HEC MONTRÈAL

Determinants of rail capacity on a capacity-constrained urban mixed-operation rail corridor in the Greater Toronto and Hamilton Area

BY
Johannes Urbanski

GLOBAL SUPPLY CHAIN MANAGEMENT

THESIS DIRECTOR
Jacques Roy
HEC MONTRÈAL

A THESIS SUBMITTED
IN PARTIAL FULFILLMENT OF REQUIREMENTS
FOR A MASTER OF SCIENCE
IN ADMINISTRATION

February 2019

Résumé

Le but de ce mémoire de maîtrise est d'évaluer les facteurs qui influencent la capacité des corridors ferroviaires en milieu urbain qui font face à une croissance soutenue de la demande en passagers et en transport de marchandises. Également, l'appréciation des valeurs foncières restreint la croissance de la capacité d'une ligne et crée une pression économique pour intensifier l'utilisation des voies existantes plutôt que d'en bâtir de nouvelles. Ainsi, ce mémoire tente d'explorer comment la planification des horaires des trains de passagers influence la capacité générale d'une ligne et la qualité de ces horaires.

Ce mémoire fait une étude de cas en modélisant le corridor Toronto-Kitchener et calcule les temps de déplacement et de blocage des voies selon deux genres de systèmes de signalisation. Les horaires de plusieurs catégories de trains de passagers sont planifiés selon cinq stratégies différentes, alors que la capacité est déterminée en ajoutant des trains de marchandises dans les créneaux horaire disponibles.

Les résultats suggèrent que la périodicité d'un horaire a un impact positif important sur la capacité d'une ligne, alors que la présence d'une symétrie d'horaire et de correspondances coordonnés semblent avoir un impact légèrement négatif. Toutefois, les gains majeurs de capacité sont obtenus en adoptant un système moderne de signalisation. Une prochaine étude pourrait tenter d'isoler l'effet des différentes caractéristiques d'un horaire en augmentant considérablement le nombre de scénarios d'horaire calculés.

Mots clés : Transport ferroviaire, capacité ferroviaire, corridors ferroviaires urbains, opérations partagées, stratégies de planification d'horaire, planification tactique, horaire périodique, horaire symétrique

Abstract

The purpose of this master thesis is to investigate the factors determining train capacity on urban rail corridors facing sustained growth in demand for passenger and freight transportation services. At the same time, rising property prices constrain the growth of track capacity and create economic pressure to increase the utilisation of the existing tracks over building new ones. Therefore, this thesis aims to explore how the scheduling of passenger trains affects overall train capacity and timetable quality.

This thesis relies on modelling the Toronto-Kitchener corridor as case study and calculates travel and blocking times based on two different signalling system classes. Various categories of passenger trains are scheduled according to five different timetable strategies, while the capacity is determined by adding freight train slots into any remaining gaps in the schedule.

The results suggest that timetable periodicity has a strong positive effect on train capacity, while the presence of timetable symmetry and of coordinated transfers appear to have a slightly negative effect. However, by far the largest capacity gains can be achieved by adopting a modern signalling system with very short block lengths. Future research should aim at isolating the effect of the various timetable characteristics by drastically increasing the number of timetable scenarios calculated.

Keywords: Railway transportation, railway capacity, urban rail corridors, mixed operations, timetable strategies, tactical planning, timetable periodicity, timetable symmetry

Table of Contents

List of Tables

List of Figures

List of abbreviations and acronyms

ATP	Automatic train protection
CBTC	Communications-based train control
CN	Canadian National
CNR	Canadian National Railways (previous name of Canadian National)
CP	Canadian Pacific
CPR	Canadian Pacific Railways (previous name of Canadian Pacific)
ETCS	European Train Control System
GEXR	Goderich–Exeter Railway
GO	GO Transit
GOA	Grade of automation
HSR	High-Speed Rail
IEC	International Electrotechnical Commission
IFIT	Integrated fixed-interval timetable
IM	Infrastructure manager
Jct.	Junction
LZB	Linienzugbeeinflussung (German ATP system)
ML	Metrolinx
MP	Mile post
RER	Regional express rail
TOC	Train operating company
TTC	Toronto Transit Commission

TTP	Train Timetabling Problem
UIC	Union International des Chemins de fer (International Union of Railways)
UPX	Union Pearson Express (or: UP Express)
USRC	Union Station Rail Corridor
VIA	VIA Rail Canada

Acknowledgements

This thesis would probably have never been completed had Jacques Roy not been my thesis supervisor, who patiently supported me throughout the last four years of my rather intermittent research-and-reduction process and somehow managed to find the “sweet spot” in the frequency of his follow-up emails: long enough to allow me to focus on my work commitments, but short enough to not completely lose track of the ultimate goal (the submission of this thesis). Having outlined in my initial thesis proposal the intent to cover the countless operational interferences inherent to mixed operations of passenger and freight rail services, Jacques’ advise was invaluable in helping me to mercilessly cut down the scope of what might have even satisfied the requirements of a Ph.D. thesis to something which could possibly be written in parallel to the commitments inherent to a full-time employment.

I would also like to thank Raf Jans for his suggestions concerning the modelling process, which made me regret even more not having completed his “Decision Support Tools” module. My biggest thanks, however, are owed to my wife, which had to endure my preoccupation with my thesis for most of 2018, and to my son, whose approaching expected date of birth created the kind of deadline I unfortunately needed to finally get this thesis out of my way and to make space for much more important commitments.

Disclaimer

Throughout the entire research and redaction process, I have been employed within VIA Rail Canada, which is the operator of the inter-city trains on the Kitchener Corridor and thus on the corridor I have chosen as case study for this thesis. However, none of my colleagues or supervisors has exercised any influence on the scope or content of this thesis, just like this thesis did not rely on any information, data or software which would have not been accessible to a non-employee. Furthermore, it should be noted that references to VIA Rail are only made in three chapters (Chapters 1, 2 and 5, i.e. Introduction, Data Sources and Conceptualisation) and for the sole purpose of describing the historic context and *status quo* on the Kitchener Corridor.

Even though VIA Rail and Metrolinx (through its subsidiaries GO Transit and UP Express) operate passenger services over the same corridor and thus compete for the same track capacity, their respective passenger services are highly complementary (a significant proportion of VIA Rail's customers use GO Transit commuter trains to access VIA's main Hub at Toronto's Union Station). Furthermore, both organisations rely on separate funding sources for operational funding (federal funds in the case of VIA Rail and provincial funding in the case of Metrolinx), while their interests may overlap when it comes to lobbying the various levels of government to invest in infrastructure upgrades of the corridors both railroads share. In any case, the modelling and conclusions concern hypothetical future passenger rail services without any presumption of which railroad would operate them.

1. Introduction

1.1. Topic and Context

1.1.1. Topic

This thesis deals with the design and scheduling of passenger rail services and aims at improving the understanding of the determinants of train capacity when operating high-frequency rail corridors with train types of different speed profiles, frequencies and stopping patterns. The main question to be answered refers to how the way in which local, regional and inter-city passenger train services are scheduled affects capacity utilisation and the utility perceived by the passenger, while ensuring that a reasonable number of slots remains available for freight trains. This will require the development, modelling and benchmarking of timetable concepts for passenger trains following various timetable strategies, for which a case study will be provided with the Toronto-Kitchener corridor as a real-world setting.

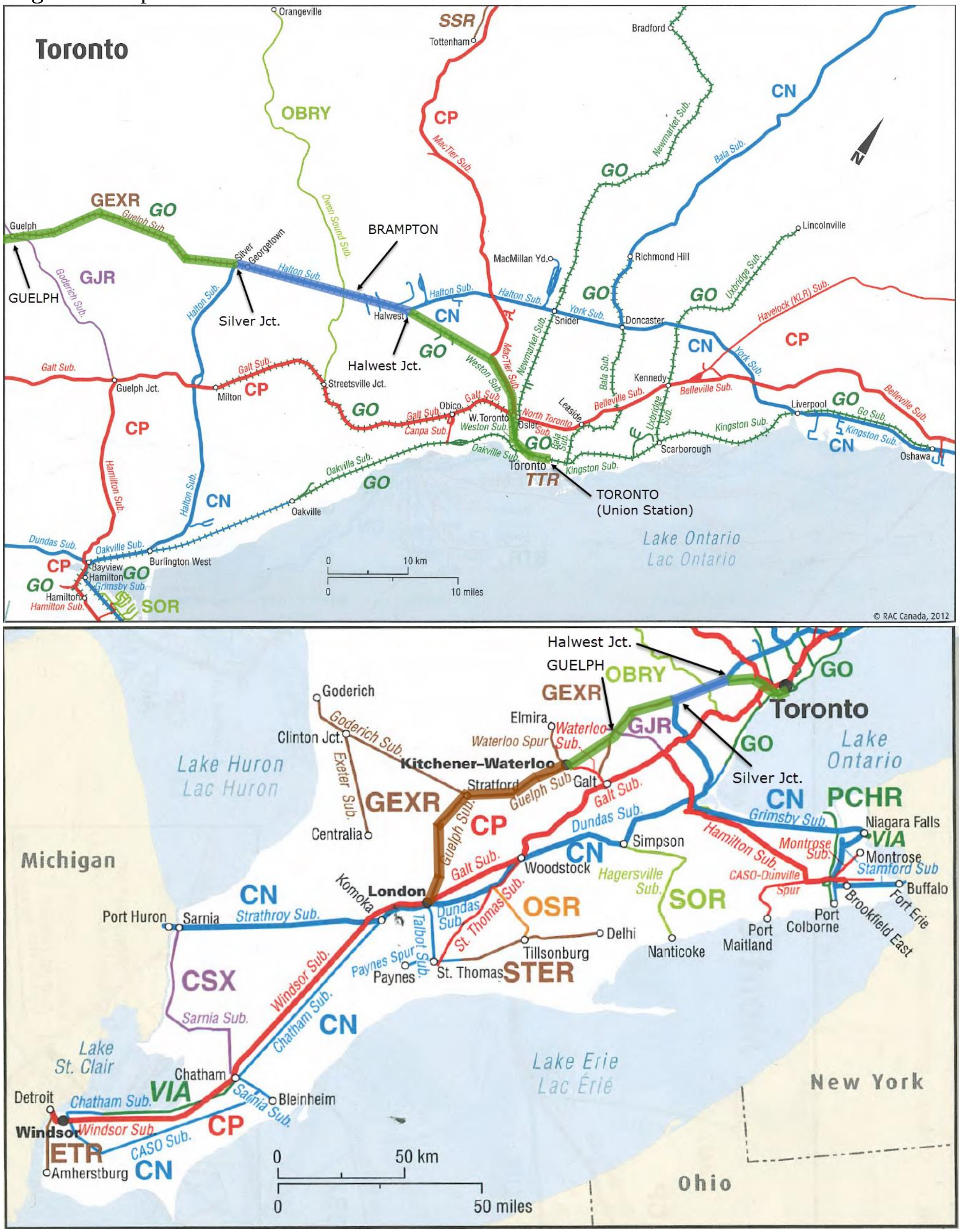
1.1.2. Context

After decades of decline following the Second World War, passenger rail services in North America and Europe have seen a renaissance in recent years. However, the forces of globalization and suburbanization on one side and of fierce intra- and intermodal competition on the other have simultaneously led to increased rail traffic and the rationalization of railway infrastructure, which results in increased train volumes meeting a capacity-constrained and increasingly congested rail network. Given that the expansion of rail capacity is very costly (even more so in urban areas, where rail congestion also tends to be the most acute) while the required financial resources are limited, the ongoing increase in rail traffic will have to be accommodated mostly through a more efficient usage of the existing rail infrastructure. (Abril, et al., 2008)

1.2. The Toronto-Kitchener corridor

The Toronto-Kitchener corridor (or shorter: Kitchener Corridor) will serve as a case study for all timetable purposes and centers on the former Brampton Subdivision, which was built by the Toronto & Guelph Railway (T&GR) between 1851 and 1856 and reached from Toronto over approximately 143 km to Stratford, passing Brampton, Guelph and Kitchener. The T&GR became part of the Grand Trunk Railway (GTR) and as such was absorbed by the Canadian National Railways (CN), which reorganized the Brampton Subdivision in 1965 into three separate subdivisions: the Weston Subdivision (from Toronto Union to Halwest Jct. at Bramalea station), the Halton Subdivision (from Halwest Jct. to Silver Jct., just west of Georgetown station) and the Guelph Subdivision (from Silver Jct. via Kitchener to Stratford and extended to its new terminus at London). Whereas the Halton Subdivision still forms a crucial part of CN's transcontinental network and the main freight route between Toronto and Chicago, Metrolinx (ML) as the province of Ontario's commuter rail agency has been able to acquire the Weston Subdivision in 2009 and the Guelph Subdivision east of Kitchener in 2014 (Kalinowski, 2014), while VIA Rail considers doing the same for the remainder of the Guelph Subdivision (VIA Rail, 2018a). An overview of the current ownership of the Kitchener Corridor (and other railway corridors in Southwest Ontario) is provided in Figure 1 below. (Smith, 2017)

Figure 1: Maps of the Toronto-Kitchener corridor



Note: Green indicates ownership by Metrolinx, blue by CN and brown by GEXR.
Adapted from: Canadian Railway Association (2012, pp. 10-11)

The Kitchener Corridor is one of three remaining rail corridors between Toronto and London, of which a second one is also operated by CN (the Oakville and Dundas subdivisions via Oakville, Brantford and Woodstock), while a third line is operated by Canadian Pacific (the Galt subdivision via Mississauga, Milton, Cambridge and Woodstock). Given that the Toronto-Brantford-London corridor is at least double-tracked in its entirety, Canadian National routes almost its entire freight traffic onto this more southern corridor and has in fact leased the Guelph Subdivision (before partly selling it to Metrolinx) to the Goderich–Exeter Railway (GEXR), which operates regular freight services as a "short line" operator. Nevertheless, the Halton Subdivision remains in CN ownership and accommodates approximately 20 freight trains per day[1] by routing its freight trains from and to Chicago, Detroit and Buffalo around downtown Toronto.

Whereas CP terminated its Toronto-London-Windsor passenger service in 1971 (CP Rail, 1971a; 1971b), CN continued its passenger services on both of its corridors until VIA Rail took over all of CN's (and CP's) remaining passenger operations in 1976 as a Crown Corporation which had just been founded for this exact purpose. The Kitchener Corridor saw 4 trains per day and direction during WWII (CNR, 1939; 1941; 1943; 1945), a figure which increased to 6 in the 1950s (CNR, 1956) and then declined to only 2 trains since the most recent cuts by the federal government in 2012 (Waterloo Region Record, 2012). GO Transit, the subsidiary of Metrolinx which operates Commuter Rail services in the Greater Toronto and Hamilton Area on behalf of the government of Ontario, first expanded its Commuter Rail service to Georgetown in 1974 and absorbed CN's Toronto-Guelph commuter train pair in November 1975 (CN, 1975). GO Transit's Georgetown service was temporarily extended to Guelph between 1990 and 1993 before it was renamed in

[1] Both directions combined for the short 3 km long segment of the Halton Subdivision which falls into the municipal boundaries of Toronto, see City of Toronto (2017).

2012 after its new terminus in Kitchener (see map shown in Figure 2). As of December 2017, GO Transit operates four peak-direction Toronto-Kitchener train pairs, which are complemented by two Toronto-Georgetown and seven mid-day train pairs which terminate at Mount Pleasant (with no weekend operations). (Transit Toronto, 2017)

Figure 2: Map of GO Transit's current Commuter Rail network (as of December 2017)

Source: GO Transit (2017)

In recent years, Metrolinx (the parent of GO Transit) has started to acquire as much of the rail infrastructure it operates on as it could get hold off, as part of a strategy which aims at eventually operating electrical trains operated at high frequencies and throughout the entire day and on all weekdays including the weekend. Despite being operated under a separate brand name ("Union Pearson Express") and the failed attempt to market it as a premium airport shuttle for business travelers, Metrolinx' introduction of four express trains per hour between Union Station and Pearson Airport marks the first line which exemplifies the "Regional Express Rail" (RER) standard, which it hopes to establish across its current Commuter Rail network (Metrolinx, 2015).

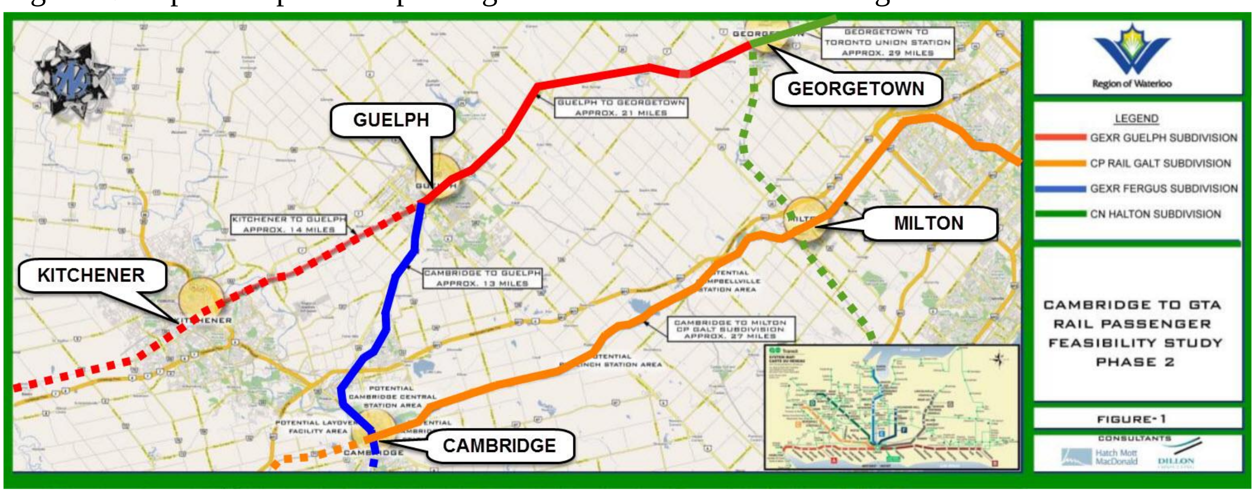
In the meantime, the province of Ontario has commissioned multiple studies for the construction of a High-Speed Rail corridor from Toronto via Pearson Airport, Guelph and Kitchener to London and eventually Windsor (Collenette, 2016) and made the idea one of their central election promises (Bellemare, 2014). However, for as long as the Halton segment of the Kitchener Corridor is shared with CN's core freight network, CN seems highly unlikely to accept such dramatic increases in frequencies (let alone: electrification) on that segment. This resistance against increased passenger rail services (as well as increased public concern about transporting dangerous goods near urban cores and through densely populated suburban areas following the inferno of Lac-Megantic) has led to calls for rerouting CN's trains between Halwest Jct. and Milton by building a "Missing Link" along the 407 Highway and CP's Galt Subdivision, which would allow most freight trains to completely bypass the Kitchener Corridor (Davis, 2018).

While Kitchener and Waterloo are relentlessly lobbying for improved passenger rail connections by positioning themselves as the "Canadian Silicon Valley" and consequently positioning the Kitchener Corridor as an "Innovation Corridor" which urgently depends on dramatically improved rail links from Commuter Rail over Regional Express Rail to High Speed Rail (CBC News, 2016), Cambridge as the third major city forming (together with four smaller townships) the Regional Municipality of Waterloo needs to first fight to claim back its spot on the Canadian passenger rail map. This is the result of a dramatic departure of passenger rail to the city, which was a significant railway hub 100 years ago with main line intercity service between Toronto and Chicago serving the rail station of the pre-amalgamated city of Galt[2] and running on the subdivision of the same name, branch line service provided by CN between Hamilton and Owen Sound (via Harrisburg and Guelph) as well as from Galt to Elmira (via Kitchener and Waterloo) and electric streetcar service to the neighboring cities of Kitchener, Waterloo and Brantford provided by the Grand River Railway and the Grand Valley River Railway, with the latter being replaced in 1916 by the parallel Lake Erie and Northern Railway (Canadian Electric Railway Map Collection, 2016). However, passenger rail service disappeared from the region starting with the Galt to Elmira service in 1932

[2] Galt, Preston and Hespeler were amalgamated to the city of Cambridge in 1973.

(Ontario Railway Map Collection, 2017), followed by the two electric streetcar services in 1955 (CP, 1954; 1955) and only 4 years later CN's Hamilton-Owen Sound service[3] (CNR, 1959), before CP terminated the era of passenger rail service in the area by withdrawing its Toronto-Windsor service in 1971. Whereas Cambridge's demands to restore passenger services have historically focused on the Galt Subdivision and extending GO Transit's Milton service to Cambridge (Dillon Consulting & Hatch Mott MacDonald, 2014), these efforts have recently shifted towards the Fergus Subdivision (which had already been used by CN's Hamilton-Owen Sound service and is currently leased by CN to GEXR) and would allow to connect Cambridge with GO Transit's Kitchener service in Guelph (Davis, 2018). Both potential passenger rail corridors into Cambridge (CP Galt Subdivision via Milton and GEXR Fergus Subdivision via Guelph) are shown in Figure 3 below.

Figure 3: Map of the potential passenger rail corridors into Cambridge



Note: The various subdivisions are coloured in red (Metrolinx - Guelph), orange (CP - Galt), blue (GEXR – Fergus) and green (CN – Halton), while subdivision segments not relevant for restoring passenger service into Cambridge are shown as a dotted line.
Adapted from: Dillon Consulting & Hatch Mott MacDonald (2014, p. 4)

[3] The service still survived north of Guelph (i.e. between Guelph and Owen Sound) until it was abandoned altogether in 1971 (CN, 1970; 1971).

Despite some unique particularities, the Kitchener Corridor shares many similarities with other metropolitan corridors in North America: to provide four examples across the continent, the Deux-Montagnes line in Montreal, the Northeast Corridor on the US East Coast, the metropolitan Commuter Rail corridors in California and Florida East Coast all have main passenger corridors where freight trains either share tracks with commuter and intercity trains today or are undergoing civil engineering projects which will result in their introduction (as shown in Table 1 below). Furthermore, such corridors can also be found across Europe and Japan. The corridor chosen for this case study is therefore representative for similar capacity-constrained metropolitan rail corridors in North America and beyond, which should ensure a high relevance of any results obtained from this case study.

Table 1: Comparison of the presence of various rail service categories on selected shared-use corridors worldwide (today / in the future)

Corridor	Freight	Light Rail/ Metro	Commuter/ Regional	Inter-City	High-Speed Rail
Kitchener Corridor (Toronto)	**Yes / Yes**	**No / No**	**Yes / Yes**	**Yes / Yes**	**No / Yes**
Deux-Montagnes (Montreal)	**Yes** / No	**No** / Yes	**Yes** / No	No / **Yes**	**No** / No
California (CalTrain, LA Metro)	**Yes / Yes**	**No / No**	**Yes / Yes**	**Yes / Yes**	**No / Yes**
Florida East Coast	**Yes / Yes**	**No / No**	No / **Yes**	**Yes / Yes**	**No** / No
Aachen-Cologne-Siegburg (Germany)	**Yes / Yes**	**No / No**	**Yes / Yes**	**Yes / Yes**	Yes / **Yes**
Japan (countless corridors)	**Yes / Yes**	**No / No**	**Yes / Yes**	**Yes / Yes**	**No** / No

Source: Compiled by the author.

1.3. Problem

The problem explored by this thesis is how to most efficiently allocate scarce track capacity on busy multiple-tracked and multi-use rail corridors. In the words of Cordeau, Toth & Vigo (1998, p. 381),

> "*[r]ail transportation problems can […] be classified into categories according to the planning horizon considered. At the strategic level, one is mainly concerned with the acquisition or construction of durable resources that will remain active over a long period of time. The tactical level is related to medium and short term issues, and generally involves the specification of operating policies that are updated every few months. Finally, the daily tasks that are performed by taking account of the fine detail of the system belong to the operational level*."

Therefore, the *strategic level* includes long-term considerations, such as network planning and line planning, while the *tactical level* refers to more medium-term considerations, such as timetable generation, railway track allocation (or: train routing) or the scheduling of rolling stock or train crews, as opposed to the *operational level*, which concerns short-term planning and refers to real-time management (Lusby, Larsen, Ehrgott, & Ryan, 2011).

