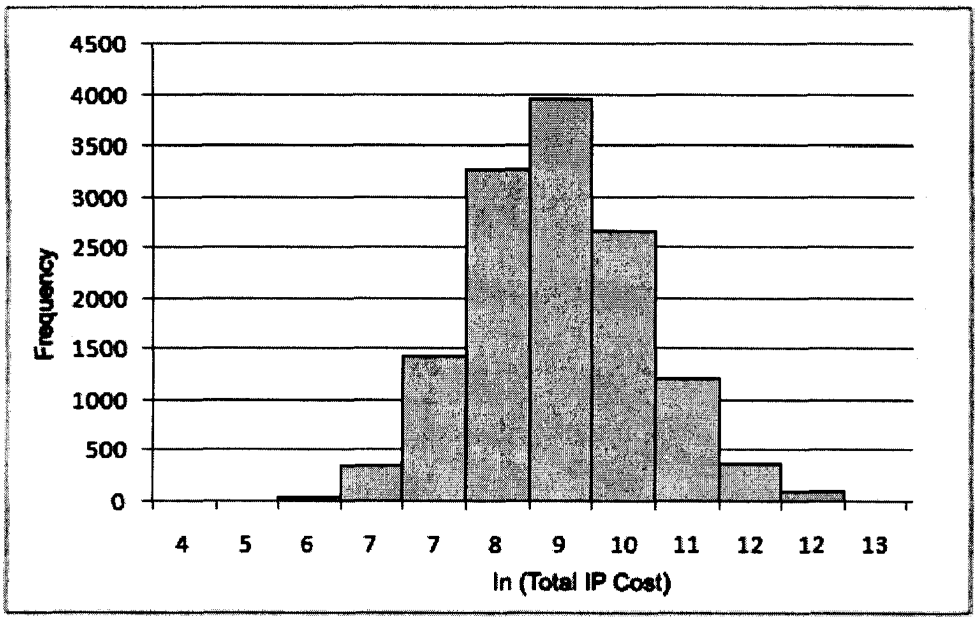

Figure 7.1b: Frequency distribution of total IP cost transformed on the natural logarithemic scale. The transformed distribution is approximately normal.

7.2.1 Model C2: ED TTD as a Binary Variable by the 8 Hour Definition of Delay

For Model C2, the outcome variable total IP cost was transformed on the natural log scale to account for the skewed distribution and the exposure variable ED TTD was included as a binary variable, using the 8 hour definition of admission delay. As such, for patients with ED LOS > 8 hours, the binary delay variable = 1. For ED TTD < 8 hours, the binary variable delay=0 and they are the reference group. Included were the covariates age, sex, ED triage urgency, arrival by ambulance, ICU admission, site of ED and CMG. This model can be summarized with the equation:

$$\text{In (IP Cost)} = \text{intercept} + \beta_1(\text{Delay}) + \Sigma_i\beta_i(\text{Covariates}_i) \quad \textbf{(6)}$$

Table 7.2: Results of the multiple regression model C2, with the outcome variable total inpatient cost modeled on the natural logarithmic scale, and the exposure variable ED TTD dichotomized as less or more than 8 hours (R_{adj}^2=0.41, $F_{349,13110}$=28.0, p<.0001).

Predictor	Coefficient	Impact of Factor (Natural Units)	Confidence Intervals	p value
Admission Delay (ref = no)	0.047	1.048	0.014 – 0.08	<.0001
Triaged most urgent*	0.167	1.18	0.11 – 0.23	<.0001
Triage moderately urgent*	0.058	1.06	0.0064 – 0.11	0.028
Ambulance (ref = no)	0.18	1.20	0.15 – 0.21	<.0001
Sex (ref = male)	-0.040	0.96	-0.071 – -0.009	0.021
ICU/surgery (ref =no)	0.23	1.26	0.19 – 0.28	<.0001
Age (years)	0.009	1.01	0.0082 – 0.010	<.0001
Site of ED** (University vs Victoria)	0.012	1.01	-0.019 – 0.043	0.45
CMGs 001-901	Included in model to adjust for the effects of disease condition, individual values are not shown			

* Triaged most urgent = CTAS 1,2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group
** Victoria hospital is the reference group

Results are shown in Table 7.2. The coefficient for delayed (ED TTD > 8 hrs) patients was 0.0473 (p<.0001). As we transform the outcome variable IP cost back from the natural log scale in equation (6), we take the exponent of the coefficient for ED TTD, exp (0.0473) to obtain 1.048. This means that delayed patients have on average 4.8% higher IP cost compared to patients who were not delayed, adjusted for age, sex, ED triage urgency, arrival by ambulance, ICU admission, site of ED, and CMGs. Coefficients for other covariates in Model C2 can be transformed for interpretation in the same manner. Patients triaged as high urgency in the ED on average costs 18% more in their hospital stay than patients triaged as low urgency (p<.0001). Similarly, patients triaged as moderately urgent on average have 6% higher IP cost compared to low ED triage urgency patients (p=0.028). Patients who arrived by ambulance on average have 20% higher total IP cost compared to those who relied on self transportation to the ED

(p<.0001). Male patients on average cost 4% less for their IP stay compared to female patients (p=0.021). Patients admitted to the ICU on average cost 26% more for their IP compared to patients admitted to all other hospital wards (p<.0001). Age is positively associated with IP cost such that older patients are more likely to cost more, with one additional year adding on average 1% to IP cost (p<.0001). The site of ED visit was not a statistically significant determinant of total IP cost (p=0.45). CMGs were included in model to adjust for the effects of disease conditions, individual values are not shown in Table 7.2. In brief summary, 191 of the 340 CMGs categories met statistical significance (p<.05), of which 104 CMGs have p values <.0001. The beta coefficients for CMG categories ranged from -2.4 to 3.14, which means that CMG as a proxy for disease condition influence IP cost both ways.

7.2.2 Model C3: ED TTD by Quartiles

For Model **C3**, ED TTD was categorized into quartiles and the lowest quartile was used as the reference group. The log normal model transforms the outcome variable, IP cost, on the natural log scale and the relationship to the exposure variable ED TTD can be summarized as

$$\ln(\text{IP cost}) = \text{intercept} + \beta_1(2^{nd}\ \text{ED TTD Quartile}) + \beta_2(3^{rd}\ \text{ED TTD Quartile}) + \beta_3(4^{th}\ \text{ED TTD Quartile}) + \Sigma_i\beta_i(\text{Covariates}_i) \qquad \textbf{(7)}$$

To transform ln (IP cost) back to IP cost we take the exponents of the right hand side of the equation:

IP cost = exp [intercept + β_1(2nd ED TTD Quartile) + β_2(3rd ED TTD Quartile) + β_3(4th ED TTD Quartile) + $\Sigma_i\beta_i$(Covariates$_i$)]

IP cost = e ^intercept * e^β_1(2nd ED TTD Quartile) * e^β_2(3rd ED TTD Quartile) * e^β_3(4th ED TTD Quartile) * e^ $\Sigma_i\beta_i$(Covariates$_i$)

Table 7.3: Results of the multiple regression model C3, with the outcome variable total inpatient cost modeled on the natural logarithmic scale, and the exposure variable ED TTD categorized by quartiles, with the first quartile as the comparison group (R^2_{adj}=0.41, $F_{351,13108}$=27.9, p=<.0001). Covariates included were ED triage urgency, arrival by ambulance, sex, ICU admission, age, site of ED, and CMG.

Predictor	Coefficient	Impact of Factor (Natural Units)	Confidence Intervals	p value
2nd quartile ED TTD (215 min - 359.5 min)	-0.011	0.99	-0.055 – 0.032	0.60
3rd quartile ED TTD (359.5 min – 535 min)	0.048	1.05	0.036 – 0.093	0.034
4th quartile ED TTD (535 min - 3254 min)	0.076	1.08	0.031 – 0.12	0.001
Triaged most urgent*	0.17	1.19	0.12 – 0.23	<.0001
Triage moderately urgent*	0.06	1.06	0.008 – 0.11	0.022
Ambulance (ref = no)	0.18	1.20	0.15 – 0.21	<.0001
Sex (ref =male)	-0.039	0.96	-0.07 – -0.009	0.011
ICU (ref = no)	0.22	1.25	0.17 – 0.27	<.0001
Age (years)	0.009	1.01	0.008 – 0.01	<.0001
Site of ED** (University vs Victoria)	0.011	1.01	-0.02 – 0.042	0.48
CMGs 001-901	Included in model to adjust for the effects of disease condition, individual values are not shown			

* Triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group
** Victoria hospital is the reference group

From the values summarized in Table 7.3, the coefficient for the 2nd quartile of ED TTD was -0.011. As we transform IP cost back from the natural log scale, we take the exponent of this coefficient, exp(-0.0114) to obtain 0.989. This means on average 2nd quartile ED TTD patients cost 1% less than patients in the lowest quartile of ED TTD, adjusted for age, sex, ED triage severity, arrival by ambulance, ICU admission, site of ED and CMG, although this association is not statistically significant (p=0.60). Similarly, for 3rd quartile ED TTD patients, we take exponent of the coefficient in the model exp(0.048) to obtain 1.049, which means on average 3rd quartile ED TTD patients have 4.9% higher total IP cost compared to 1st quartile ED TTD patients, and this association is statistically significant (p=0.03). For 4th quartile ED TTD patients, we take exp(0.0756) to obtain 1.079, which means on average 4th quartile ED TTD patients have 7.9% higher total IP cost compared to 1st quartile ED LOS patients (p=0.001). Coefficients for other covariates in Model C3 were transformed for interpretation in the same manner. Patients triaged as high urgency in the ED on average costs 19% more in their hospital stay compared to patients triaged as low urgency (p<.0001). Similarly, patients triaged as moderately urgent in the ED on average have 6% higher IP cost compared to low ED triage urgency patients (p=0.022). Patients who arrived by ambulance also have 20% high total IP cost on average compared to those who relied on self transportation to the ED (p<.0001). Male patients on average cost 1% more for their IP stay compared to female patients (p=0.011). Patients admitted to the ICU on average costs 25% more compared to patients admitted to all other hospital wards (p<.0001). Age is positively associated with total IP cost such that older patients are more likely to cost more, with one additional year adding on average 1% to total IP cost (p<.0001). The site

of ED visit did not show a statistically significant association with total IP cost (p=0.48). CMGs were included in model to adjust for the effects of disease conditions, individual values are not shown in Table 7.3. The association between CMG and IP cost was statistically significant for 193 categories, of which 105 CMG categories had p values of <.0001. For this covariate, statistical significance is driven by sample size within each CMG category and small frequencies generally failed to show statistical significance. In this model, a wide range of coefficients of association was obtained for the 340 CMG categories, from highly positive association of 3.2 to the opposite of -2.4.

7.2.3 Model C4: ED TTD as Continuous Variable

For Model C4, the outcome variable IP cost was transformed on the natural log scale to account for the skewed distribution and the exposure variable ED TTD was modeled continuously. Included were the covariates age, sex, ED triage urgency, ambulance arrival, ICU admission, site of ED and CMG. This model can be summarized with the equation

$$\ln(\text{IP cost}) = \text{intercept} + \beta_1(\text{ED TTD minutes}) + \Sigma_i\beta_i(\text{Covariates}_i) \quad \textbf{(8)}$$

Results are shown in Table 7.4.

