Applying Operations Research to the Inpatient Stroke Rehabilitation System

by

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Dalhousie University is located in Mi’kma’ki, the ancestral and unceded territory of Mi’kmaq. We are all treaty people. We recognize that African Nova Scotians are a distinct people whose histories, legacies, and contributions have enriched that part of Mi’kma’ki known as Nova Scotia for over 400 years.

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To the One in whom

I live and move and have my being.

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Abstract

The Canadian best practice guidelines recommend stroke patients receive a minimum three hours of therapy per day in inpatient rehabilitation. However, few patients receive this because cost is considered a barrier. The purpose of the study was to develop a linear programming model to assess the tradeoff of cost and guideline achievement. The objective function was to minimize the cost of inpatient rehabilitation. Decision variables included the cost of therapy and length of stay. Constraints included hours of therapy and the relationship between the amount of therapy and length of stay. The optimal solution showed minimal cost when patients received 3 hours of therapy per day. This results in a 24.3-day length of stay, costing $18,253.55 per patient. The Canadian average length of stay in rehabilitation and therapy cost an additional $1,470.13, compared with the optimal solution from the model. This demonstrates that more therapy may result in cost savings.

List of Abbreviations Used

Abbreviations	Meaning
ADLs	Activities of Daily Living
alphaFIM	Alpha Functional Independence Measure
BI	Barthel Index
DES	Discrete Event Simulation
ESD	Early Supported Discharge
FIM	Functional Independence Measure
HBCR	Home-Based Community Rehabilitation
LOS	Length of Stay
LP	Linear Programming
LTC	Long Term Care
mRS	Modified Rankin Score
NIHSS	National Institute of Health Stroke Scale
OT	Occupational Therapist
PT	Physiotherapist
SLP	Speech Language Pathologist

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Chapter 1: Introduction

A stroke occurs when there is a disruption of blood flow to the brain, either due to a blockage, known as an ischemic stroke, or due to bleeding in the brain, known as a hemorrhagic stroke (Truelsen et al., 2006). Stroke is the leading cause of severe physical disability worldwide and in Canada (Adamson et al., 2004; Canadian Stroke Network, 2011). In Canada, approximately one-hundred thousand stroke events occur each year with approximately fifty thousand resulting hospital admissions (Holodinsky et al., 2022). The burden of having a stroke is extensive, impacting all levels of society, from individuals who have experienced a stroke to the broader healthcare and economic system. Seventy-five percent of stroke patients will be disabled in some capacity (Ontario Stroke Network, 2012). The first-year post-stroke is estimated to result in an average of $53,001 CAD ($61,934 CAD-inflated adjustment for 2023) in direct healthcare costs for each patient. This cost to the Canadian economy is even higher when accounting for indirect healthcare costs. Individual patient impairments and healthcare costs are linked given that more disabling strokes result in higher direct and indirect healthcare costs (Mittmann et al., 2012). Stroke rehabilitation is one of the primary ways to manage the personal and economic burdens of stroke.

Stroke rehabilitation involves providing therapies and interventions that enable stroke survivors to reach optimal functional capacity (Hebert et al., 2016). This has an obvious impact on the quality of life of the individual, but also impacts the broader healthcare system and society. Fewer impairments, limitations, and restrictions following a stroke decrease healthcare utilization, reliance on social services for income, long-term care admission, and increase meaningful participation in society (Tyagi et al., 2018).

The three primary ways to provide stroke rehabilitation are inpatient, home-based community, and center-based community rehabilitation. Center-based community rehabilitation involves stroke survivors accessing therapeutic interventions from an outpatient clinic; home-based community rehabilitation involves patients receiving rehabilitation at home; and inpatient rehabilitation involves patients living in a rehabilitation unit while receiving therapeutic interventions (Crocker et al., 2013; Langhorne et al., 2011; Laver et al., 2020).

The number of stroke survivors living with disabilities is expected to increase from 405,000 in 2013 to between 654,000 and 726,000 by 2038 (Heart and Stroke Foundation, 2019; Krueger et al., 2015). As the number of Canadians living with stroke-related impairments increases, it is critical to ensure that the stroke rehabilitation system is equipped to provide the required rehabilitative care. Evaluating the stroke rehabilitation system must include measures used to assess both the effectiveness of the treatment and the cost-effectiveness of treatment services to ensure that healthcare resources are used efficiently and sustainably (Langhorne et al., 2002). There are many ways in which the stroke rehabilitation system can be improved; however, this study will focus on inpatient stroke rehabilitation as it is the setting that requires the most resources.

Inpatient stroke rehabilitation is one of the more time- and resource-intensive ways to provide rehabilitation. It is designed to provide therapy for patients with moderate-to-severe physical impairments. Given space and human resource constraints, it is important that this system operates efficiently to avoid bottlenecks that negatively impact access. In Canada, it is estimated that 25% of stroke survivors who are eligible for inpatient rehabilitation do not have access to inpatient care, and delays in admission to rehabilitation units can result in poorer functional outcomes (Willems et al., 2012). Once patients have been admitted, the majority do not receive the recommended amount of therapy per day, which results in longer than necessary stay within the rehabilitation units (R. Teasell, Meyer, Foley, et al., 2009; R. Teasell, Meyer, McClure, et al., 2009). When patients eventually complete their therapy, delays in being discharged from the unit due to factors external to the inpatient rehabilitation unit can result in rehabilitation unit beds being occupied by patients who no longer need to be in the unit (Tan et al., 2010). From admission to therapy time to discharge, efficient flow through the system is critical to ensure that inpatient rehabilitation can keep up with the increasing stroke burden.

Within inpatient stroke rehabilitation, the time spent with therapists is critical to ensuring that functional goals are met. As previously mentioned, the average patient in an inpatient stroke rehabilitation program does not receive the recommended amount of therapy. However, given the complexities and constraints of the Canadian healthcare system, the solution to this issue is not simply to provide more therapy time, as there is no unlimited supply of funds and human resources. It is important to account for the various factors that go into decision making when looking for solutions to complex healthcare problems. Operations research methodologies have been used to identify optimal solutions for complex healthcare issues, but to date (to the best of our knowledge) have not been applied to inpatient stroke rehabilitation and, more specifically, to improve suboptimal therapy time.

Therefore, the objective of the current work was to apply the operations research methodology of linear programming to the problem of low therapy time in inpatient stroke rehabilitation in the Canadian healthcare context. The outcomes of this model will include the optimal therapy time and length of stay to minimize cost. Chapter 2 - Background provides a background of literature related to therapy time for inpatient stroke rehabilitation. The purpose of this chapter is to provide the rationale for Chapter 3 - Methods, which focuses on the methodology of linear programming. Chapter 4 – Results, focuses on the results of the linear programming model. Chapter 5 – Discussion contextualizes the results of the present work within the existing literature, focusing on comparison of the results, implications and limitations of the current work and areas for future research.

1.1 Clarification of Terms and the Conceptual Framework

Before proceeding, it is important to establish the terminology used in this thesis. Various publications have used the terms 'therapy intensity,' 'therapy duration,' and 'therapy amount' to refer to the amount of therapy provided to a patient in units of time (Chan, 2015). Although these terms are commonly used in literature, it can be confusing to have such variability when translating research into clinical practice. For example, when it comes to exercise prescription and therapeutic parameters, physiotherapists use the term 'intensity' to refer to the amount of exertion required to perform a task. Conversely, 'time' refers to the total duration of the therapy in units of time. To avoid confusion or misinterpretation, in this work the term 'therapy time' refers to the amount of time a patient receives therapy as measured in units of time as it is a term that will be understood in both research and clinical application.

The International Classification of Function (ICF) is used to describe disability, which is conceptualized as "the outcome of a complex, multidimensional interaction between a person's health condition(s) and context" (Federici et al., 2017, p. 2347). Figure

1 describes the relationship between the components of the ICF model and an example of how that components may apply to a patient with a stroke. In this framework, impairment describes an issue at the level of body functions and structures. Limitations describe the difficulty of executing specific activities, and restrictions describe the difficulty of participating in meaningful life situations. Environmental factors describe facilitators and barriers to the functioning of a person, and although personal factors are not considered within the official model, they are an important consideration when describing disability.

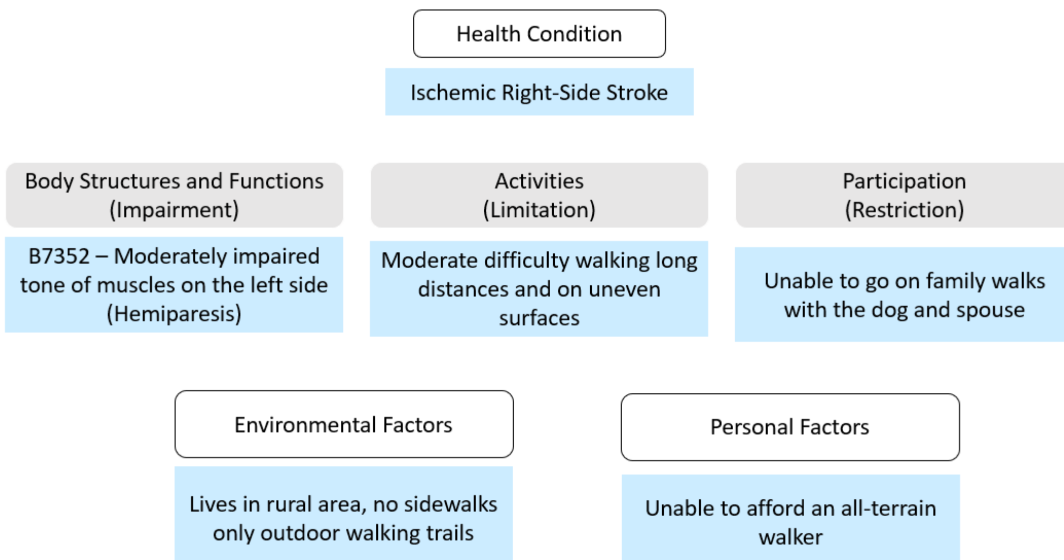

Figure 1: Example of the use of ICF Model Terms

Chapter 2: Background

2.1 The Burden of Stroke in Canada

2.1.1 Definition of Stroke

A stroke is defined as a “syndrome of rapidly developing symptoms or signs of focal loss of cerebral function with no apparent cause other than that of vascular origin” (Warlow, 1998, p. 1). This can cause impairments in movement, cognition, perception and sensation. Due to the heterogeneous etiology of stroke, the type, severity, and duration of stroke related impairments vary significantly. As previously mentioned, fifty-thousand stroke events result in hospitalization each year and the number of Canadians living with the impact of stroke is expected to increase in the next 10 years. Given the high prevalence of stroke and stroke related impairments, it is important to not only understand the incidence of stroke each year, but also the impact of these impairments on the individual and broader society.