This thesis seeks to assess the impact of certain operational characteristics (i.e. the independent variables) onto various measures of the capacity of a rail corridor and of the service quality by which that corridor is served (i.e. the dependent variables), both of which are described below. It will therefore focus on the tactical level of railway planning strategies, relying mainly on timetable generation and on railway track allocation, while partly delving into the strategic planning level by considering the stopping pattern and frequency aspects of line planning.

1.3.1. Independent variables

The research conducted in this thesis will focus on two independent variables: the primary independent variable is the *timetable strategy*, which describes a certain philosophy under which the various train services are scheduled (i.e. the timing and sequence of the various services), while the second independent variable is the *signalling method* (i.e. the nature and length of the blocks occupied by a given train movements), which influences the minimum headway between two subsequent train movements using the same track segment.

1.3.2. Dependent variables

The changes in these independent variables are evaluated regarding their impact on *capacity* and on the *quality* of the operations, with capacity referring to the number of trains and passengers transported and quality referring to measures like the average travel time of passengers and scheduled delays (as consequence of timetable conflicts).

1.3.3. Controlling variables

The relationship between independent and dependent may also be influenced by the characteristics of the trains operating within the network (e.g. maximum speed or acceleration and deceleration capabilities) and of the services (e.g. train type, stopping pattern, station dwell time and frequency) and infrastructure (e.g. track layout) on which these trains operate. Therefore, the influence of these contributing variables needs to be eliminated by making sure that they does not change across the various timetable scenarios.

1.4. Purpose

This research intends to investigate the relationship between the choice of timetable strategy applied when scheduling passenger trains on capacity-constrained urban rail corridors and the resulting train capacity and timetable quality. By identifying relevant metrics, it offers a logical, transparent and objective method of comparing different timetable concepts and allows transport planners to benchmark them against existing timetables or to compare them to the goals set by the transport policy makers.

In order to quantify the results in a realistic setting relevant for North American transportation planners, a case study will be provided with the Toronto-Kitchener corridor, which is an already capacity-constrained rail corridor which hosts various freight and passenger rail services today. The rail corridor is used by various railroads and agencies, which all have announced plans to further increase their rail services, thus exacerbating the necessity of increasing the available capacity and the utilisation thereof, while minimizing the need for costly infrastructure upgrades.

This research is very timely, as Canada’s intercity passenger railroad and the respective provincial passenger rail agencies of Ontario and Quebec are currently planning various transport initiatives which aim at increasing both the number and the heterogeneity of passenger rail services in the metropolitan areas of Montreal and Toronto-Hamilton. At the same time, the financial resources and physical space for providing all potentially conflicting rail services with separate tracks are naturally limited. This creates an increased need for an improved understanding of how rail service design affects the maximum number of trains which can operate over a given rail corridor in a peak hour.

1.5. Structure

The thesis will start with an introduction of the topic, the context, the purpose and an outline in Chapter 1, followed by a presentation of the rail corridor selected for the case study in Chapter 2. Chapter 3 will then provide a literature review about previous research on these issues and start to identify key performance criteria for benchmarking the timetable concepts to be developed later in Chapter 8. Chapter 4 will then formulate and describe the methodology based on the four steps of conceptualization, modelling, model-solving and implementation, which will form the following Chapters 5, 6, 7 and 8. The results of the timetable concepts developed will be presented and benchmarked in Chapter 9, before Chapter 10 discusses the trade-offs encountered during the modelling and the implications for other rail bottlenecks. Finally, Chapter 11 concludes this thesis by formulating recommendations for rail infrastructure and transportation planners and by identifying areas for future research.

2. Data for the Toronto-Kitchener corridor

2.1. Timetables

The first major source for data required to model the Toronto-Kitchener corridor is timetable data, which is published and regularly updated by GO Transit (GO), UP Express (UPX) and VIA Rail (VIA). This section presents the most recent timetables published by these operators before providing an overview over the service extensions already announced or hinted by these operators.

2.1.1. Current timetables

The Toronto-Kitchener corridor is currently served by three passenger rail services (GO Transit, UP Express and VIA Rail), following the timetables shown in Tables 2 to 4 below:

Table 2: GO Transit timetable for its Kitchener line (effective 23 June 2018)

Days of operation	Monday to Friday (except Statutory Holidays)															
Train # (eastbound)	200	202	204	206	208	210	212	214	268	270	272	274	276	278	280	282
Kitchener			05:24		06:04		06:47	07:10								
Guelph			05:48		06:28		07:11	07:34								
Acton			06:05		06:45		07:28	07:51								
Georgetown			06:23	06:48	07:03	07:16	07:46	08:09								
Mount Pleasant		05:55	06:32	06:57	07:12	07:25	07:55	08:18	09:00	09:55	11:00	12:00	13:00	14:00	15:00	15:52
Brampton		06:03	06:39	07:04	07:19	07:32	08:02	08:25	09:09	10:04	11:09	12:09	13:09	14:09	15:09	16:01
Bramalea	05:54	06:12	06:49	07:14	07:29	07:42	08:12	08:35	09:16	10:11	11:16	12:16	13:16	14:16	15:16	16:09
Malton	06:00	06:18	06:55	07:20	I	07:48	08:18	08:41	09:22	10:17	11:22	12:22	13:22	14:22	15:22	16:14
Etobicoke North	06:06	06:24	07:01	07:26	I	07:54	08:24	08:47	09:28	10:23	11:28	12:28	13:28	14:28	I	I
Weston	06:12	06:30	07:07	07:32	I	08:00	08:30	08:53	09:34	10:29	11:34	12:34	13:34	14:34	I	I
Bloor	06:20	06:38	07:15	07:40	I	08:08	08:38	09:01	09:42	10:37	11:42	12:42	13:42	14:42	I	I
Toronto (Union Station)	06:32	06:50	07:27	07:52	07:55	08:20	08:50	09:13	09:53	10:49	12:00	12:54	13:54	14:54	15:54	16:39
Days of operation	Monday to Friday (except Statutory Holidays)															
Train # (westbound)	269	271	273	275	277	279	281	203	205	207	285	209	211	289		
Toronto (Union Station)	08:55	09:48	10:53	11:53	12:53	13:53	14:53	15:35	16:20	16:50	17:02	17:20	17:50	18:50		
Bloor	09:04	09:57	11:02	12:02	13:02	14:02	15:02	15:45	16:30	I	17:12	17:30	18:00	19:00		
Weston	09:12	10:05	11:10	12:10	13:10	14:10	15:10	15:54	16:39	I	17:21	17:39	18:09	19:09		
Etobicoke North	09:18	10:11	11:16	12:16	13:16	14:16	15:16	16:01	16:46	I	17:28	17:46	18:16	19:16		
Malton	09:24	10:17	11:22	12:22	13:22	14:22	15:22	16:08	16:53	I	17:35	17:53	18:23	19:23		
Bramalea	09:30	10:23	11:28	12:28	13:28	14:28	15:28	16:16	17:01	17:19	17:43	18:01	18:31	19:31		
Brampton	09:38	10:31	11:36	12:36	13:36	14:36	15:36	16:24	17:10	17:28	17:52	18:10	18:40	19:40		
Mount Pleasant	09:44	10:37	11:42	12:42	13:42	14:42	15:42	16:30	17:16	17:34	17:58	18:16	18:46	19:46		
Georgetown								16:42	17:28	17:44		18:28	18:56	19:56		
Acton										17:58		18:43	19:10	20:10		
Guelph										18:13		18:58	19:28	20:25		
Kitchener										18:45		19:32	19:57	20:57		

Created by the author with data from: GO Transit (2018)

Table 3: Current timetable for the Union Pearson Express

Days of operation	Daily									Days of operation	Daily								
Pearson Airport	05:27	05:42	05:57	06:12	every	00:12	00:27	00:42	00:57	Union Station	05:30	05:45	06:00	06:15	every	00:15	00:30	00:45	01:00
Weston	05:38	05:53	06:08	06:23	15	00:23	00:38	00:53	01:08	Bloor	05:38	05:53	06:08	06:23	15	00:23	00:38	00:53	01:08
Bloor	05:44	05:59	06:14	06:29	minutes	00:29	00:44	00:59	01:14	Weston	05:44	05:59	06:14	06:29	minutes	00:29	00:44	00:59	01:14
Union Station	05:52	06:07	06:22	06:37	until	00:37	00:52	01:07	01:22	Pearson Airport	05:55	06:10	06:25	06:40	until	00:40	00:55	01:10	01:25

Created by the author with data from: Triplinx (2018)

Table 4: VIA Rail Timetable for its Toronto-London-Sarnia service (effective June 17, 2017)

TORONTO → LONDON → SARNIA

TRAIN		85	87
DAYS / JOURS		1234567	1234567
Toronto, ON	DP	10:55	17:40
Malton		11:16	18:01
Brampton		11:29	18:14
Georgetown		11:40	18:26
Guelph		12:06	18:51
Kitchener		12:32	19:18
Stratford		13:09	19:55
St. Marys		13:33	20:23
London	AR	14:17	21:09
	DP		21:14
Strathroy			21:37
Wyoming			22:05
Sarnia, ON	AR		22:20

SARNIA → LONDON → TORONTO

TRAIN		84	88
DAYS / JOURS		1234567	1234567
Sarnia, ON	DP	06:10	
Wyoming		06:26	
Strathroy		06:59	
London	AR	07:22	
	DP	07:32	19:51
St. Marys		08:16	20:41
Stratford		08:40	21:05
Kitchener		09:18	21:42
Guelph		09:44	22:12
Georgetown		10:10	22:37
Brampton		10:20	22:47
Malton		10:32	
Toronto, ON	AR	10:53	23:17

TORONTO SARNIA

Source: VIA Rail (2018b, pp. 24-25)

2.1.2. Service expansion plans

Concerning future plans for serving the Toronto-Kitchener corridor, Metrolinx (as parent of GO Transit and the UP Express) has so far provided the most detailed information, starting with an initial business case for their "Regional Express Rail" concept (Metrolinx, 2015) in which they've outlined seven different scenarios with widely varying service levels, depending on the desired level of capital expenditure to be invested by the various governments concerned. As shown in Table 5 below, the "Full Build" scenario (Scenario 4) featured an all-stop backbone service operated 4 times per hour between Union Station and Mount Pleasant and a regional service between Union Station and Kitchener operating 2 times per hour (non-stop to Bramalea and all-stops thereafter), complemented by an all-stop rush-hour service operated between Union Station and Georgetown 3 times per hour and in peak-direction only. Conversely, the recommended scenario ("Scenario 5") restricted the Union Station to Kitchener service to peak-hours and peak-direction only, while changing the terminus of the all-stops 4 times per hour service from Mount Pleasant to Bramalea and instead increasing the rush hour service between Union Station and Georgetown from 2 to 3 trains per hour.

In the meanwhile, Metrolinx has set up a dedicated "Regional Planning" webpage for the Kitchener GO line, which shows a service very similar to Scenario 5 of the initial business case, but with the rush hour service cut back again from 3 to 2 trains per hour and its terminus moved back from Georgetown to Mount Pleasant (Metrolinx, 2018a). It also features hourly mid-day service between Union Station and Mount Pleasant, like the one which was recently reinstated after its temporary suspension to facilitate construction along the corridor (Transit Toronto, 2017), but no longer makes any reference to UP Express.

Table 5: Service patterns for various scenarios on the Toronto-Kitchener corridor, as proposed by Metrolinx in the initial business case for Regional Express Rail

	Scenario 1 (Do Minimum)	Scenario 2 (Two-Way All-Day)	Scenario 3 (10-Year Plan)	Scenario 4 (Full Build)	Scenario 5 (Optimized)
Services: All-day Contra-Peak, Off-Peak	No service	1 train per hour Kitchener–Union of which approximately 80% are operated by D1BL12 and 20% are operated by DBL6.	4 trains per hour Mount Pleasant–Union D1BL12 [2 x VIA daytime services to and from Kitchener]	2 trains per hour Kitchener - Union (express Bramalea–Union) of which approx. 64% operated by EMUBL4 and 36% operated by EMUBL8 4 trains per hour Mount Pleasant–Union of which approx. 62% operated by EMUBL4 and 38% operated by EMUBL8	4 trains per hour Bramalea–Union of which approx. 62% operated by EMUBL4 and 38% operated by EMUBL8
Services: Weekend	No service	1 train per hour Kitchener–Union D1BL6	1 train per hour Mount Pleasant–Union D1BL6 [VIA service to and from Kitchener]	2 trains per hour Kitchener–Union EMUBL4 (express Bramalea–Union) 4 trains per hour Mount Pleasant–Union EMUBL4	4 trains per hour Bramalea–Union EMUBL4
Services: Three-hour peak 2024	5 trains Kitchener–Union D1BL12 1 train Mount Pleasant–Union D1BL12 2 trains Georgetown–Union D1BL12 2 trains Bramalea–Union D1BL12 Total of 10 trains (increase of 2 trains over 2014) and 18,500 seats. Trains added from Bramalea as demand grows. No potential to add trains from beyond Bramalea	Per Scenario 1	6 trains Kitchener–Union D1BL12 10 trains Mount Pleasant–Union D1BL12 Total of 16 trains (increase of 8 trains over 2014) and 29,600 seats. Trains can be added from Mount Pleasant or Bramalea as demand grows. No potential to add trains from beyond Mount Pleasant. 1 x VIA p.m. Peak service serving Malton, Brampton, Georgetown, Guelph & Kitchener	6 trains Kitchener–Union EMUBL8 (express from Bramalea) 12 trains Mount Pleasant–Union EMUBL8 5 trains Georgetown–Union stopping E1BL12 Total of 22 trains (increase of 14 trains over 2014) and 25,864 seats. Trains added as demand grows.	6 trains Kitchener–Union D1BL6 (express Bramalea-Union) 12 trains Bramalea–Union EMUBL8 4 trains Georgetown–Union D1BL12 Total of 21 trains (increase of 13 trains over 2014) and 26,976 seats. Trains added as demand grows.
Services: UP Express (Two-Way All-Day)	4 trains per hour DMU3	4 trains per hour DMU3	4 trains per hour DMU3	4 trains per hour EMU3	4 trains per hour EMU3

Source: Metrolinx (2015a, pp. 21-22)

Concerning intercity rail services, VIA Rail is undergoing an ambitious programme to increase its frequencies throughout its busy *Quebec-Windsor Corridor*, which is centered on replacing its ageing fleet and building a dedicated passenger rail corridor between Toronto, Ottawa, Montreal and Quebec City, in order to reduce its dependence on increasingly unreliable rolling stock and host railways unable or unwilling to provide it with more track capacity (Thomas, 2017). West of Toronto, VIA Rail has announced plans to reinstate a morning train from Stratford via Kitchener to Toronto and an evening train to return in the evening, which were both cut in 2012, as well as introducing new train services which serve the counter-peak direction such as morning trains from Toronto to Kitchener (VIA Rail, 2016). Furthermore, VIA Rail's 2016-2020 Corporate Plan laid out a plan to increase frequencies on the Toronto-Kitchener-London line from 2 to 5 trains per day

(VIA Rail, 2016a)[4]. Even though VIA Rail has started tests with RDCs (Rail Diesel Cars) on this line to run these additional frequencies (Outhit, 2016), VIA Rail appears to still be in discussions with its host railroads (i.e. CN, Metrolinx and GEXR) regarding any frequency increases in Southwestern Ontario (VIA Rail, 2017; VIA Rail, 2018c).

In the meanwhile, the provincial government of Ontario has proposed a High-Speed Rail (HSR) service between Toronto and London, which it expects to operate with three trains per hour during peak hours and two trains per hour during the rest of the day and which would stop at the existing rail stations of Toronto (Union Station), Malton (for Pearson Airport), Guelph, Kitchener and London (Collenette, 2016). This would require track sharing with UP Express, GO RER, VIA Rail and at least some limited local freight services, even if most freight traffic would have to be rerouted via a projected freight bypass from Halwest Junction to Milton, which is known in public discussions as "the missing link" and would roughly follow the 407 and 401 Highways. However, the project has always been closely associated with the previous liberal government in Toronto (Gerson, 2018), which got all but washed away in the provincial elections of June 2018 by the Progressive Conservative Party of Ontario. While his liberal predecessor, Kathleen Wynne, had promised to provide the $11 billion needed to fund the first stage from Toronto to London, the province's new conservative Prime Minister, Doug Ford, has so far voiced little commitment beyond completing the ongoing environmental assessments (D'Amato, 2018).

[4] It should be noted, however, that the Summary of the more recent 2017-2021 Corporate Plan (VIA Rail, 2018a) no longer includes a figure which quantifies planned frequency increases for individual routes.

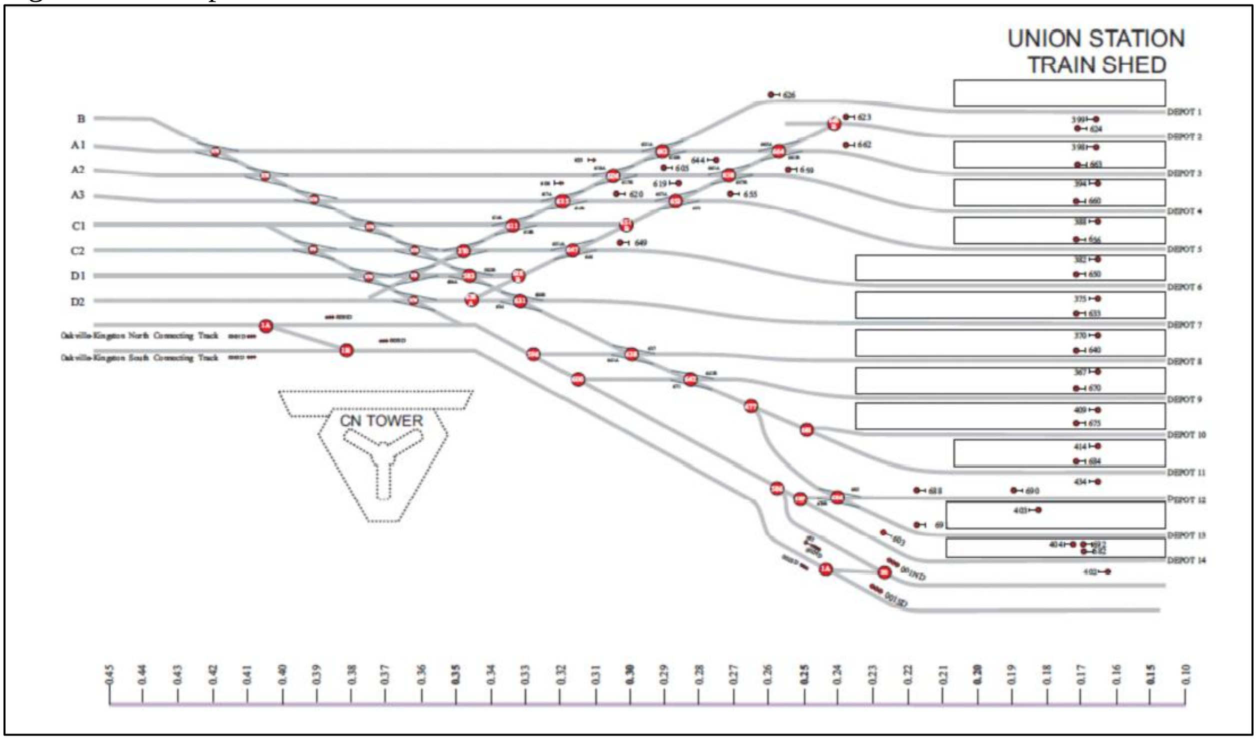
2.2. Infrastructure

The second major source for data needed to model the Toronto-Kitchener corridor is track plans, which show the tracks on which trains can operate, the switches over which they can switch from one track onto the other and (in the case of more detailed track plans) the signals which control the usage of the following track segment (usually referred to as "block") and restrict it to no more than one train in any given block.

2.2.1. Current track layout

The most recent publicly accessible track plans of the USRC (Union Station Rail Corridor) and the Kitchener Corridor located by the author originate from an electrification study submitted by Parsons Brinckerhoff (a multinational engineering and design firm now owned by WSP of Montreal) to Metrolinx in October 2014. This "conceptual design report" comprises a main report (Parsons Brinckerhoff, 2014) and five additional documents which cover the Lakeshore West corridor, the Kitchener Corridor, the Lakeshore East corridor, the USRC and some maintenance facilities (Parsons Brinckerhoff, 2014a; 2014b; 2014c; 2014d; 2014e). The report includes track plans, which in the case of Union Station show 12 platforms, 14 platform tracks and 2 non-platform tracks at its southern end, as shown in Figure 4 below:

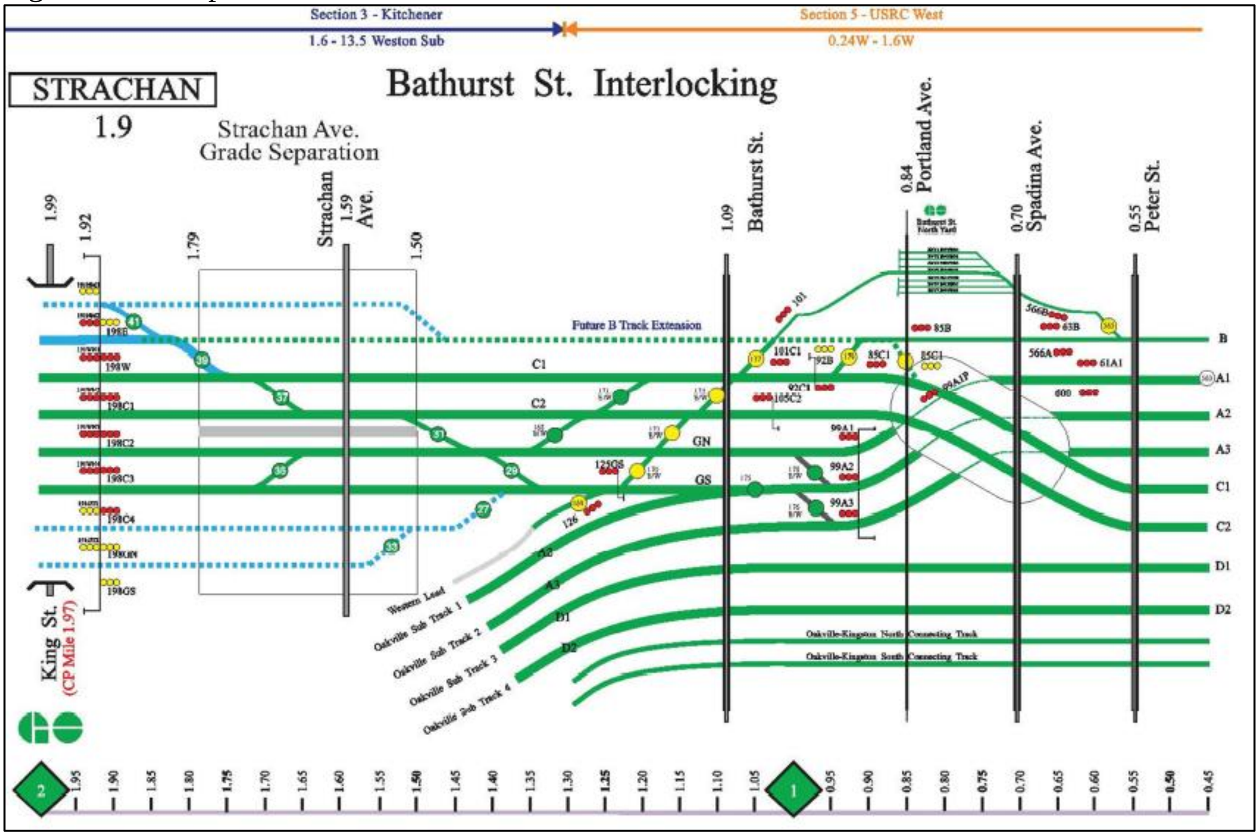
Figure 4: Track plan of the Western side of the Union Station.