Table 7.4: Results of the Multiple Regression Model of the Outcome Variable Total Inpatient Cost Modeled on the Natural Logarithmic Scale, with Continuous Predictors ED TTD minutes and Age, and categorical Covariates ED Triage Urgency, Arrival by Ambulance, ICU Admission, Site of ED, and CMGs ($R^2_{adj} = 0.41$, $F_{348,13111} = 28.16$, $p<.0001$)

Predictor	Coefficient	Impact of Factor (Natural Units)	Confidence Intervals	p value
ED TTD minutes	0.00014	1.00014	0.00009 – 0.0002	<.0001
Triaged most urgent*	0.17	1.19	0.11 – 0.23	<.0001
Triage moderately urgent*	0.060	1.06	0.008 – 0.11	0.024
Ambulance (ref = no)	0.18	1.20	0.15 – 0.21	<.0001
Sex (ref = Male)	-0.038	0.96	-0.069 – -0.0078	0.014
ICU (ref = no)	0.22	1.25	0.18 – 0.27	<.0001
Age (years)	0.009	1.01	0.008 – 0.01	<.0001
Site of ED** (University Hospital vs Victoria)	0.012	1.01	-0.02 – 0.042	0.46
CMGs 001-901	Included in model to adjust for the effects of disease condition, individual values are not shown			

* Triaged most urgent = CTAS 1-2, triaged moderately urgent = CTAS 3, the least urgent triage group (CTAS =4,5) is the reference group
** Victoria hospital is the reference group

The R^2_{adj} value for Model C4 was 0.41 and the overall relationship was significant ($F_{348,13111}=28.16$, $p<.0001$). The coefficient for the ED TTD minutes was 0.00014. As we transform IP cost back from the natural log scale, we take the exponent of the ED TTD coefficient, exp (0.00014) to obtain 1.00014. This means on average each additional minute of ED TTD adds 0.014% to the total IP cost, adjusted for age, sex, ED triage urgency, ambulance arrival, ICU admission, site of ED and CMG (p<.0001). Coefficients for other covariates in Model C4 were transformed for interpretation in the same manner. Patients triaged as high urgency in the ED on average costs 19% more in

their hospital stay than patients triaged as low urgency (p<.0001). Similarly, patients triaged as moderately urgent on average have 6% higher IP cost compared to low ED triage urgency patients (p=0.024). Patients who arrived by ambulance on average cost 20% more than those who relied on self transportation to the ED (p<.0001). Male patients on average have 4% lower total IP cost compared to female patients (p=0.014). Patients admitted to the ICU on average incur 25% higher cost for their IP stay compared to patients admitted to all other hospital wards (p<.0001). Age is positively associated with IP cost such that older patients are more likely to cost more, with one additional year adding on average 1% to total IP cost (p<.0001). The site of ED visit was not a statistically significant determinant of total IP cost in this model (p=0.46). CMGs were included in model to adjust for the effects of disease conditions, individual values are not shown in Table 7.4. In brief summary, 191 of 340 CMG categories meet the criterion for statistical significance with p=<.05, of which 104 categories were highly statistically significant with p values <.0001. The beta coefficients for CMG categories ranged from -2.4 to 3.19, which means that CMG as a proxy for disease condition influences IP cost in either direction.

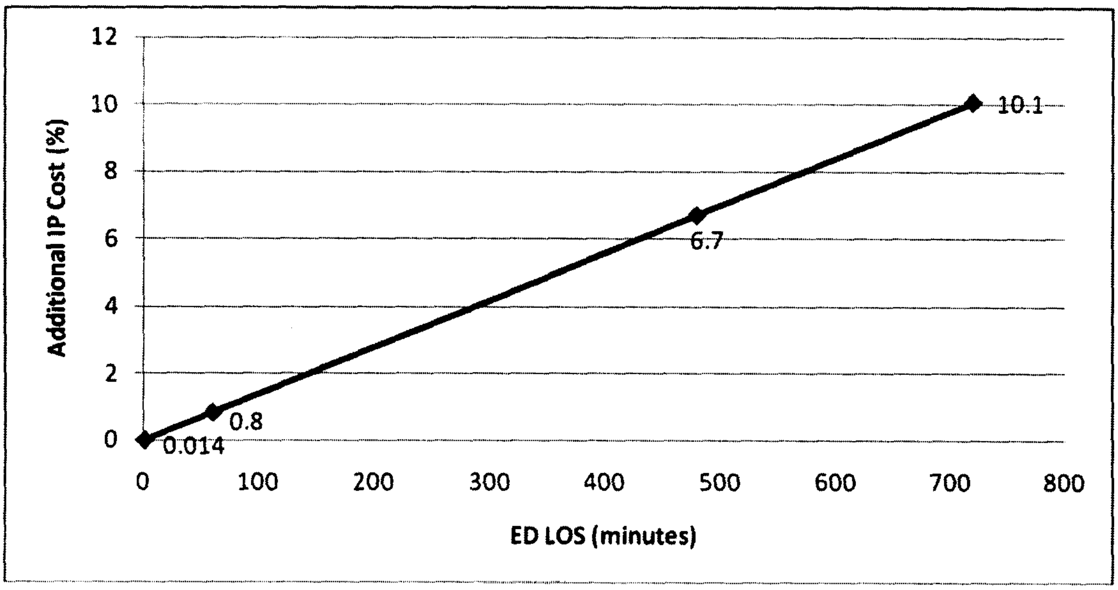

Figure 7.2: Additional percentage increase in IP cost as ED TTD Increases.

From Model C4, it can be concluded that each additional minute of ED TTD on average adds 0.014% to total IP cost ($p<.0001$). As such, the greater the total IP cost the progressively larger the corresponding 0.014% increase, as illustrated in Figure 7.2. Additional 60 minutes of ED TTD would translate to e^(0.00014*60) = 1.008 = 0.8% increase in overall IP cost. Using the same calculation, an additional 8 hours (480 minutes) ED TTD translates to 6.7% increase in overall IP cost; an additional 12 hours (720 minutes) ED TTD translates to 10.1% higher overall IP cost. In our study, the average IP cost was $11,064, 60 minute delay in the ED adds $88.51 to this total, additional 8 hours in the ED would add $708.10 and additional 12 hours in the ED would add $1,174.46 to this total.

CHAPTER EIGHT: IMPACT OF ED DELAYS

In Model L2 and Model C2, we estimated that on average ED admission delay adds 7.2% to the overall IP LOS and 4.8% to total IP cost, respectively. Although the percentage increases seem small, 4,198 patients in our study were delayed and here we illustrate the cumulative effects.

8.1 Aggregate Impact of ED Delay

Figure 8.1 shows the calculation for the estimated impact of admission delay for IP LOS. With estimated mean IP LOS of 10 days per visit and an average increase in IP LOS of 7.2%, the 4,198 patients who experienced admission delay in our study stayed an excess of 3,038 days in hospital. Using the 95% confidence interval, the excess IP LOS due to admission delay could be as high as 11%, adding 4,767 patient days or as low as 3.2% adding 1,372 patient days.

Figure 8.2 shows the calculation for the estimated impact of admission delay for IP cost. With estimated mean IP cost of $11,154 per patient and an average of 4.8% cost increase per patient, the 4,198 delayed patients incurred an excess cost of $2,268,014. Using the 95% confidence limits the excess IP cost due to admission delay could be as low as $680,576, or as high as 11%, or $3,908,499.

Total Number of Patients Delayed N = 4,198	X	Average IP LOS per Patient 10 Days	X	Average Increase in IP LOS Due to Admission Delay 7.2%	=	Additional IP LOS Due to Admission Delay 3,038 Days

Figure 8.1: Aggregate impact of admission delay in additional IP LOS days for the patient population delayed in our study

Total Number of Patients Delayed N = 4,198	X	Average IP Cost per Patient $11,154	X	Average Increase in IP Cost Due to Admission Delay 4.8%	=	Additional IP Cost Due to Admission Delay $ 2,268,014

Figure 8.2: The overall impact of admission delay on IP cost for the study population

CHAPTER NINE: DISCUSSION

9.1 Summary of Key Findings

We tested hypotheses H1-H3 on the association of ED admission delay and hospital care outcomes using univariate analysis and multivariate models.

9.1.1 Findings Related to Hypothesis One: ED Delay and IP LOS

For hypothesis H1, we found consistent evidence that ED admission delay is associated with increased IP LOS from both univariate and multivariate analyses. In Model L2, we determined the additional IP LOS attributable to an extended ED LOS for patients awaiting inpatient beds by comparing patients whose ED TTD was over 8 hours to those who were admitted sooner. After adjusting for age, sex, ED triage urgency, mode of arrival, ICU admission, site of ED, and CMGs delayed patients had on average a 7% longer IP LOS compared to patients who were not delayed. ED LOS is commonly prolonged by other factors, and may affect patient outcomes even when less than 8 hours [62]. In order to explore this possibility further, in Model L3 we divided ED TTD into quartiles. Results show that IP LOS in the 2nd, 3rd, and 4th quartiles of ED TTD was increased by 5%, 13% and 15%, respectively over the IP LOS for patients in the 1st quartile of ED TTD (<215 minutes). In Model L4 we modeled ED TTD as a continuous variable, and found that each additional minute of ED LOS is associated with a 0.019% increase in IP LOS, after being adjusted for the same factors delineated above.($p<.0001$). Longer ED delays have a progressively bigger impact. Projected to the worst case scenario, an ED TTD of 24 hours resulted in a 31.5% increase in IP LOS.

We also looked at the association between ED TTD and IP LOS using PH models. From model PH1, patients with ED admission delay are more likely to have longer hospital stays compared to those not delayed, after adjustment for age, sex, ED triage urgency, arrival by ambulance, ICU admission, site of ED and CMG ($p<.0001$). In Model PH2 we modeled ED TTD as a continuous variable in minutes and also found that longer stay in the ED increased the likelihood of longer hospital stay, after adjusting for the same covariates.

9.1.2 Findings Related to Hypothesis Two: ED Delay and Total IP Cost

For hypothesis H2, we found partial evidence from univariate analysis to support the proposed affect on IP cost. After adjusting for confounders, the results of the multivariate models support the hypothesis that ED admission delay is associated with higher total IP cost. In Model C2, patients who stayed in the ED for more than 8 hrs were compared to those who had ED TTD less than 8 hrs. IP cost was 4.8% higher on average for those delayed, after adjusting for age, sex, ED triage urgency, ambulance arrival, ICU admission, site of ED and CMG. In Model C3 we categorized ED TTD into quartiles. Our results show that compared to the 1st quartile of ED TTD, patients whose ED TTD was in the 2nd quartile had lower IP costs, although this associations was not statistically significant ($p=0.60$). However, total hospital cost of patients whose ED TTD was in the 3rd and 4th quartile of ED was 5% and 8% higher than 1st quartile ED TTD patients on average ($p=0.034$, $p=0.001$).

From Model C4, on average each additional minute of ED LOS adds 0.013% to the total IP cost, adjusted for age, sex, ED triage urgency, ambulance arrival, ICU

admission, site of ED and CMG (p<.0001). The magnitude of the effect of delay on IP costs increases with greater delays. For instance, an 8 hour ED delay is associated with a 6.2% increase in IP cost and a 24 hr ED delay is associated with a 20.5% increase in IP cost.