2.1.2 Consequences of Stroke

Personal Consequences

Stroke can have a significant impact on the health status of individuals. The extent, severity, and duration of impairments can vary dramatically among individuals, but they can generally be divided into cognitive and physical impairments. Cognitively, patients may have difficulties with memory, orientation, attention, and language. They are also at an increased risk of depression and dementia compared to the general population (Hachinski et al., 2019; Hackett et al., 2005; Kutlubaev & Hackett, 2014). Physical impairments include hemiparesis, difficulties with talking and swallowing, decreased motor control, decreased muscle strength, pain, fatigue, impaired balance, and disrupted sensation. Both cognitive and physical impairments associated with stroke will impact a person's ability to participate in meaningful activities.

A study conducted in the Netherlands found that one in two stroke survivors had restricted participation in exercise, household tasks, and outdoor activities and did not return to work 1-year post-stroke (van der Zee et al., 2013). Another study found that 43% and 34% of stroke patients were dissatisfied with their ability to self-care and participate in leisure situations, respectively (Hartman-Maeir et al., 2007). And independence in activities of daily living (ADLs), cognitive abilities, and neurological deficits were significant predictors of return to work (Edwards et al., 2018). These participation restrictions can have a negative impact on patients' quality of life after stroke.

Economic Consequences

Broadly, strokes place a heavy burden on the economy. In Canada, stroke costs the Canadian economy $3.6 billion each year, (Heart and Stroke Foundation, 2019), with the first-year post-stroke costing an estimated $53,001 CAD per patient ($61,934 CAD inflated adjustment for 2023) in direct healthcare costs. In the United States and Europe, direct costs accounts for the majority of economic cost associated with stroke, with approximately 70% of costs related to direct care and 30% of costs indirect (Di Carlo, 2009). When adding the economic burden of informal care, it has been estimated that stroke costs an additional €11.1 billion for 27 countries in the European Union (Di Carlo, 2009). Given the aging population, the total number of individuals at increased risk for stroke is rising. However, advances in medical care have decreased the mortality of stroke, meaning that more individuals are surviving after a stroke (Lackland et al., 2014).

The personal and economic burdens of stroke are immense and given the expected increase in individuals living with the consequences of stroke, we can expect that this burden will only increase. Stroke rehabilitation can play a vital role in mitigating impairments related to stroke and, consequently, decrease the personal and societal consequences of stroke.

2.2 Overview of the Stroke Rehabilitation

Stroke rehabilitation is used to provide therapy and interventions that help stroke survivors achieve their "optimal physical, cognitive, emotional, communicative, and/or social functional level" (Hebert et al., 2016, p. 460). Interdisciplinary teams typically provide these interventions. Physiatrists primarily contribute to the coordination of patient care and follow the patient from admission to discharge; however, the primary therapeutic intervention providers are physiotherapists (PT), occupational therapists (OT) and speech-language pathologists (SLP). The roles of OTs and PTs can overlap; however, PTs generally provide therapies to improve balance, gait, muscle strength, cardiovascular endurance, and coordination, while OTs provide interventions that target cognitive impairment, upper extremity function, and improve daily living, occupation, and leisure activities (Langhorne et al., 2011). SLPs provide therapies to improve language, communication, and swallowing abilities (Langhorne et al., 2011). Other healthcare providers, including psychologists, nurses, pharmacists, social workers, kinesiologists, nutritionists, rehabilitation assistants, and recreational therapists, can be involved in the stroke rehabilitation process (Richards et al., 2018). Given the multidisciplinary nature of stroke rehabilitation, it is important to have categorizations and scales used across professions that allow for a common language when describing the impairments and limitations of stroke patients.

2.2.1 Scales Used in Stroke Rehabilitation

Broadly speaking, stroke survivors' impairments are categorized as mild, moderate, or severe. The National Institute of Health Stroke Scale (NIHSS) indicates the stroke severity, while the modified Rankin Scale (mRS), the Functional Independence Measure (FIM), Alpha Functional Independence Measure (alphaFIM) and Barthel Index (BI) each measure functional capacity and activities of daily living. The mRS was used to determine the global outcomes for stroke survivors. Individuals are ranked from 0 (no symptoms) to 5 (severe disability) and are compared to their pre-stroke activities (Heart and Stroke Foundation, 2015). Due to the poor definitions and the insensitivity of this scale, it is rarely used to provide specific recommendations in stroke rehabilitation. Consequently, the FIM, alphaFIM, and BI are more commonly used to determine rehabilitation needs and progress in patients with stroke, while the NIHSS is used in the acute phase to quantify the severity of the stroke and change in severity after acute treatment.

The alphaFIM was specifically designed to assess the disability and functional status of stroke patients in an acute hospital setting (Ontario Stroke Network, 2015; Stillman et al., 2009). It is an abbreviated version of the FIM and consists of six components (Table 1). The administration of the alphaFIM requires certification (Ontario Stroke Network, 2015). The Ontario triage guidelines for post-stroke rehabilitation recommend that patients with an alphaFIM score greater than 80 (categorized as mild) should be referred to community-based rehabilitation, those with a score between 40 and 80 (categorized as moderate), and those with a score less than 40 should be referred to inpatient rehabilitation or an alternative program such as restorative care (Ontario Stroke Network, 2015). AlphaFIM has been shown to be a reliable and a valid tool to measure functional ability in the acute hospital settings (Hinkle et al., 2010).

Table 1: Alpha FIM Components

Scale	Components
Motor Scale	Eating
	Grooming
	Bowel Management
	Transfers
Cognitive Scale	Expression
	Memory

The Barthel Index (BI) is used to assess activities of daily living in stroke patients. It is a 10-item instrument that measures an individual's level of disability in terms of activities of daily living. Two items have a 2-point system, six items have a 3-point system, and two items have a 4-point system, allowing individuals to score between 0 and 20 points. Lower scores indicate more dependence on caregivers for ADLs, and higher scores indicate more independence for ADLs. The BI has been shown to be a poor tool for assessing rehabilitation progress in stroke survivors, as it can be insensitive to changes in functional abilities and can suffer from ceiling effects (Duncan et al., 1997; Kwon et al., 2004).

Table 2: Barthel Index

The Barthel Index	
Bowels	3-point scale
Bladder	3-point scale
Grooming	2-point scale
Toilet Use	3-point scale
Feeding	3-point scale
Transfers	4-point scale
Mobility	4-point scale
Dressing	3-point scale
Stairs	3-point scale
Bathing	2-point scale

The FIM is considered the gold standard for assessing activities of daily living (Spackman & JG, 2016). It measures the severity of disability and rehabilitation outcomes (Black et al., 1999). The FIM consists of 18 items in six categories: self-care, sphincter control, mobility, locomotion, communication, and social cognition (Timbeck & Spaulding, 2004) (Table 3). The ability of the individual to perform each of the 18 items is assessed using a 7-point scale, which ranges from 1 - total assistance required to 7 - complete independence. The scores range from 17 to 126, with a higher score indicating a lower level of disability. The FIM can be further divided into a cognitive and motor sub-scale. To provide a FIM score, healthcare practitioners must be trained and certified.

Table 3: Items on the Functional Independence Measure

Scale	Category	Components
Motor Sub-Scale	Self-Care	Eating
		Grooming
		Bathing
		Dressing – Upper Body
		Dressing – Lower Body
		Toileting
	Sphincter Control	Bladder Management
		Bowel Management
	Transfers	Bed, Chair, Wheelchair Transfer
		Toilet Transfer
		Tub/Shower Transfer
	Locomotion	Walk/Wheelchair
		Stairs
Cognitive Subscale	Communication	Comprehension
		Expression
	Social Cognition	Social Interaction
		Problem Solving
		Memory

These scales, particularly the FIM, are often used to classify patients, determine their rehabilitation needs, and set realistic goals. There is variability in how the FIM scores are used to categorize patients into groups. Timbeck and Spaulding (2004) reviewed the literature on FIM use in stroke rehabilitation and found that different studies used different cut-offs for classifying patients as mild, moderate, or severe. Patients with FIM cut-off scores ranging from greater than 70 to > 100 were classified as mild, those with FIM cut-off scores ranging from less than 37 to less than 54 were classified as severe, and those with scores between the mild and severe ranges were classified as moderate. It is important to note that there is no universal definition for mild, moderate, and severe patient groups, and that various rehabilitation units categorize patients differently.

FIM has been used to predict the discharge destination and long-term care required after stroke rehabilitation (Black et al., 1999; Saji et al., 2015). Studies have shown that patients with a FIM score less than 50 at rehabilitation admission will remain dependent on caregivers for activities of daily living upon discharge (Timbeck & Spaulding, 2004). Conversely, patients with an admission FIM score greater than 90 are more likely to be independent in most activities of daily living upon discharge (Timbeck & Spaulding, 2004).

Since the impairments related to stroke are vast, rehabilitation post-stroke is also vast. Interventions aimed at reducing these limitations include physical fitness training, mental practice with motor imagery, music therapy, biofeedback, and electrostimulation (Langhorne et al., 2011). The stroke rehabilitation system facilitates delivery of these interventions to stroke survivors.

2.2.2 Stroke Rehabilitation Branches

The stroke rehabilitation system has three branches: inpatient, center-based community, and home-based community rehabilitation. Inpatient stroke rehabilitation involves a multidisciplinary team that provides interventions for stroke survivors living within a rehabilitation unit (Langhorne et al., 2011). Inpatient stroke rehabilitation is provided to patients with moderate-to-severe disabilities, while community rehabilitation is provided to patients with mild-to-moderate disabilities. Center-based community rehabilitation, also known as outpatient rehabilitation, involves a patient living at home and going to a rehabilitation unit with multidisciplinary teams or specific practitioner clinics to receive rehabilitative therapies. Home-based community rehabilitation (HBCR) involves rehabilitation therapies that a patient can receive without leaving home, and this is further divided into two categories, Early Support Discharge (ESD) and Telerehabilitation. HBCR, which is primarily administered through in-person visits with a team of therapists, is known as ESD. HBCR, which is primarily managed through technologies that facilitate virtual interactions, is referred to as telerehabilitation.

2.2.3 Accessibility to Stroke Rehabilitation

Lynch et al. (2017) noted that all cohorts of patients with stroke benefit from some form of rehabilitation. Stroke rehabilitation should be accessible to all stroke survivors and there is no firm medical ground for denying stroke patients access to rehabilitation based on age, stroke severity, or stroke type (Stroke Unit Trialist' Collaboration, 2013). In many high-income countries, the availability of inpatient rehabilitation services is considered limited, which leads to prioritizing patient cohorts who are deemed to receive the most benefit from rehabilitation and tend to exclude patient cohorts who are older or have more severe disabilities (Lynch et al., 2017; Putman et al., 2007; R. Teasell, Meyer, McClure, et al., 2009). In Australia, it is estimated that 10% of stroke survivors who are responsive to stroke therapy and would have fully recovered are not provided with rehabilitation (Lynch et al., 2019). Factors such as dementia or living in residential care before stroke are associated with not receiving rehabilitation (Lynch et al., 2019). In lower- and middle-income countries, access to rehabilitation services is even more limited; for example, only 40% of stroke survivors in Rwanda receive any form of rehabilitation (Bernhardt et al., 2020).