Source: Morrison Hershfield Ltd. (2012, p. 46)

Concerning the Kitchener Corridor, the track plans show 4 tracks which split from the Lakeshore Corridor at Bathurst Street (see *Figure 5* below). Due to the lack of connecting switches west of Strachan Avenue, the southernmost of these 4 tracks (Track C3 in Figure 5 below) can only be used by GO's Milton service and splits off towards CP's Galt Subdivision, just northwest of Bloor Station. Table 6 provides an overview over the number of tracks available for passenger operations along the Kitchener Corridor.

Figure 5: Track plan of the Kitchener Corridor and the USRC at Bathurst Street



Source: Morrison Hershfield Ltd. (2012a, p. 69)

Table 6: Number of available main tracks on the various segments of the Kitchener Corridor

Subdivision (owner)	Segment Start (Mile Post)	Segment End (Mile Post)	# of main tracks	Operators (Passenger/Freight)
USRC/Weston (ML)	Union Station (MP 0.0)	Bathurst Street (MP 1.09)	6	P: GO, UPX, VIA
Weston (ML)	Bathurst Street	Woodbine Jct. (MP 13.4)	3	P: GO, UPX, VIA
	Woodbine Jct.	Halwest Jct. (MP 16.8)	2	P: GO, VIA
Halton (CN)	Halwest Jct. (MP 11.1)	Peel (MP 14.8)	3	P: GO, VIA F: CN, GEXR
	Peel (MP 14.8)	MP 15.7	2	P: GO, VIA F: CN, GEXR
	MP 15.7	Norval (MP 18.9)	3	P: GO, VIA F: CN, GEXR
	Norval (MP 18.9)	Silver Jct. (MP 30.0)	2	P: GO, VIA F: CN, GEXR
Guelph (ML)	Silver Jct. (MP 30.0)	Kitchener	1	P: GO, VIA F: GEXR

Source: Compiled from data provided in Morrison Hershfield Ltd. (2012a)

2.2.2. Infrastructure expansion plans

As with the service patterns, Metrolinx' initial business case for Regional Express Rail is so far the most detailed infrastructure upgrade plan available for the Kitchener Corridor. As shown in Table 7 below, Scenario 4 calls for full electrification of the Kitchener Corridor and for the construction of at least one additional track along virtually its entire length, whereas Scenario 5 limits itself to electrification east of Bramalea only and the addition of an supplementary track to east of Mount Pleasant, thus avoiding the need to negotiate with CN over the electrification of the segment of the Halton Subdivision included in the Kitchener Corridor (which is widely believed to be infeasible without the construction of the "Missing Link" already mentioned in Section 1.2, as it forms part of CN's crucial Toronto – Chicago freight corridor) and to build a costly fly-over west of Mount Pleasant (Metrolinx, 2015a). Concerning Ontario's HSR plans, the province's Final Report assumed for the Kitchener Corridor that the existing tracks would be shared between its HSR trains and all other trains and that track and station capacity would be added as required, while the HSR service was only expected to receive its own dedicated tracks west of Kitchener (Collenette, 2016).

Table 7: Infrastructure requirements for various scenarios on the Kitchener Corridor, as proposed by Metrolinx in the initial business case for Regional Express Rail

	Scenario 1 (Do Minimum)	Scenario 2 (Two-Way All-Day)	Scenario 3 (10-Year Plan)	Scenario 4 (Full Build)	Scenario 5 (Optimized)
Infrastructure	Station modifications (Mount Dennis and Kitchener)	Per Scenario 3 plus: Passing tracks between Georgetown and Kitchener 2 new tracks from Mount Pleasant to Georgetown Credit River grade separation over CPR Halton Sub Modify 1 additional stations (Georgetown)	Per Scenario 1 plus: New (3rd/4th) tracks Union to Mount Pleasant New track and tunnel under Highway 401 Torbram Road grade separation Layovers: Heritage (8 consists); Kitchener Shirley Av. Modify 5 additional stations (Etobicoke North, Malton, Brampton, Mount Pleasant)	Per Scenario 3 plus: 33 miles double track from Georgetown to Kitchener. 2 new tracks from Mount Pleasant to Georgetown Credit River grade separation over CPR Halton Sub Modify 3 additional stations (Georgetown, Acton, Guelph) Electrification to Kitchener	Per Scenario 3 plus: Electrification to Bramalea

Source: Metrolinx (2015a, p. 22)

Concerning the stations to be served in the future, Metrolinx recently evaluated more than 50 potential new station locations along its Commuter Rail network. Out of the 17 stations for which it conducted and published an "Initial Business Case", 3 stations lie on the Kitchener Corridor: Downtown West (Liberty Village), St. Clair, and Breslau (Metrolinx, 2018b). In addition, Metrolinx plans to build a new intermodal station at Mount Dennis, thus allowing passengers to transfer onto the future Eglinton Crosstown Light Rail Transit, which is expected to become operational in 2021 (Metrolinx, 2016). Finally, the station in Kitchener will be moved a few hundred meters from its current location towards the West, in order to connect with the new iON Light Rail system in Kitchener and Waterloo, which is expected to open during 2018 and to eventually reach Cambridge in a second stage (GrandLinq, 2018; Region of Waterloo, 2018). This means that Parkdale and Breslau will be the only former passenger rail stations to see passenger service restored (though at a slightly modified location and in the case of Parkdale under a different name: Liberty Village), as there are currently no plans to reopen the abandoned rail stations at Norval, Limehouse, Rockwood and Mosborough, just like there are no detailed studies available so far for upgrading GEXR's Fergus Subdivision to allow restoring passenger service from Guelph to Cambridge.

Table 8: List of rail stations along the Kitchener Corridor

Miles	Station Name	Passenger service (rail only)	Connections (rail only)
0.0	Toronto (Union)	GO, VIA, UPX	Other GO and VIA services, Subway (TTC)
2.1	Liberty Village	Future station for RER	Streetcar (TTC, short walk)
2.3	Parkdale	(station abandoned by CN in 1975)	Streetcar (TTC)
4.0	Bloor	Metrolinx, UPX	Subway and Streetcar (TTC, short walk)
4.9	West Toronto	(station served by CN and then by VIA until 1989)	CP rail service
5.3	St. Clair	Future station for RER	Streetcar (TTC)
6.8	Mount Dennis	Future station for RER and GO Transit (under construction)	Crosstown Light Rail Transit (under construction)
8.4	Weston	GO, VIA (until 1977), UPX	
11.0	Etobicoke North	GO	
14.7	Malton	GO, VIA	
17.3	Bramalea	GO	
21.1	Brampton	GO, VIA	
24.0	Mount Pleasant	GO	
26.7	Norval	(station abandoned by CN between 1937 and 1939)	
29.2	Georgetown	GO, VIA	
32.3	Limehouse	(station abandoned by CN in 1958)	
35.6	Acton	GO	
41.0	Rockwood	(station abandoned by CN in 1975)	
48.8	Guelph	GO, VIA	
53.4	Mosborough	(station abandoned by CN in 1954)	
57.5	Breslau (new)	Future station for GO	
58.4	Breslau	(station abandoned by CN in 1964)	
62.7	Kitchener	Current station for GO and VIA	
62.9	Kitchener (new)	Future station for GO and VIA (under construction)	iON Light Rail (under construction)

Note: the Toronto Transit Commission (TTC) is the municipal operator of bus, streetcar and subway routes in Toronto.

Sources: Compiled by the author with data from Morrison Hershfield Ltd. (2012a), CNR (1937; 1939; 1953; 1954; 1957; 1958), CN (1964a; 1964b; 1975) and VIA Rail (1976; 1977; 1988; 1989).

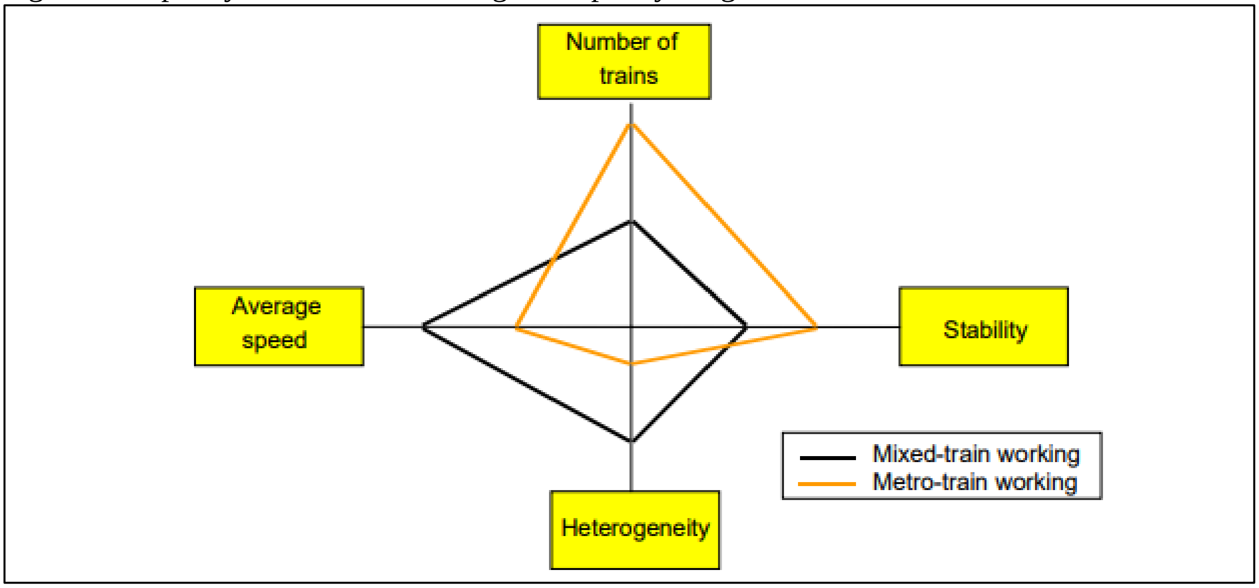
3. Literature Review

3.1. Railway Capacity

The literature identifies various ways of defining railway capacity. In the most basic definition, a time period (e.g. one hour) is divided by the headway time (Abril, et al., 2008), while Pouryousef, Lautala and White (2015, p. 30) define the capacity of a rail corridor as "the number of trains that can safely pass a given segment within a period of time." However, Martin (2014) remarks that whatever theoretical maximum number of trains is calculated, is unlikely to be reached in practice. Similarly, Lai and Barkan (2009, p. 33) define rail capacity as "a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan (Level of Service (LOS))", but add an extensive list of infrastructure and operational factors, which all mitigate rail capacity, such as the length of a subdivision, the length, spacing, and uniformity of sidings, the spacing of intermediate signal spacing, the ratio between single, double, or multiple track sections, the count of peak trains, the average and variability in operating speed, the heterogeneity in train types (train length, power to weight ratios), the presence of dispatching priorities and of course the applicable schedule.

In the words of Abril et al. (2008, p. 775), "[t]he goal of capacity analysis is to determine the maximum number of trains that would be able to operate on a given railway infrastructure, during a specific time interval, given the operational conditions". They differentiate between four types of capacity, where *theoretical capacity* refers to the mathematical maximum number of train figures given the shortest feasible headway, *practical capacity* refers to the actual capacity for train movements when considering much more realistic assumptions, *used capacity* refers to the proportion of practical capacity which is currently used for train movements and *available capacity* refers to the difference between the practical capacity and the used capacity.

Figure 6: Capacity balance determining the capacity usage

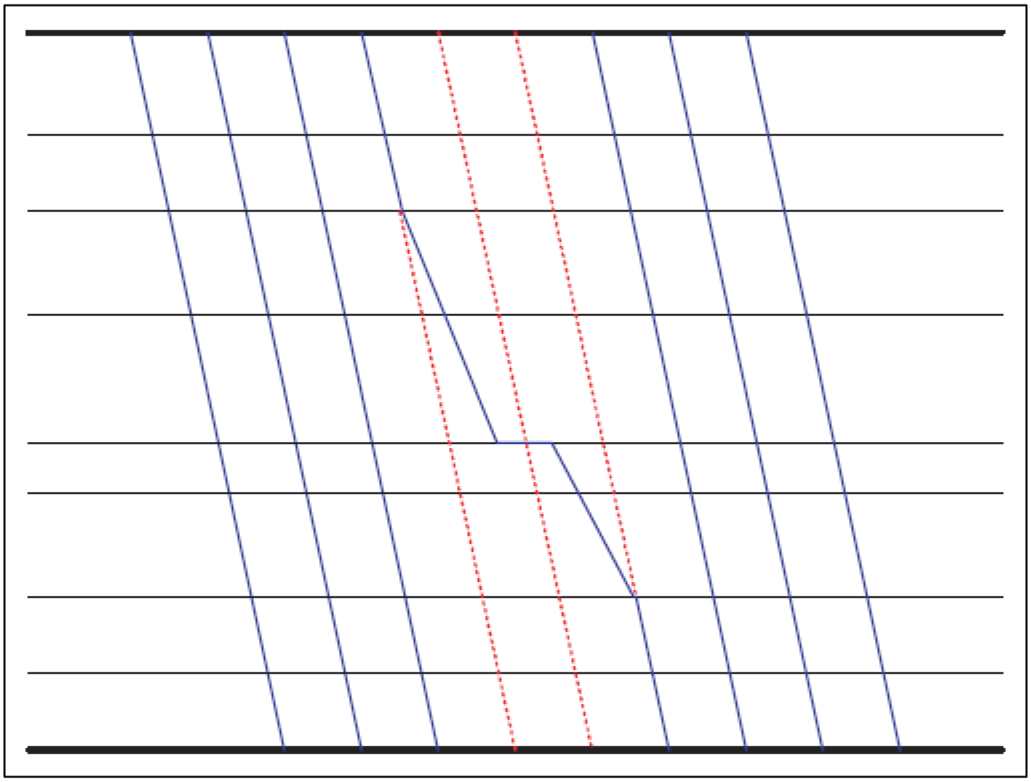


Source: UIC (2004, p. 3)

The International Union of Railways (UIC) consequently states that "[c]apacity as such does not exist. Railway infrastructure capacity depends on the way it is utilised" (UIC, 2004, p. 2). As shown in Figure 6, the number of trains on any given infrastructure is interdependent with the average speed of these trains, the heterogeneity of the train types and the stability of the timetable used and varies substantially depending on the operating mix of the trains and the timetable under which they operate. As observed by Dicembre & Ricci (2011), increasing the operating speeds drives the braking distance and consequently the minimum headway, while increasing the timetable stability necessitates longer recovery and buffer times and higher levels of train heterogeneity escalates minimum headways even further, which demonstrates that train capacity is negatively related to all 3 other dimensions of the capacity balance. In the observation of Landex (2009), heterogeneous operation at high train volumes may also slow down faster trains, which also points at conflicts between the other dimensions. Nevertheless, this slack might be avoided by adding stops to the faster train, changing the order of the trains or letting faster trains overtake slower ones. At the same time, the fastest trains will consume the most capacity as they require longer block sections.

As noted in Preston et al. (2011), the nodes (junctions and stations) impose the key constraints onto rail corridor capacity and simulation results from a main line in the UK indicate that they may account for over half of the capacity utilisation of a busy rail corridor. The authors consequently suggest that reducing dwell times at stations, clearing times at points and minimum headways between two subsequent trains would have a significant effect on capacity. However, the ability of unlocking some of the capacity captured by the nodes is constrained by the time consumed by passenger embarkation and disembarkation, routing to and from the platforms, the traditional design of switches and of the infrastructure and technology which assigns the authority for train movements in strict accordance to rules ensuring safe operations by considering factors such as sighting distance, braking distance (including a safety margin) and overlaps. Similar observations have motivated Abril et al. (2008) to expand the UIC model shown in Figure 6 above by a fifth dimension (*commercial stops*), in order to account for the increases in travel time (lost due to deceleration, station dwell time and acceleration) and headway time resulting from stops along the line, while noting that adding stops can lead to the suppression of slots – especially if only selected trains stop at a given station, as shown in Figure 7 below.

Figure 7: Slot suppression due to the addition of a stop for a selected train



Note: The blue lines represent train movements over time (x-axis) and along an assumed train line (y-axis), with the horizontal black lines representing train stations. The red dotted lines refer to train slots lost due to the fourth train stopping at the fourth intermediate station.
Source: Abril et al. (2008, p. 796)

3.2. Railway track allocation (scheduling)

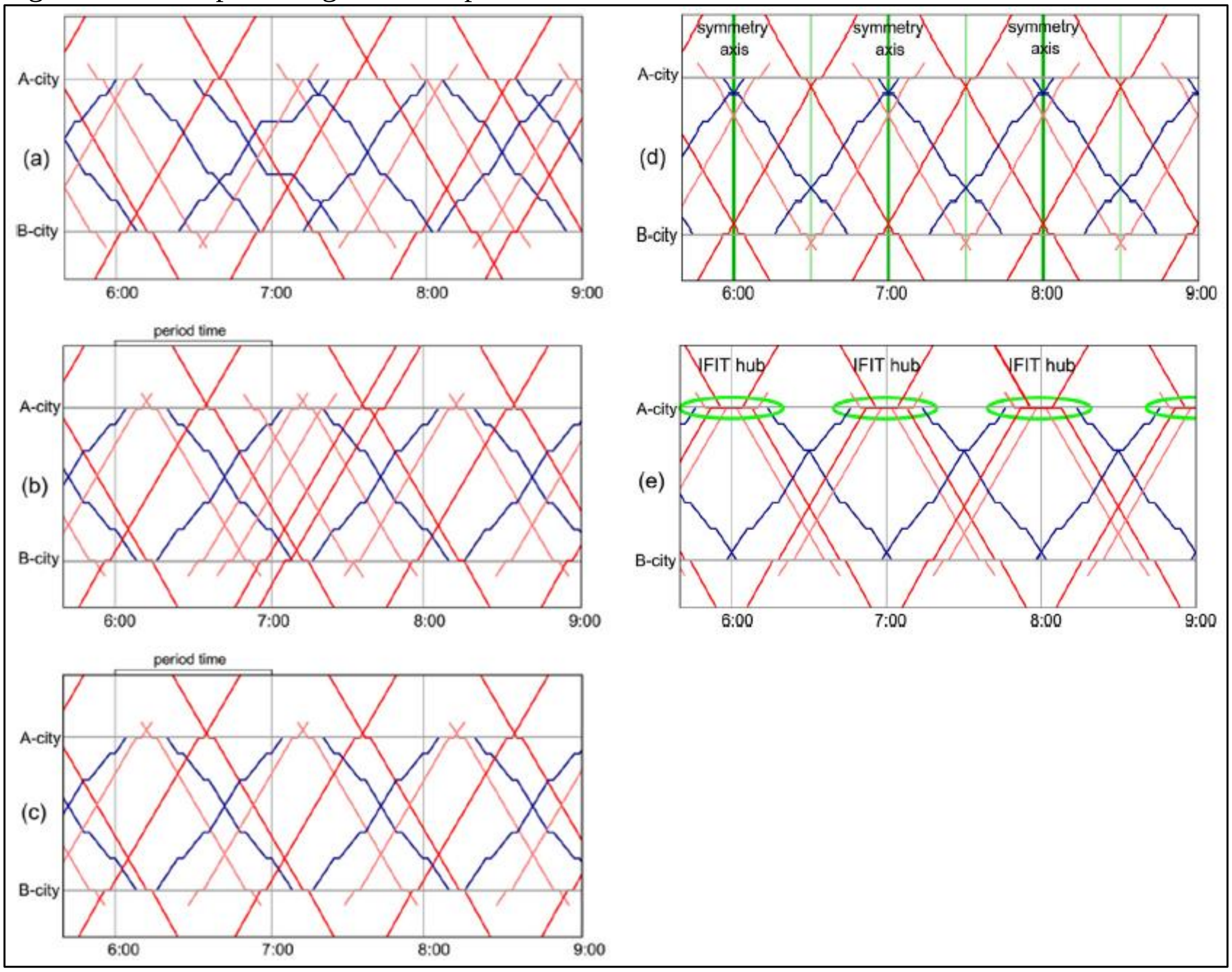
The observations presented in the previous section highlight the importance of railway track allocation in ensuring an efficient utilisation of the available capacity. As already noted at the beginning of this chapter, railway scheduling refers to the planned allocation of rail capacity to individual trains, which concerns the usage of any railway track – from mainline tracks over siding tracks to platform and storage tracks – and is known in the literature as the Train Timetabling Problem (TTP). In the observation of Cordeau, Toth & Vigo (1998), the train timetable problems occur for freight and passenger trains alike, though in slightly different forms, as freight trains in North America often operate without a schedule and are dispatched on an ad-hoc basis. This situation is very different from the railroad industry in Europe or passenger trains in general, but still requires the insertion of dedicated freight time slots into the timetables along any freight routes to which these freight trains can be assigned (Harker, 1995). In either case, the fundamental objective of the TTP can be described as the allocation of track capacity of a railway network over time in a conflict-free manner (Lusby, Larsen, Ehrgott, & Ryan, 2011).

When allocating railway capacity, Arbil et al. (2008) identify three groups of methods in the literature, where analytical methods represent the most basic approach by modelling the environment faced by a railroad through mathematical formulas or algebraic expressions, such as the line delay model developed by Chen and Harker (1990) for single-tracked corridors and refined by Harker and Hong (1990) for partially double-tracked corridors or the Lagrangian relaxation solution approach proposed by Caprara et al. (2006). Optimisation models evaluate railway capacity by obtaining optimal saturated railway timetables, with the Schedule Analysis (SCAN) system proposed as a mixed integer linear programming model by Jovanovic and Harker (1991) exemplifying a fixed velocity model, while the nonlinear mixed integer program formulated by

Kraay, Harker and Chen (1991) represents a variable velocity model. Finally, simulation methods like the continuous Linear Programming (LP) approach developed by Vansteenwegen and Van Oudheusden (2007) or software solutions like OpenTrack (OpenTrack Railway Technology Ltd., 2018) allow to analyse the robustness of a timetable by introducing randomly occurring events such as delays.

Liebchen (2006) identifies four different timetabling classes – *scheduling every trip individually*, *periodic timetables*, *symmetric periodic timetables*, and *integrated fixed-interval timetables* (IFIT) – and considers each class of timetables as a refinement of the previous ones. Generally, the latter three timetable classes are grouped as *periodic timetables* in the railway literature and treated as the Periodic Event Scheduling Problem (PESP), which has been described and studied extensively by Liebchen & Möhring (2007), while non-recurring timetable patterns are classified as *non-periodic timetables* (de Fabris, Longo, Medeossi, & Pesenti, 2014). As shown below in Figure 8, Caimi, Kroon, & Liebchen (2017) add a fourth class of periodic timetables, where an otherwise periodic timetable construct is supplemented by additional runs. The most obvious reason for such a *partially periodic timetable* is the presence of peak travel times (such as between 6:30 and 7:30 in Figure 8(b)), during which additional trains have to be inserted and these additional trains might not necessarily run with the same stopping patterns as other train services forming part of the periodic timetable construct or in the exact middle between two consecutive slots of such a train service.