9.1.3 Findings Related to Hypothesis Three: ED Delay and IP Mortality

There was no statistically significant evidence from univariate analysis to support our last hypothesis H3. After including confounders in the multivariate models, there was also no difference in the risk-adjusted IP mortality rates. We will discuss these conclusions further in the context of the current body of research in section 9.3.3.

9.1.4 Other Determinants of Hospital Outcomes

There were a number of other important determinants of IP LOS. Age and sex are patient level characteristics commonly included in hospital outcome analysis. The association between the sex of the patients and IP LOS was not consistent. In Model L2 female patients had a 7% shorter IP LOS on average compared to male patients (p<.0001), whereas in all other IP LOS models, female patients had longer IP LOS. These findings were not statistically significant. We found that increasing age was associated with an increase of approximately 1% in IP LOS. It is generally agreed that older patients consume more health care resources due to ailments associated with the natural aging process.

We also included three variables as proxies for disease urgency and severity: arrival by ambulance and ICU admission and ED triage urgency. Arrival by ambulance is consistently associated with a 13-14% longer IP LOS. It was the highest impact covariate in our model. Conversely, ICU admission is associated with a 13-14% decrease in IP LOS from Models L2-L4. This is consistent with the hazard ratios from Model PH1 and PH2, in which ICU admission is associated with increased likelihood of ending hospital treatment. Since ICU patients are typically sicker than other hospital patients, higher mortality rate in the ICU could lead to shorter IP LOS. The association of ED triage urgency levels and hospital outcomes is hot consistent across models.

For our second outcome total IP cost, arrival by ambulance is consistently associated with a 21-22% increase in total IP cost. ICU admission is associated with a 21-27% increase in IP cost. This is consistent with the literature and is expected as patients admitted to the ICU are more ill and therefore require more resource-intensive care [29].

9.2 Internal Validity

ED LOS is affected by individual patient and disease characteristics as well as system-level factors. Through multivariate analysis, we tried to isolate the impact of ED LOS by controlling for known confounders. Studies show that the presence of co-morbidity is significantly associated with longer LOS and hospital costs. We believe that

our severity adjusted LOS and costs provide a more accurate measure of hospital outcomes [96-98].

To avoid the pitfall of fitting models with assumptions of normality to skewed distributions, we transformed our outcome variables, IP LOS and IP cost, into their natural logs. In addition, we checked residual fit and variance inflation of the models to confirm the validity of our conclusions.

9.3 External Validity

9.3.1 ED Delay and IP LOS

A few studies have examined the association of ED LOS and IP LOS. Krochmal et al conducted a 3 year study of 26,020 ED admissions and found that ED LOS > 1 day is associated with 10-13% increase in IP LOS [56]. The impact of ED delay was estimated to be 8,455 excess hospital days. A key difference from our study is that Krochmal et al determined the ED LOS to be > 1 day by midnight bed census, regardless of ED arrival time. As such, their estimated impact was not patient specific and may be an underestimate. Our findings from Model L4 show that 24 hours of delay in the ED increases overall IP LOS by 31%.

Our results confirmed the "dose-dependent" relationship between prolonged ED LOS and IP LOS reported by Australian researchers Liew et al [62]. They defined excess IP LOS using the state average IP LOS as the benchmark for the relevant diagnosis-related group. They found that patients who stayed 8-12 hours in the ED were 20% more

likely to have above average inpatient LOS. As ED LOS increased over 12 hours, this probability increased to 50%. Their model estimated an additional 0.39 IP days with ED LOS > 8 hrs, and an additional 2.35 IP days with ED LOS > 12 hrs. From our analysis, Model L4 estimated that total IP LOS would increase 9.5% with an additional 8 hrs in ED LOS, and 14.7% with an additional 12 hrs in the ED. Using the mean IP LOS of 10 days in our patient data set, this would translate to an increase of 0.95 IP days with an additional 8 hr stay in the ED, and an increase of 1.47 days with an additional 12 hr stay in the ED.

Moloney et al reported a 59 bed acute care unit shortened both the ED wait times for a hospital bed and IP LOS [67]. The total saving of 4,039 bed-days was calculated by comparing actual bed days post-implementation, to expected bed-days. They also extrapolated savings of bed days for the hospital at approximately 10%.

Two studies reported on the impact of ED delays on IP LOS for specific patient groups. Bayley et al conducted a prospective cohort study comparing the IP outcomes of chest pain patients who waited for IP admission to those who did not, using a 3 hour ED LOS to define delay [57]. They did not find statistically significant associations between ED wait time and hospital LOS for these patients. These findings conflict with our analysis. Two possible reasons are: 1) our study analyzed the entire ED patient population, and 2) IP LOS may not be the most clinically relevant outcome measure for chest pain patients.

Chalfin et al. used "admit decision to ED exit" time of 6 hrs to define delay of critically ill patients[48]. The authors chose a 6 hr cutoff because it corresponded to the mean wait time in the ED for critically ill patients and because a previous study demonstrated adverse outcomes associated with ED stay beyond 6 hours. The shorter ED LOS cut off may be warranted as these patients usually need urgent and high level care most appropriately provided in the ICU, suggesting that they should be transferred expeditiously after initial stabilization in the ED. This study examined a different segment of ED care but found a similar association. Thus, any delay in the ED, whether before or after decision to admit, impacts subsequent hospital LOS.

Richardson also used ED LOS > 8 hours to define admission delay and its association with IP LOS. Statistical analysis using t tests showed that on average, delayed patients stayed 6.5 hours longer in the ED and 0.8 days longer as inpatients. The estimated impact was 700 bed-days per year. This effect may be an underestimate, as the author truncated IP LOS at a maximum of 10 days in order to facilitate analysis. The calculated mean IP LOS was 4.2 days whereas the full distribution of IP LOS in their study had a mean of 5.9 days. For comparison, in our model, an additional 6.5 hours in the ED translates to a 7.4% increase in IP LOS.

9.3.2 ED Delay and IP Cost

Four studies addressed the association between prolonged ED stay and hospital costs. The earliest study conducted by Krochmal et al. found that ED LOS > 1 day is associated with longer inpatient LOS. They estimated an opportunity loss of US$6.8

million over the three year study period [56]. However these researchers assessed patient records based on whether or not the payor was Medicare, and this selection could have biased their results. Falvo et al also conducted a study in the US that summarized potential loss in patient revenue due to ED admission delay. A total of 2,949 productive hours were estimated to be lost based on a predetermined benchmark of 2 hours boarding time. Using the median net IP revenue of $5,432 per patient, the opportunity loss in potential IP revenue due to boarding was $2,949,576 [30]. Using revenue instead of actual cost data may actually underestimate the impact, as hospital revenue is typically determined by using cost-to-charge ratios and patient fee collection rates. Further evidence on the association between ED delay and IP costs was reported by Moloney et al, who found that decreasing ED LOS decreased IP costs. They reported that transferring ED patients waiting for IP beds to a 59 bed efficiency unit yielded a total cost benefit of 1.7 million Euros [67]. Bayley et al determined the risk adjusted additional cost to the hospital from extended ED stay of chest pain patients, defined as ED LOS > 3 hours [57]. In contradistinction to our study their analysis demonstrated no increase in total hospital costs from ED delays. One possible explanation is the difference in defining extended ED stay. In their study 91% (n=739) of patients were delayed compared to the 31% (n=4198) delayed patients in our analysis. Although the definition for ED delay used by Bayley et al was chosen a priori and relevant for chest pain patients, the highly unbalanced groups may have affected statistical significance in the analysis.

In these studies that estimated the financial burden of ED delay, cost derivations differed widely. Krochmal et al estimated the daily cost of $800.00 per patient by

dividing total hospital funding into the total number of patient-days during the 3-year study period [56]. This method, although simple, is not patient specific and omits information as to where and how costs are incurred. Moloney et al predicted average cost of bed days per patient using multivariate modeling taking into consideration general versus specialist level of care and case mix [67]. Alternatively, Falvo et al used historical case-mix data to estimate admission probability and expected inpatient utilization [30].

In order for cost estimates to be informative and relevant to resource decision making, they must be as precise and accurate as possible. Furthermore, economic outcomes of admission delay in US studies were reported in terms of potential loss in patient revenue. To highlight the strengths in our study, the costs in our data are patient specific and based on services delivered instead of indirect and average estimates from accounting costs, cost-to-charge ratio, collection rate and revenues. We report an alternate cost estimation methodology with improved relevance and generalizability to publicly funded health care systems.

9.3.3 ED Delay and IP Mortality

We did not find any statistically significant association between ED admission delay and IP mortality. In terms of previous research, only one study demonstrates this association for the general ED population. Richardson et al found that ED crowding is associated with an increase in patient mortality at 10 days [34]. A key difference is that they used "mean daily occupancy" as the independent variable, which is a less precise measure of ED crowding and associated delay compared to our study. In addition,

Richardson et al studied a larger population of patients for a longer period. As such, it is possible we had insufficient sample size to detect a true difference between the mortality rates of delayed and non-delayed patients since overall hospital morality rates are generally low.

Studies that have established this association focused exclusively on higher risk patient groups, who have a pre-existing higher risk of mortality given the severity, frailty, and complexity of disease condition. Carr et al studied a small population of trauma patients and found that increased ED LOS is an independent risk factor for pneumonia. The association may be attributed to the fact that the study population is highly selected, and the end point is more common in that group [22]. For other high risk patient groups, both Saukkonen et al and Tilluckharry et al reported no statistically significant differences in hospital LOS or mortality for ICU patients [21, 49]. However, Chalfin et al used ED LOS of 6 hours to define delay for their critically ill patients and found higher mortality rate for delayers, even though only 2% (n=1,036) of their study population was delayed [48].

9.4 Limitations

Although our study is the first to demonstrate impact of admission delay using Canadian data, it has several potential limitations.

First, the independent variable used in this study was ED LOS, a validated measure of ED throughput and a marker of overcrowding. The ideal measure would be admission delay minutes, but this information was not accurately captured in our data.

Secondly, the definition of "first visit" is based on the start date of the study period and may not denote the first visit to an ED or disease episode in their life time. As such "first visit" and "repeat visit" are defined by our observation period of April 1st 2006 to March 30th 2007. Thirdly, it has been noted that resource use per day is not constant and not all hospital days are economically equivalent [45]. Although we attempted to capture variable costs that change directly with patient care, these are accumulated totals over the entire inpatient stay. Examining daily variable costs may provide further evidence of higher levels of care.

It should be noted that a study of LOS at a US trauma center found that 4% of patients experienced average discharge delay of 6 days [44]. Prolonged inpatient LOS may be caused by limitations in post-discharge care, such as lack of rehabilitation beds or difficulties coordinating outpatient care. Because our data did not provide information on possible discharge difficulty, we cannot rule out the possibility that discharge delay also contributed to longer IP LOS.

Conclusions based on the characteristics of patients from Southwestern Ontario may not be applicable to other ED populations. Even within Canada, the study results may not be comparable to other Canadian hospitals since not all hospitals use the Case Costing system. The study is generalizable to other health care settings only to the extent that patterns of care and cost proportions are comparable to those in a Canadian hospital [40]. Lastly, the use of a retrospective methodology and the inherent inability to identify the cause of delay is a limitation of our study. Although our study does not allow the

reason for the admission delay effect on IP outcomes to be identified, it allows possible explanations to be examined.