Each branch of the stroke rehabilitation system faces unique accessibility challenges. Inpatient rehabilitation is resource intensive. There are a limited number of beds, and it requires 24/7 housing and care for stroke patients. This can lead to admission criteria that are not based on evidence but on what the unit can handle. Literature on the accessibility of community rehabilitation is limited because there are organizational structures that make the system difficult to study as it is a combination of private and public healthcare. Barriers to outpatient rehabilitation have been identified, including depressive symptoms and educational levels (Ladwig & Werheid, 2020).

2.3 Inpatient Stroke Rehabilitation System

The inpatient stroke rehabilitation system offers rehabilitation to moderate to severe stroke survivors. There are four main stages (Figure 2). The first is admission, where a patient is referred to the rehabilitation unit, assessed for eligibility, and admitted to the unit. The second is the initial assessment, in which a patient is assessed for rehabilitation needs, and patient rehabilitation goals are set. In the third stage, the patient begins and continues rehabilitative therapy until the rehabilitation goals are met. In the final stage, a patient who meets the rehabilitation goals is discharged from the unit. The patient will either return to the same level of pre-stroke independence or a lower level of pre-stroke independence and consequently requires a higher level of care. This can be living alone at home, with a caregiver, or in a long-term care facility.

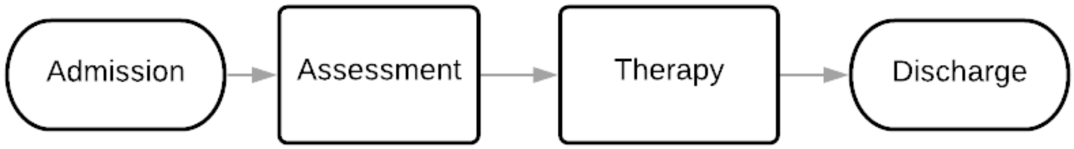

Figure 2: Stages of the patient flow through inpatient stroke rehabilitation

2.3.1 Admission to Inpatient Stroke Rehabilitation

There is no firm medical ground for denying moderate-to-severe stroke patients access to inpatient rehabilitation based on age, stroke severity, or stroke type (Stroke Unit Trialists' Collaboration, 2013). However, the criteria used to select patients for inpatient rehabilitation vary across countries and within rehabilitation units within a country. Lynch et al. (2017) performed a scoping review to assess admissions recommendations and actual admissions for 14 high-income countries worldwide. They found that some guidelines recommended that all moderately and severely impaired stroke patients should have access to inpatient stroke rehabilitation, and others recommended that inpatient rehabilitation should be restricted to patients who are likely to be discharged into the community. Additionally, they found that despite similarities in home-based community rehabilitation services in these countries, the proportion of stroke survivors admitted to inpatient rehabilitation varied greatly.

Willems et al. (2012) conducted a study to determine the number of patients who required inpatient rehabilitation in Ontario, Canada. The patients were screened using the stroke rehabilitation candidacy screening tool, which assesses the patient's rehabilitation candidacy and rehabilitation readiness. Candidacy was assessed using the alphaFIM score, patient's ability to follow commands, patient rehabilitation goals, and verbal consent. A patient was considered suitable if they were medically stable and could sit upright for a minimum of one hour, twice a day. Using these criteria, they determined that approximately 37% of stroke survivors meet the criteria for inpatient rehabilitation; however, 25% of stroke survivors who meet the criteria did not receive inpatient rehabilitation. The primary reason for this was the lack of beds in the unit. Within the province, between 9% and 43% of stroke survivors in the region were admitted to an inpatient rehabilitation program, which indicates a high variance in admission practices.

The criteria officially stated by a rehabilitation unit and the criteria used to predict admission to the rehabilitation unit are often different. It has been shown that age, pre-stroke function, and functional level post-stroke are the best predictors of who will be accepted into inpatient rehabilitation (Hakkennes et al., 2012, 2013; Hakkennes et al., 2011). There is compelling evidence that the functional status of post-stroke patients is a strong predictor of their outcome after inpatient rehabilitation. However, evidence on age is mixed. Some studies have shown that age is not correlated with functional gains following inpatient rehabilitation, while other studies have shown the opposite effect (Black-Schaffer & Winston, 2004; Denti et al., 2008; Luk et al., 2006). One explanation is that age is not a good predictor of outcomes after stroke rehabilitation; however, older individuals tend to have more comorbidities, which can affect functional outcomes from stroke rehabilitation. It is also important that patients are admitted into rehabilitation relatively early after stroke. Early admission is associated with better functional outcomes at discharge and a shorter length of hospital stays (Paolucci et al., 2000; R. W. Teasell et al., 2008).

2.3.2 Assessment of Rehabilitation Potential and Goals

When a patient enters an inpatient stroke rehabilitation unit, one of the first steps in the rehabilitation journey is the assessment of the rehabilitation potential and setting of rehabilitation goals. The definition of rehabilitation potential varies, and it depends on the clinician. It has been defined as the visible achievement of goals or outcomes over time (Burton et al. 2015). Rehabilitation potential and initial assessments are usually therapist-driven and may involve multidisciplinary teams of therapists, doctors, and nurses. The initial assessment involves obtaining a patient's initial functional status using a measurable scale, such as the FIM or BI. This initial assessment is critical and has a significant impact on the care that is provided.

The practitioner's concept of the patient's rehabilitation potential has a strong impact on the way the therapist manages the patient. The interviews with OTs, PTs, and SLPs in stroke rehabilitation units revealed the concept of rehabilitation potential was based on the responsiveness of the patient to therapy offered rather than predictive variables (Burton et al. 2015). The factors that impacted a practitioner's assessment of rehabilitation potential included the mood and motivation of the patient. Practitioners found it difficult to quantify the impact of these factors because they did not know the patient's personality before stroke. Rehabilitation potential was one of the bases for rationing therapy to patients, advocating for patients who may have been disadvantaged in the system, and managing patient expectations.

Along with rehabilitation potential, setting rehabilitation goals is an important aspect of initial and ongoing patient assessment. Goal setting is also therapist-driven and can involve a multidisciplinary team. There is limited evidence on the effect of goal setting on patient outcomes; however, it is an effective way to measure progress and review rehabilitation plans (Sugavanam et al., 2013). The adoption of patient-centered goal setting is limited; consequently, a patient's involvement in goal setting can range from no involvement to full involvement at all stages (Rosewilliam et al., 2011). Barriers to patient participation in goal setting include a patient's lack of understanding of the consequences of stroke, the process of rehabilitation, limited motivation, depression, and psychological issues (Sugavanam et al., 2013). Practitioner-based barriers include cultural differences between the practitioner and patient, difficulty in scheduling goal-setting meetings, and difficulty in getting patients to express goals. Organizational factors, such as high workload and staffing issues, can also negatively impact goal setting (Sugavanam et al., 2013).

Assessments of rehabilitation potential and goal setting can set the tone for a patient's stay in an inpatient stroke rehabilitation unit; consequently, it is important to do these correctly. A healthcare practitioner's conception of patient rehabilitation potential is affected by both quantifiable measures and therapist judgments; this has the potential to transform the patient's experience in rehabilitation. Patient-centered goal setting is limited in practice, although the framework of patient-centered healthcare is encouraged in many countries, including Canada. The barriers associated with setting patient-centered goals may be reduced by including psychological professionals to address patient mood and motivation, taking steps to improve therapist-patient communication, and improving organizational issues, such as scheduling.

2.3.3 Therapy in Inpatient Rehabilitation

During inpatient rehabilitation, patients can receive a variety of therapies depending on their needs. As previously mentioned, patients tend to receive most of the therapy from three healthcare professionals: PTs, OTs, and SLPs. A United Kingdom study found that 92%, 87%, and 57% of stroke survivors in inpatient stroke care required physiotherapy, occupational therapy, and speech therapy, respectively (Gittins et al., 2020).The exact type of therapy a patient receives is specific to the patient, but general guidelines are used to determine the total hours of therapy. The best practice guidelines in Canada for providing therapy in an inpatient stroke rehabilitation setting recommend that each patient receive a minimum of 3 hours of required therapy per day, 5 days per week (Herbert et al., 2016). Within the United Kingdom, the best practice recommendation is that a patient should receive at least 45 minutes of each required therapy, at least five days per week (Clark et al., 2018).

Gittens et al. (2020) conducted a study assessing approximately 95,000 inpatient stroke rehabilitation patients in England, Wales, and Northern Ireland. They found that patients received between 2 and 14 minutes of each required therapy per day, which is significantly below the United Kingdom best practice guidelines. In Canada, Canadian guidelines have also not been met. In a rehabilitation unit in Ontario, patients received an average of 90 minutes of therapy per day, 5 days per week, well below the recommended 3 hours per day (Foley et al., 2012). A rehabilitation unit in Newfoundland and Labrador also had comparable results, with patients receiving an average of 104 min of therapy per day, 5 days per week (Barrett et al.,2018).

There is evidence to support the idea that providing more therapy is better for the functional outcome of the patient after rehabilitation so it is important to investigate why the majority of patients do not receive the recommended amount of therapy (Foley et al., 2012; Hu et al., 2010; Kwakkel et al., 1997; Schneider et al., 2016; H. Wang et al., 2013a). Clark et al. (2018) investigated why patients in the UK do not receive the UK guidelines for inpatient stroke therapy. They found that the factors that influenced therapy provision, in order of influence, were: (i) time spent by a therapist in information exchange, (ii) time spent by a therapist in non-patient contact activities, (iii) staffing levels and deployment, (iv) patient factors, (v) limited knowledge of the evidence for therapy frequency and intensity, (vi) the influence of an external audit, and (vii) limited use of therapy timetabling. It is important to note that many factors related to patients not receiving the recommended amount of therapy were organizational or systematic factors, rather than patient-specific factors. Consequently, the goal of providing recommended therapy is more likely to be achieved when organizational rather than individual changes are made.

When investigating impact of best practice therapy time in Ontario, Meyer and O'Callaghan, et al. (2012) predicted that increasing rehabilitation time to three hours per day, seven days per week would save costs for the healthcare system, improve patient outcomes, and allow more patients to access the inpatient rehabilitation system. Meyer and Britt, et al., (2012) tested the effect of implementing length of stay benchmarks and increasing therapy time in a specific rehabilitation unit in Ontario and found that this intervention resulted in an average length of stay reduction of 5.7 days. Despite the many benefits of meeting and exceeding the guidelines for patient therapy time, implementing these recommendations has been difficult (Bayley et al., 2012).

While Meyer and colleagues' work provides some guidance on how these changes could be implemented to inpatient stroke rehabilitation systems outside Ontario, their template is specific to Ontario. For example, staffing levels will have a direct impact on the realization of best practice recommendations for rehabilitation time; however, to date, limited research has been conducted to determine the appropriate staffing level for therapists. Meyer et al. (2012) assumed that therapists would spend 6 hours of their 7.5 hour-day providing therapy, yet studies have shown that therapists only spend 33-66% of their time delivering therapy, a result which may have led Meyer et al. (2012) to underestimate the number of therapists required (Putman et al., 2007).