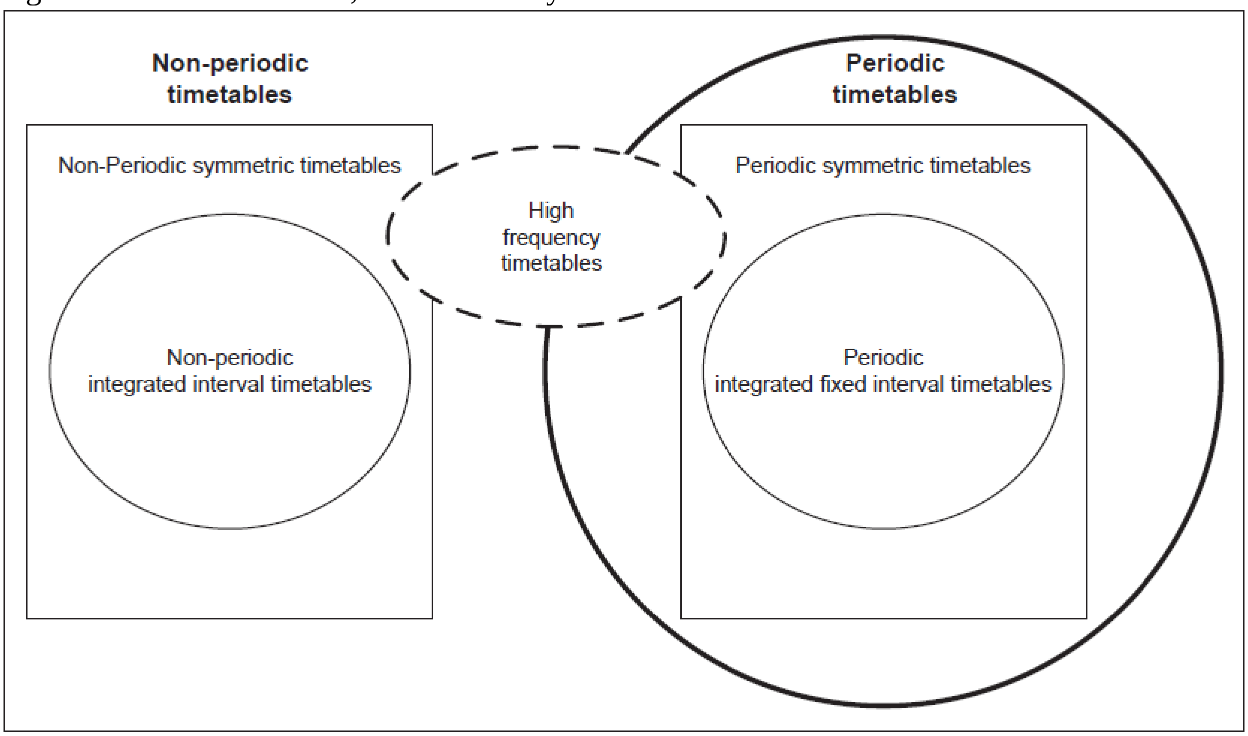
Figure 8: Time-space diagram examples for various timetable classes



Note: timetable categories shown above are (a) individual trips, (b) a partially periodic timetable, (c) a periodic timetable, (d) a symmetric timetable and (e) an integrated fixed interval timetable Source: Caimi, Kroon, & Liebchen (2017, p. 291)

As shown in Figure 9 below, Schittenhelm (2013) argues that the same structural features which define the classes of periodic timetables (i.e. the presence of symmetry and/or integrated intervals) can also be applied to non-periodic timetables (as *non-periodic symmetric timetables* and *non-periodic integrated interval timetables*), while introducing a seventh timetable class called *high frequency timetables*, which are mostly known from Subway systems where trains depart at so short intervals that timetables only specify a first and last departure between which customers can expect short waiting times of no more than just a few minutes. The same author refines non-periodic and periodic timetables into 24 subclasses (3 non-periodic, 7 non-symmetric periodic, 14 symmetric periodic), while pointing out that periodic timetables often change their periodicity characteristics (i.e. presence or absence of changes in operational patterns throughout the day, the degree of such changes and their number) and thus their pattern multiple times during the day, in response to changes in demand patterns, which might favour significantly different timetable patterns at different times of the day[5].

Figure 9: Timetable classes, as classified by Schittenhelm



Source: Schittenhelm (2013, p. 33)

When contrasting non-periodic and periodic timetables, Schittenhelm (2013) also notes that even though non-periodic timetables theoretically allow a more efficient scheduling by avoiding unnecessary timetable constraints which impede efforts to maximize rolling stock and

[5] To provide one example: the presence of a peak travel direction (e.g. from the suburbs into the city center in the morning and in the opposite direction in the afternoon) often necessitates the insertion of supplementary peak-direction-only trains into an otherwise symmetrical timetable.

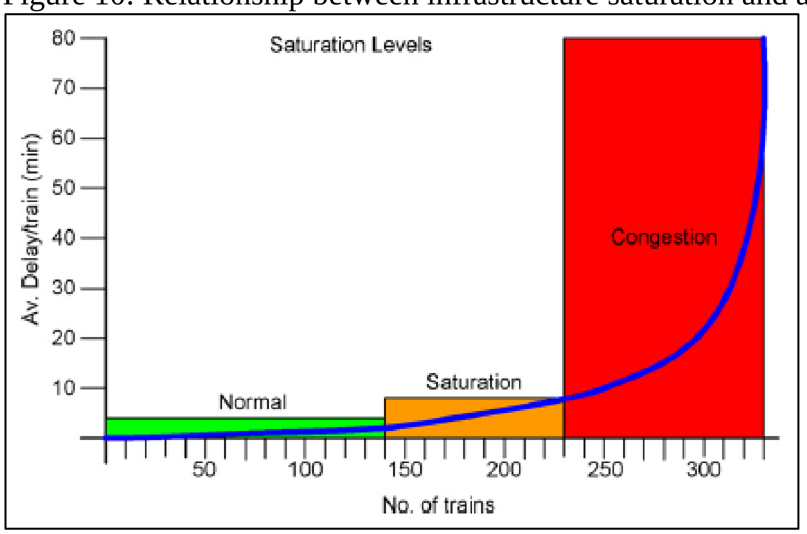
infrastructure utilization, experiences from the railway industry suggest that companies operating their passenger trains on a periodic timetable actually tend to achieve increased utilization levels, presumably because the presence of one or a very small number of patterns which are repeated throughout the day reduces the timetable complexity, thus facilitating optimisation efforts. Tyler (2003, p. 5) therefore argues that complex operating environments call for a basic pattern which is used over the entire day and supplemented or reduced as required by changes in demand, while keeping changes to the selected pattern to a minimum:

> *"Rather than search for a theoretical 'best' solution it is usually therefore more sensible to test a relatively small number of feasible and acceptable solutions to match the market and if, as is typically the case, the pattern of demand is fairly stable through the day, to select one pattern and to treat it as a 'standard hour'. In other words, that pattern is replicated every hour from the start to the end of the service, with a greater or lesser degree of adjustment to cater for peak-hour travel."*

3.3. Timetable quality and attractiveness

In the words of Caimi, Kroon, & Liebchen (2017, p. 287), "[a] railway timetable describes the planned movements of the trains in the railway system, but it can also be considered as the planned utilization of the railway infrastructure." As described in the previous sections, one challenge of railway scheduling is to ensure an efficient utilisation of the available infrastructure (tracks and platforms), as well as an efficient deployment of rolling stock (and operating staff). However, a significant operational concern is that of *timetable stability*, which Goverde (2008, p. 119) defines as "the ability of [a] railway system to recover from delays", given a certain timetable, and differentiates between *local stability* (i.e. an open system's ability to offset delays so that the sum of output delays is smaller than the sum of input delays) and *global stability* (i.e. a closed system's ability to settle initial delays in finite time[6]). Both abilities are severely hindered when the infrastructure is operated at high saturation levels, as shown in Figure 10 below.

Figure 10: Relationship between infrastructure saturation and average train delays



Source: Abril et al., (2008, p. 779)

[6] In the words of Goverde (2008, p. 119), an "*open system* is a subnetwork or railway line with trains entering and exiting", while a "*closed system* is a closed network of rail circulations".

The industry standard of fostering timetable stability is to add time supplements to all scheduled services, in the form of running time supplements, dwell time supplements and buffer times between train paths, to offset a certain level of delays, which are often incurred en-route (e.g. signalling problems or temporary slow orders) or at stations (e.g. high passenger volumes, waiting for delayed connections), or to reduce the risk of knock-on delays from already delayed trains (Schittenhelm, 2011). Even though many countries use their own national standards, the UIC has published its own recommendations regarding travel time supplements, which are summarized in Figure 11 below.

Figure 11: Running time supplements for various train types, as recommended by the UIC

Table 4: UIC recommended percentage running time supplements for locomotive hauled passenger trains [10]

Weight [tons]	Speed [km/h]			
	≤ 140	141-160	161-200	> 200
≤ 300	3%	3%	4%	5%
301-500	4%	4%	5%	6%
501-700	4%	5%	6%	7%
> 700	5%	5%	6%	7%

Table 5: UIC recommended percentage running time supplements for multiple unit passenger trains [10]

Speed [km/h]				
≤ 140	141-160	161-200	201-250	> 250
3%	4%	5%	6%	7%

Table 6: UIC recommended running time supplements for freight trains [10]

Speed [km/h]	
≤ 120	> 120
- 1min/100km + 3% running time or - 3min/100km or - 4% running time	As for passenger trains – see Table 4

Note: In addition to the speed-based travel time supplements shown above, the UIC recommends a distance-based travel time supplement of 1.5 minutes per 100 km for locomotive hauled trains or 1 minute per 100 km for multiple unit passenger trains.
Source: Schittenhelm (2011, p. 7)

Further to the operational characteristics described in this section so far, Schittenhelm (2010) notes that a rail timetable also determines various characteristics which influence the attractiveness of passenger rail travel, such as the scheduled travel time, the transfers required to make a certain railway journey, planned transfer time (which determines transfer reliability), the number of departures (which determines hidden waiting time), flexibility (concerning the operating hours) and the presence or absence of regular intervals (or repeating patterns). In order to assess the attractiveness of the seven timetable classes he identified (refer to the preceding Section), Schittenhelm (2013) proposed an extensive framework, which Tyler (2003, p. 5) has summarized by underlining the advantages of the integrated fixed-interval timetable (IFIT):

> "*As argued by its proponents, the advantages of a Taktfahrplan*[7] *over a conventional timetable derive from six characteristics:*
>
> - *that the methodology delivers a logical and coherent timetable across a network;*
> - *that it articulates a well-defined hierarchy of services;*
> - *that connectivity between services, and thus for a journey on any relation (place-pair), is optimised;*
> - *that systematic planning and regularity together make the best use of capacity;*
> - *that a repeating pattern is simple to market and memorable for customers; and*
> - *that the service in one direction is the mirror-image of that in the reverse direction.*"

As exemplified by the continued success of the Swiss railway system, periodicity has been proven to be one of the most important parameters regarding timetable attractiveness towards the customers, as regular intervals allow them to easily remember the departure time[8]. High frequency

[7] *Taktfahrplan* (formed from the words Takt-fahr-plan ['rhythm-journey-plan']) is a term coined by Swiss timetable visionaries who developed a system-wide coordinated timetable based on clear rules, repetition and consistency, which has become established in German and is used in Tyler (2003) and elsewhere in the railway literature in the absence of a satisfactory phrase in English.

[8] This of course necessitates that the gap between two consecutive departures is a divisor of 60 minutes. While this is a long-established standard in Switzerland and other parts of Europe, some transit agencies in North America still operate headways off non-divisors, as is the case with night buses in Montreal, which the STM often operates at headways of 40 or 45 minutes, resulting in 3 or even 4 alternating departure time patterns.

timetables require even less planning efforts from passengers by providing them the opportunity to show up at a station randomly without risking long waits. However, high levels of predictability come at the expense of timetable flexibility as timetable planners face trade-offs when seeking high timetable attractiveness, which place constraints on line selection (as heterogeneity increases capacity consumption) and at stations (by requiring many vehicles to be at the same station and having to thus provide a considerable number of station and platform facilities which are basically deserted outside of the respective IFIT hub times). The disadvantages of IFITs therefore include the *rigidity of the timetable* (which constrains the efficient cycling of rolling stock and staff), the inability to offer a large number of station pairs with *direct connections* (imposing the inconvenience and risks of transfers onto the passenger) or a timetable which is *easily adaptable to market demands* (such as offering a large proportion of passengers a seat with a small number of departures), as well as managing the complexity of reaching agreements across all concerned train operating companies (TOCs) and infrastructure owners during the timetable planning process. (Schittenhelm, 2010; 2013)

The conflicting desires to provide fast connections and to ensure robust operations require a clever design of timetables, which typically aims at simultaneously minimising passenger travel and waiting times and the number of vehicles and drivers required to operate the timetable (Caimi, Kroon, & Liebchen, 2017). The reputation of a TOC therefore depends on factors like the punctuality, reliability, seating capacity and level of seating comfort offered by its trains as well as on its ability to keep its operating costs and thus the cost to its passengers and the taxpayer at a reasonable level (Schittenhelm, 2010). Even though electronic timetabling tools have become increasingly available to timetable planners and promise to drastically reduce the efforts in identifying efficient solutions, de Fabris, Longo, Medeossi, & Pesenti (2014, p. 8) stress that only a skilled timetable planner familiar with the large complexity of local and global constraints can determine the feasibility of a timetable solution and its adherence to the "set of empiric rules currently used in practice". Therefore, Tyler (2003, p. 5) could have had just as well the Toronto-Kitchener corridor in his mind when he noted that

> "*[o]n multi-purpose, multi-route railways trade-offs are unavoidable between, on the one hand, the commercial requirements for different types of service, with various acceleration-curves, running speeds, stopping patterns, junction movements and inter-relationships, and on the other, the obligation to obtain the best practicable return on the high cost of the infrastructure, or to properly justify an enhancement. For a network the equations are complicated, not least because it is not obvious what the objective function should be and how it should be measured.*"

3.4. Summary

Railway scheduling refers to the planned allocation of rail capacity to individual trains, while the real-time adjustment to the railway schedules is known as railway dispatching. There are different ways to define and thus determine railway capacity, but the term generally refers to the number of trains which can be routed through a given rail network segment in a given period of time without causing excessive delays to any of the trains in the system. Like with motorways, the maximum vehicle throughput is the highest when all vehicles travel at the same constant speed, in the same direction and without any stops. Therefore, the train characteristics determined by the railway service design of the individual trains (as well as by the choice of rolling stock) directly impact railway capacity. Furthermore, railway capacity decreases as the rail service heterogeneity (i.e. the variety of different rail services and their variation in train and service characteristics) increases. Consequently, the available rail corridor capacity needs to be shared between freight, commuter, regional, intercity and even high-speed trains, where an ideal allocation maximizes the utility provided to the customers of transportation services for any given rail corridor, while minimizing the disutility of delays, other operational disruptions and other passenger inconveniences as well as avoiding costly infrastructure upgrades.

4. Methodology

4.1. Overview

In reference to the three groups of methods of allocating railway capacity identified in Section 3.2, optimisation methods would undoubtedly appear as best suited for the timetable problem presented in this thesis. In absence of access to the kind of professional software which would be required to optimise a timetable problem of the size as treated by this thesis, the author had to base his methodology on Microsoft Excel. Unfortunately, this forced software choice limited the search for timetable solutions to analytical methods, which may produce solutions which are not optimal and cannot be checked for robustness (through simulation). The methodology of this thesis will consequently be based on a modelling approach, as outlined in this chapter.

Chapter 5 will conceptualise the case study by defining the exact area studied (i.e. the line from Toronto Union to Kitchener and Cambridge, formed by the USRC, the Weston, Halton and Guelph subdivisions and an underutilised branch line of the GEXR network called the Fergus Subdivision), and the assumed physical characteristics (e.g. track layout) and operational constraints (e.g. minimum headways). This will involve determining which parameters (e.g. speed and acceleration properties, stopping pattern) and timetable strategies (e.g. symmetric periodic timetable, integrated fixed-interval timetable) to include in the modelling process, while keeping the number of timetable scenarios to be modelled manageable. Then, *Chapter 6* will model the problem, assuming uniform acceleration (for the sake of simplicity, but still using individual real-world acceleration and deceleration values) and by estimating realistic speed limits depending on line curvature, to determine run-times for the individual train types depending on the applicable values for the various variables. Afterwards, *Chapter 7* will solve the model by scheduling the number of passenger trains for each of the timetable scenarios described in Chapter 5 and by then inserting as many additional freight train slots as possible without violating any constraints. Finally, *Chapter 8* will implement the model by presenting the modeled timetable scenarios and determining the need for variants of the timetable scenarios identified in Chapter 5.

4.2. Timetable planning

As outlined by Caimi, Kroon, & Liebchen (2017), the planning process of railway timetabling involves the train operating companies (TOCs) to create their preferred timetables and the infrastructure manager (IM) to integrate these timetable requests into one final timetable, which allocates the available infrastructure in a feasible, but ideally also transparent and fair manner. The timetabling process therefore starts with the TOCs determining their line systems with the line types, frequencies[9] and stopping patterns for the various train services, which enables the construction of the timetable for a timetable period[10]. This forms the base of the *generic weekly timetable*, which covers all 24 hours of all seven weekdays. Any planned deviations from the generic weekly timetable are then specified in the *daily timetables* for every calendar day, to account for planned infrastructure work restricting infrastructure availability during pre-defined periods of the year or seasonal deviations in demand[11]. All train path requests are then received by the IM, who then must allocate specific tracks and platforms to the individual train movements. As the various TOCs have been creating their requests individually from each other, it is quite likely that service requests from one operator conflict with those of another (by requiring the same

[9] Depending on the chosen timetable class, "frequency" may refer to the number of trains per hour (in the case of periodic timetables) or day (in the case of non-periodic timetables).
[10] Depending on the chosen timetable class, "timetable period" may refer to the length of one single or multiple periods which repeats themselves throughout the day (periodic timetables) or to the entire day (non-periodic timetables).
[11] For instance, lower demand for peak-hour weekday departures between Christmas and New Year's Eve or higher demand on summer weekends towards popular leisure destinations or during major festivities and similar events.

track segment or platform at the same time), in which case the IM must resolve these conflicts by either modifying some of the requested train paths, changing their departure time or by adding or increasing dwell times at intermediary stations or siding tracks. Therefore and except for those cases where the entire network is only operated by one single TOC, the competition of multiple TOCs for the same limited resources (i.e. track capacity), requires a significant level of cooperation between the infrastructure manager and the various TOCs. (Caimi, Kroon, & Liebchen, 2017)

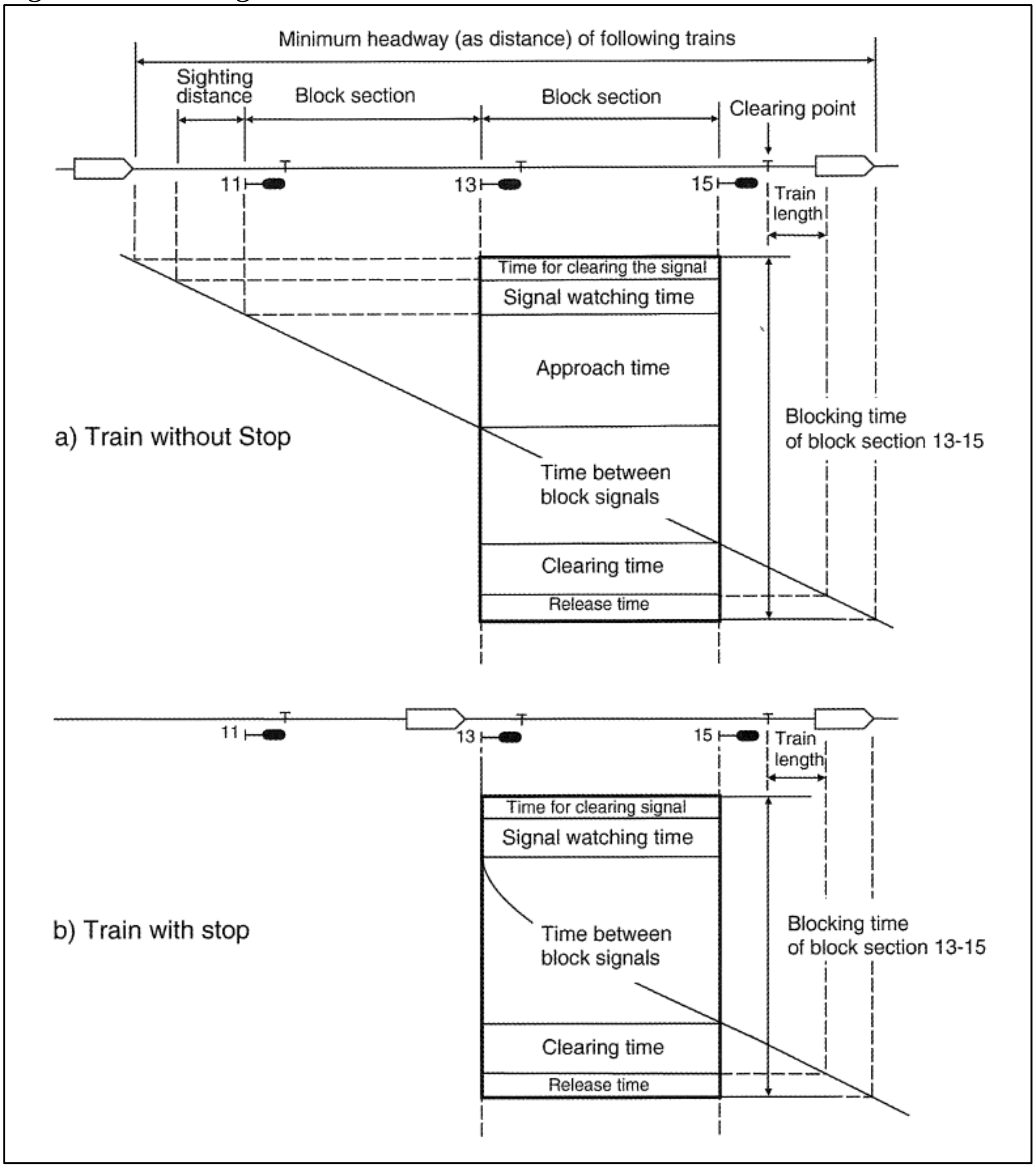
For the purposes of this thesis, train services will be designed in accordance with the existing timetables and future expansion plans presented for the various TOCs serving (or planning to do so) the Toronto-Kitchener corridor. In contrast and following a suggestion by Meirich & Nießen (2016), freight trains will be accommodated for by adding dedicated slots into the resulting timetables until the practical capacity is reached. This allocation of excess capacity (i.e. capacity not reserved for passenger services) for freight movements does not only better suit the nature of freight services which does not favor strict timetables with exact departure or arrival times, but also allows to quantify the practical capacity under the specific timetable concept by adding the least arbitrary train type. Conveniently, the presence of such freight slots also establishes the theoretical capacity and acts as a buffer which increases timetable robustness as only a small number of these slots is likely to be actually used on a given day, thanks to the comparatively low freight train volumes mentioned in Section 1.2. Given that the shortage of capacity is most evident during peak-hours on a normal weekday, each timetable scenario will be modelled for these periods of peak demand for track access.

4.3. Timetable modelling

An important factor in train timetabling is finding the right level of detail to represent the infrastructure and train dynamics. Considering that a node is a representation of an arbitrary location in a railway network and that a link is a connection between any two nodes, microscopic models contain a high level of details on nodes and links, whereas macroscopic models only contain aggregated information (Radtke, 2008). Unlike their macroscopic peers, microscopic models consequently take a vast range of operational constraints into considerations, such as the applicable speed profile of individual trains (even on low-speed alternative routings, e.g. when the use of non-mainline platforms requires switching tracks at less than line speeds), the exact routing of each train (thus identifying train path conflicts even if only a diamond crossing is shared by two trains' paths) and exact blocking times. As shown below in Figure 12 below, the blocking time refers to the time elapsed between the moment the signal for a train to enter the block is given and the moment the block has been cleared and released and includes the following blocking time elements (Pachl, 2014):

- Time for clearing the signal: delay until the signal electronics and/or mechanics have set the signal at the block entry to "clear" (e.g. green).
- Signal watching time: delay until the train driver can see and correctly interpret the signal.
- Approach time: travel time of the train while approaching the signal.
- Time between block signals: travel time between two subsequent block signals.
- Clearing time: delay until the last train axle has passed the clearing point.
- Release time: delay until the block has been released and can be assigned to a different train.