9.5 Directions for Future Research

Future research should be conducted prospectively in order to identify information on ED workload, patient acuity, capacity and performance, as well as other indexes that may contribute to ED overcrowding and caseload. These would include the availability and access to consultations and evaluation which have the potential to cause delay. At this point, we can only speculate as to whether or not the delay was due to unavailability of hospital beds or other barriers during assessment, evaluation and treatment. Two studies suggested that patients who experience delay may receive different treatment from the non-delayed group. For example, patients may be more likely to be admitted to "outlying" rather than "home" wards, where staffing or organizational issues may prolong LOS [45, 46].

Our study provided some evidence that the performance of the hospital depends on care delivery in the ED. We could not establish an association between ED delay and adverse clinical outcomes with the limited clinical information that was available to us. Future studies, preferably prospectively designed, with clinical details on assessment and treatment may provide a fruitful line of inquiry.

9.6 Conclusions

ED patients with admission delay had increased hospital LOS and higher IP costs. This suggests the need to identify factors associated with admission delay as well as specific determinants of adverse outcomes. The total costs of waiting in publicly funded EDs are not known. Ours is the first Canadian study to demonstrate the financial impact of ED admission delay. Research findings in this area would be valuable in making an urgent case for strategies to relieve access block and improve overall institutional efficiency.

APPENDICES

Appendix A Literature Review Search Methodology

Table A.1: Example of combination keyword search conducted in the PubMed database

Search Terms	Number of Articles Located
ED, blocking, cost*[a]	4
emergency, blocking, cost[a]	8
ED, waiting, cost[a]	47
ED, admission, blocking[a]	3
emergency, admission, blocking[a]	14
ED, cost, throughput[b]	13
emergency, cost, throughput[b]	16
ED, waiting, throughput[c]	14
emergency, waiting, throughput[c]	21
ED, admi*, cost*, delay[c]	8
ED, admission, outcome*, delay[c]	17

[a] Searches conducted July 16th, 2007
[b] Searches conducted July 18th, 2007
[c] Searches conducted July 19th, 2007

Table A.2: Inclusion and exclusion criteria

Include:	• Studies discussing a particular condition (i.e., chest pain or heart failure) with detailed analysis of LOS in ED, inpatient treatment periods, or associated costs • Discussions or recommendations of how to reduce blocking in the ED by consulting experts • Analysis of newly implemented strategy to improve throughput in the ED with numerical cost effectiveness data • Articles in English • Articles published after 1994
Exclude:	• Surveys or literature reviews • Opinion articles • Articles with no quantitative measures of times, money, or mortality • Articles discussing ED outcomes specific to a particular patient payment system (i.e., Medicare in the US) and/or wealth associated blocking in the ED • Articles focusing on experiences of physicians and nurses in the ED • Articles not in English • Articles published prior to 1994

Appendix B Case Costing Types

Table B.1: Cost Types, Description and Examples from the LHSC Case Costing Database

Cost Type	Description	Examples
VDL - Variable Direct Labour	• Labour costs that vary directly & proportionately with direct patient care activities	• Unit Producing Personnel (UPP) • Employee worked salaries adjustments and accruals • Vacation entitlement expenses MD Purchased Services & Stipends • UPP Benefits • Employee benefit salaries, adjustments & accruals • Employer portion of benefits • Meal allowance • Unclassified benefits, adjustments & accruals • Purchased benefits • Benefit contribution in lieu & accruals • Purchased service personnel, adjustments & accrual • MD Fee for Service
FDL - Fixed Direct Labour	• Labour costs that remain constant to support direct patient care	• Management & Support (M&S) &MD • Employee worked Salaries, adjustments and accruals • Vacation entitlement expenses • M&S and MD Benefits • Employee benefits salaries, adjustments & accruals • Employer portion benefits • Meal, travel and uniform allowance • Unclassified benefits, benefit contribution dollars in lieu & accruals • Purchased benefits, adjustments & accruals
VDO - Variable Direct Other	• Other costs that vary directly & proportionately with direct patient care activities	• Referred Out Expenses
FDO - Fixed Direct Other	• Other costs that remain constant to support direct patient care	• Postage, Telephone, Travel, Fees etc.
VDS - Variable Direct Supplies	• Supply costs that vary directly & proportionately with direct patient care volume	• Medical & Surgical Supplies • Patient specific supplies and departmental specific supplies like office supplies etc.
FDE - Fixed Direct Equipment	• Maintenance costs that remain constant supporting direct patient care activities	• Equipment maintenance, repairs & service contracts • Minor equipment purchases • Equipment maintenance, software fees etc.
FDF	• Fixed Direct Facilities	• Building & Ground maintenance expenses, amortization, interest etc.
FI - Fixed Indirect Costs	• Overhead costs, that cannot be specifically traced to direct patient care	• All of the Indirect Departments such as Administration, Finance, Information Management, Housekeeping etc.

Appendix C ED Discharge Disposition Frequency Table

Table C.1: Frequency of Patients by Destination Upon ED Discharge in the Final Dataset.

Discharge Disposition from the ED	Frequency (%)
Discharged to Residence	75 (0.55)
Triaged left not seen	7 (0.05)
Seen but Left without Treatment	1 (0.01)
Left Against Medical Advice	20 (0.15)
Admitted to ICU/OR	1936 (14)
Admitted from Ambulatory	11524 (85)
Tx-Acute other facility	12 (0.09)
Tx-clinic within Facility	1 (0.01)
Transfer to Emergency Department	33 (0.24)
Transfer to Clinic	7 (0.05)
Transfer to home care setting (i.e. nursing home)	2 (0.01)

Appendix D CMG Frequency

The most frequent CMGs are summarized in Table A.5; CMGs with the longest IP LOS are summarized in Tables A.6; and Table A.7 illustrate that the most costly CMGs. There is some overlap of CMGs in the three tables but in general the most costly CMGs are not the most frequent. However, there is some overlap in Table A.6 and Table A.7, which indicates that IP LOS and IP Costs are correlated; that is, the longer the patient stays in hospital, the higher the total costs.

Table D.1: The Most Frequent CMGs

Group	Description	Frequency	Percentage
294	Esophageal/Gastro/Miscellaneous diagnoses	593	4.4
222	Heart Failure	432	3.2
143	Pneumonia/Pleuri	409	3.0
013	Spec Cerebrovascular Dis/Exc	380	2.8
140	Chronic Obstructive Pulmonary Disorder	309	2.3
142	Chronic Bronchitis	290	2.2
281	Gastrointestinal Hemorrhage	262	2.0
666	Major Low/Upper Extremity Procedure-Tra	258	1.9
297	Other Gastrointestinal Diagnosis	248	1.8
485	Nutrition/Miscellaneous Metabolic Diagnoses	238	1.8
529	Lower Urinary Tract Infection	230	1.7
662	Femur/Pelvic Procs for Tr	230	1.7
290	GI Obstruction	213	1.6
329	Biliary Tract Diseases	209	1.6
262	Simple Appendectomy	207	1.5
188	PTCA with Complic Cardiac Co	205	1.5
483	Diabetes	201	1.5
813	Drug Reactions	201	1.5
237	Arrhythmia	197	1.5
325	Pancreas Dis-excl Maligna	195	1.5
253	Major Intestinal/Rectal P	174	1.3
208	AMI-No Cath-No Spec Card	173	1.3
818	Complications of Treatment	160	1.2
022	Seizure/Headache	157	1.2
751	Septicemia	157	1.2
521	Renal Failure No Dialysis	152	1.1
842	Signs & Symptoms	151	1.1
447	Cellulitis	148	1.1
137	Respiratory Infection/Inflammation	142	1.1
847	Other Specified Aftercare	126	0.9
351	Joint Replacement for Tra	123	0.9
242	Chest Pain	122	0.9
218	Card Cath-No Spec Card Co	121	0.9
617	Abortive Outcome with D&C	119	0.9
756	Post-Op/Post-Traumatic In	107	0.8
028	Other Nervous System Diagnosis	106	0.8
001	Craniotomy Procedures	105	0.8
138	Respiratory Neoplasms	100	0.7
326	Liver Disease exclude Cirrhosis/Ca	98	0.7
289	Inflammatory Bowel Disease	96	0.7
683	Intracranial Injuries	93	0.7

Table D.2: CMGs with the Longest Average IP LOS (in Days)

Group	Description	Frequency	Percentage	IP LOS (Days)
310	Liver Transplant	6	0.04	59
725	Major Leukemia	9	0.07	59
125	Tracheostomy	22	0.16	55
552	Testes Procedures	4	0.03	53
840	Other Admissions with Surgery	19	0.14	50
772	Dementia with Axis 3	30	0.22	45
880	Amp Low Limp with Major Vasc S	14	0.10	44
656	Spinal Procedure with Thorac/Abdomen-Tr	1	0.01	44
830	Ext Burn with Graft/Wound Debridement/Br	3	0.02	44
902	Post-op Comp with Unrelated OR Procedure	8	0.06	42
650	Tracheostomy/Gastrost-Tra	22	0.16	41
765	Post-Op/Post-Traumatic In	2	0.01	40
311	Major Pancreatic Procedure	7	0.05	40
383	Joint Replacement for Mal	9	0.07	39
355	Reattach or Low Ext/Shld	4	0.03	37
906	MNRH Unrelated OR Procedure	15	0.11	35
769	Bipolar Mood-Man-No ECT with A	2	0.01	35
040	Tracheostomy & Gastrostomy	16	0.12	32
176	Card Valve Replacement with Pump/Card	19	0.14	32
900	Extensive Unrelated OR Procedure	36	0.27	30
126	Resection of Lung	6	0.04	30
427	Skin Graft/Wound Debridement for Ulcer/	5	0.04	29
128	Minor Respiratory Procedure	5	0.04	29
881	Amputation Low Limb except T	30	0.22	28
076	Major Head & Neck Procedure	5	0.04	28
251	Gastrostomy/Colostomy Procedure	91	0.68	28
890	Other Thoraco-Abdominal Procedure	10	0.07	27
861	CNS Infection with HIV	2	0.01	27
750	Multisystem/Unspecific Site Infection/	88	0.65	27
788	Org Mental with Phys Dis w A	15	0.11	27
386	Other Ortho Oncology Procedure	1	0.01	26
379	Other Musculoskeletal PrMNRH	3	0.02	25
884	Other Amputations (incl T	6	0.04	24
733	Major Ill-Defined Neoplasm	1	0.01	24
075	Radical Laryngectomy/Glossectomy	2	0.01	24
006	Crpl Tnl Rls/Specific Nervous System	1	0.01	23
901	Non-Extensive Unrelated OR Procedure	81	0.60	23
012	Multiple Sclerosis/Cerebel Di	14	0.10	23
776	Schizophrenia/Psychiatry No ECT w	17	0.13	23
219	Endocarditis	12	0.09	22
847	Other Specified Aftercare	130	0.97	22