Providing therapeutic interventions is the purpose of the inpatient rehabilitation system; however, the amount of therapy provided to patients is below the standard set in Canada. The benefit of providing Canadian standard therapy time is that it improves individual patient outcomes and leads to better rehabilitation units and healthcare systems. However, little research has been conducted on how to achieve the Canadian standard of rehabilitation time in clinical practice. Questions about how to schedule rehabilitation, therapist-to-patient ratio, and the optimal time use of a therapist are unanswered in the literature, leaving healthcare administrators with little guidance on how to implement the best practice guidelines.

2.3.4 Discharged from the Rehabilitation Unit

Patients are typically discharged from a rehabilitation unit after they have completed their rehabilitation goals. Approximately 75% of patients are discharged to the community, and 25% are discharged to an institutional setting (Ouellette et al., 2015; Wong et al., 2016). The factors that predict a patient's discharge destination are age, functional status at admission, availability of a caregiver, and living arrangements before stroke (Chevalley et al., 2021; Pereira et al., 2014; Tanwir et al., 2014). The discharge of a patient can be either prompt or delayed depending on the elapsed time between the target and actual discharge date.

A patient is typically categorized as ready to leave the rehabilitation unit when they have successfully fulfilled their rehabilitation goals, although they can be discharged even if they cannot complete their rehabilitation goals. Discharge delays can be related to a variety of factors. Patients may have an extended stay in the rehabilitation unit as they await admission to a long-term care home or modifications to their home, such as stairs or bed lifts (Lai et al., 2017; Tan et al., 2010). Other social factors include living alone, the absence of a caregiver at the time of stroke, and the need to get a caregiver (Lai et al., 2017). In Singapore, it is estimated that 35.6% of stroke patients have a delay in discharge from inpatient rehabilitation, and approximately 35% of Canadian stroke survivors will exceed their target length of stay (Lai et al., 2017; Tan et al., 2010)

Delays in discharging patients can cause a backup in the inpatient rehabilitation unit as the number of beds is limited. As previously mentioned, one of the reasons for patients not being admitted into rehabilitation is a lack of bed availability, and this is exacerbated when patients who are ready to be discharged take up rehabilitation beds. There is limited literature on the impact of discharge delay, and studies should be conducted to determine the impact on the stroke rehabilitation system.

2.4 Operations Research in Stroke Rehabilitation

Operations research (OR) is a field of study that focuses on applying advanced analytical methods to optimize an objective or outcome based on specific decisions (Manson, 2006). OR was first introduced in a military setting and has been used to solve many healthcare problems since 1952 (Flagle 2002). Within healthcare, OR is typically used to optimize organizational productivity, including scheduling, resource planning, clinical and administrative modeling, treatment evaluations and layout design (Fakhimi & Probert, 2013). OR techniques include linear programming, discrete event simulations, mathematical modeling, Markov models, and forecasting. Although OR techniques have been used to optimize treatment efficiency in the acute aspect of stroke care to maximize patient outcomes, their use in stroke rehabilitation is significantly less common in the literature (Chemweno et al., 2014; Churilov et al., 2013).

Linear programming involves the development and optimization of a mathematical model to determine the best solution within a set of constraints. This methodology is ideal when there is a clear objective that depends on specific decision variables and various constraints on the variables. A linear program can be used to find an optimal solution. A limitation of this methodology is that it does not include stochasticity within the model and requires linear relationships between the objective and decision variables.

2.4.1 Linear Programming Models

Linear programming is a mathematical model that either minimizes or maximizes a linear function, subject to a set of constraints. The three components of linear programming are the objective function, decision variables, and a set of constraints. The objective function is a linear equation representing the problem to be solved. The goal is to either minimize or maximize the linear equation. The decision variables are a set of variables involved in the linear expressions of the objective function and constraints. The constraints are a set of linear equations that the decision variables must satisfy to obtain a feasible optimal solution. A diagram of linear programming models is shown in Figure 3. There are several types of linear program subtypes and extensions, such as integer linear programming, which constrains decision variables to be integers, and goal programming, which contains multiple objective functions, but the basic components of linear programs are the same.

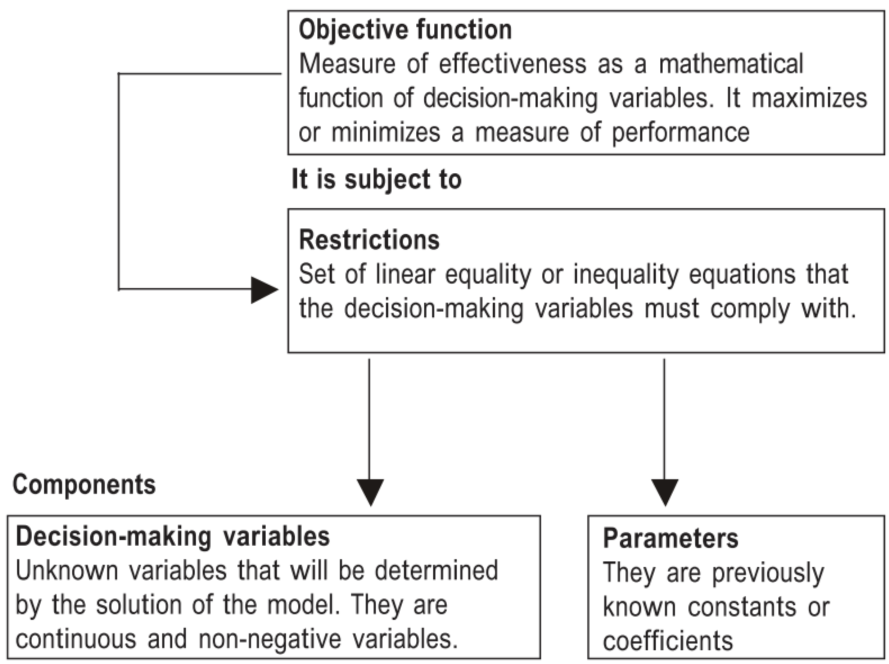

Figure 3. Reprint of the linear programming model components from Moreira (2003)

Linear programming models are rarely found in inpatient stroke rehabilitation literature. A few articles have used linear programming for general inpatient rehabilitation and outpatient clinics. Braaksma et al., (2014) used linear programming to schedule appointments for a multiple discipline team in a rehabilitation unit. Meyer et al., (1992) used linear programming to determine the optimal case mix for inpatient cardiac rehabilitation. Another study used the linear programming technique of data envelopment analysis to evaluate the efficiency of inpatient rehabilitation facilities in the United States (Harrison & Kirkpatrick, 2009). For outpatient clinics, linear programming, specifically goal programming has been used to determine optimal scheduling for multiple disciplinary teams and nurses (Güler, 2013; S. P. Wang et al., 2014).

One of the benefits of linear programming is that it inherently accounts for the resource limitations in the solution. The relationships between these constraints and decision variables allow for optimal solutions that balance competing interests, such as cost reduction and effective patient care. Many issues in the inpatient rehabilitation system can be reduced to a resource allocation problem such as determining the optimal case mix of patients admitted, staffing to patient ratios, and the feasibility of providing best-practice therapy time.

2.5 Rationale

The inpatient rehabilitation system has complex issues that impact the ability of this system to deliver excellent care to the stroke survivor population. Issues with admission criteria, timely admission and discharge, and the amount of therapy provided to patients have negative impacts on patient outcomes. The solution to these issues is not always evident as many factors are involved with making widespread changes to the way that healthcare services are provided to patients. Policymakers and healthcare administrators are required to balance cost, patient outcome, and resource constraints when making decisions to address these issues. Qualitative research can help inform these decisions, but this type of research typically focuses on a specific issue within the system. The research objectives of these studies are usually to isolate a specific component of a system to determine how making changes in that specific component will impact the system rather than consider the interactions between all elements of a system. Furthermore, many studies in this area do not use methodologies that can study these interactions.

OR methodologies are designed specifically to consider a variety of factors and interactions, and consequently, it is an ideal research methodology to use when looking at decision-making with complex issues. Therefore, the purpose of this work is to apply operations research methodologies, specifically linear programming to the inpatient rehabilitation system to address some of the complex issues within it.

This study focuses on the trade-off between providing best practice recommendations for therapy time and the cost of providing this therapy to inpatient stroke patients. While providing a minimum of 15 hours of therapy per week is the best practice standard in Canada, very few patients receive the recommended amount of therapy. Last et al. (2022), when discussing facilitators and barriers to participation in therapy, identified adequate staffing as a driver for achieving recommended daily therapy times. However, budget constraints can cause health administrators to be cautious about adding staff, especially if it is considered to be infeasible (M. Meyer, personal communication, March 2, 2021). Therefore, the purpose of this study is to develop a linear programming model which determines the trade-off required to meet Canadian guidelines for therapy time in inpatient stroke rehabilitation.

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Chapter 3: Methods

3.1 Model Framework and Inputs

The model that is described in this section is for a stroke patient with moderate impairments, which is determined by the Rehabilitation Patient Group algorithm for classification of stroke patients, which considers FIM score and age (Sutherland & Walker, 2008). Therapy time was comprised of the three core therapies of physiotherapy, occupational therapy, and speech language therapy. All patients were assumed to receive physiotherapy and occupational therapy, while half of the patients were assumed to receive speech language therapy (Meyer et al., 2012).

A linear equation which represents the relationship between therapy amount and total length of stay is shown in Equation 1. This equation represents that a stroke patient with moderate impairment will spend 35.037 days in the inpatient rehabilitation unit if no therapy is received, and the length of stay is reduced by 0.1473 days for every hour of therapy received. This relationship represents the average reduction in length of stay for each hour of therapy received. This equation was formulated based on the current Canadian practices and the estimated impact of changes to these practices. The average Canadian inpatient stroke rehabilitation unit provides 10 hours of therapy per week and moderate patients stay in the unit for 30 days. When estimating the impact of increasing therapy intensity, Meyer et al. (2012) estimated that an increase to 3 hours of therapy, 7 days per week would result in a 5-day length of stay reduction for moderate stroke patients. This was further validated as Meyer et al., (2012) looked at the impact of benchmarking and increasing therapy time at a rehabilitation unit in Ontario. They found patients in the intervention cohort had an average length 5.7 shorter than the baseline cohort.

$$y\ [\boldsymbol{length\ of\ stay}] = -0.1473x[\boldsymbol{total\ therapy\ hours}] + 35.037 \qquad (1)$$

Table 4 summarizes the cost inputs for each therapist per hour and the patient length of stay. This was derived from Meyer et al. (2012).