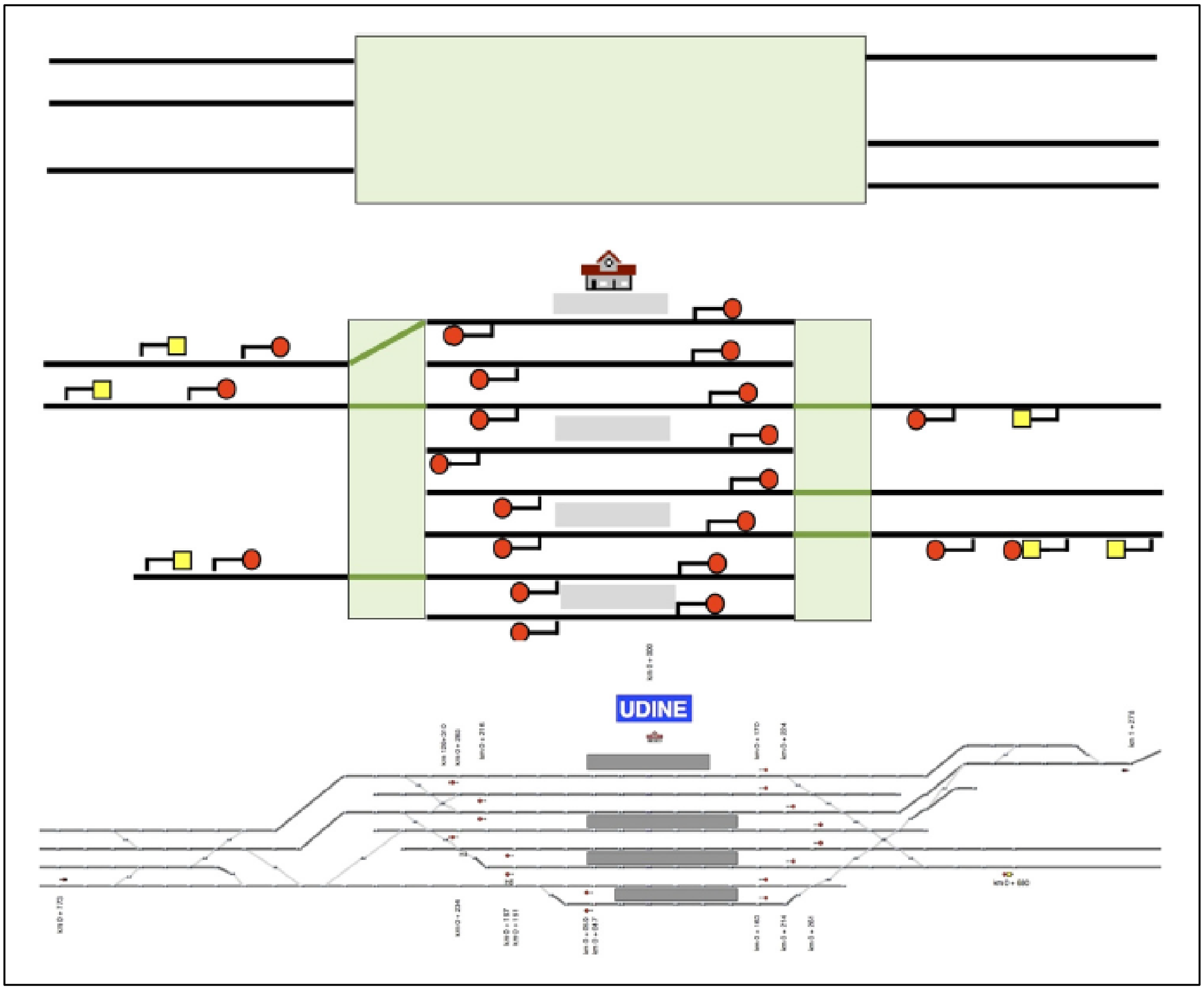
Figure 12: Blocking time of a block section



Note: It should be noted that even though the approach time can be eliminated from the minimum headway (if signal #13 does not switch to "clear" before the train has reached it – as shown in the lower part), the low initial speed when entering the block resulting from the need to stop (or to decelerate in preparation of a stop) in front of signal #13 until the moment it switches from *stop* (e.g. red) to *clear* (e.g. green) increases the "time between block signals" (and thus the trains' overall travel time).
Source: Pachl (2014, p. 24)

Given that the choice between macroscopic and microscopic modelling embodies a problematic trade-off between risking an oversimplified representation of the network structure and exhausting available computing time, de Fabris, Longo, Medeossi & Pesenti (2014) seek a middle-ground by proposing a mesoscopic model, which respects the rigid separation between stations and line sections typical for macroscopic models, while taking microscopic considerations like exact train routing, the signalling system and rolling stock characteristics into account when computing running times. As shown in Figure 13 below, a *microscopic model* may show all tracks, switches, platforms and various types of signals in their approximative location (schematic view), while a *macroscopic model* may only show the main tracks as lines and the entire station area as a box. Conversely, a *mesoscopic model* may also show the station tracks, simplified symbols for the signals and switches represented by lines which connect main line tracks with station tracks. Unfortunately, most microscopic elements are beyond the computation abilities available to the author, which is additionally limited by the functionality of Microsoft Excel, which is inferior to any professional timetabling software like RailSys or OpenTrack. The same is also true for using the UIC 406 timetable compression approach when measuring capacity usage; even though a more simplified alternative exists with the Capacity Utilisation Index (CUI) used in the UK (Gibson, Cooper, & Ball, 2002). Nevertheless, the modelling approach chosen in the following two chapters will model running times for every train type and stopping pattern separately and prevent the simultaneous assignment of conflicting train paths.

Figure 13: Macroscopic, Mesoscopic and Microscopic models of a station



Note: The mesoscopic model is shown between the macroscopic (above) and microscopic (below) representation of the same Italian station. The dark green lines in the light green boxes at both ends of the station in the mesoscopic representation arbitrarily selected train paths which can be assigned simultaneously without causing any conflicts between them.
Source: de Fabris, Longo, Medeossi & Pesenti (2014, p. 4)

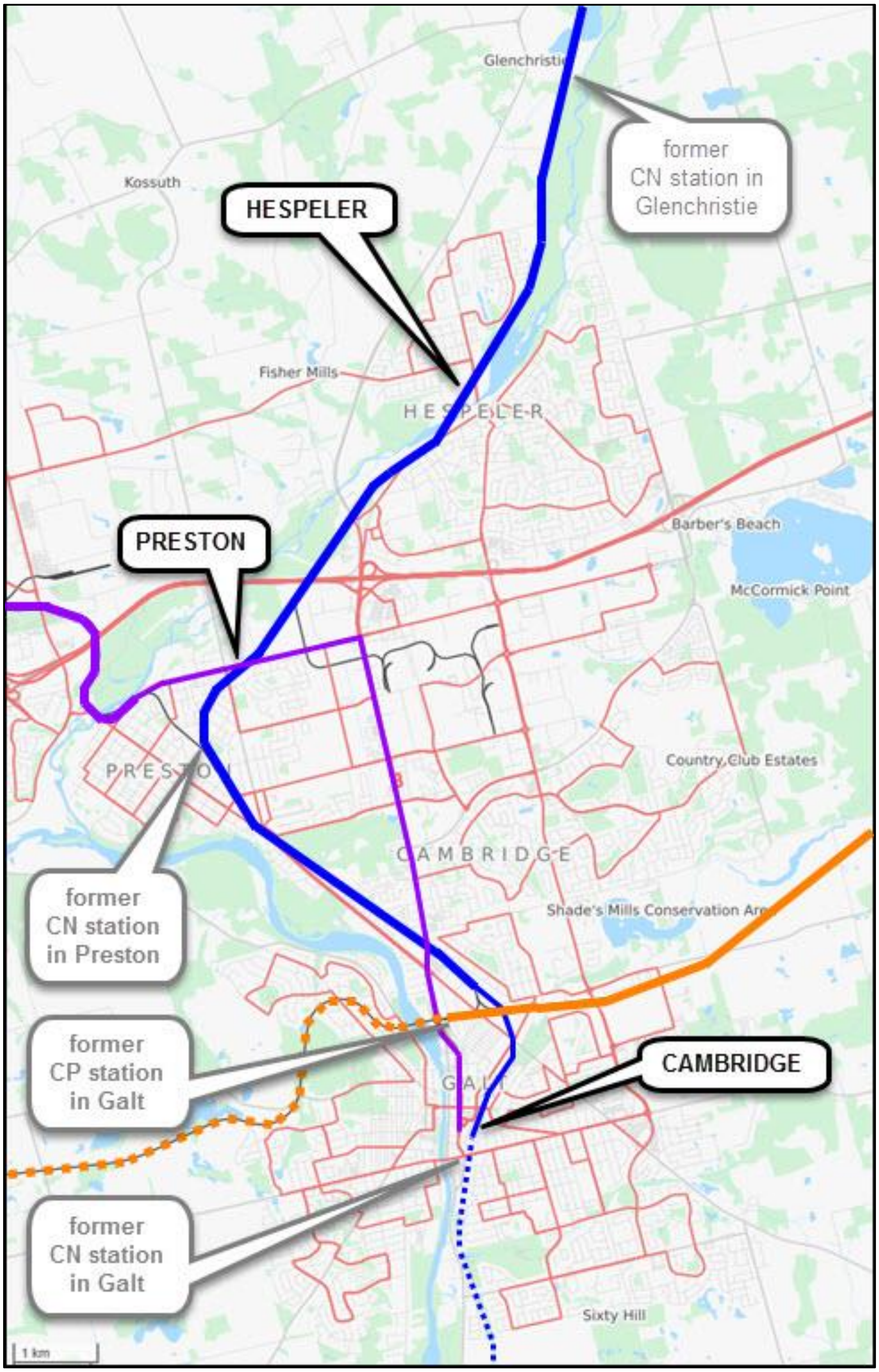
5. Conceptualisation

5.1. Rail infrastructure

Before the case study can be modelled, the scope of the modelling process needs to be defined: for the purposes of this thesis, the study area shall comprise the railway corridor from Toronto Union to Kitchener, which is formed by the Union Station Rail Corridor, the Weston, Halton and Guelph subdivisions. In order to provide a more interesting application for an integrated fixed-interval scenario, the railway line from Guelph to Cambridge (an underutilised branch line which is part of the GEXR network and known as the Fergus Subdivision) will be included into the study area to allow transfers in Guelph between Cambridge and both ends of the Toronto-Kitchener corridor.

Concerning the rail stations to be included for the Modelling process, it shall be assumed that all 4 proposed stations identified in Section 2.2.2 (Liberty Village, St. Clair, Mount Dennis and Breslau) are reopened. Similarly, it shall be assumed that all 12 stations which are currently served along the Kitchener Corridor remain open, with Kitchener station moving to its new location above King Street West with the already completed light rail station. Out of the rail stations served by CN's passenger trains on the Fergus Subdivision until their last trip in June 1959, four stations fall into the study area: Glenchristie, Hespeler, Preston and Galt. Whereas Glenchristie is nothing but a ghost village today (Langan, 2001), the former stations of Hespeler, Preston and Galt lie well within significant residential areas. As shown in Figure 14 below, the station locations shall be assumed at the old station in Hespeler (thus allowing connections with the existing bus network) and at slightly modified locations in Preston and Galt, in order to allow intermodal connections with the planned "Phase 2" extension of the iON light rail from Kitchener to Cambridge near the intersection of Eagle St North and Concession Rd in Preston and at the Ainslie bus terminal in downtown Cambridge. A list of all rail stations to be included in the modelling process and their station codes (which have been assigned by the author partly by copying from the station codes already used by VIA Rail and will be used throughout the following Chapters) is provided in Table 9.

Figure 14: Assumed station locations in the city of Cambridge



Notes: Map overlay shows bus transit routes as red lines and rail tracks as black lines. Fergus Subdivision shown in blue, Galt Subdivision shown (for comparison purposes) in orange and the proposed iON light rail in violet. Thick lines refer to already existing and operational ROWs. Adapted from: OpenStreetMap (2018) with iON routing provided by Region of Waterloo (2017)

Table 9: List of all stations to be included in the modelling process

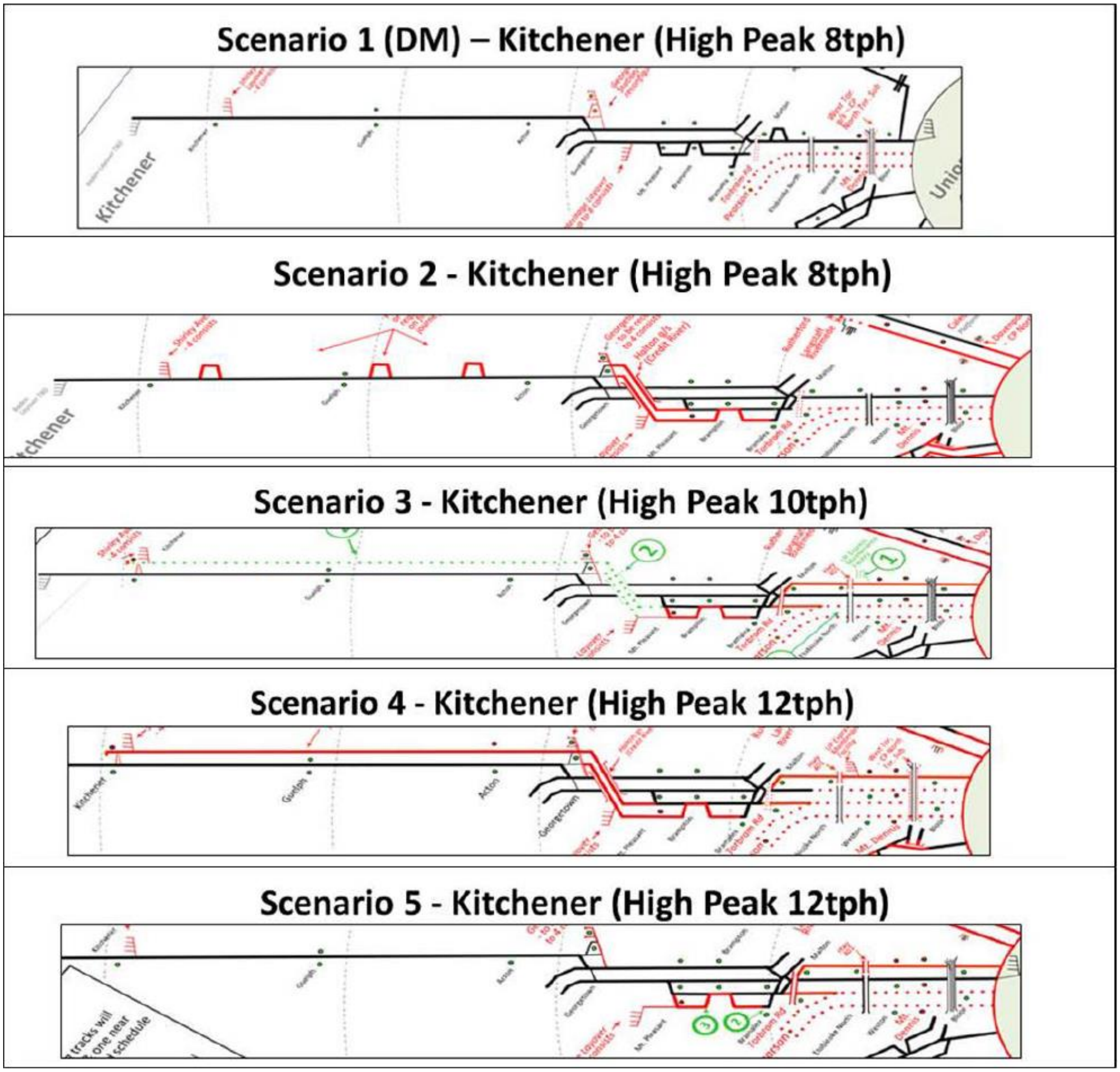
Miles	Station Name	Code	Connections (rail only)
0.0	Toronto (Union)	TRTO	Other RER and Inter-City services, Subway
2.1	Liberty Village (new)	LBTV	Streetcar (short walk)
4.0	Bloor	BLOR	Subway and Streetcar (short walk)
5.3	St. Clair (new)	STCL	Streetcar
6.8	Mount Dennis (new)	MTDN	Light Rail Transit (under construction)
8.4	Weston	WEST	
11.0	Etobicoke North	ETBN	
14.7	Malton	MALT	
17.3	Bramalea	BRML	
21.1	Brampton	BRMP	
24.0	Mount Pleasant	MTPL	
29.2	Georgetown	GEOG	
35.6	Acton	ACTN	
48.8	Guelph	GLPH	
57.5	Breslau (new)	BRSL	
62.9	Kitchener (new)	KITC	Light Rail (under construction)
Stations along the Cambridge branch			
57.6	Hespeler (reopened)	HESP	
60.1	Preston (new)	PRST	Light Rail (proposed)
64.8	Cambridge (new)	CMBR	Light Rail (proposed)

Source: adapted from Table 8.

An important factor constraining the number of trains which can be inserted into the timetables to be modelled in the following chapters is the number of available tracks and the approximate location of switches and platforms. As shown in Figure 15, Metrolinx assumes that the entire shared segment of the Kitchener Corridor (i.e. the Halton Subdivision between Halwest Jct. and Silver Jct.) can be quadruple-tracked, except for a short segment around Brampton rail station, where only a third track is to be added (Metrolinx, 2015a). Even though all grade separations from the road network (i.e. bridges and overpasses) seem to either have already a third and fourth track in place or a provision for such expansion made on the first 5.5 km west of Halwest Jct. (as shown in Figure 16), a review of recent imagery available through Google Earth did not show any such provisions for the five or so rail bridges within the urban core of Brampton, which constrain the available space within the existing right-of-way to two tracks. While the cost of expanding these road underpasses might be far from prohibitive, widening the existing rail corridor at the current rail station in Brampton from its current 2 tracks (see Figure 17) and at the Georgetown viaduct from its current provision for 3 tracks (see Figure 18) would be much more significant, given the need to relocate a Heritage Railway Station[12] or to build an additional viaduct next to the existing one.

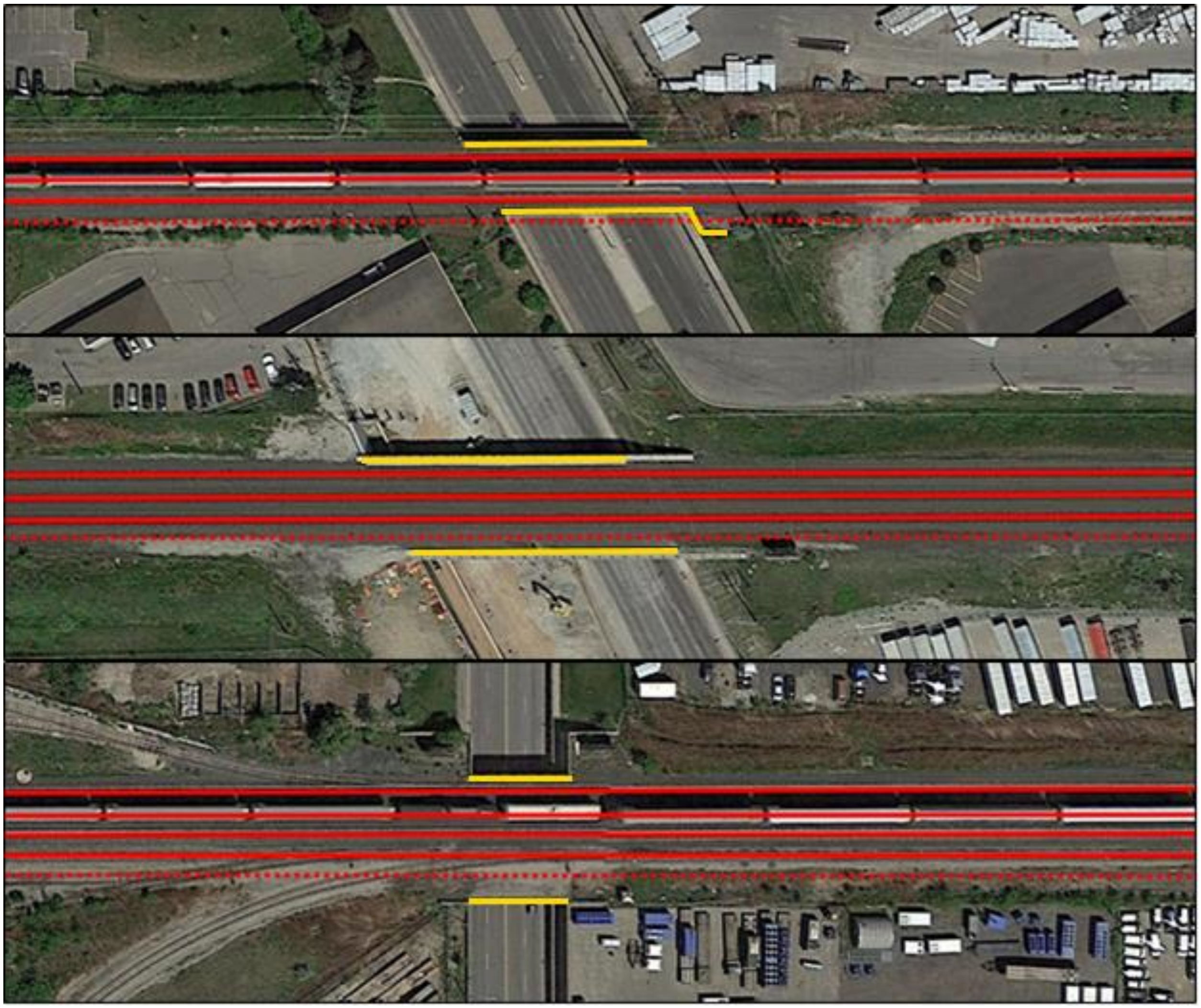
[12] The former Canadian National Railways Station (currently served by GO Transit and VIA Rail) was designated a Heritage Railway Station in 1992 (Parks Canada, 2018).

Figure 15: Track plans published by Metrolinx for various RER scenarios on the Kitchener Corridor



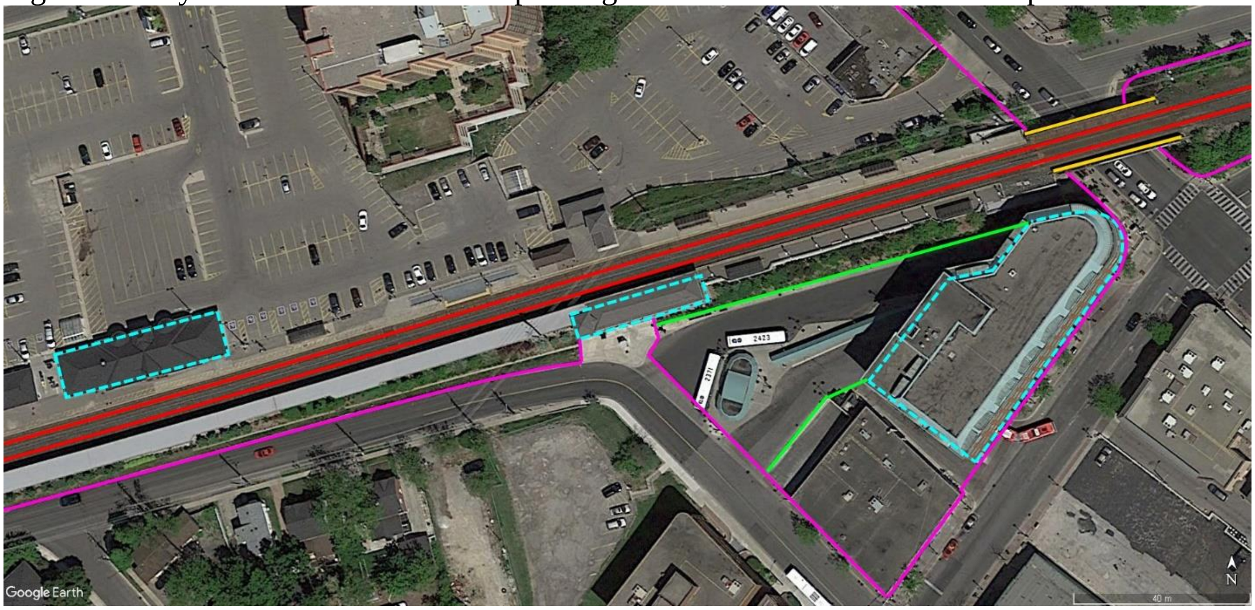
Note: the track plans and frequencies (tph = trains per hour) shown in this figure refer to the scenarios described in Table 5.
Source: Metrolinx (2015a, pp. 23-27)

Figure 16: Rail overpasses between Halwest Jct. and downtown Brampton with at least 3 tracks laid and provisions for at least one additional track



Note: Shown are the rail overpasses of the Halton Subdivision at Kennedy Road South (top, MP 14.32), Dixie Road (middle, MP 12.39) and Rutherford Road South (bottom, MP 13.74), representing an existing bridge for 3 tracks with a provision for an additional bridge to be added for a fourth track at a later point (top), an existing bridge with 3 tracks already laid and space for a fourth one (middle) and an existing bridge with already 4 tracks laid and with a space for at least one more track (bottom).
Source: Google Earth, with lines representing the tracks (red) or limits of the bridge (yellow) added by the author.