Table D.3: The Most Costly CMGs

Group	Description	Frequency	Percentage	Total IP Cost
552	Testes Procedure	4	0.03	137,330
125	Tracheostomy	22	0.16	137,126
310	Liver Transplant	6	0.04	102,205
656	Spinal Procedure with Thorac/Abdomen-Tr	1	0.01	100,462
650	Tracheostomy/Gastrost-Tra	22	0.16	92,395
902	Post-op Complication with Unrelated OR Procedure	8	0.06	92,003
126	Resection of Lung	6	0.04	83,381
128	Minor Respiratory Procedures	5	0.04	80,660
176	Card Valve Replacement with Pump/Card	19	0.14	74,049
725	Major Leukemia/Lymphoma Procedure	9	0.07	72,699
830	Ext Burn with Graft/Wound Debridement/Br	3	0.02	67,670
654	Intracr w Wound Debridement/L Ext-T	1	0.01	53,811
040	Tracheostomy & Gastrostomy	16	0.12	50,979
840	Other Admissions with Surgery	19	0.14	50,659
750	Multisystem/Unspecific Site Infection	88	0.65	50,261
177	Card Valve Replacement-Pump-No Crd	5	0.04	48,368
880	Amp Low Limb with Major Vascular S	14	0.10	48,305
311	Major Pancreatic Procedure	7	0.05	47,274
659	Thorx/Abdomen with Wound Debridement/L Ext-	8	0.06	46,263
252	Major Esophageal/Stomach/Duodenal	4	0.03	45,277
890	Other Thoraco-Abdominal Procedure	10	0.07	44,444
383	Joint Replacement for Mal	9	0.07	43,525
900	Extensive Unrelated OR Procedure	36	0.27	42,888
377	Wound Debridement/Skin Graft Mskl	11	0.08	40,688
076	Major Head & Neck Procedure	5	0.04	38,211
386	Other Orthopedic Oncology Procedure	1	0.01	37,706
355	Reattach or Low Ext/Shld	4	0.03	37,004
885	Aortic Replacement	34	0.25	36,855
075	Radical Laryngectomy/Glossectomy	2	0.01	36,352
772	Dementia with Axis 3	30	0.22	35,190
181	Other Cardio/Thor Pr-Pump-C	1	0.01	34,880
658	Femur with Wound Debridement/Low Ex-Tr	18	0.13	34,833
185	Perm Pacemaker-Spec Cardiac	11	0.08	34,422
141	Pulmonary Edema	21	0.16	34,405
252	Major Esophagus/Stomach/Duodenum	91	0.68	34,083
127	Major Respiratory Procedure	49	0.36	33,636
653	Intracr/Fem w Thorax/Abdomen-Tr	5	0.04	33,421
906	MNRH Unrelated OR Procedure	15	0.11	33,323
901	Non-Extensive Unrelated OR Procedure	81	0.60	32,022
178	Coronary Bypass-Pump/Car	78	0.58	31,600
882	Wound Deb/Other Amputation-Major Vas	3	0.02	31518

Appendix E. Multivariate Model Validation – Assessment of Fit

The purpose of this section is to confirm that the data were in keeping with the assumptions of the regression models. Goodness of fit of the regression model was examined using residual analysis.

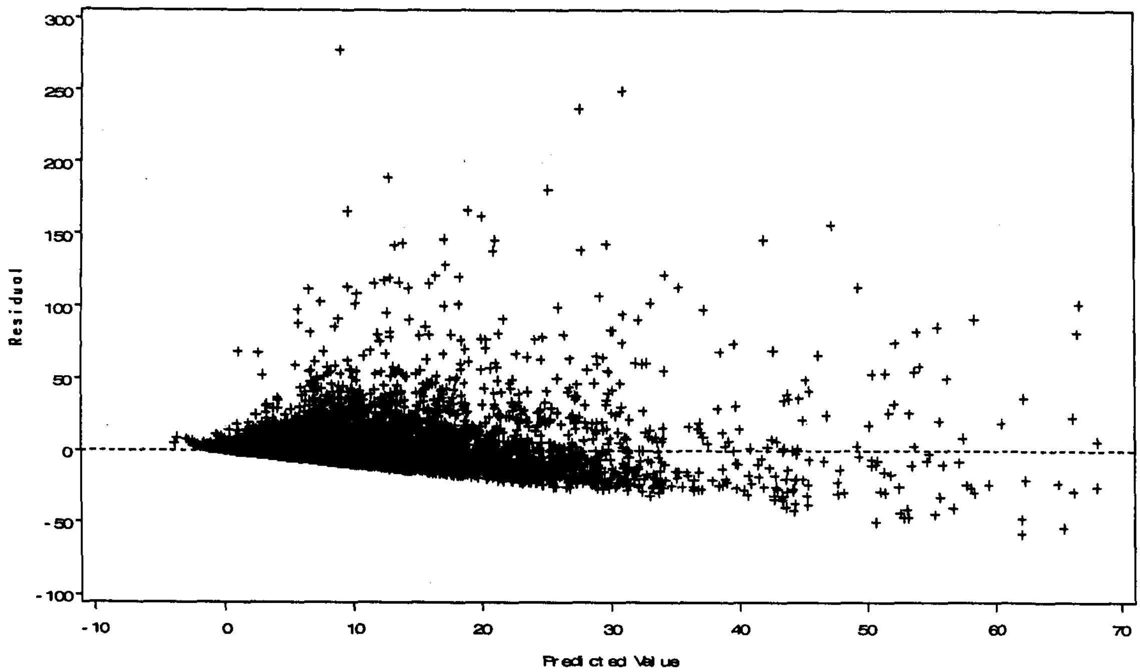

Figure E.1: Residuals of Model L1: IP LOS = intercept + β_1(ED TTD minutes) + $\Sigma_i\beta_i$(Covariates$_i$)

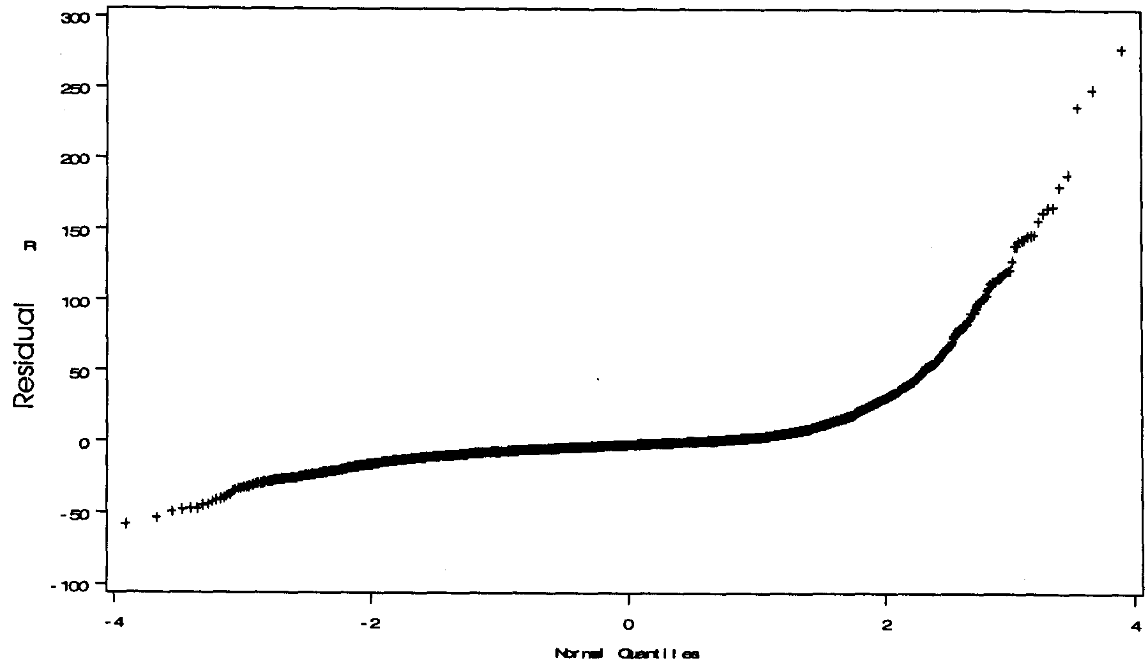

Figure E.2: QQ plot of Model L1: IP LOS = intercept + β_1(ED TTD minutes) + $\Sigma_i\beta_i$(Covariates$_i$)

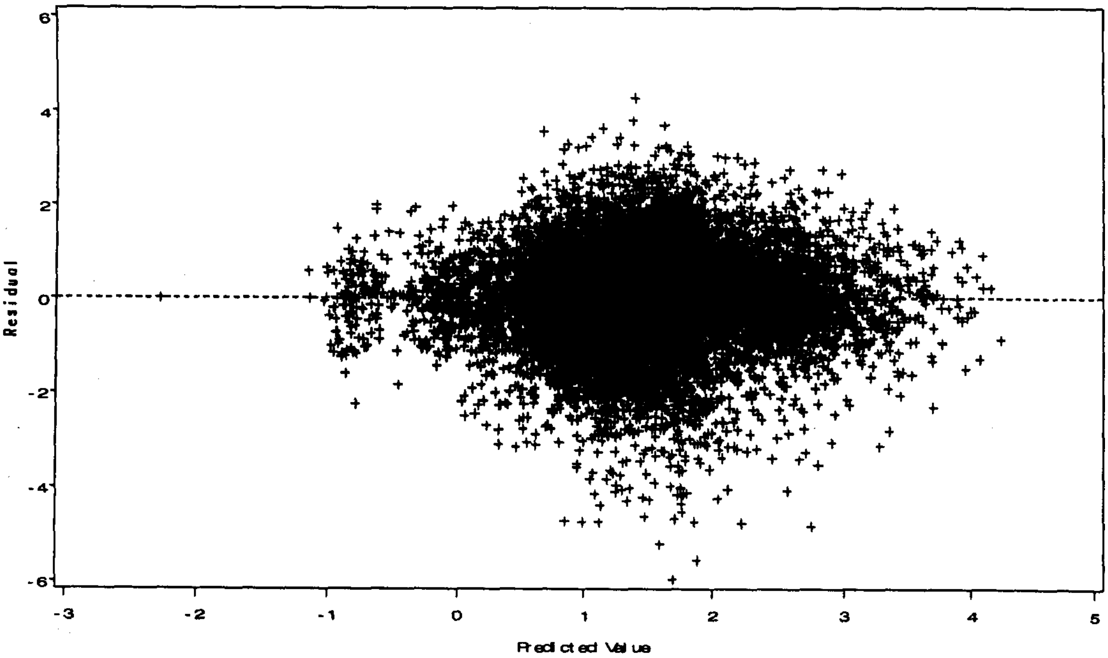

Figure E.3. Residuals of Model L2: ln (IP LOS) = intercept + β_1(Delayed or not) + $\Sigma_i\beta_i$(Covariates$_i$)