Table 4: Cost estimates for linear programming model

Parameter	Symbol	Value
Host of hiring PT per hour	C_1	\$50
Cost of hiring OT per hour	C_2	\$50
Cost of hiring SLP per hour	C_3	\$52
Cost of LOS per day per patient	C_4	\$600

3.1.2 Linear Programming Model

The full linear programming model is shown in Table 5. The objective function is to minimize the cost of providing care to the patient (equation (2). The decision variables are the hours of physiotherapy (h_{PT}), occupational therapy (h_{OT}), and speech-language pathology (h_{SLP}) provided across a patient's entire rehabilitation stay (the total length of stay (LOS)) per patient. The hours of therapy are measured in hours and the LOS is in days. To ensure that the amount of therapy provided is not worse than the current situation and reasonable from a patient stamina perspective, a constraint is included to ensure that the total therapy time (h_{total}) is greater than 10 hours and does not exceed 21 hours in a 7 day period (equation (3) and (4). The total amount of therapy is equal to the sum of the hours provided by the 3 core therapy disciplines (equation (5). To model the ratio of therapy provided by each of the core therapy disciplines, two constraints are added to ensure a patient would receive equal amounts of physiotherapy and occupational therapy; and the time spent with a speech-language pathologist is half that of a physiotherapist (equation (6) and (7). The relationship between the length of stay and total therapy hours, which was determined using a linear regression equation, is added as a constraint (equation (8). The final constraint ensures that the hours of therapy provided by each therapist and the total days the patient spent in therapy were non-negative (equation (9). This model was solved using Excel Solver (Microsoft, Version 2208, Redmond, WA).

Table 5: Linear programming model

$$Minimize\ cost = c_1 h_{PT} + c_2 h_{OT} + c_3 h_{SLP} + c_4 LOS \qquad (2)$$

Subject to constraints:

$$\mathrm{h}_{total} \geq \frac{10}{7} * LOS \qquad (3)$$

$$\mathrm{h}_{total} \leq \frac{21}{7} * \mathrm{LOS} \qquad (4)$$

$$\mathrm{h}_{total} = \mathrm{h}_{PT} + \mathrm{h}_{OT} + \mathrm{h}_{SLP} \qquad (5)$$

$$\mathrm{h}_{PT} = \mathrm{h}_{OT} \qquad (6)$$

$$\mathrm{h}_{PT} = 2\mathrm{h}_{SLP} \qquad (7)$$

$$LOS = -0.1473 h_{total} + 35.037 \qquad (8)$$

$$h_{total,} h_{PT}, h_{OT}, h_{SLP}, LOS \geq 0 \qquad (9)$$

3.1.3 Sensitivity Analysis

Sensitivity analysis was conducted to determine the robustness of the model and the optimal solution. It is focused on the relationship between the length of stay and the total therapy received (equation 8), and the relative cost of therapy and length of stay. The relationship between LOS and therapy time was analyzed because it was inferred based on previous work and has not been investigated in the literature. The cost ratios were investigated as they may vary between regions and between patients. To make the results more applicable, a percentage of cost was used instead of absolute cost.

Chapter 4: Results

4.1 Main Findings

For a stroke patient with moderate impairments, the linear optimization model described in Chapter 3 gives an optimal solution of 29.2 hours, 29.2 hours and 14.6 hours of PT, OT and SLP respectively during the patient's LOS. The optimal solution results in a 24.3-day LOS. The hours of therapy are distributed across the 24.3-day LOS, which is equal to 1.2 hours, 1.2 hours and 0.6 hours of physiotherapy, occupational therapy, and speech language therapy respectively per day. It is equivalent to a total of 3 hours of therapy per day and meets the Canadian best practice guidelines. The minimized cost obtained from the objective function of the model is $18,253.55 per patient.

4.2 Sensitivity Analysis

4.2.1 Sensitivity Test 1: Therapy Time and Length of Stay Equation

To test the sensitivity of the length of stay and the therapy hour variables, the slope (m) of the linear equation for LOS was changed and the effect on the optimal solution was assessed (equation 8). The changes to the value of the slope in equation 8, which represents the length of stay and therapy time constraint. The values for the slope of equation 8 were changed from the original -0.1473 in 10% increments, ranging from a -50% change to a 50% change in the absolute value of the slope (equations 11- 20). A graphical representation is shown in Figure 4.

This demonstrates how the optimal solution changes with overall increases or decreases in strength of the relationship between therapy time and LOS. The summary of *sensitivity test 1* is shown in Table 6 and Table 7. No other aspects of the original model were modified.

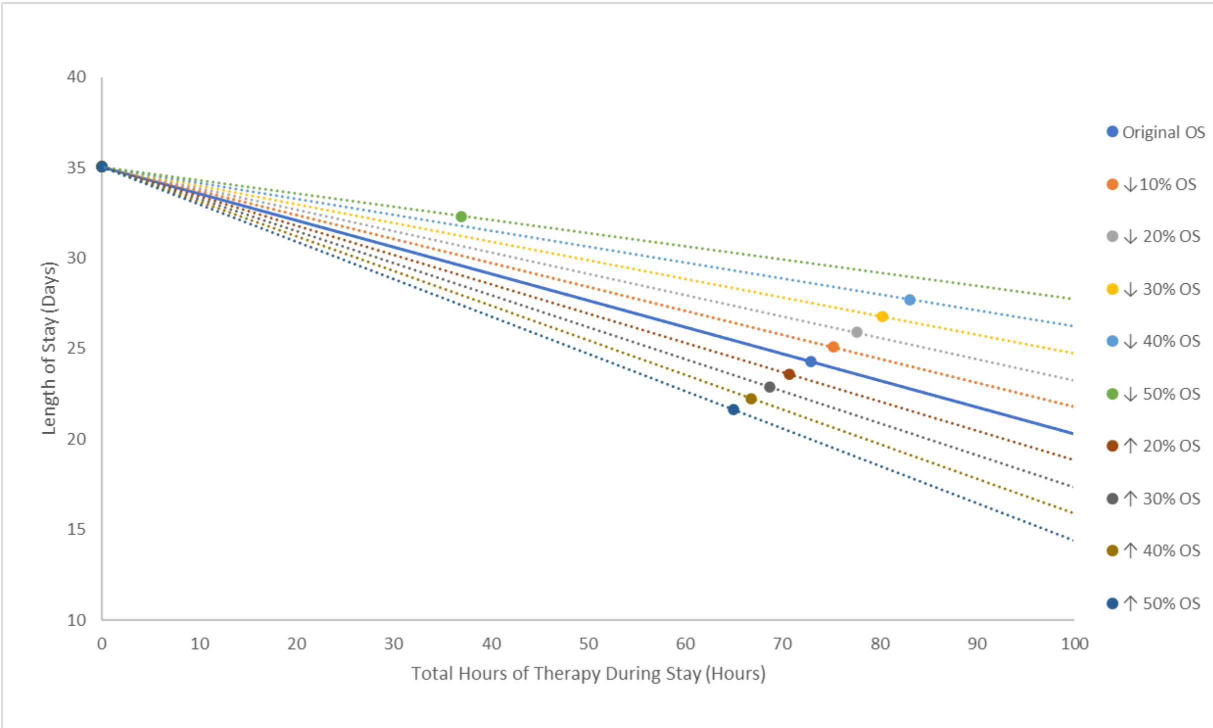

Figure 4: Graphical representation of sensitivity test 1 and the optimal solution (OS) associated with each 10% increment. The optimal value for each scenario is shown with dot. The solid line represents baseline scenario, and the dotted lines represent each sensitivity scenario.

The results of *sensitivity test 1* showed that the optimal solution for total therapy time and length of stay changed, however, the total hours of therapy per day remained 3 hours per day for all assessed changes except the 50% decrease in absolute slope (See Figure 6 and Figure 5)

. In the case of the 50% decrease in slope, the optimal solution was 14.7 hours of OT and PT each and 7.4 hours of SLP, leading to a 32.3-day LOS. This resulted in 1.14 hours of therapy per day.

Table 6: Sensitivity Analysis for Decrease in m for linear equation for therapy time and length of stay.

Change	Equation Modification		New Optimal Solution	Daily therapy hours
10%	$LOS = -0.1326h_{total} + 35.037$	*(10)*	$h_{PT} = 30.0\ hrs$ $h_{OT} = 30.0\ hrs$ $h_{SLP} = 15.0\ hrs$ $LOS = 25.1\ days$ $Total\ Cost = \$18,830.65$	3.0 hrs
20%	$LOS = -0.1178h_{total} + 35.037$	(11)	$h_{PT} = 31.1\ hrs$ $h_{OT} = 31.1\ hrs$ $h_{SLP} = 15.5\ hrs$ $LOS = 25.8\ days$ $Total\ Cost = \$19,445.44$	3.0 hrs
30%	$LOS = -0.103h_{total} + 35.037$	(12)	$h_{PT} = 32.1\ hrs$ $h_{OT} = 32.1\ hrs$ $h_{SLP} = 16.1\ hrs$ $LOS = 26.8\ days$ $Total\ Cost = \$20,101.73$	3.0 hrs
40%	$LOS = -0.088h_{total} + 35.037$	(13)	$h_{PT} = 33.2\ hrs$ $h_{OT} = 33.2\ hrs$ $h_{SLP} = 16.6\ hrs$ $LOS = 27.7\ days$ $Total\ Cost = \$20,803.86$	3.0 hrs
50%	$LOS = -0.073h_{total} + 35.037$	(14)	$h_{PT} = 14.7\ hrs$ $h_{OT} = 14.7\ hrs$	1.14 hrs

Change	Equation Modification	New Optimal Solution	Daily therapy hours
		$h_{SLP} = 7.4\ hrs$ $LOS = 32.3\ days$ $Total\ Cost$ $= \$21{,}251.56$	

Table 7: Sensitivity Analysis for increase in absolute m for the linear relationship between therapy time and length of stay

Change	Modified Equation		New Optimal Solution	Daily therapy hours
↑ 10%	$LOS = -0.162h_{total} + 35.037$	(15)	$h_{PT} = 28.3\ hrs$ $h_{OT} = 28.3\ hrs$ $h_{SLP} = 14.1\ hrs$ $LOS = 23.8\ days$ $Total\ Cost = \$17{,}710.77$	3.0 hrs
↑ 20%	$LOS = -0.177h_{total} + 35.037$	(16)	$h_{PT} = 27.5\ hrs$ $h_{OT} = 27.5\ hrs$ $h_{SLP} = 13.7$ $LOS = 22.9\ days$ $Total\ Cost = \$17{,}199.33$	3.0 hrs
↑ 30%	$LOS = -0.191h_{total} + 35.037$	(17)	$h_{PT} = 26.7\ hrs$ $h_{OT} = 26.7\ hrs$ $h_{SLP} = 13.4\ hrs$ $LOS = 22.2\ days$ $Total\ Cost = \$16{,}716.61$	3.0 hrs
↑ 40%	$LOS = -0.206h_{total} + 35.037$	(18)	$h_{PT} = 26.0\ hrs$ $h_{OT} = 26.0\ hrs$ $h_{SLP} = 13.0\ hrs$ $LOS = 21.6\ days$ $Total\ Cost = \$16{,}260.24$	3.0 hrs
↑ 50%	$LOS = -0.221h_{total} + 35.037$	(19)	$h_{PT} = 25.3\ hrs$ $h_{OT} = 25.3\ hrs$ $h_{SLP} = 12.6\ hrs$ $LOS = 21.1\ days$ $Total\ Cost = \$15{,}828.12$	3.0 hrs