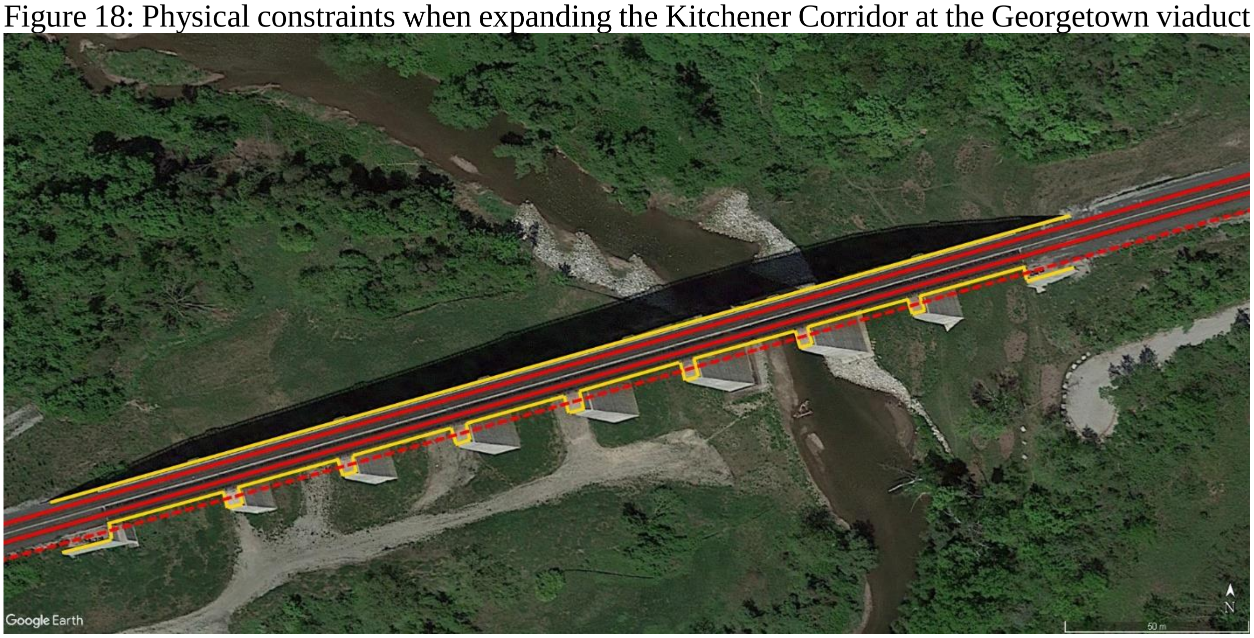
Figure 17: Physical constraints when expanding the Kitchener Corridor at Brampton rail station



Note: The buildings highlighted with a dotted line represent (from left to right) the station building, the southern station entrance building and 8, Nelson St West (a 6-story office/commercial building).

Source: Google Earth, with lines representing the tracks (red) and limits of the bridge (yellow), relevant buildings (light blue), public roads (violet) and regional bus station (green) added by the author.

Figure 18: Physical constraints when expanding the Kitchener Corridor at the Georgetown viaduct



Source: Google Earth, with lines representing the tracks (red) and limits of the bridge (yellow) added by the author.

For the purposes of this thesis, it shall be assumed that the current track plan on the Kitchener Corridor is supplemented in a way that there are four tracks available between Union Station (Mile 0.0[13]) and Woodbine Junction (Mile 13.25) and from there on three tracks until just east of Brampton (Mile 20.45) and then again from west of Brampton (Mile 21.55) until Silver Junction (Mile 29.7) with all remaining segments (Mile 20.45-21.55 on the Halton Subdivision and the entire Guelph Subdivision) being assumed to be double-tracked. Conversely, the Fergus Subdivision is assumed to remain single-tracked (and the last 2 miles to be rebuilt up to the assumed station location in Cambridge), while no changes in the track layout are assumed for the USRC. However, given that the focus of this thesis is on optimising the capacity usage on multi-tracked rail corridors rather than on single-tracked branch lines or major rail nodes, the track capacity is regarded as unconstrained on these rail segments. This means that the modelling process will not consider track availability when scheduling trains on the Fergus Subdivision the USRC and on the final approach to Kitchener station, as it is assumed that potential train path conflicts would be addressed by adding tracks as required by whatever timetable concept was to be selected for implementation. Complete track plans of the entire Kitchener Corridor and the Fergus Subdivision to Cambridge are shown in Appendix I and include all track additions discussed in this section.

[13] It should be noted that these mile markers are not identical with the Mile Posts (MP) of the various subdivisions, as the Halton Subdivision has a different starting point than the Weston and Guelph subdivisions (CN's McMillian Yard instead of Toronto Union Station), while the Fergus Subdivision counts from the other end of the corridor (from the junction with the Dundas Subdivision near Lynden). In order to avoid jumps at Halwest Jct. (from 16.8 to 11.1 miles), Silver Jct. (from 24.1 to 30.0 miles) and towards Cambridge at Guelph Jct. (from 49.5 to 30.0 and from there on counting backwards), all mileage provided within this Thesis in the format "Mile X.X" is counted from Union Station.

5.2. Signalling and train control systems

The next step of the conceptualisation stage is to define the characteristics of the signalling and interlocking systems. In order to demonstrate the impact of the chosen signalling system on the achievable train capacity, the modelling process will be done separately for a signalling system based on blocks between two consecutive stationary signals and for a modern train control system based on in-cab signalling and Automatic Train Protection (ATP). Ideally, the in-cab signalling scenario would be modelled using a “moving block” (where the minimum headway between two subsequent trains is the calculated braking distance of the following train travelling at its current speed plus a safety margin), but this would require professional timetabling software not available to the author. Instead, a “fixed block” (where the minimum headway between two trains is determined by the number of blocks which lie within the braking distance of the following train plus a *safety margin* which equals a certain number of blocks) will be used for this second scenario. To avoid confusion, the scenario variant with stationary signals shall be referred to as “variable block”, while the in-cab signalling shall be referred to as “fixed block”. In terms of the classification provided by the International Electrotechnical Commission (IEC) and shown in Table 10, scenario variants with a “variable block” shall assume Grade of Automation (GOA) 1 (i.e. *non-automated*), whereas “fixed block” operations shall assume GOA2 (i.e. *semi-automated*).

Table 10: Grades of Automation, as defined by the IEC

Grade of Automation Definition Summary

With Increasing GOA

Basic functions of train operation		On-sight	Non-Automated	Semi-Automated	Driverless	Unattended
		GOA0	GOA1	GOA2	GOA3	GOA4
Ensure safe movement of trains	Ensure safe route	Ops Staff (route by systems)	Systems	Systems	Systems	Systems
	Ensure safe separation of trains	Ops Staff	Systems	Systems	Systems	Systems
	Ensure safe speed	Ops Staff	Ops Staff (partial by system)	Systems	Systems	Systems
Drive train	Control acceleration and braking	Ops Staff	Ops Staff	Systems	Systems	Systems
Supervise guideway	Prevent collision with obstacles	Ops Staff	Ops Staff	Ops Staff	Systems	Systems
	Prevent collision with persons on tracks	Ops Staff	Ops Staff	Ops Staff	Systems	Systems
Supervise passenger transfer	Control passengers doors	Ops Staff	Ops Staff	Ops Staff	Ops Staff	Systems
	Prevent injuries to persons between cars or between platform and train	Ops Staff	Ops Staff	Ops Staff	Ops Staff	Systems
	Ensure safe starting conditions	Ops Staff	Ops Staff	Ops Staff	Ops Staff	Systems
Operate a train	Put in or take out of operation	Ops Staff	Ops Staff	Ops Staff	Ops Staff	Systems
	Supervise the status of the train	Ops Staff	Ops Staff	Ops Staff	Ops Staff	Systems
Ensure detection and management of emergency situations	Detect fire/smoke and detect derailment, detect loss of train integrity, manage passenger requests (call/evacuation, supervision)	Ops Staff	Ops Staff	Ops Staff	Ops Staff	Systems and/or staff in OCC

Systems (including CBTC) assume responsibility for more functions

Source: Keevill (2016, p. 10)

Given that a moving block system is nothing else than a fixed block system with extremely small block lengths, choosing a sufficiently small block length will closely resemble the performance of a moving block system. In order to reach a compromise between the maximisation of capacity utilisation and modelling effort, the block length shall be arbitrarily set at 0.05 miles or 80.5 meters, which is slightly shorter than the 100 meters used by *Linienzugbeeinflussung* (LZB) as the fixed-block system used on most German rail lines with train speeds exceeding 160 km/h (Wegener, 2010). Such a block length should result in up to 1,296 blocks per modelled train movement[14] and compares to the average spacing of 0.59 and 0.95 miles for the signal locations assumed by Parsons Brinckerhoff (2014b) for the future state of the Weston and Halton subdivisions, respectively, which represents between 12 and 19 blocks of 0.05 miles length each. Considering that 0.1 miles

[14] Longest train route modelled (Toronto-Cambridge: 64.8 miles) divided by a block length of 0.05 miles.

(80.5 meters) is equivalent to more than three passenger car lengths (see next Section), one single block length shall suffice as safety margin between the authorized train paths (often called *movement authorities*) of any two trains.

5.3. Selection of parameters

The next step of the Conceptualisation stage is to define the parameters which differentiate the various train types to be modelled and relate to either the assumed rolling stock type or the service characteristics. The train services to be modelled are classified as Inter-City, Inter-Regional, Airport Shuttle, Regional Express Rail and freight services, which are currently operated by either VIA Rail (Inter-City), Metrolinx (Inter-Regional, Regional Express Rail and the Airport Shuttle – with the first two replacing the current Commuter Rail service) and CN (freight trains).

An overview of acceleration and deceleration capabilities of various rolling stock types in the United Kingdom is presented in Table 11, and the labels chosen by Powell & Palacin (2015) suggests that the Class 390 Pendolino would be representative for the Inter-City service, the Class 156 Super Sprinter for the Inter-Regional and airport shuttle services and the Class 323 for the Regional Express Rail (RER) service. The acceleration values will therefore be set at 0.37, 0.75 and 0.99 m/s^2, respectively, while the assumed deceleration value will be 0.8 m/s^2 as a middle value for all three train types. Considering that the High Speed Rail Safety Requirements defined by the Federal Rail Administration (FRA) set 110 mph as the maximum speed for any rail line featuring regular level crossings with public roads (shown as Tier IB in Table 12), this speed shall be assumed the design speed (i.e. the maximum speed to be reached in revenue service) for Inter-City trains, while slightly slower speed limits shall apply to the other two rolling stock types (100 and 90 mph, respectively).

Table 11: Example acceleration and deceleration values for railway vehicles in Great Britain

Vehicle	Maximum acceleration (m/s^2)		
	Traction	Service brakes	Emergency brakes
Class 390 Pendolino (intercity EMU)	0.37	0.88	1.18
Class 156 Super Sprinter (regional DMU)	0.75	0.7–0.8	0.7–0.8
Class 323 (suburban EMU)	0.99	0.88	1.18
London Underground 1992 tube stock	1.3	1.15	1.4
Tyne and Wear Metrocar	1.0	1.15	2.1 (*)
Manchester tram (Ansaldo T-68)	1.3	1.3	2.6 (*)
Sheffield Supertram (Siemens-Düwag)	1.3	1.5	3.0 (*)
Croydon tram (Bombardier FLEXITY)	1.2	1.3	2.73 (*)
Nottingham tram (Bombardier)	1.2	1.4	2.5 (*)

Source: Powell & Palacin (2015, p. 99)

Table 12: Evolving tiers of passenger rail service (according to the FRA)

Tier	0	IA	IB	IC	II	III	IV	V
Description	Regional rail	Conventional	Emerging HSR	HSR Regional	HSR Mixed Operations	HSR Mixed Passenger	HSR Dedicated	HSR Express
Max. Speed mph	0-65	0-79	80-110	111-125	126-150	0-150	0-150	0-200/220
Other traffic on same track	None (or temporally separated)	Mixed passenger and freight	Mixed passenger and freight	Mixed passenger and freight	Mixed passenger and freight	Conventional passenger only	None	None
Track class	- Class 4	- Class 4	- Class 5/6	- Class 7	- Class 8	- Class 8	- Class 8	- Class 9
Signals, train control	Traffic control	PTC	PTC; vital and perimeter protection above 90	PTC; vital and perimeter protection above 90	Per IC and ROW safety strategy integrated			
Public highway-rail grade crossings	Automated warning; supplementary measures where warranted	Automated warning; supplementary measures where warranted	Sealed corridor; evaluate need for presence detection and PTC feedback	Barriers above 110, see 213.247 Presence detection tied to PTC above 110	See IC None above 125	See IC None above 125	None at any speed	None at any speed
Private highway-rail grade crossings	Automated warning or locked gate	Automated warning or locked gate	Automated warning or locked gate and dispatch control over entry	None or as above	None above 125	None above 125	None at any speed	None at any speed
ROW safety plan	System Safety Program / Collision Hazard Analysis				SSP/CHA and specific approval process for new service similar to 236.361			
MOW safety management plan	Address within SSP framework; no separate approval required				Separate plan approval; integrate with SSP/CHA			
Equipment	CEM – end frame strength dynamic test	Present Tier I plus Cab End Frame Strength, or equivalent safety (including option for alternative to buff strength)			Present Tier II (including option for alternative to buff strength)	See Tier IA-C	Define	Define
Occupied car forward	OK	OK			Prohibited	Up to 125 mph only	OK	Prohibited
On-board emergency systems	Per Parts 238 and 239 (including glazing, emergency egress and rescue access, lighting, signage, etc.)							
System Safety Programs	Required; Review is for completeness; Audits for follow through				Integrate Subpart G, Part 238	Required; FRA reviews management decisions and may disapprove		

Source: Hynes (2011, pp. 20-21)

Based on the current fleet types and train lengths present on the Kitchener Corridor, 3-car trains shall be assumed on the Airport Shuttle, 8-car trains for the Inter-City service and 12-car trains for all other passenger services, with all cars being 85 feet (25.9 meters) long and formed by multiple units (i.e. self-propelled, as opposed to locomotive-hauled trains). For freight trains, the values need to be based on a more North American example and can be derived from Edwards (2010) for acceleration (300 seconds to reach 40 mph from standstill equals 0.06 m/s^2), from Mokkapati

(2011) for deceleration (37 seconds to reach standstill from 40 mph equals 0.48 m/s^2) and from Dingler, Lai, & Barkan (2009) for maximum speed (50 mph for bulk freight trains) and train lengths (6325 feet or 1928 meters for bulk freight trains)[15]. The acceleration, deceleration and design speed values retained for the various train types are summarized together with the applicable recovery margins (refer to Figure 11) in Table 13 below.

Table 13: Assumed rolling stock characteristics for the various train types

Train type	Inter-City	Inter-Regional & Airport Shuttle	Regional Express Rail	Freight
Design speed	110 mph (177 km/h)	100 mph (161 km/h)	90 mph (145 km/h)	50 mph (80 km/h)
Acceleration	0.37 m/s^2	0.75 m/s^2	0.99 m/s^2	0.06 m/s^2
Deceleration	0.8 m/s^2			0.48 m/s^2
Train length	680 ft. (207.3 m)	1.020 ft. (310.9 m) Airport Shuttle: 255 ft. (77.7 m)		6325 ft. (1928 m)
Recovery margin	5% (RER: 4%, freight: 3%) of travel time plus 1 minute per 100 km.			

Source: Compiled by the author with values derived from Powell & Palacin (2015), Edwards (2010), Mokkapati (2011) and Dingler, Lai, & Barkan (2009)

Concerning the service characteristics, every passenger rail service will need to be defined in terms of stopping pattern (i.e. at which station to stop), frequency (i.e. the headway between two consecutive departures - for peak and off-peak separately) and dwell time (i.e. the scheduled duration of every station stop). In reference to the "Scenario 4 (Full Build)" shown in Table 5 (see page 16) the UP Express (airport shuttle) is expected to continue at 4 trains per hour throughout the day. However, it shall be assumed that the current stop at Weston is moved to the future station at Mount Dennis to provide a connection with the Crosstown LRT. Similarly, RER trains are assumed to make all stops while operating all-day and with 4 trains per hour between Toronto and

[15] Dingler, Lai & Barkan (2009) also provide speed (70 mph) and train length (5659 ft or 1725 m) for intermodal freight trains; however, for the purposes of this Thesis, the bulk freight train shall be assumed to be more representative of the freight traffic to be modeled.

Bramalea with every second train continuing to Georgetown. Unlike what has been stated by Metrolinx (2015a) in Table 5, it shall be assumed that the Inter-Regional trains will also stop at Mount Dennis and Bloor stations (rather than running non-stop between Bramalea and Union Station), in order to allow connections onto the Bloor-Danforth line at Bloor, as well as onto the Crosstown LRT and the Airport Shuttle at Mount Dennis. Furthermore, it shall be assumed that Inter-City trains operate in two train sections which are split in Guelph, with one train continuing to Kitchener and the other serving the Fergus Subdivision into Cambridge.

Drawing from the recommendations of the *Final Report of the Special Advisor for High Speed Rail in Ontario* (Collenette, 2016), the Inter-City rail service shall be assumed to stop in Kitchener, Guelph, near Pearson Airport and Union Station. However, given the lower design speed of the inter-city service (177 km/h vs. the 250-300 km/h proposed for HSR) and thus lower travel time penalty for adding an additional stop, an additional stop shall be assumed in Brampton (with its population of approx. 600,000), while the Airport stop shall be placed at Mount Dennis to provide a fast and convenient transfer not just to Pearson Airport (using the Airport Shuttle), but also to large areas within Northern Toronto (thanks to the future Crosstown LRT and other transfer connection available at Mount Pleasant station). Considering that combining the service assumptions of Metrolinx (2015a) and Collenette (2016) would accumulate to 4 trains per hour throughout the day (2 HSR, 2 Inter-Regional) and even five during peak-hours (3 HSR, 2 Inter-Regional) and thus represent a somewhat exaggerated service level, it shall be assumed that the Inter-City and the Inter-Regional services both operate twice per hour each during peak hours and once during the rest of the day. Similarly, it shall be assumed that only one RER train each per hour terminates at Georgetown or Bramalea, while the remaining 2 trains terminate in Mount

Pleasant[16]. Finally, the scheduled dwell time per station stop shall be assumed to be 20 seconds for RER, 60 seconds for Inter-City and 40 seconds for all other passenger services[17]. All these service characteristics are summarized for the various passenger rail services in Table 14 below.

Table 14: Assumed characteristics of the various passenger rail services to be modelled

Train type	Inter-City	Inter-Regional	Airport Shuttle	RER
Stops to be served	Union Mount Dennis Brampton Guelph* *Train splits into two separate train portions west of Guelph: A: Kitchener [to: London] B: Hespeler B: Preston B: Cambridge	Union Bloor Mount Dennis Bramalea Brampton Mount Pleasant Georgetown Acton Guelph Breslau Kitchener	Union Bloor Mount Dennis [to: Airport]	Union Liberty Village Bloor St. Clair Mount Dennis Weston Etobicoke North Malton Bramalea Brampton (2/3)* Mount Pleasant (2/3)* Georgetown (2/1)* * Trains per hour (Peak/Off-Peak)
Frequency (per hour)	Peak: 2 Off-peak: 1	Peak: 2 Off-peak: 1	Peak: 4 Off-peak: 4	Peak:4 Off-peak: 4
Dwell time (per station stop)	60 seconds (Guelph: 120 seconds)	40 seconds	40 seconds	20 seconds

Source: Own work.

[16] This ensures that there are still 4 RER or Inter-Regional trains per hour serving Brampton and Mount Pleasant at off-peak times and 2 trains per hour serving Georgetown.

[17] An exception will be made for Inter-City trains in Guelph, which are assumed to have a prolonged dwell time of 120 seconds, in order to account for the operational process of splitting the westbound train into two separate train portions or merging two eastbound train portions together into one single train.

5.4. Selection of timetable strategies

Out of the various timetable categories identified in the literature review, the timetable strategies to be modelled will be individual trips as well as the partially periodic timetable, symmetric timetable and integrated fixed interval timetable (IFIT). As already mentioned in the previous chapter, all timetable concepts will only be modelled for the peak hours of the afternoon. The exception will be the partially periodic timetable, which will additionally cover the morning peak, in order to account for its asymmetric rail traffic patterns which might affect train capacity differently when the peak-direction is the reverse in the morning. For this scenario only, the peak frequencies shall only apply for the peak direction (morning: towards Toronto, afternoon: towards Kitchener/Cambridge), while the off-peak frequencies shall also apply for the counter-peak direction.

5.5. Dividing the Corridor into segments

When modelling the train movement, the entire Kitchener Corridor needs to be divided into countless segments, which must start and end at a known position along the corridor (which results in a known length) and have the same speed limit applicable for the entire block length. Also, there must be only one station and/or block signal present in any given segment and their stopping point (i.e. the point at which the train is expected to stop if it has a scheduled station stop or if it must wait until the signal clears) must be located at the end of a segment. Given that the train can only accelerate to a higher speed limit once it has passed in its entirety beyond the point at which the new speed limit takes effect, it is not sufficient to calculate only the travel times at the trains' head end, but we also need to be able to determine the travel times at its tail end. Furthermore, we also need to determine the start times for the "time for clearing the signal", for the "signal watching time" and for the "approach time" as well as the end times of the "clearing time" and of the "release time", in order to calculate the blocking times for every single block (refer back to Figure 12 in Section 4.3).

It should also be noted that the need to model travel times at the trains' head and tail ends separately can only be avoided if all segments are of identical lengths[18] and that the block length chosen for the fixed block modelling (0.05 miles or 80 meters) is barely larger than the shortest train (Airport Shuttle) and only a small fraction of the longest train (the freight train). The segment length shall therefore be set at the same length, meaning that the segments will be identical with the blocks used for the fixed block modelling, while all signal locations and speed limit changes must be rounded to the nearest 0.05 miles[19].

[18] A segment can be considered "cleared" once the train head has travelled (after leaving the current segment) through a number of segments with a combined length which exceeds the train's length. For instance: if a given train fits into 3 blocks and the current block is segment #12, we can safely assume that segment #12 is cleared when the train has reached the end of segment #15 (i.e. 3 segments later).

[19] The station locations are already rounded to the nearest 0.1 miles (as shown in Table 9).

5.6. Assumed signal locations

While the fixed block signalling system uses virtual signals, which are shown to the driver on a screen inside his cab, the variable signalling system still relies on conventional, stationary signals which are located beside the tracks along the entire corridor. Most signal locations were provided in Parsons Brinckerhoff (2014b) and Morrison Hershfield Ltd. (2012a), but some locations had to be identified by using Google Maps and Google Street View. Additional signals are assumed to insert an additional track change just west of Bramalea, to signal trains which transfer between the Kitchener Corridor and the Fergus subdivision at Guelph Junction, to split up a 6-mile-long block between Guelph and Breslau and to allow trains to switch tracks on the final meters into Kitchener rail station. Furthermore, the two "future signal bridges" in Guelph were slightly moved away from Guelph station to ensure that the last signal block before Guelph station can already be released while the Inter-Regional train makes its station stop. All signal locations assumed for the modelling of the variable block signalling are shown for the Weston, Halton and Guelph subdivisions[20] in Table 15 below, which also indicates whether signals only apply to trains traveling in one of the possible two directions.

[20] No signal locations need to be assumed for the USRC or the Fergus Subdivision, as these segments are regarded as having unconstrained capacity, as discussed in the previous section.