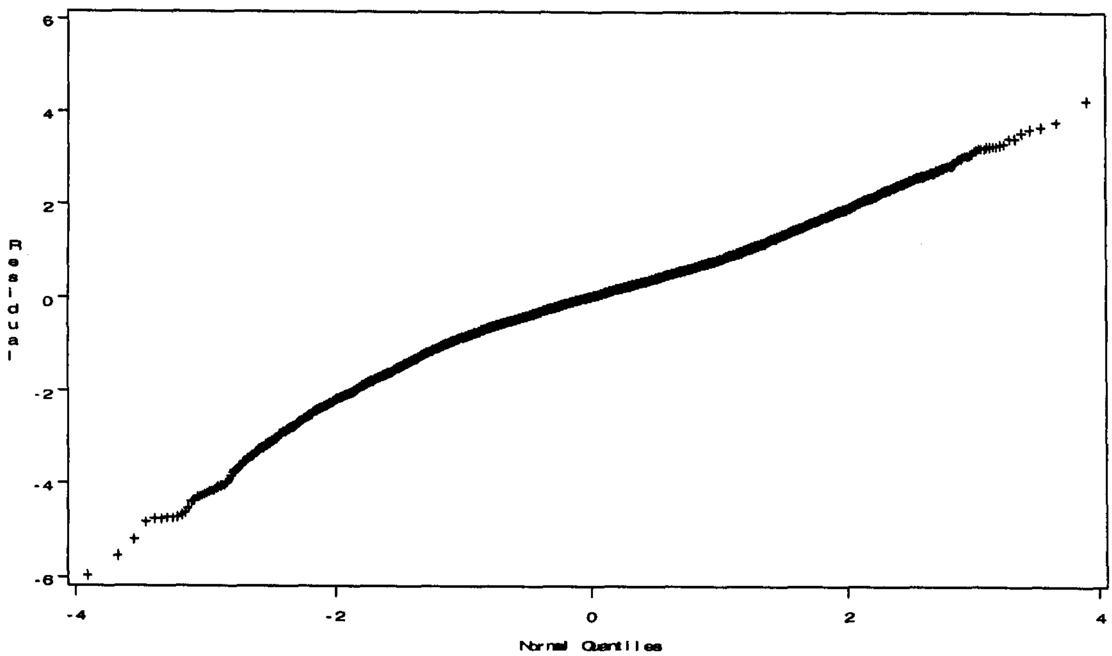

Figure E.4. QQPlot of Model L2: ln (IP LOS) = intercept + β_1(Delayed or not) + $\Sigma_i\beta_i$(Covariates$_i$)

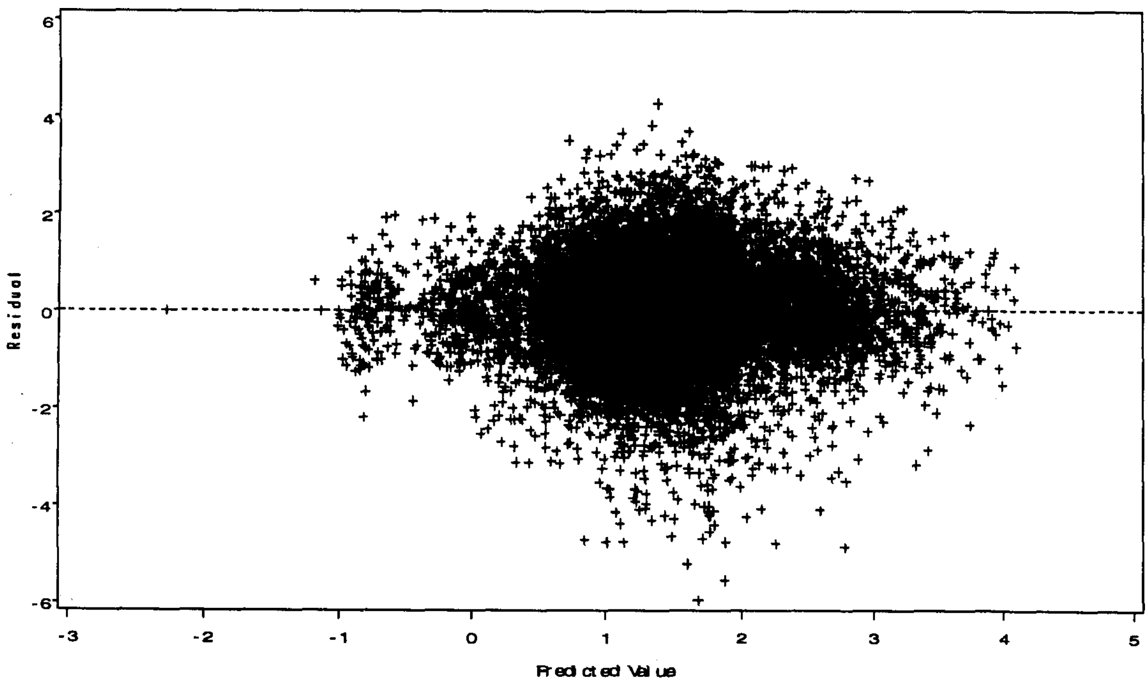

Figure E.5: Residual for Model L3: ln (IP LOS) = intercept + β_1(2nd ED TTD Quartile) + β_2(3rd ED TTD Quartile) + β_3(4th ED TTD Quartile) + Σ_i(β_iCovariates$_i$)

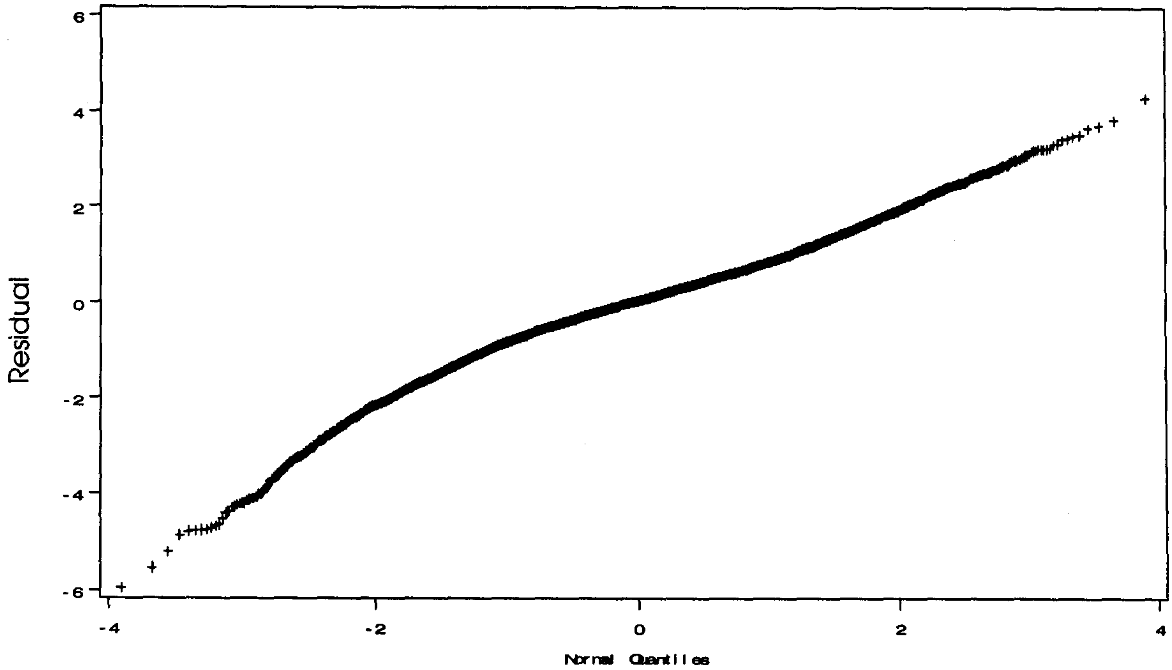

Figure E.6: QQplot for Model L3: In (IP LOS) = intercept + β_1(2nd ED TTD Quartile) + β_2(3rd ED TTD Quartile) + β_3(4th ED TTD Quartile) + $\Sigma_i(\beta_i Covariates_i)$

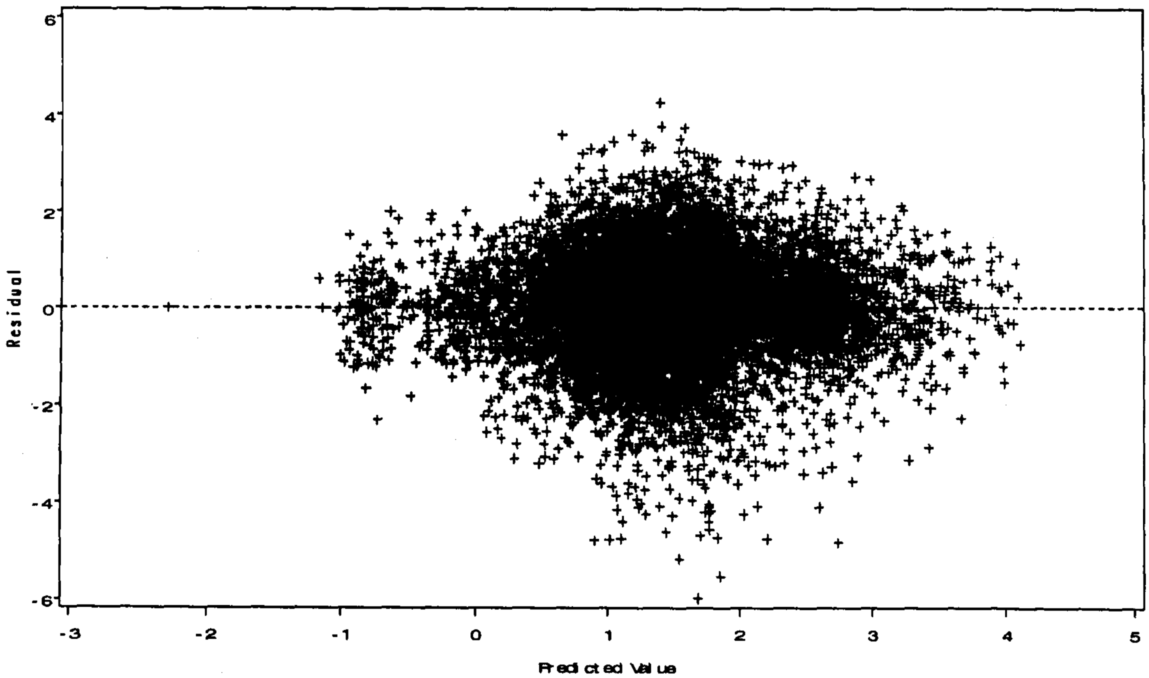

Figure E.7. Residuals for Model L4: In (IP LOS) = intercept + β_1(ED TTD minutes) + $\Sigma_i(\beta_i Covariates_i)$