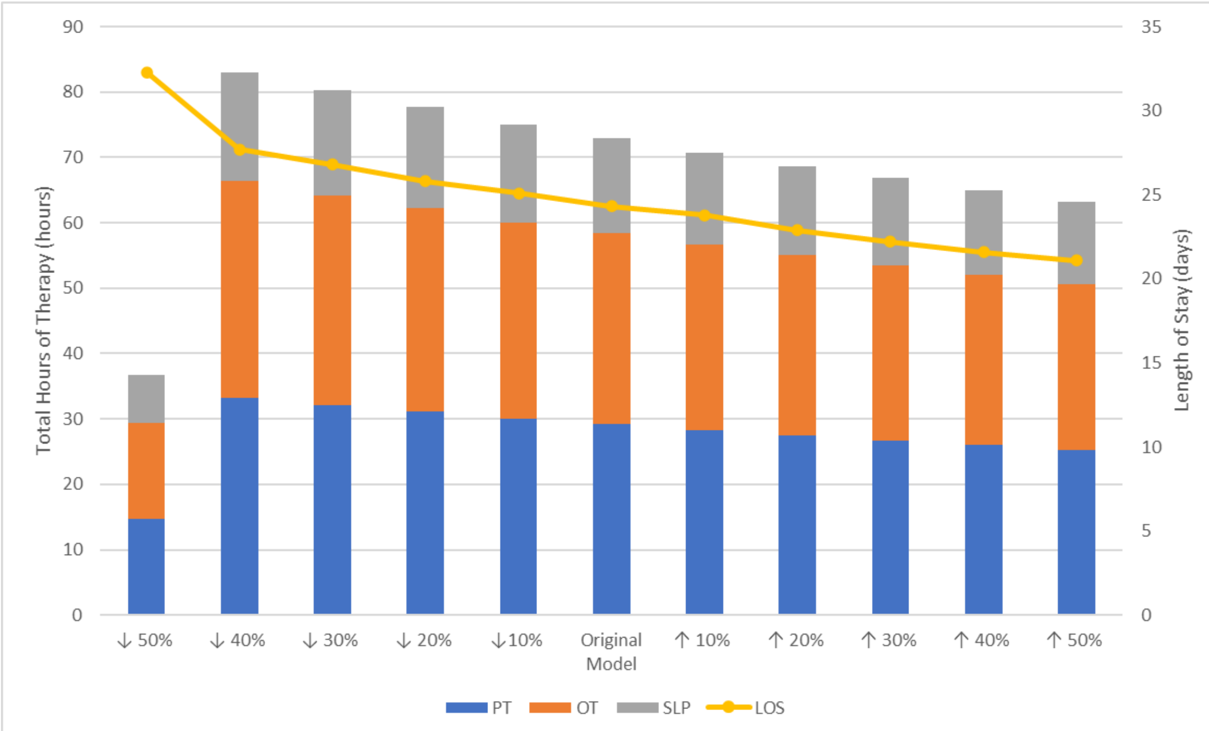

Figure 6 - Sensitivity Test 1: Optimal solution for total hours of therapy and total length of stay

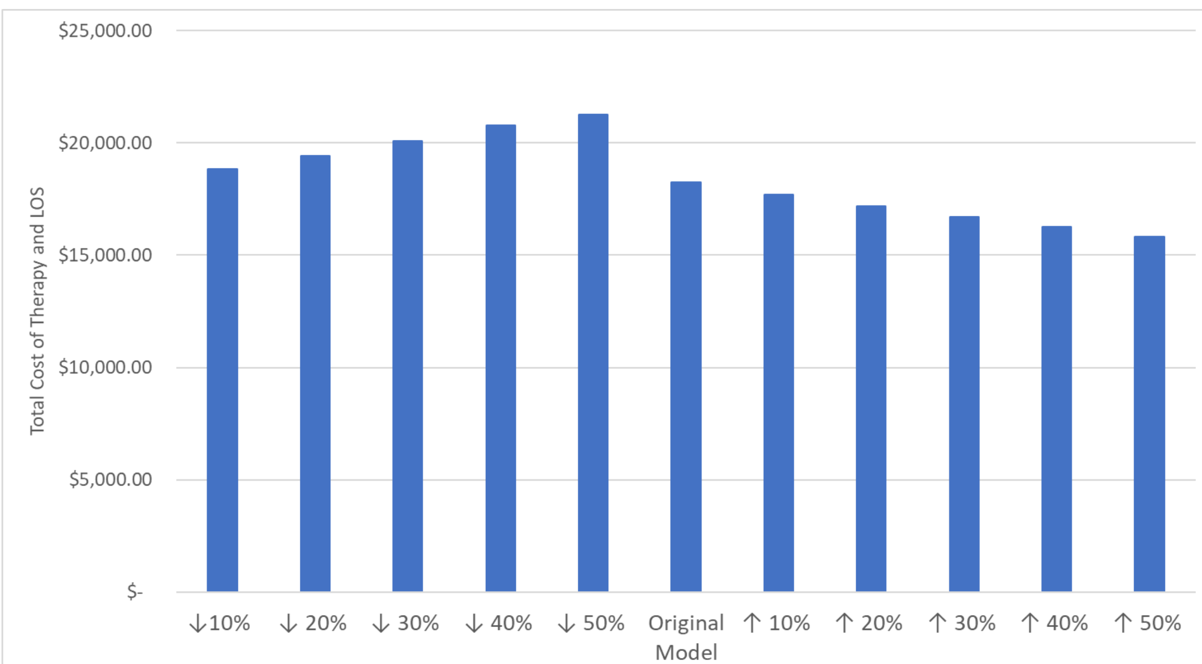

Figure 5 Sensitivity Test 1 - Total Cost of Therapy and LOS in the Optimal solution

4.2.2 Sensitivity Analysis 2: Percentage of Cost of Therapy and LOS

In sensitivity test 2, we investigated how changes in the percentage of cost of therapy provision to cost of length of stay would impact the optimal solution. In the original objective function (equation 2), the cost of 1 LOS day is \$600 and the total cost of 1 hour of therapy from all rehabilitation disciplines is \$152. The percentage of the cost of 1 day LOS to the cost of daily therapy, given by $\left(\frac{Cost\ of\ 1\ LOS\ day}{Cost\ of\ 3\ hours\ of\ therapy} \times 100\right)$, is approximately 400%. The percentage of cost was examined in 50 % increments, from a 200% to 600% percentage of 1 day LOS cost to therapy time cost. To implement this in the objective function, the parameter C4, which represents the cost of 1 LOS day, was manipulated while all other parameters remained the same (equation 2). No other components of the original model were modified. The result of the analysis is shown in Table 8.

Table 8: Sensitivity Analysis for Changes in the percentage of cost between cost of therapy provision and cost of length of stay

Percentage	LOS Parameter	New Optimal Solution	Daily Therapy Time
200%	\$305	$h_{PT} = 13.7\ hrs$ $h_{OT} = 13.7\ hrs$ $h_{SLP} = 6.85\ hrs$ $LOS = 30.0\ days$ $Total\ Cost = \$10{,}873.88$	1.14 hrs
250%	\$380	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$12{,}907.73$	3 hrs

Percentage	LOS Parameter	New Optimal Solution	Daily Therapy Time
300%	\$456	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$14{,}754.47$	3 hrs
350%	\$532	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$16{,}601.21$	3 hrs
Original (400%)	\$600	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$18{,}253.55$	3 hrs
450%	\$684	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$20{,}294.68$	3 hrs
500%	\$760	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$22{,}141.42$	3 hrs

Percentage	LOS Parameter	New Optimal Solution	Daily Therapy Time
550%	\$836	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$23{,}988.16$	3 hrs
600%	\$912	$h_{PT} = 29.2\ hrs$ $h_{OT} = 29.2\ hrs$ $h_{SLP} = 14.6\ hrs$ $LOS = 24.3\ days$ $Total\ Cost = \$25{,}834.90$	3 hrs

The results of the sensitivity analysis test 2 show that the optimal solution remains the same with for all increments except for the 200% cost percentage (See Figure 7 and Figure 8). In all other percentage of cost tested, the optimal solution was to provide the same hours of total therapy over the same length as the original optimal solution. When the percentage of cost was 200% the optimal solution was to provide 34.25 total hours of therapy across a 30-day LOS, which resulted in 1.14 hours of therapy per day.

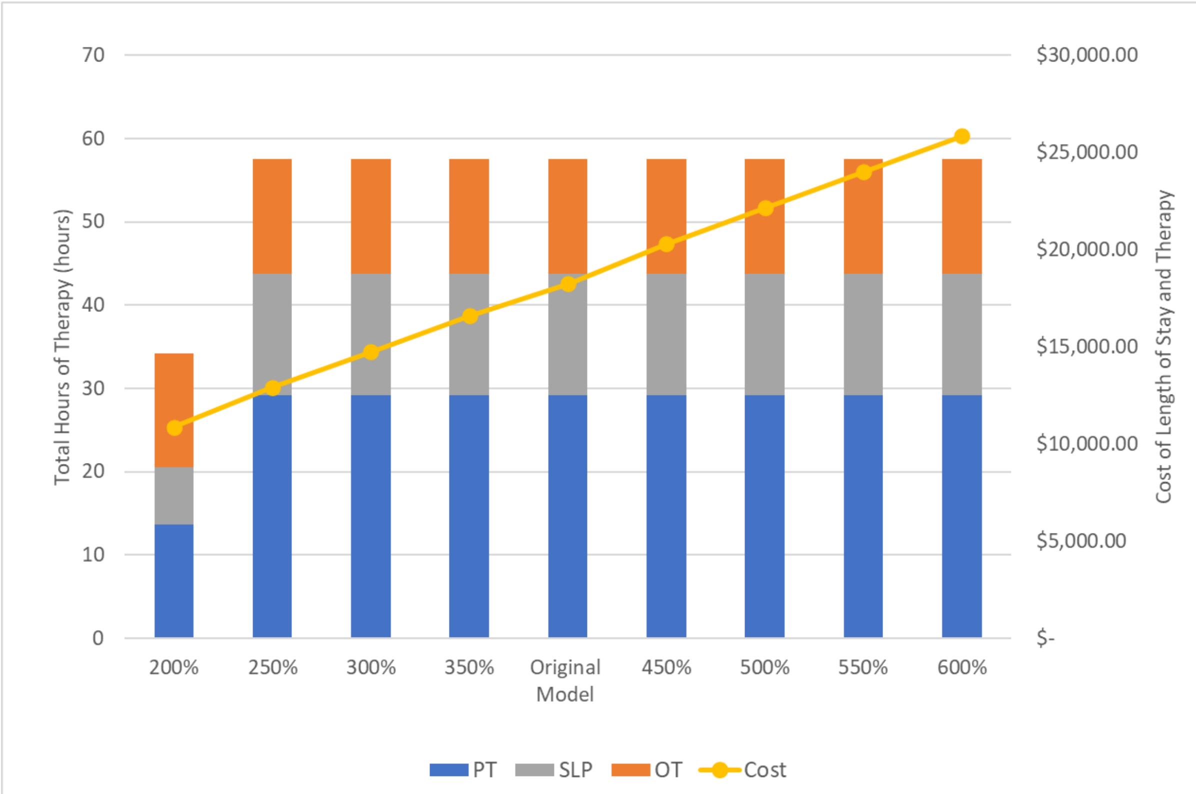

Figure 7 - Sensitivity Test 2 - Total hours of therapy and cost associated with the optimal solution for each iteration