Table 15: Assumed signal locations along the Kitchener Corridor

MP	Description	MP	Description	MP	Description
WESTON Subdivision		HALTON Subdivision		GUELPH Subdivision	
1.30	Assumed	17.30	Known (E)	30.05	Known
1.90	FSB	17.85	Assumed (W)	31.80	Known
2.35	FSB	18.90	SB	34.20	Known
3.00	FSB	20.35	SB (W)	36.10	Known
3.60	FSB	20.75	Known (E)	39.15	Known
4.15	FSB	21.35	Known (W)	41.30	Known
4.70	FSB	21.75	SB (E)	44.00	Known
5.35	FSB	23.05	SB (W)	46.20	Known
5.85	FSB	23.50	SB (E)	48.55	FSB [M]
6.60	FSB	24.60	FSB (W)	49.05	FSB [M]
7.15	FSB (W)	25.05	FSB (E)	49.45	Assumed (W)
7.55	FSB (E)	26.00	FSB	49.85	Assumed (E)
7.95	FSB	27.00	FSB	50.25	Known
8.50	FSB	28.65	FSB (W)	52.90	Known
9.20	FSB	29.05	FSB (E)	55.25	Assumed
9.70	FSB	29.45	FSB (W)	56.20	Assumed
10.25	FSB (E)			58.90	Known
10.85	FSB			60.60	Known
11.60	FSB			62.45	Assumed (W)
12.25	FSB			62.65	Assumed (E)
12.90	FSB				
13.65	FSB				
14.25	FSB				
15.05	FSB				
15.50	FSB				
16.20	FSB				
16.80	Known				

Note: Signal locations marked as SB and FSB are reported as “Signal Bridges” and “Future Signal Bridges” in the “vertical conflicts” section of the Metrolinx Electrification Study referenced below, while signal locations marked as “Known” were located with Google Earth and Google Street View. Finally, (W) and (E) refer to signals which face only to westbound or eastbound train movements, respectively, while [M] indicates that the signal location has been slightly modified compared to the positions indicated by the sources mentioned below.

Extracted from: Parsons Brinckerhoff (2014b) and Morrison Hershfield Ltd. (2012a) and supplemented with information obtained through Google Earth and Google Street View.

5.7. Assumed speed limits

Speed limits are important inputs when calculating travel times and may vary according to the current line (*line speed limits*), the current line segment (*local speed limits*), the current track routing (*track speed limits*) and the train's rolling stock type (*vehicle speed limits*), where the maximum allowable speed is always determined by the lowest of these values. While vehicle speed limits have already been discussed and determined as part of the train-specific parameters earlier in this Chapter, the remaining three sets of speed limits are determined by the assumed train infrastructure, namely: track class, track curvature and the angle of the switches used (when they are set into diverging position).

5.7.1. Line speed limits

The main factor affecting line speed limits is the standard of maintenance observed by the railway owner. These standards are set by Transport Canada (2018) and currently encompass 5 different track classes and generally allow slightly higher maximum speeds for passenger trains than for freight trains. As shown in Table 16, these track classes only cover speeds up to 95 mph (153 km/h) currently with an exception made for certain fleet types, which allows VIA Rail to operate some trains at 100 mph (161 km/h) on Class 5 tracks. This means that Canadian rail regulations do not currently allow rail operations in excess of 100 mph. However, certain parts already mention speed limits higher than 100 mph, such as the Grade Crossing Regulations, which prohibit anyone from constructing "a grade crossing if […] the railway design speed would be more than 177 km/h (110 mph)" (Government of Canada, 2018, p. 12). This suggests that certain provisions have already been made by the Canadian regulator to allow passenger speeds of up to 110 mph at some point in the future, which would allow the introduction of a sixth Track Class, just like the Track Class 6 in place south of the border (Federal Railroad Administration, 2008).

Table 16: Maximum allowable operating speeds (by track class, in mph)

Maximum allowable operating speeds		
Over track that meets all of the requirements prescribed in this part for-	**The maximum allowable operating speed for freight trains is -**	**The maximum allowable operating speed for passenger trains is -**
Class 1 track	10	15
Class 2 track	25	30
Class 3 track	40	60
Class 4 track	60	80
Class 5 track	80	95*

* For LRC Trains, 100

Source: Transport Canada (2018)

For the purposes of this thesis, it shall be assumed that a new Track Class 6 is introduced and adopted on the Weston, Halton and Guelph subdivisions, and that the maximum allowable operating speed would be 110 mph on these lines, while the corresponding limit remains at 80 mph for freight operations. Furthermore, given that most trains will have to change tracks within the USRC, the assumed line speed within the USRC shall be 45 mph (Class 3), while the comparatively low number of trains to operate on the Fergus Subdivision, the relatively short distance between Guelph and Cambridge and the prevalence of curves requiring local speed limits for most of the line's length (see next Section) make 80 mph (Class 4) appear as an economic choice for the Cambridge branch.

5.7.2. Local speed limits

The main factor affecting local speed limits is the curvature of specific line segments and the applicable superelevation. In order to offset the centrifugal forces, which may cause anything between passenger discomfort and train derailment if the train takes the curve at an excessive speed, the outer rail is usually elevated so that the train tilts slightly towards the inner of the curve, thus creating some gravitational forces which act in the opposite direction of the centrifugal forces. In addition, railroads often apply a so-called "*unbalanced superelevation*", which is the increment by which the *equilibrium superelevation* (i.e. the superelevation which would be needed to completely offset – or: balance – the gravitational forces) exceeds the actual superelevation applied to the curve. Railroads in North America generally apply the formula shown in Figure 19 to determine the equilibrium superelevation. Given that the formula does not treat actual and unbalanced superelevation differently, it is sufficient to determine one single value for the maximum permissible superelevation. While FRA regulations allow up to 3 inches of unbalanced superelevation and a maximum actual superelevation of 7 inches on Track Classes 3 through 5[21], the limit of 5 inches of total superelevation used by Caltrain in California for their own urban mixed-operation rail corridors (Caltrain, 2011) seems to be a reasonable assumption to be adopted within this thesis.

[21] It should be noted that the track classes defined by the FRA are slightly different than those defined by Transport Canada and that, for instance, the maximum speed of Track Class 5 is 90 mph (145 km/h) rather than 95-100 mph (153-161 km/h) north of the border.

Figure 19: Formula used by North American railroads to determine equilibrium superelevation

Equilibrium superelevation shall be determined by the following equation:

$$\mathbf{e = 0.0007\, D_c V^2}$$

where:

- e = total superelevation required for equilibrium, in inches.
- V = maximum design speed through the curve, in miles per hour (MPH)
- D_c = degree of curvature, in degree

The total superelevation e is expressed as follows:

$$\mathbf{e = E_a + E_u}$$

where:

- E_a = actual superelevation that is applied to the curve
- E_u = unbalanced superelevation (amount of superelevation not applied to the curve)

Source: Caltrain (2011, p. 15)

Starting from the first equation[22] provided in Figure 19, we can isolate the maximum permissible degree of curvature, which then becomes an input for a different equation (Calvert, 2004), which can be used to calculate the minimum permissible radius for the 5mph-increments shown in Table 17[23]:

(1) $$e = 0.0007 * D_c * v^2$$

(1a) $$D_c = \frac{e}{0.0007v^2}$$

(2) $$R = \frac{c}{2*\sin\frac{d}{2}}$$

(2.1) $$R = \frac{l_{chord}}{2*\sin\left(\frac{Dc}{2}\right)} = \frac{100ft}{2*\sin\left(\frac{Dc}{2}\right)} = \frac{15.24m}{2*\sin\left(\frac{Dc}{2}\right)}$$

---

[22] One word on equations: within this thesis, the numbering of equations will follow the following format: 1a.1a, where the first number stands for the base equation, the letter before the dot changes with every transformation of the base equation, the number after the dot changes with every adaptation of an equation and the letter after the dot changes with every new version of the equation. Furthermore, the equations will often follow the syntax of formulas used by Microsoft Excel, such as MIN, MAX, IF, ROUNDUP and OFFSET, which can be found on various websites, such as ExcelFunctions (2018).

[23] It should be noted that the degree of curvature (D_c) needs to be converted to radians before being inserted into Equation 2.1.

Table 17: Maximum curvature and minimum radius required for a given maximum speed

Speed limit (mph)	Curvature (degrees)	Radius (ft)	Radius (m)
15	31.75	183	56
20	17.86	322	98
25	11.43	502	153
30	7.94	723	220
35	5.83	983	300
40	4.46	1,284	391
45	3.53	1,625	495
50	2.86	2,006	611
55	2.36	2,427	740
60	1.98	2,888	880
65	1.69	3,389	1,033
70	1.46	3,931	1,198
75	1.27	4,512	1,375
80	1.12	5,134	1,565
85	0.99	5,796	1,766
90	0.88	6,497	1,980
95	0.79	7,239	2,207
100	0.71	8,021	2,445
105	0.65	8,844	2,696
110	0.59	9,706	2,958

Source: own calculations with equations provided by Caltrain (2011) and Calvert (2004)

These minimum radii can now be used to determine the local speed limits along the Kitchener Corridor by using the circle drawing function built-into Google Earth Pro to measure the curvature of any apparent curve along its alignment[24]. Additionally, a local speed limit of 15 mph shall be assumed for the first 0.55 miles of the USRC, in order to account for the need for almost every train to switch tracks in the approach to/from Union Station and the slow permissible speed for traffic using the diverging track (see next Sub-section), while a local speed limit of 45 mph shall

[24] Even though the current local speed limits could be potentially obtained by the respective railroads, these speed limits reflect the current level of track maintenance and superelevation. Consequently, these speed limits might be significantly lower than what the actual track curvature and a superelevation of 5 inches might allow.

apply for the final 0.45 miles into Kitchener for very similar reasons. All local speed limits assumed for the Kitchener Corridor are summarized in Table 18 below:

Table 18: Local speed limits assumed along the Kitchener Corridor

Subdivision	Start (Mile)	End (Mile)	Radius (m)	Speed limit (mph)
USRC (Mile 0.00-1.30)	0.00	0.55	n/a	15
Weston (Mile 1.30-16.85)	1.30	2.35	1.07	65
	2.35	3.60	1.90	85
	5.35	6.60	2.30	95
	8.50	9.70	1.90	85
	16.80	16.85	2.30	95
Halton (Mile 16.85-30.00)	16.85	17.30	2.30	95
	29.45	30.00	1.90	85
Guelph (Mile 30.00-62.90)	30.00	30.05	1.90	85
	32.50	33.50	1.90	85
	33.50	34.40	1.07	65
	34.40	36.10	1.90	85
	41.10	41.90	1.07	65
	44.40	46.35	2.30	95
	46.35	48.55	1.90	85
	48.55	49.45	1.07	65
	49.45	49.85	1.90	85
	57.50	58.90	2.30	95
	58.90	62.45	1.90	85
	62.45	62.90	n/a	45
Fergus (Mile 49.80-64.80)	49.80	50.00	0.17	25
	51.70	52.80	0.47	40
	55.90	60.10	1.07	65
	60.10	60.60	0.57	45
	60.60	61.30	1.07	65
	63.00	64.80	0.57	45

Note: for practical reasons, start and end locations listed above were deliberately chosen to coincide with signal locations (see previous Section) or station locations (see Table 9), wherever they were located near the actual start and ends of the corresponding curves.
Source: own work.

5.7.3. Track speed limits

The main factor affecting track speed limits is the angle of the switches used (when they are set into diverging position). The diverging tracks of the four standard switch designs used on Canadian railroads have angles of 1:8, 1:12, 1:16 or 1:20 (and are therefore called #8, #12, #16 or #20 turnouts), which correspond with the four speed restrictions which can be signalled with Canadian signals: 15 mph (*slow* speed), 25 mph (*diverging* speed), 30 mph (*medium* speed) and 45 mph (*limited* speed) (Keay, 2014?). According to the track plans included in the Metrolinx Electrification Study, the switches used outside Union Station only allow 15 mph, while #16 turnouts are used for the rest of the USRC (Parsons Brinckerhoff, 2014d). On the main tracks of the Weston and Halton subdivisions which form the Kitchener Corridor, however, #20 turnouts dominate (Parsons Brinckerhoff, 2014b). For the purposes of this thesis, it shall be assumed for the entire Kitchener Corridor (including the Fergus Subdivision), that all switches where passenger trains are regularly scheduled to take the diverging track allow speeds of 45 mph, except for the switches directly outside Union Station, where the speed limit is assumed to remain at 15 mph.

Another concern is the actual location of track changes (i.e. a pair or series of switches, which allows trains to change from one track to the other) and a definition of which train routings can be done without using a diverging track at any switch (i.e. without slowing down from the applicable line or local speeds). As shown in the track plans presented in Appendix I, the current track changes are assumed to be supplemented by additional track changes to the west of Bramalea station and to the east of Mount Pleasant Station (i.e. track changes VI and IX)[25]. An overview of all 15 track

[25] These additional track changes were necessary to allow freight trains to bypass Bramalea Station and to allow RER trains to turn around on Track H2 in Mount Pleasant Station with short headways.

changes, their exact location and the non-diverging routings is provided in Table 19 below. Furthermore, the track speed is limited to 45 mph on Track H0 at Georgetown station.

Table 19: Assumed track change locations along the Kitchener Corridor

Track change		Position (Mile)		Non-diverging routings
#	Name	Start	End	(all other routings are limited to 45 mph)
I	NICKLE	7.20	7.55	K2, K1, E2, E1
II	HUMBERVIEW	9.85	10.20	K2, K1, E2, E1
III	WOODBINE JCT.	13.10	13.30	K2⇔W1, E2⇔W2, E1⇔W3
IV	AIRWAY	15.50	15.90	W1, W2, W3
V	HALWEST JCT.	16.80	17.20	W1, W2, W3
VI	BRAMALEA WEST*	17.60	17.80	W1⇔H1, W2⇔H2, W3⇔H3
VII	PEEL	20.45	20.70	H1, H2
VIII	BRAMPTON WEST*	21.40	21.60	H1, H2
IX	MOUNT PLEASANT EAST*	23.25	23.45	H1, H2, H3
X	NORVAL	24.75	24.95	H1, H2, H3
XI	GEORGETOWN EAST*	28.65	29.05	H1, H2, H3
XII	SILVER JCT.	29.45	29.75	H1⇔G1, H2⇔G2
XIII	ROCKCUT	41.30	41.85	G1, G2
XIV	GUELPH JCT.	49.45	49.85	G1, G2
XV	SHARTZ*	55.25	26.20	G1, G2

Note: Track change names refer to the official names given by CN, except for those marked with an asterisk (*), which have been assigned by the author.
Source: own work, with geographical measurements from Parsons Brinckerhoff (2014b) and own measurements made with the help of Google Earth, as well as some missing CN location names provided in Walker (2008) and Roberts & Stremes (2015).

6. Modelling

6.1. Speed profiles and behaviour sections

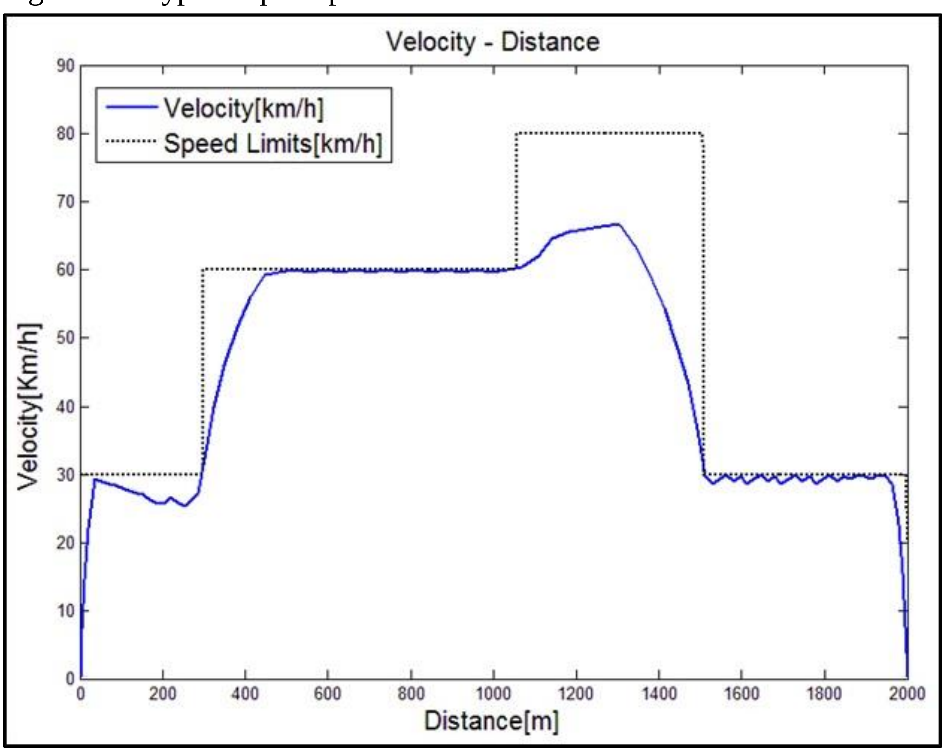
When considering the fundamentals of train movements, the movement of a train is not that different from the movement of a car: the train accelerates from standstill to the maximum allowed speed for that track (or any lower speed, as desired by the train driver) and its speed gets regularly adjusted to comply with the currently applicable speed limits. However, unlike with road traffic, where it is generally accepted if drivers hover around the speed limit, speed limits for rail traffic must not be exceeded and even small increases over the applicable speed limit can already result in investigations by the railroads and the regulators concerned. This means that a train can only accelerate beyond the current speed limit once it has completely passed the point at which a higher speed limit takes effect. Similarly, the train's speed must have already fallen below the speed limit by the time it reaches the point where the more restrictive speed limit takes effect. Brünger & Dahlhaus (2014) differentiate between the four types of behaviour sections into which every single moment of a train movement falls:

- Acceleration sections: the train increases its speed as the tractive effort exceeds the resistances working against the movement
- Constant movement (cruising) sections: the train travels at constant speed, as the tractive effort equals the resistances working against the movement
- Coasting sections: the train travels without tractive effort and therefore loses speed over time as the train runs out until it either stops by itself or changes into acceleration or braking
- Braking sections: the train reduces its speed as the train applies its brakes[26]

[26] It should be noted that all these observations assume level tracks, as the presence of gravitational forces on a slope may slow down the train even when it increases its tractive efforts, accelerate (rather than slow down) a coasting train, require the train to brake (rather than accelerate) in order to hold the current speed or accelerate a train even when it applies its brakes.

Arguably the best way to visualise a train movement is a speed profile, such as the one provided in Figure 20, which shows a train (presumably a streetcar) first accelerating from standstill (e.g. after a stop or waiting for a green traffic light) to the speed limit of 30 km/h and then coasting until the speed limit changes. Once the speed limit doubles, the train accelerates further to 60 km/h and then moves at constant speed. After the speed limit increases again, the train accelerates further, but changes to braking before reaching the applicable maximum speed of 80 km/h in order to get below the new speed limit of 30 km/h before it takes effect. The train then travels at constant speed before braking to standstill after exactly 2000 meters. This means that this simple train movement can be broken into 8 behaviour sections (acceleration – coasting – acceleration – constant – acceleration – braking – constant – braking) and that the length of any train movement is the sum of the lengths of all its behaviour sections.

Figure 20: Typical speed profile for a rail movement



Adapted from: Ghaviha, Bohlin, Wallin & Dahlquist (2015, p. 379)

6.2. Uniform acceleration

As mentioned in Chapter 4, this thesis will assume a uniform acceleration model when estimating travel times. The main advantage of this approach is to reduce the mathematical complexity by assuming one single acceleration value and one single deceleration value per train type rather than deriving an exact acceleration and braking curve from calculating the tractive effort, which depends on countless variables like train weight, the gradient of the track, the train's traction and resistance and its current speed (Brünger & Dahlhaus, 2014). Even though this simplification comes naturally at the expense of accuracy, the fact that this thesis aims to make relative comparisons between different scenarios (rather than providing exact and absolute measurements) allows the author to argue that such approximation appears as reasonable for the purposes of this research. In order to keep its complexity as manageable as possible, this model will need to be calculated from scratch, as described in the remainder of this chapter.

For all three section types, the travel time is calculated by using the following two textbook formulas for uniform acceleration[27]:

(3) $$v_1 = v_0 + a * t$$

(4) $$v_1^2 = v_0^2 + 2\ a * s$$

These two formulas can be transformed to isolate *time* (t) and *distance* (s), respectively, for a known *acceleration* (a) value and then be used to calculate the time and distance required to change from an *initial speed* (v_0) to an *end speed* (v_1):

(3a) $$t = \frac{v_1 - v_0}{a}$$

[27] It should be noted that throughout the modelling process, the values need to be entered into the corresponding equations in [m] for distances, [m/s] for speeds, and [m/s^2] for accelerations, in order to obtain correct results.

(4a) $$s = \frac{v_1^2 - v_0^2}{2a}$$

Considering that constant movement is characterized by the absence of any change in speed (acceleration or deceleration), the textbook equation for *uniform motion* applies for constant movement sections:

(5) $$s = v * t$$

Given that coasting is more of an operational phenomenon which is often encouraged by railway managers to increase the energy-efficiency of their operations by saving energy while approaching a braking section (Albrecht, 2014), it shall be assumed that the train driver always operates at the maximum possible speed, when taking all applicable speed limits and the vehicle-specific acceleration and braking values into consideration. For the purposes of this thesis, coasting shall therefore be treated as an operational inefficiency which is accommodated by the running time supplements already mentioned in Section 3.3.

6.3. Behavioural sections in a given segment

6.3.1. Entry and exit speeds

Considering that every train movement starts from standstill (just like every journey starts with the first step), acceleration is the prerequisite of every movement. In order to better explain how acceleration and deceleration are modelled, we shall temporarily neglect any speed limits and just assume a line with two stations in-between which there is nothing else to constrain the speed of the train than its acceleration and deceleration capabilities and the requirement to start accelerating from a standstill at the first station and to come to standstill again at the second station.

Starting from Equation 4, we can calculate the acceleration curve's exit speed of the first segment by knowing the segment's length, the train's entry speed (which would be zero in this example, as the first segment of this train movement starts from standstill at a station stop) and the acceleration value:

(4) $$v_1^2 = v_0^2 + 2\ a * s$$

(4b) $$v_1 = \sqrt{v_0^2 + 2 * a * s}$$

(4b.1) $$v_{acc\_1} = \sqrt{v_0^2 + 2 * a_{acc} * s}$$

The acceleration therefore follows a line with the following functional equation:

(6) $$f_{acc}(x) = v_0 + a_{acc} * x$$

Similarly, every train movement ends eventually and inevitably as the result of deceleration (braking). Starting again from Equation 2, we can calculate the braking curve's entry[28] speed of

[28] Even though the braking curve is computed in the opposite direction of the train travel, the terms "entry speed" and "exit speed" refer to the direction of travel, meaning that regardless of whether a train is accelerating or

the last segment by knowing the segment's length, the exit speed (which) and the deceleration value[29]:

(4c) $$v_0 = \sqrt{v_1^2 - 2 * a * s}$$

(4c.1) $$v_{red\_0} = \sqrt{v_1^2 - 2 * a_{red} * s}$$

The deceleration therefore follows a line with the following functional equation, where the exit speed equals the entry speed of the following segment:

(7) $$f_{red}(x) = v_{red\_0} + a_{red} * x = \sqrt{v_1^2 - 2 * a * s} + a_{red} * x$$

So far, we have assumed that the entry speed of a segment always equals the previous segment's exit speed of the acceleration curve, while the exit speed of a segment equals the subsequent segment's entry speed of its braking curve. Naturally, a train cannot accelerate and brake simultaneously; therefore, the exit speed must be either the exit speed of the acceleration or of the braking curve (whichever is lower), while the entry speed is always the exit speed of the previous segment:

(8) $$v_0 = v_{1\_previous}$$

(9) $$v_1 = MIN(v_{acc\_1}, v_{red\_1})$$

This requires a modification of the mathematical definition for the entry speed of the braking curve (Equation 4c.1) to be calculated from the following segment's braking curve's entry speed rather than from the current segment's train exit speed:

---

decelerating, the entry speed refers to the speed at the moment when the train's head enters a segment or block, while the exit speed refers to the speed at the moment when the train's head exits the same segment or block.

[29] Deceleration is the opposite of acceleration; therefore, deceleration values are usually provided as negative acceleration values (e.g. -0.5 m/s^2), so that the same formulas can be applied to describe acceleration and deceleration processes. This practice is also adopted within this thesis.