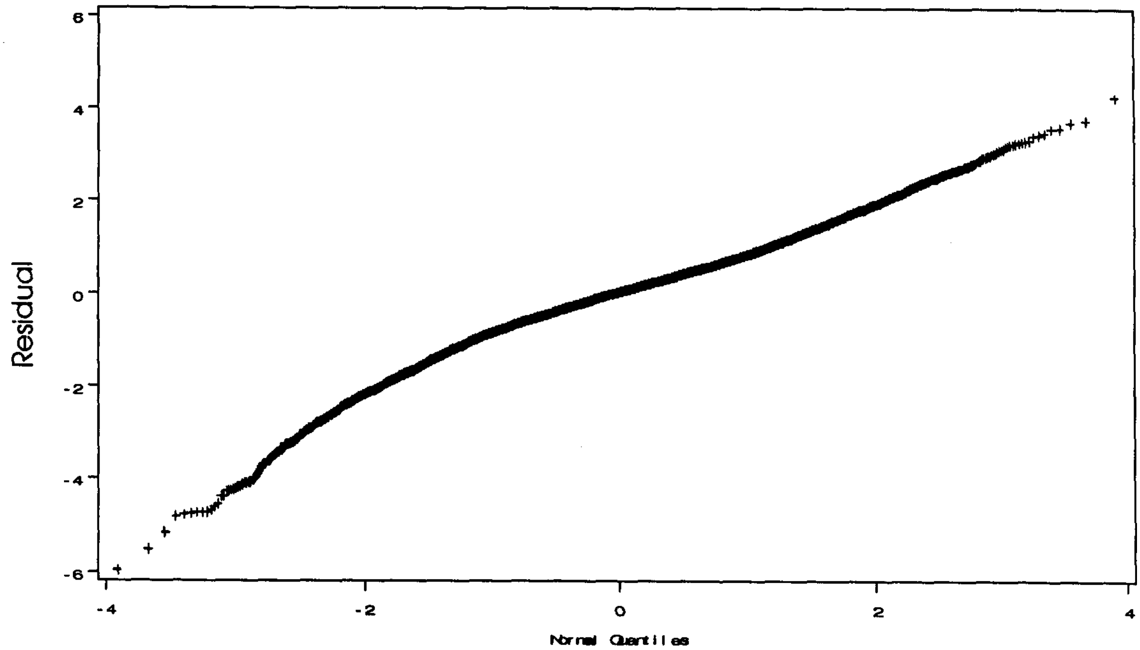

Figure E.8. QQplot for Model L4: In (IP LOS) = intercept + β_1(ED TTD minutes) + $\Sigma_i(\beta_i Covariates_i)$

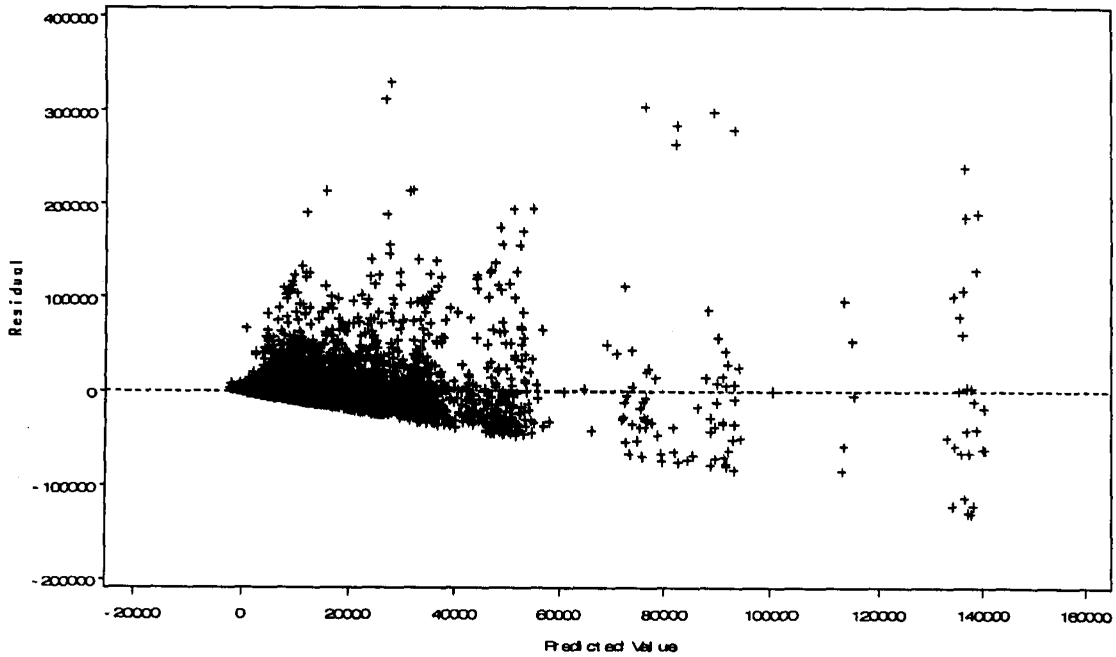

Figure E.9: Residual plot for Model C1: IP cost = intercept + β_1(ED TTD minutes) + $\Sigma_i\beta_i(Covariates_i)$

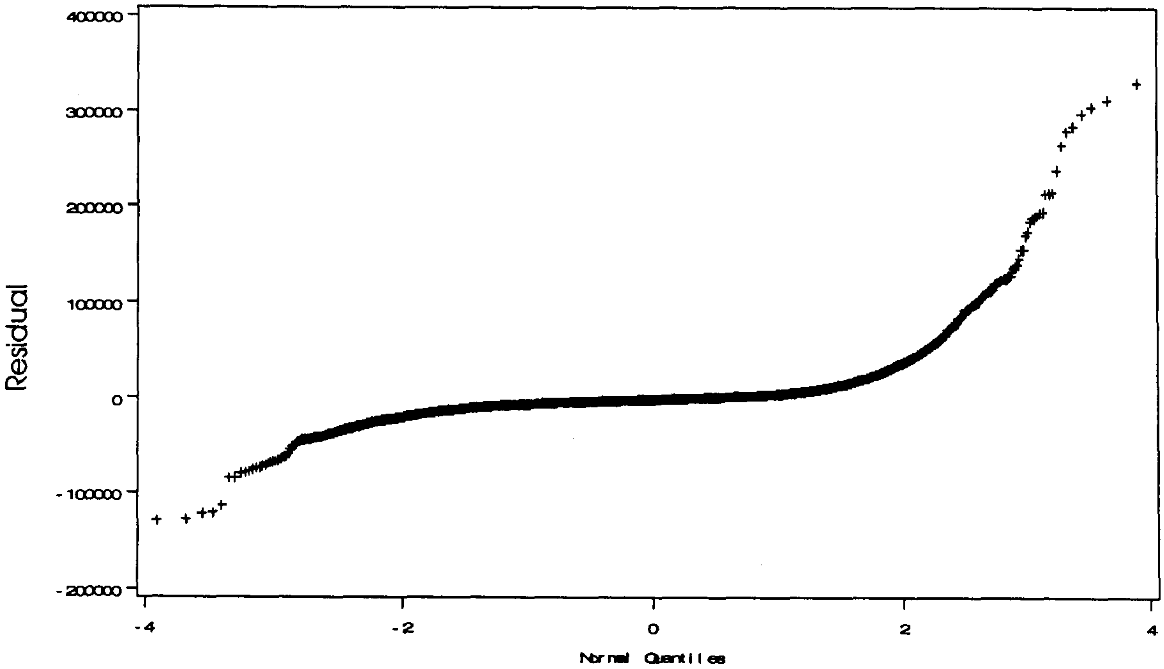

Figure E.10: QQ plot for Model C1: IP cost = intercept + β_1(ED TTD minutes) + $\Sigma_i\beta_i$(Covariates$_i$)

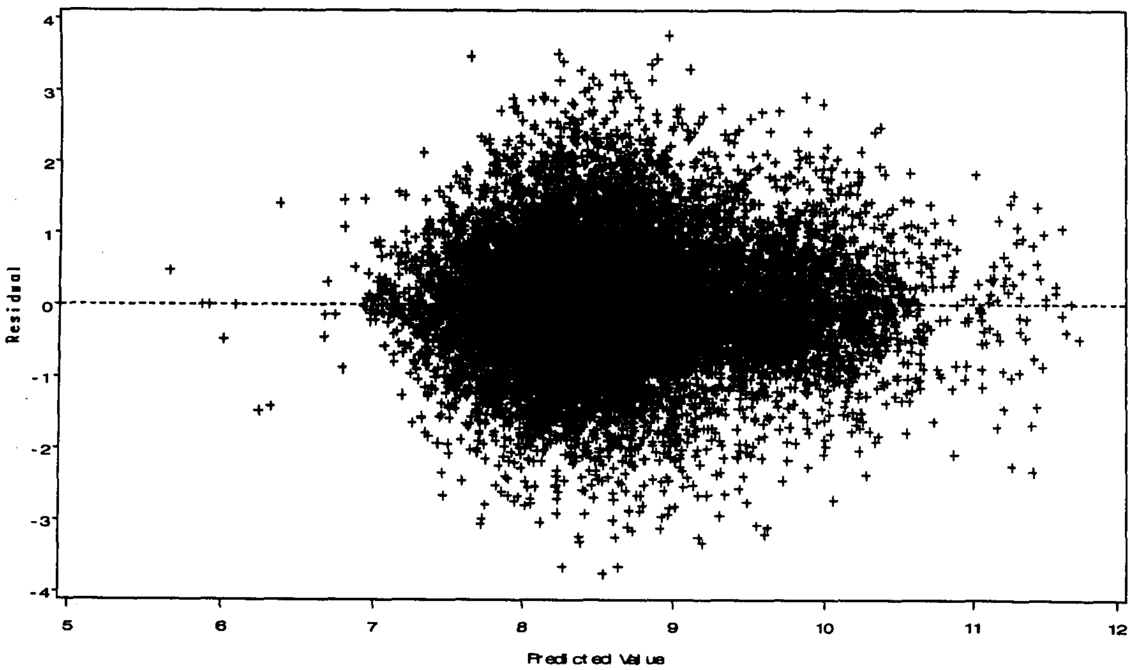

Figure E.11: Residual plot for Model C2: In (IP Cost) = intercept + β_1(Delay) + $\Sigma_i\beta_i$(Covariates$_i$)

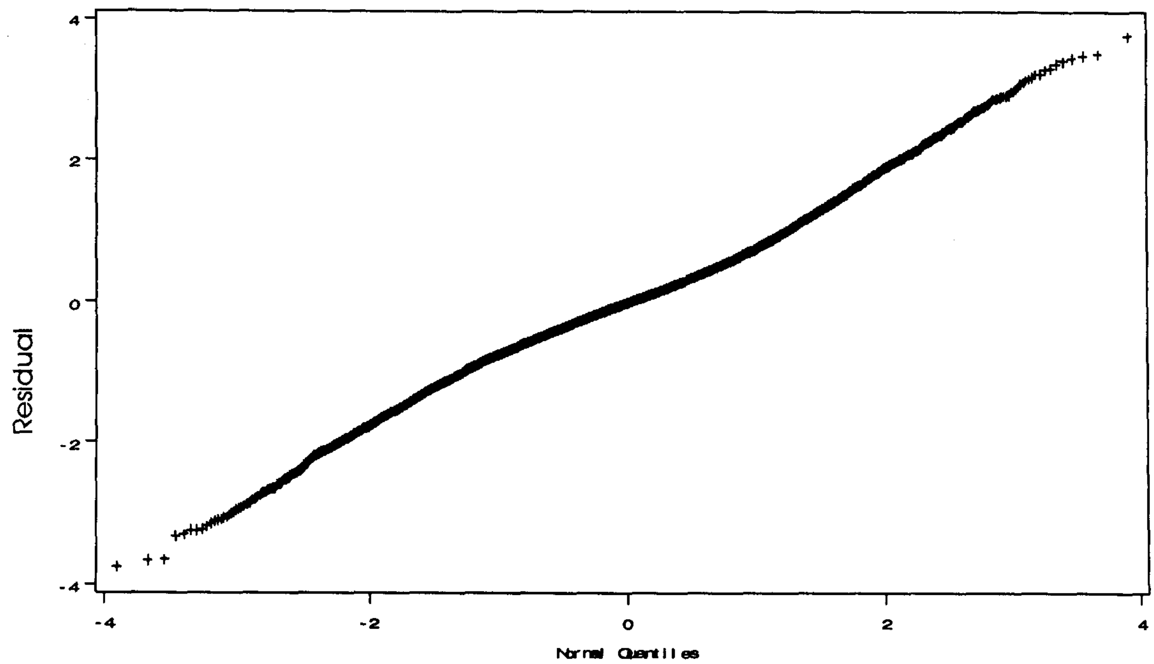

Figure E.12: QQ plot for Model C2: ln (IP Cost) = intercept + β_1(Delay) + $\Sigma_i\beta_i$(Covariates$_i$)