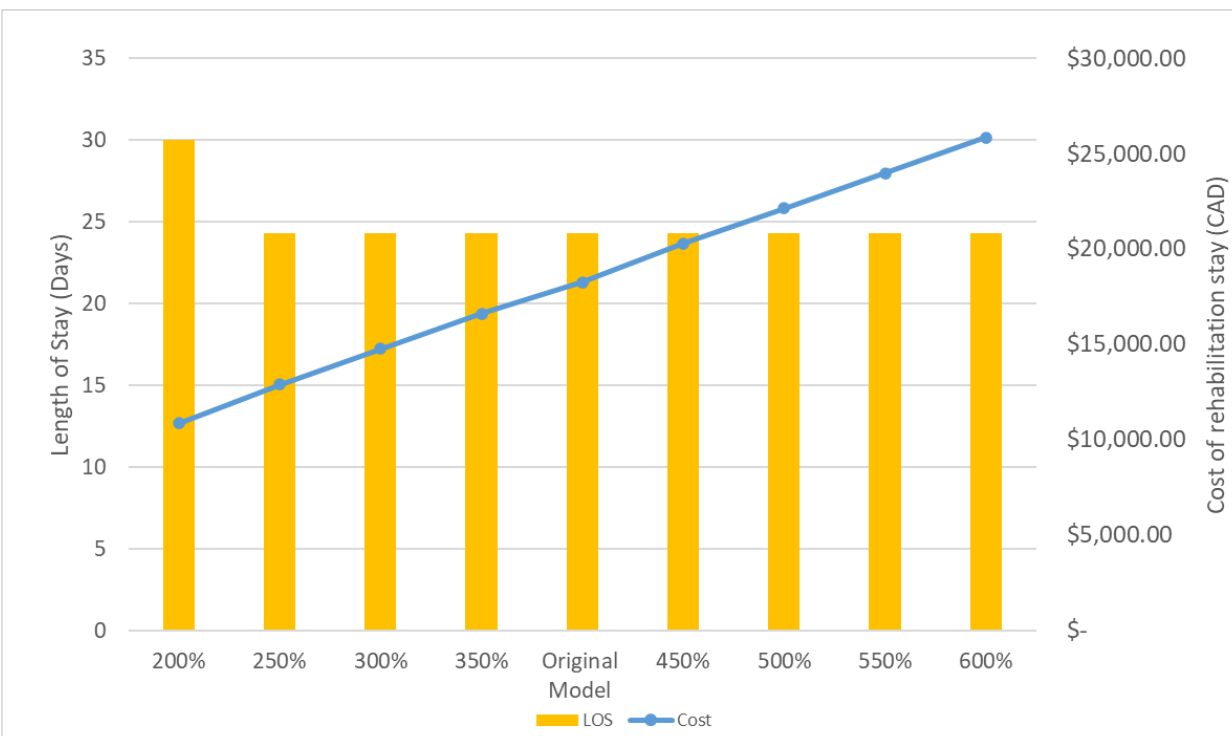

Figure 8 - Sensitivity Analysis 2: Total hours of therapy and cost associated with the optimal solution for each iteration.

Chapter 5 Discussion

This LP model shows that a shift towards providing more therapy may reduce costs, a phenomenon that is primarily driven by a reduction in length of stay for patients. The optimal solution resulted in a total of 3 hours of therapy per day with 1.2 hours for OT and PT each and 0.6 hours for SLP, meeting the best practice recommendation for therapy. This resulted in a LOS of 24.3 days and a total cost of $18,253.55 CAD per patient. Based on this model, the cost associated with current Canadian average hours of therapy and length of stay is $19,723.68. Therefore, the optimal solution from the LP model provides $1,479.13 cost savings per patient. The comparison of the LP optimal results and the current Canadian practice is shown in Table 9. These results show that when looking at the trade-off between providing therapy and cost, there actually is no trade-off required as providing additional therapy results in cost savings, allowing for a solution that at best achieve best practice guidelines for therapy and savings in cost and at worse, is cost-neutral.

Table 9. Linear Programming Optimal Solution versus Current Canadian Average

	Canadian Average	Model Solution
Hours of Therapy per Week	8 hours	21 hours
Length of Stay	30 days	24.3 days
Length of Stay Cost	$18,000	$14,579.51
Cost of hiring therapist over LOS duration	$1,723.68	$3,674.04
Total Cost	$19,723.68	$18,253.55

This is further explored in the sensitivity analysis, which reveals two additional aspects of the LP model and the optimal solution. The first finding is that when all other variables are unchanged the LP model solution remains optimal up to a 40% decrease in the absolute slope of the therapy time to length of stay linear relationship. This means that even if the LP model overestimated the strength of the relationship between therapy time and length of stay, the optimal solution is still valid even with a 40% decrease in the slope. When looking at the implications of this result for stroke rehabilitation, the primary message is that providing additional therapy, even if not as effective as estimated by results from Meyer et al, (2012) can still be beneficial from a cost perspective. This result holds even if the therapy provided is not consistently efficient and effective at improving functional gains and subsequently reducing LOS.

The second finding is that the solution is optimal until the cost of length of stay is twice as much as the cost of providing 3 hours of therapy. In practical terms, it helps to account for a situation with variability in the cost of therapy provision and housing patients in a LOS unit. The cost benefits of providing therapy increase when the cost of housing patients is high and decrease when the cost of housing patients is low. This can have several implications for the application of these results. At the level of the patient, certain patients may cost more to house within the unit due to variables such as complex dietary needs and transportation to frequent appointments outside of the unit. Organizational factors may also impact the cost ratio of therapy provision and housing such as the pay scale for therapists and therapist ratios.

In the situation where providing additional therapy would not be more cost effective and gives information that decision makers can use to ensure that providing additional therapy is cost effective. An example of this would be a situation where the cost of housing patients in an inpatient rehabilitation setting is relatively inexpensive. From a purely cost-saving perspective, it would be more beneficial to provide patients with therapy using a less expensive source such as utilizing therapy assistants to provide most of the additional rehabilitation.

When assessing the behavior of the model itself, the results and sensitivity analysis show that the constraint of minimum and maximum therapy time drive the results as the results in all iteration tended to extreme. For the iterations in which the optimal solution was the minimum amount of therapy, a further decrease in the minimum therapy would likely result in improvement in cost saving and increased LOS. However, the ethics of providing patients with sub-optimal care for the sake of saving costs would come into question. In the iterations where the optimal solution was the maximum amount of therapy, a further increase in the maximum therapy constraint would likely result in further cost saving and a decrease in LOS. However, the realism of the model would decrease for at least two reasons. First, fatigue is one of the most common post-stoke impairments and patients likely would not be able to tolerate significantly more hours of therapy per day. Second, even if patients could tolerate many hours of therapy, there would likely be diminishing returns on the effectiveness of therapy.

Overall, the results from this study indicate that the best practice amount of therapy provides rehabilitation units with a net cost saving compared to the current Canadian average of therapy hours. Furthermore, previous research showed that more daily therapy, specifically daily therapy of more than 3 hours, is associated with greater functional independence outcomes for patients (Wang et al., 2013b). Therefore, providing additional therapy may decrease the cost while the patient is in the inpatient stroke rehabilitation unit and result in increased functional independence. This can have significant personal, societal, and economic implications even after a patient has left inpatient rehabilitation as improved recovery may lead to reduced caregiving requirements and caregiver burden.

5.1 Comparison to Previous Work

It is difficult to directly compare this modeling study with previous work because this is a relatively understudied aspect of stroke rehabilitation. The few studies on inpatient rehabilitation are in a different healthcare context.

A study conducted in Japan considered direct medical costs before and after the adoption of a healthcare policy that incentivized higher-intensity stroke rehabilitation. In this healthcare context, there is a unique system of convalescent rehabilitation units, which provide intensive core therapies to patients' post-stroke. This unit is designed for patients who require assistance for ADLs after their acute hospital stay and the maximum length of stay in this unit is 180 days. In April 2011, a new policy was introduced that incentive increased rehabilitation time and Nagayama et al., (2021) conducted a retrospective study to investigate the effect of the incentive high intensity rehabilitation on medical costs. Note that the use of the term 'intensity' in this study refers to the therapy time and not effortfulness of therapy.

The low intensity and high intensity groups in Nagayama et al. (2021) had an average therapy time of 89.7 mins and 135.3 minutes of therapy 7 days per week, respectively. The length of stay for the higher intensity group was higher, but non-significant compared to the low intensity group with LOS of 96.3 days and 93.5 days, respectively. Results indicated that the high intensity rehabilitation group was associated with higher rehabilitation medical costs but lower total medical costs one year after discharge. When comparing the results of these studies with the current work, there is a conflict in the results given that the more therapy time resulted in increased medical rehabilitation costs. To make an accurate comparison, it is important to note how the model's conceptual framework differs from the studies.

The LP model was developed with an assumption that functional gains would be the target criteria for discharge and these targets would apply regardless of the therapy time. To consider the context of functional gains we can look at another study conducted in Japan in an overlapping time to Nagayama et al., (2021). In the study by (Kamo et al., 2019), high intensity rehabilitation was defined as ≥ 15 hours of therapy per week and low intensity being defined as less than 15 hours per week. Kamo et al. (2019) found that patients who undergo higher intensity rehabilitation have better motor and cognitive gains as assessed by the FIM compared to the lower intensity group, and a greater percentage of these patients were discharged home (Kamo et al., 2019). And the high intensity group achieved higher functional gains compared to the low therapy group in the same length of time.

In the context of this model where functional gains are the basis for discharge, patients in a Japanese healthcare context stayed past their functional gain discharge date, meaning that the cost numbers are not an accurate picture the LP model in this study. An accurate comparison would be studies that focus on when functional milestone or gains were achieved. This would provide a better comparison of when a patient would theoretically be discharged vs. when they are discharged. Additionally, within the other studies, the reason for discharge is not stated, so it is possible that LOS numbers are not an accurate representation of when level of functional gains were achieved, but other factors such as discharge delay.

5.2 Implications for Stroke Rehabilitation

The optimal result suggested that providing the best practice recommendations for therapy hours is cost effective, and consequently from a monetary lens, it should be feasible to implement this in the current Canadian healthcare system. However, practical implementation requires more than simply having the money to pay for more therapy as other resources such as human and hospital space facilities are also required to increase the therapy time. There are a variety of ways to increase the therapy time, including increasing the amount of therapy provided by the primary rehabilitation therapist and providing therapy to multiple patients at a time. Each of these strategies will have different benefits and barriers to implementation in stroke rehabilitation units. Note that due to personal experience and expertise, the majority of the discussed implications will come from a physiotherapy perspective.

5.2.1 Increasing Therapy Time with the Primary Rehabilitation Team

The most direct way to increase therapy is to increase the time in therapy provided by OTs, PTs and SLPs. One aspect that must be considered is the ratio of therapist to patients required to achieve the best practice guidelines. There is little research that looks directly at appropriate therapist to patient ratios for inpatient rehabilitation. Communications with subject matter experts indicates that a 1:6 ratio of therapist to patients is a common benchmark for physiotherapy staffing ratios (personal communication, A. MacDonald, December 9, 2020). The work of M. Meyer et al., (2012) supports this, where it is assumed that therapist would spend 6 hours of their 7.5 hour-day providing therapy and consequently be able to see 6 patients for 1 hour per day. This assumes an 80% therapy time efficiency for therapist. However, studies looking at the time allocation of therapist suggest that a different ratio may be more appropriate.

A study by Putman et al. (2006) investigated the time allocation of OTs and PTs on stroke rehabilitation units in 4 European Countries. The therapist self-reported their activities at 15 minutes intervals during the day. The activities were broadly divided into therapeutic activities and non-therapeutic activities. Therapeutic activities included tasks such as mobility training, ADL training, neuropsychological training, and other trainings. Non-therapeutic activities included patient and unit-related co-ordination and other tasks such as breaks or giving advice to external parties. Patient related coordination included patient administration, discussions about patients, ward rounds and team conference. Unit related coordination included unit administration, training, supervision and discussions about the team and unit. The results showed that PTs and OTs only spend 33-66% of their time in inpatient rehabilitation delivering therapy with 25-33% of their time being spent on patient coordination tasks. Although this study was not done in a Canadian healthcare context, it does provide some insight about how OTs and PTs allocate their time in an inpatient stroke rehabilitation unit.

Given that therapists are often required to do other tasks apart from providing therapy directly to patients, it is important that time spent in other tasks is appropriately accounted for to determine the number of therapists required to meet the recommended hours of therapy. Simply advising therapists to spend more time on therapy may not be feasible since there are specific tasks that therapist need to engage in before and after providing therapy, including liaising with the team about the status of the patient, documentation after a therapy is provided and order equipment. Changing this time ratio may be difficult to implement as it would involve not only the therapist, but also the other patient coordination stakeholders such as other healthcare staff and family.

The model developed in this work accounted only for the cost of increasing the number of therapists. It did not consider the ways that therapists currently spend their time. With this model, it was demonstrated that increasing the hours of therapy is cost-effective. However, the implementation may not be feasible because physiotherapy, occupational therapy and speech language pathology are all regulated professions in high demand. The number of therapists in the workforce is controlled through admission and licensing. Regions with stroke units may not have the therapists to hire, even if the option is cost effective.

Therapy assistants can also be used to increase the total time that patients receive therapy. Physiotherapy Assistant, Occupational Assistant and Communication disorder therapist can increase the total time patients receive therapy.

5.2.2 Increasing the Amount of Therapy with Group Sessions

Circuit classes and group sessions are another way that therapy time can be increased without changing the number of staffing hours. When group therapy is used to increase therapy amount, it is important to consider the type of intervention that is to be provided because not all interventions are suitable to a group setting.

A randomized control trial study by Renner et al., (2016) compared group and individual task training to improve walking. The study included patients diagnosed with first stroke who could walk and stand independently, and those that could walk with assistance. For the group therapy intervention, the patients were paired to perform tasks and to observe the other perform the tasks. The time spent in the group and individual sessions were equal and the characteristics between groups were similar apart from a lower Motricity Index score in the individual training group. After 6 weeks, the patients from both groups had similar outcomes including but not limited to the stroke impact scale mobility domain, functional ambulation and the 6-minute walk test. All other mobility related outcomes were statistically the same except the modified stairs test, providing evidence that group therapy is as effective as individual training to improve mobility in the appropriate stroke survivors.

However, the relationship between increased therapy time in circuit training and reduction in length of stay is not straightforward in the literature. McDonell et al., (2023) compared circuit class training to individual therapy in a retrospective observational study. Participants in the individual therapy completed 30 minutes sessions 5 times a week with the physiotherapist plus additional therapy with the physiotherapy assistant for those with an appropriate level of function. Those in the circuit group received 60 minutes of group therapy 5 times per week. The group therapy involved a 1:3 therapist to patient ratio and this group also received physiotherapy assistant led therapy sessions. The results showed that those in the circuit therapy group received on average 8 minutes more of physiotherapy per day compared to the individual therapy group. Patients in the group therapy also had a higher, but not statistically significant increase in their FIM score. The two groups also had similar length of stays when the covariant of stroke onset and admission to rehabilitation was adjusted for during sensitivity analysis.

The results from this study demonstrate that group therapy classes may be as effective as individual classes for improving functional outcomes post-stroke. However, it is important to consider how group therapy is offered from a resource perspective. If offering group therapy involves additional staffing, then it may be difficult to get buy-in from a cost-perspective even if the group therapy achieves similar functional gains to individual therapy.

5.3 Implications for Policy and Decision Making

Given the complexity of implementing the best practice guidelines for stroke rehabilitation therapy, the responsibility of increasing therapy time must be shifted from the therapist to the healthcare organizations. Therapists work within the constraints of the organization. Therefore, it is the responsibility of organizational managers to provide adequate resources that improve the system so that the best practice guidelines can be achieved.

There are limited peer reviewed journal articles on the changes that rehabilitation units have made to increase therapy time. Shafei et al., (2022) conducted a scoping review that considered quality improvement in stroke rehabilitation. The authors noted that the majority of studies on the subject were only available as conference abstracts and concluded that “QI [quality improvement] studies published as full papers are the tip of the iceberg” (Shafei et al., 2022, pp. 2928–2929). None of the full-length articles in the scoping review looked at quality improvement regarding improving therapy time. However, a few conference abstracts focused on methods to increase therapy time in individual rehabilitation units in Canada.

For example, Hahn (2019) reported on organizational changes that were implemented to increase therapy time in Vancouver, Canada. The changes included reducing the number of meetings required by therapist, optimizing multi-disciplinary rounds, and rescheduling operations and rehabilitations. Before the changes, stroke patients received between 20-60 minutes of therapy per day and after the intervention, between 60-320 minutes of therapy per day. It is also important to note that prior to this intervention, therapists spent 70 minutes of each day providing direct therapy and after the changes they spent 200 minutes per day providing direct therapy. They reported that these changes did not increase resource costs to the healthcare system. Although this abstract does not provide enough detail to inform implementation in other settings, it does provide some evidence that therapy time can be improved without increasing costs.

Although there is limited evidence that directly applies to increasing therapy time, studies in other areas of organization change in stroke rehabilitation have noted some facilitators to effective organizational change. Janzen et al. (2016) who focused on building knowledge to action programs in stroke rehabilitation, noted that guidelines need to be clear, comprehensive, and concise, and that vague recommendations should be avoided because they are difficult to apply and measure, and can contribute to lower success and compliance rates. It is also important that implementation is tailored to the setting in terms of specific interventions and measures of intervention success. Implementation can also be negatively impacted by lack of monitoring by staff and staff turnover (Vratsistas-Curto et al., 2017).

When the current study is viewed in the context of organizational change in stroke rehabilitation, it is important that organizations consider all the factors which may impact their ability to achieve the best practice recommendations for therapy time. The time used by therapist must be quantified to tease out areas for improved efficiency. It is only after this that the human resource need can be understood. If additional human resources are still required to meet best practice recommendations, then individual organizations can determine how cost can be optimized within their organization. Benchmarking the amount of therapy, length of stay and target functional level along with documentation of deviations from targets are also important to ensure that the impact of change is monitored.

5.4 Limitations

Modeling studies have inherent limitations. Models cannot account for all the variables that would impact the system. Linear programming models are limited because it reduces a complex system with complex relationships into a series of linear mathematical relationships. It is difficult to determine how closely the model reflects the system it represents without a significant amount of data. Sensitivity analysis helps to tease out the sensitivity of the results to changes, but it is difficult to investigate all scenarios. Additionally, the current LP model does not account for uncertainty or stochasticity.

One of the variables that is not accounted for in this model is the impact of weekend therapy hours and time of admission. If a unit does not provide therapy on the weekend, then the admission date of the patient will have a large impact on the hours of therapy they might receive in a 7-day period. For example, if the patient is admitted on a Friday and has a 10-day LOS, they will miss 4 days of therapy due to no therapy on the weekend. If that same patient is admitted on a Monday, they would only miss 2 days of therapy as their LOS only falls along a single weekend. The impact of admission date on therapy amount is not addressed within this model as this model assumed therapy can be offered on all day but this variable could be explored in further development of this LP model.

In the current LP model, the relationship between therapy time and length of stay is based on previously published work. There may have been other confounding factors not considered by the authors which may contribute to the change in length of stay with increased therapy time. For future validation, it would be beneficial to look at primary data on therapy time and length of stay to determine the relationship between the two.

5.5 Areas for Future Research

Given the limited evidence for a clear relationship between therapy time and length of stay, future studies should look at quantifying this relationship. This linear programming model can be expanded to capture additional complexities of the relationship between length of stay, therapy time, patient responsiveness, and therapist efficacy. A more informative methodology may involve using simulation models.

Simulation models can be used to create theoretical models of a system which can be manipulated to test how changes may impact the system. Specifically, a discrete event simulation model could be used to investigate issues related to optimization, prediction, and comparison of the stroke rehabilitation system. There are a variety of ways to investigate some of the issues identified in the stroke rehabilitation system. For example, the issues of providing enough therapy could theoretically be solved by hiring more therapists, by utilizing therapy assistants, by using group therapy, by diverting patients who have milder disabilities to community rehabilitation or by minimizing delayed discharge. Each of these practical solutions will have different consequences, some of which are anticipated and others which may be surprising. The development of a discrete event simulation model allows for reduced uncertainty when making decisions on possible changes.

Chapter 6: Conclusions

Results from the LP model developed in the thesis and the Canadian guidelines recommendation to provide at least 3 hours of therapy per day indicate that the current practice in Canada is neither providing patients with the best care nor saving money for the healthcare system. While it is good for individual clinicians to be informed about the benefits of achieving the best practice guidelines for therapy time, it is critical to recognize the level at which change must occur for best practice guidelines to be implemented. When contextualizing the result from this model with current literature in stroke rehabilitation, it seems the main barrier to patients receiving the best practice therapy is at the organizational level. Components such as limited number of staff, rehabilitation beds and inefficient flow through the stroke care pathway impede implementation of best practice amounts of therapy. As healthcare progresses, it is important that research is carried out on these factors, published, widely shared and implemented as simple changes may have significant impact on the quality of life of a patient after a stroke.

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