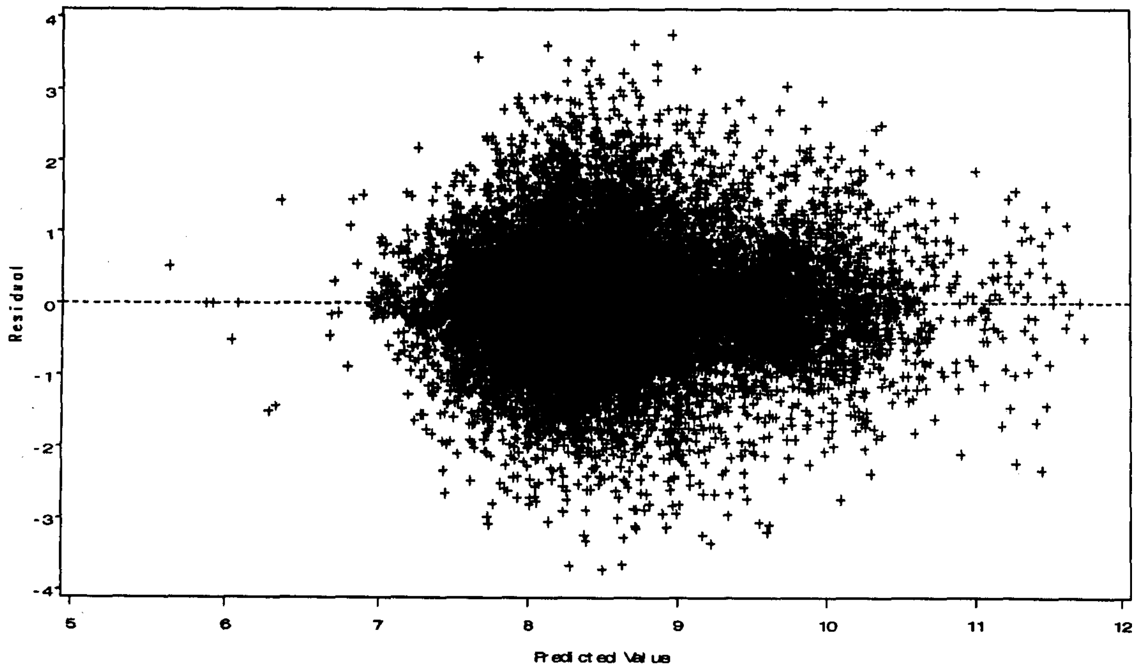

Figure E.13: Residual plot for Model C3: ln (IP cost) = intercept + β_1(2nd ED TTD Quartile) + β_2(3rd ED TTD Quartile) + β_3(4th ED TTD Quartile) + $\Sigma_i\beta_i$(Covariates$_i$)

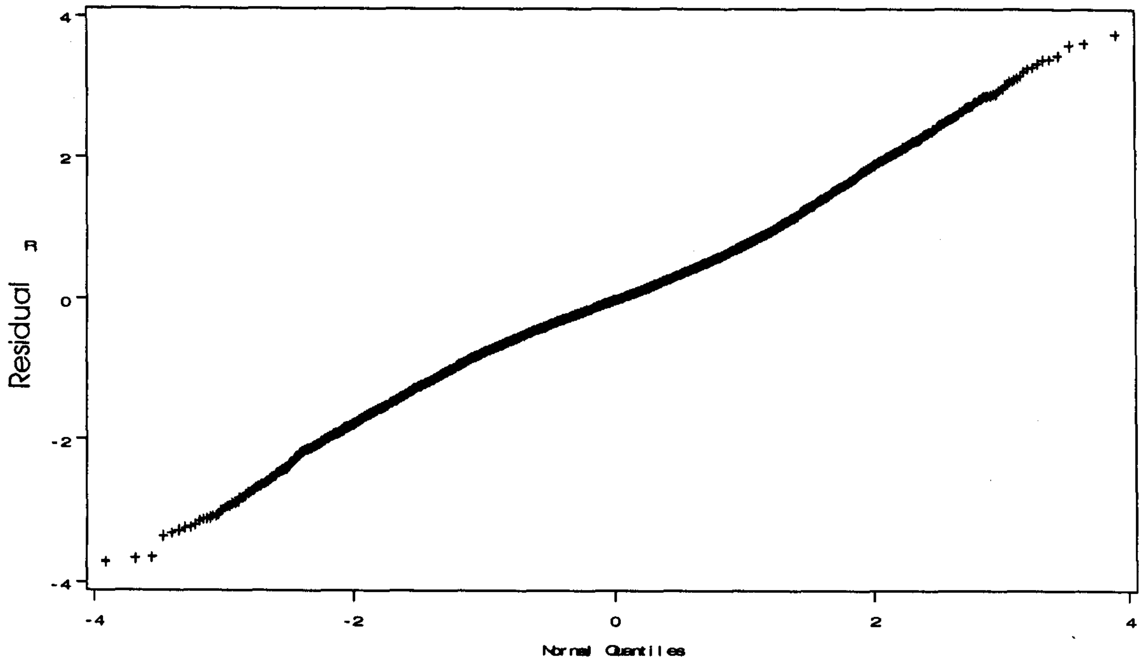

Figure E.14: QQ plot for Model C3: ln (IP cost) = intercept + β_1(2[nd] ED TTD Quartile) + β_2(3[rd] ED TTD Quartile) + β_3(4[th] ED TTD Quartile) + $\Sigma_i\beta_i$(Covariates$_i$)

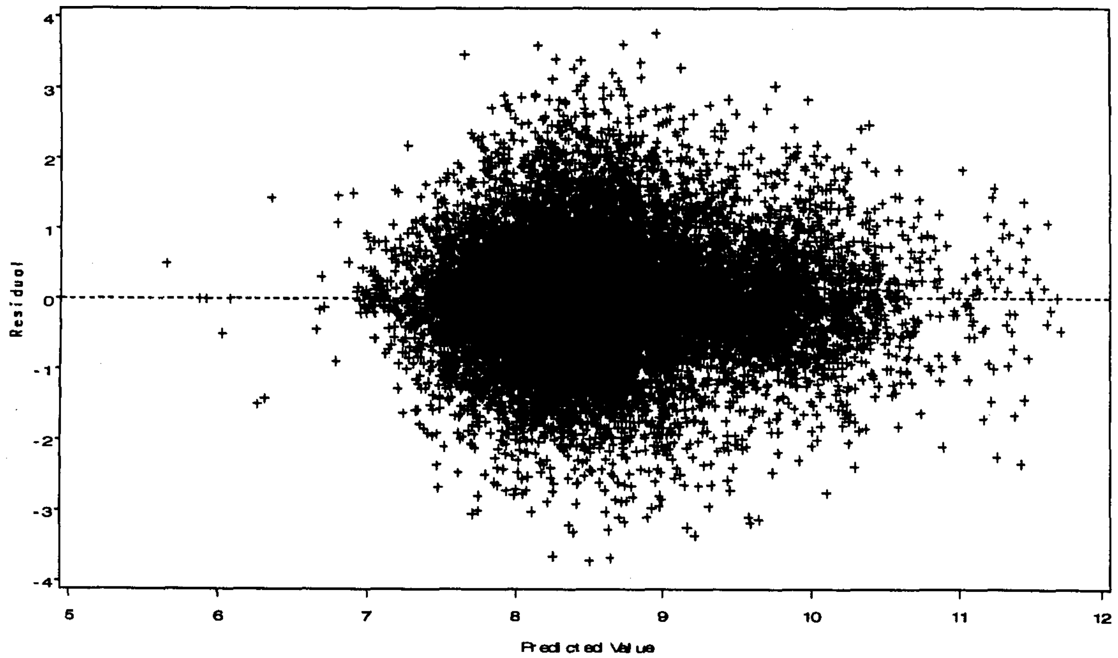

Figure E.15: Residual diagnostics for Model C4: ln (IP cost) = intercept + β_1(ED TTD minutes)

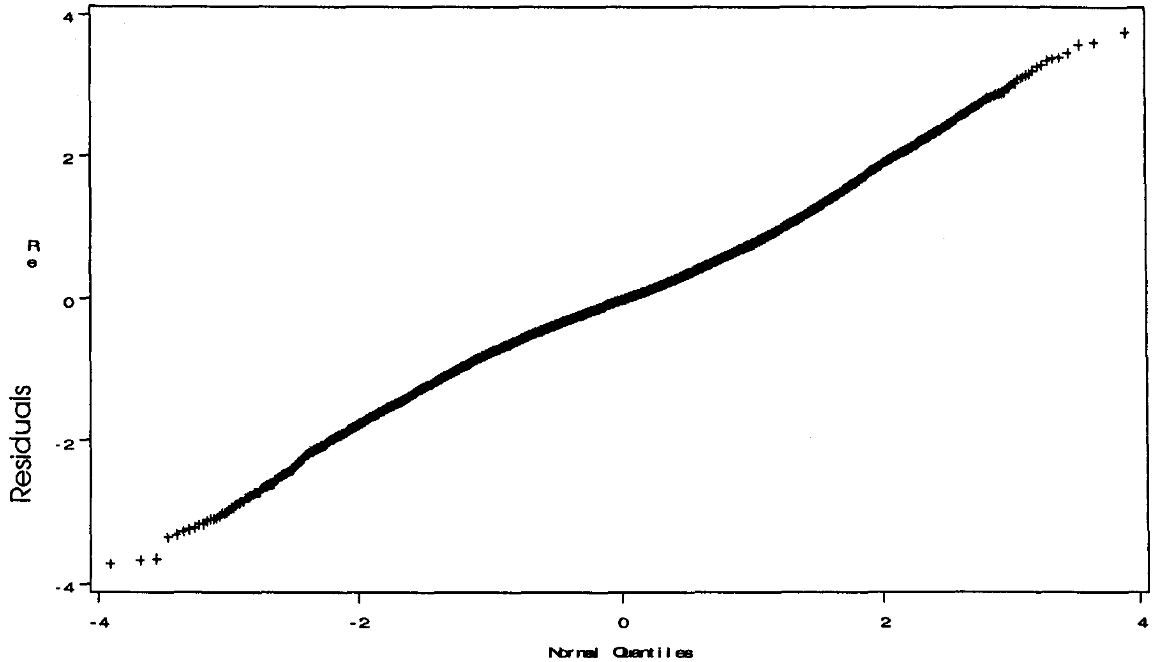

Figure E.16: QQ Plot for Model C4: In (IP cost) = intercept + β_1(ED TTD minutes) + $\Sigma_i \beta_i$(Covariates$_i$)

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