(4c.1a) $v_{red_0} = \sqrt{v_{red_1}^2 - 2 * a_{red} * s}$

(10) $v_{red\_1} = v_{red\_0\_following}$

However, the necessity to accelerate from standstill at one station and to stop to standstill at the next station is not the only factor which constrains the train's maximum achievable speed during its movement: First, the train cannot accelerate beyond any of the speed limits mentioned in Section 5.7, which apply to the line, line segment, track routing and vehicle type used in a given segment. Second, a new (more permissive) speed limit only takes effect once the train has passed (after the speed limit change) through a number of segments which represents a distance longer than the length of the train (i.e. the previous speed limit remains in force as the *effective speed limit*):

(11) $v_{max} = MIN\left(v_{max\_line}, v_{max\_local}, v_{max\_track}, v_{max\_vehicle}, v_{max\_effective}\right)$

Those segments which fall into the first train length shall be referred to as a *delay zone*, in which the effective speed limit is still the lower previous speed than the otherwise applicable speed limit:

(12) $v_{max\_effective} = IF\left(n_{DZ_{start}} > 0, MIN\left(v_{max\_eff\_previous}, v_{max\_previous}\right), v_{max}\right)$

(13) $n_{DZ\_end} = MAX\left(n_{DZ\_start} - 1, 0\right)$

(14) $n_{DZ\_start} = IF\left(v_{max} > v_{max\_previous}, n_{DZ}, n_{DZ\_end\_previous}\right)$

(15) $n_{train\ length} = ROUNDUP\left(\frac{s_{train\ length}}{s_{segment\ length}}, 0\right)$

The presence of a speed limit changes the Equations 9 and 10, as neither the train's exit speed nor exit speed of the braking curve can be higher than the applicable speed limit in either the current or the following segment:

(9.a) $$v_1 = MIN(v_{acc\_1}, v_{red\_1}, v_{max}, v_{max\_following})$$

(10.a) $$v_{red\_1} = MIN(v_{red\_0\_following}, v_{max}, v_{max\_following})$$

In order to avoid confusion, all equations relevant for the modelling process and mentioned above are repeated below in their final formulation:

(4b.1) $$v_{acc\_1} = \sqrt{v_0^2 + 2 * a_{acc} * s}$$

(4c.1a) $$v_{red_0} = \sqrt{v_{red_1}^2 - 2 * a_{red} * s}$$

(8) $$v_0 = v_{1\_previous}$$

(9.a) $$v_1 = MIN(v_{acc\_1}, v_{red\_1}, v_{max}, v_{max\_following})$$

(10.a) $$v_{red\_1} = MIN(v_{red\_0\_following}, v_{max}, v_{max\_following})$$

(11) $$v_{max} = MIN(v_{max\_line}, v_{max\_local}, v_{max\_track}, v_{max\_vehicle}, v_{max\_eff})$$

(12) $$v_{max\_effective} = IF(n_{DZ_{start}} > 0, MIN(v_{max\_eff\_previous}, v_{max\_previous}), v_{max})$$

(13) $$n_{DZ\_end} = MAX(n_{DZ\_start} - 1, 0)$$

(14) $$n_{DZ\_start} = IF(v_{max} > v_{max\_previous}, n_{train\ length}, n_{DZ\_end\_previous})$$

(15) $$n_{train\ length} = ROUNDUP\left(\frac{s_{train\ length}}{s_{segment\ length}}, 0\right)$$

6.3.2. Behavioral segment lengths

Having formulated a way to determine the exit speed of any segment (and thus the entry speed of the following segment), we now need to determine the lengths of the different behavioral sections. Conveniently, the acceleration distance in any given segment can be calculated by adapting Equation 4a:

(4a) $$s = \frac{v_1^2 - v_0^2}{2a}$$

(4a.1) $$s_{acc} = \frac{\left(MAX(v_0, v_1)\right)^2 - v_0^2}{2a_{acc}}$$

Similarly, the train cannot start braking from a speed which is higher than the entry speed of the current segment. Therefore, the deceleration distance in any given segment is:

(4a.2) $$s_{red} = \frac{\left(MIN(v_0, v_1)\right)^2 - v_0^2}{2a_{red}}$$

Finally, the remainder of the segment length is the distance travelled at constant speed:

(16) $$s_{con} = s - s_{acc} - s_{red}$$

6.3.3. Travel time within the behavioral sections

After calculating the entry and exit speeds of a given segment and the length of its behavior segments, we can finally calculate the travel times for the various behavior sections. Conveniently, the travel time spent in acceleration in any given segment can be calculated by adapting Equation 3a:

(3a) $$t = \frac{v_1 - v_0}{a}$$

(3a.1) $$\Delta t_{acc} = \frac{MAX(v_0, v_1) - v_0}{a_{acc}}$$

Similarly, the travel time in deceleration (braking) can be calculated by adapting the same equation, as follows:

(3a.2) $$\Delta t_{red} = \frac{v_1 - MAX(v_0,v_1)}{a_{dec}}$$

Finally, the travel time in constant speed can be calculated by transforming Equation 5:

(5) $$s = v * t$$

(5a) $$t = \frac{s}{v}$$

(5a.1) $$\Delta t_{constant} = \frac{s}{MAX(v_0,v_1)}$$

Consequently, the travel time[30] (net of any station or signal waiting times) in any given segment is the total of the travel times spent in acceleration, deceleration or constant movement:

(17) $$\Delta t_{segment} = \Delta t_{acc} + \Delta t_{red} + \Delta t_{constant}$$

[30] It should be kept in mind that all travel times calculated between any two points along the modelled train movement refer to the train head and may differ for other parts of the train if the train accelerates or decelerates while passing either point.

6.4. Minimum blocking time

As already mentioned in Section 3.3, the blocking time can be described as the sum of the *signal clearing time*, the *signal watching time*, the *approach time*, the *travel time*, the *clearing* time and the *block release time*. However, in order to facilitate the understanding of the various blocking time elements, the time period during which the train stops at the end of the block for either a station stop or to wait for the following signal to clear (*dwell time*) can be split off the travel time. Similarly, the clearing time can be split into the period before the train's end has travelled beyond the release point (*segment clearing time*) and after that moment (*signal release time*). The time during which any part of the train occupies the block may be called the *block occupation time* and comprises the travel time, the dwell time and the block clearing time. The time during which the train is authorized to occupy any part of the block may be called *movement authority time* and comprises the signal watching time, the approach time and the signal release time, in addition to the block occupation time and thus covering the entire period from the moment a signal is cleared to authorize the train movement within the block until the moment it has been released again. Finally, the blocking time refers to the period between which a block is assigned to a specific train movement until the moment the block is released again and becomes available to be assigned to a different train movement and thus includes signal clearing and the block release times. All the eight different blocking time elements and the three terms under which they can be grouped are shown in Figure 21 below:

Figure 21: Overview over the various blocking time elements

block	signal		train				signal	block
assigned	cleared	watched	entry	at exit	exiting	cleared	released	released
t0	t1	t2	t3	t4	t5	t6	t7	t8
clearing signal		approaching block		dwell time		releasing signal		
	watching signal		train travelling		leaving block		releasing block	
Block assigned								
Start	Movement Authority							End
	Start		Block occupied				End	
			Start			End		

Source: own work

Out of these blocking time elements, three elements are constants and shall be arbitrarily set at 5 seconds each for the signal clearing and the block release times, while the signal watching time shall be set at a more generous 10 seconds for the variable-block scenario variants and 0 seconds when a fixed block system is assumed[31]:

(18) $$\Delta t_{signal\ clearing} = \Delta t_{block\ release} = 5\ sec$$

(19) $$fixed\ blocking: \Delta t_{signal\ watching} = 0\ sec$$

$$variable\ blocking: \Delta t_{signal\ watching} = 10\ sec$$

[31] The rationale behind using different values for the two sets of scenario variants is that while GOA1 (refer back to Section 5.2) requires the driver to correctly see and interpret the (stationary) signal and to adjust the speed as required, GOA2 transfers this responsibility to the train itself. This means that while a human driver needs to have seen a clear signal (in this case: a signal which shows that the line is clear to proceed for at least 2 blocks at whatever line or local speed limits apply) for at least a few seconds before he passes it, an on-board computer can interpret this information at any location and process it within a small fraction of a second.

6.4.1. Fixed blocks

Starting with the fixed block scenario variants, the blocking time starts with the moment the clear signal[32] is requested, which is 5 seconds before the signal is required. As the fixed block signalling scenario assumes GOA2 and therefore ignores any signal watching delay, the moment when the train requires a clear signal is the moment when the train approaches the current segment[33] and requires authority to enter the current block, as its braking point is about to enter the current block:

$$t_{requested} = t_1 - \Delta t_{signal\ clearing} = t_1 - 5sec = t_0 \tag{20}$$

$$t_{required} = t_2 - \Delta t_{signal\ watching} = t_2 - 0sec = t_2 = t_1 \tag{21}$$

$$t_{approaching} = t_2 \tag{22}$$

Before we can define the moment where the train's braking point enters the current block, we need to calculate the train's braking distance (i.e. the difference between the train head's current location and its braking point considering its speed at any given moment) when it's travelling through the current block. At the moment the train head enters the current block, the (rounded up) number of subsequent segments equivalent to the train's braking distance is required to be clear ahead of the current segment for this train's movement. That number of segments can be calculated by modifying Equation 4a.2[34], while a safety margin of one segment needs to be added when determining the required number of clear segments ahead of the train. Finally, we need to subtract

[32] The reader may recall that for the fixed block scenario variants, the signals are virtual signals displayed on a screen inside the cab rather than stationary signals standing next to the tracks.

[33] Given that we have set segment length as identical to block length (i.e. 0.05 miles), the two terms could be used interchangeably in this subsection. However, given that the next subsection will only highlight the differences between assuming fixed or variable blocks, one needs to remember that when assuming variable blocks, a block refers to a group of segments located between two subsequent signals rather than one single segment.

[34] Note that while in Equation 4a.2 v_0 and v_1 stand for the start and end speed of the *deceleration process*, they stand in Equation 4a.3 for the train's speed at the start and end of the current segment. Therefore, the greater of the latter two values stands for the start speed of the braking process, while the end speed is zero and thus ignored in Equation 4a.3.

one segment to obtain the number of *subsequent clear segments required* (SCSR, i.e. *following* the current segment):

(4a.2) $$s_{red} = \frac{\left(MIN(v_0,v_1)\right)^2 - v_0^2}{2a_{red}}$$

(4a.3) $$n_{braking\ distance} = ROUNDUP\left(\frac{-v_1^2}{0.05mi*2*a_{red}}, 0\right)$$

(23) $$n_{clear\ segments\ required} = n_{braking\ distance} + n_{safety\ margin}$$

(24) $$n_{safety\ margin} = 1$$

(25) $$n_{SCSR} = n_{clear\ segments\ required} - 1 = n_{braking\ distance} + n_{safety\ margin} - 1 = n_{braking\ distance}$$

This means that t_2 is the earliest of the respective entry times of any segment that precedes the current segment, but by no more than n_{SCSR} of these preceding segments. Given that such an equation will be complicated to formulate, a graphical explanation will be provided beforehand for a short section of a westbound-traveling RER train around its station stops at Bloor and St. Clair station: As can be seen in Figure 22, the position at the end of each segment is shown in the green column, while the actual speed is shown in the two columns which changes from red to green as the speed increases and shows the train speed at the start and at the end of the segment. Furthermore, the yellow column shows the number of segments which equals the braking distance at the exit speed of the current block, while the red column shows the number of subsequent segments by which the current segment entry time must be offset (and which equals the numbers in the yellow columns as the safety margin equals the length of the current segment). Finally, the blue column shows by how many segments the earliest segment which lies no more than n_{SCSR}

segments (calculated for that preceding, not the current segment!) away from the current segment precedes the current segment.

Figure 22: Determination of the moment when movement authority is required for current segment

Fixed block					Actual speed (mph)																										
RER-fix			Length		v0	v1	n_braking_dist	n_subsequent_clear_segments_required	Movement authority required at train entry (t3) ... segments ahead of current segment																						
Segment #	Mile	Position	miles	meter	ENTRY	EXIT			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	MAX
78	3.90		0.05	80	44.0	35.9	3	3													13										13
79	3.95		0.05	80	35.9	25.4	2	2													13										13
80	4.00	Bloor	0.05	80	25.4	-	1	1													13										13
81	4.05		0.05	80	-	28.2	3	3	1	2	3	4	5	6	7	8	9	10	11	12	13										13
82	4.10		0.05	80	28.2	39.9	4	4	1																						1
83	4.15	Signal bridge	0.05	80	39.9	48.9	5	5		2																					2
84	4.20		0.05	80	48.9	56.5	6	6			3																				3
85	4.25		0.05	80	56.5	63.1	8	8			3																				3
86	4.30		0.05	80	63.1	69.2	9	9				4																			4
87	4.35		0.05	80	69.2	74.7	10	10				4																			4
88	4.40		0.05	80	74.7	79.9	11	11					5																		5
89	4.45		0.05	80	79.9	84.7	13	13					5																		5
90	4.50		0.05	80	84.7	89.3	14	14						6																	6
91	4.55		0.05	80	89.3	90.0	14	14						6																	6
92	4.60		0.05	80	90.0	90.0	14	14							7																7
93	4.65		0.05	80	90.0	90.0	14	14								8															8
94	4.70	Signal bridge	0.05	80	90.0	87.9	13	13								8															8
95	4.75		0.05	80	87.9	84.2	12	12									9														9
96	4.80		0.05	80	84.2	80.3	11	11									9														9
97	4.85		0.05	80	80.3	76.1	10	10										10													10
98	4.90		0.05	80	76.1	71.8	9	9										10													10
99	4.95		0.05	80	71.8	67.2	8	8											11												11
100	5.00		0.05	80	67.2	62.2	7	7											11												11
101	5.05		0.05	80	62.2	56.8	6	6												12											12
102	5.10		0.05	80	56.8	50.8	5	5													13										13
103	5.15		0.05	80	50.8	44.0	4	4													13										13
104	5.20		0.05	80	44.0	35.9	3	3														14									14
105	5.25		0.05	80	35.9	25.4	2	2														14									14
106	5.30	St. Clair	0.05	80	25.4	-	1	1														14									14
107	5.35	Signal bridge	0.05	80	-	28.2	3	3	1	2	3	4	5	6	7	8	9	10	11	12	13	14									14
108	5.40		0.05	80	28.2	39.9	4	4	1																						1
109	5.45		0.05	80	39.9	48.9	5	5		2																					2
110	5.50		0.05	80	48.9	56.5	6	6			3																				3
111	5.55		0.05	80	56.5	63.1	8	8			3																				3
112	5.60		0.05	80	63.1	69.2	9	9				4																			4
113	5.65		0.05	80	69.2	74.7	10	10				4																			4
114	5.70		0.05	80	74.7	79.9	11	11					5																		5

Note: values highlighted in yellow are derived by taking the maximum value of the previous segment or by subtracting one from the maximum value of the following segment, whichever is higher.
Source: own work.

As also shown in Figure 22 above, the train requires one clear segment (beyond the current segment, i.e. zero segments of movement authority plus the safety margin of one segment length) as it enters into Segment 80 and brakes into standstill for the station stop at Bloor at the end of that segment. When accelerating after the station stop, the required number of segments of movement authority increases from 3 in Segment 81 to 4, 5, 6, 8, 9, 10, 11, 13 and 14 in the subsequent segments and stays at 14 in Segments 90-93, before reducing in increments of 1 until standstill at St. Clair station at the end of Segment 106. The values for n_{SCSR} are then copied diagonally to the line for the segment number of the current segment plus n_{SCSR} (e.g. the 2 from segment 80 goes into the line for segment 80+2=82, while the 14 from segment 90 goes into the line for segment 90+4=104). The maximum of these values of n_{SCSR} of those preceding segments, for which that value does not exceed the distance between that preceding segment and the current segment, are shown in the blue column. Similar to the values of n_{SCSR} shown in the red column, these values also increase incrementally as the train leaves Bloor station, but less fast. Conversely, they drop from 14 in the segment after St. Clair (Segment 107) to only one in the following segment (Segment 108), which indicates that the end point of the braking curve had been the same for the last 14 segments (i.e. the end of Segment 106 for Segments 93-106 with Segment 107 representing the safety margin). The moment where the movement authority is required (t_2) for the current segment is consequently the moment the train enters the segment (t_3) which precedes the current segment by exactly that (maximum) value:

(22a) $$t_{approaching} = offset\left(t_3, -n_{SCSR\_maximum\ of\ values\ applicable\ to\ current\ block}, 0\right) = t_2$$

The remaining times are much easier to formulate as the entry time equals the exiting time of the previous segment, the exit time equals the entry time plus the respective travel time increments for the behavioral sections (acceleration, constant movement and deceleration) within the current segment and the exiting speed equals the exit time plus the dwell time (if the block ends at a station with a scheduled station block). Similarly, the segment clearing time is the maximum of the current segment's entry time offset by the minimum number of segments representing the train's length, while the signal release time is the maximum of the previous segment's signal release time, the current segment's clearing time and the following segment's clearing time. Finally, the signal release time of the previous block and the block release time is the signal release time plus the block release delay:

(26) $t_{entry} = t_{5\_preceeding} = t_3$

(27) $t_{at\ exit} = t_3 + t_{segment} = t_3 + \Delta t_{acc} + \Delta t_{red} + \Delta t_{constant} = t_4$

(28) $t_{exiting} = t_4 + \Delta t_{dwell} = t_5$

(29) $t_{cleared} = MAX\left(OFFSET\left(t_3\ , n_{train\ length}\ , 0\right), t_4\ , t_{6\_preceding}\right) = t_6$

(15) $n_{train\ length} = ROUNDUP\left(\frac{s_{train\ length}}{s_{segment\ length}}, 0\right) = ROUNDUP\left(\frac{s_{train\ length}}{80.5\ meters}, 0\right)$

(30) $t_{signal\ released} = MAX\left(t_{6\_follwing}\ , t_6\ , t_{7\_preceding}\right) = t_7$

(31) $t_{block\ released} = t_7 + \Delta t_{block\ release} = t_7 + 5\ sec = t_8$

Whereas the above equations are sufficient to calculate the theoretical travel and blocking times, they still lack the travel time supplements, which need to be added in order to account for any operational inefficiencies (i.e. delays). Therefore, the time elapsed in the segment (i.e. travel plus dwell time) and the segment length need to be multiplied with the applicable recovery margins (3-5% of travel time plus 1 minute per 100 km, as stated in Table 13):

(27.1) $t_{at\ exit} = t_3 + t_{segment} = t_3 + \Delta t_{acc} + \Delta t_{red} + \Delta t_{constant} * RM_{time} +$

$\Delta s_{segment} * RM_{distance} = t_4$

(28.1) $t_{exiting} = t_4 + \Delta t_{dwell} * RM_{time} = t_5$

6.4.2. Variable blocks

Concerning the scenario variants involving the variable block, only the equations determining the start and the end of the movement authority need to be adjusted, thus t_1 (also t_2, since t_1 is derived from t_2) and t_7, as the movement authority is assigned and released (by stationary signals) for all segments comprising a block simultaneously. However, while movement authority can only be assigned by a signal which is positioned to face the train and its driver, it is assumed that it can be also released after passing a signal not facing the train[35]. It is therefore necessary to divide the line into blocks (in which movement authority is assigned for all segments simultaneously) and sub-blocks (in which movement authority is released for all segments simultaneously and which may form the entirety or a part of one single block). This means that all segments of the same block are assigned the moment movement authority is required for any segment comprising that block and that all segments of the same sub-block are released the same moment as the train has cleared the first segment beyond the sub-block[36].

For identification purposes, the blocks and sub-blocks must be numbered separately and progressively (starting with Block 1 and Sub-block 1 at Toronto Union for westbound trains or Kitchener for eastbound trains). Conversely, their comprising segments are counted in the reverse direction, meaning that any block with a signal standing at its end is the Segment 1 of that block or sub-block and that the preceding segments of that block or sub-block are Segments 2, 3, 4 and

[35] Refer back to Table 15 in Section 5.6 for an overview of the assumed signalling locations along the Kitchener Corridor and an identification of those signals which only face trains travelling in one of the two directions.

[36] Whereas this of course does not allow to assign the same block to a new train movement before the entire block has been cleared, it does allow the re-assignment of the sub-block if enough sub-blocks are cleared and available to reach a block signal on a different track (i.e. via a switch). This is particularly useful when splitting two train portions, as it can help reducing the dwell time of the train portions which leave the station after the first train portion, provided that the train portions part tracks immediately after the station where the splitting took place.

so on. Adjusting the equation for the signal required time is simple, as only the constant for the signal watching period needs to be changed:

$$(21.a) \quad t_{required} = t_2 - \Delta t_{signal\,watching} = t_2 - 10sec = t_1$$

However, for the approaching time and signal release times, we need to construct a significantly different equation, as the approach now starts with entering the segment with the second-last train-facing signal before the current block in order to prevent the train from receiving any "*Clear to Stop*" signal while en-route, which is basically a yellow light requiring the train driver to prepare the train to stop in front of the next signal until he either stops in front of the following signal or that following signal switches from red ("*Stop*") to a more permissive signal. This preventable loss of travel time can be avoided by showing "*Clear to Clear*" instead, which is basically a green light indicating that the train can proceed through the next block at whatever speed the applicable line and local speed limits allow and therefore requires that the two blocks behind the signal are cleared before the train passes that signal. The approaching time of a given block[37] is therefore the entry time of the last segment (i.e. Segment 1) 2 blocks before the current block:

$$(22.b) \quad t_{approaching} = t_{3\_segment\ 1\ of\ current\ block\ number\ minus\ 3} = t_2$$

Finally, the signal clearing time is the moment when the train has cleared the first segment after the current sub-block:

$$(30.a) \quad t_{signal\,released} = IF\big(n_{current\ sub-block\ segment} = 1\,,$$

$$MAX\big(t_6, t_{6\_following}\big), t_{7\_following}\big) = t_7$$

[37] Recall that the approach times are the same for all segments within the same block.

In order to avoid confusion, all equations relevant for calculating $t_0, t_1, t_2, \dots, t_8$ are repeated below and in a formulation which is valid for both scenario variants:

(20) $t_{requested} = t_1 - \Delta t_{signal\ clearing} = t_2 - 5sec = t_0$

(21.b) $t_{required} = t_2 - \Delta t_{signal\ watching} = t_1$

(22.c) $fixed\ blocking: t_{approaching} = offset\left(t_3, -n_{SCSR\_maximum\ of\ values\ applicable\ to\ current\ block}, 0\right) = t_2$

$variable\ blocking: t_{approaching} = t_{3\_segment\ 1\ of\ current\ block\ number\ minus\ 2} = t_2$

(23) $n_{clear\ segments\ required} = n_{braking\ distance} + n_{safety\ margin}$

(24) $n_{safety\ margin} = 1$

(25) $n_{SCSR} = n_{clear\ segments\ required} - 1 = n_{braking\ distance} + n_{safety\ margin} - 1 = n_{braking\ distance}$

(26) $t_{entry} = t_{5\_preceeding} = t_3$

(27.1) $t_{at\ exit} = t_3 + t_{segment} = t_3 + \Delta t_{acc} + \Delta t_{red} + \Delta t_{constant} * RM_{time} + \Delta s_{segment} * RM_{distance} = t_4$

(28.1) $t_{exiting} = t_4 + \Delta t_{dwell} * RM_{time} = t_5$

(29) $t_{cleared} = MAX\left(OFFSET\left(t_3, n_{train\ length}, 0\right), t_5, t_{6\_preceding}\right) = t_6$

(15) $n_{train\ length} = ROUNDUP\left(\frac{s_{train\ length}}{s_{segment\ length}}, 0\right)$

(30.b) $fixed\ blocking: t_{signal\ released} =$

$MAX\left(t_{cleared\_follwing}\ , t_6\ , t_{7\_preceding}\right) = t_7$

$variable\ blocking: t_{signal\ released} = IF\left(n_{current\ sub-block\ segment} = 1\ ,\right.$

$\left.MAX\left(t_6, t_{6\_following}\right), t_{7\_following}\right) = t_7$

(31) $t_{block\ released} = t_7 + \Delta t_{block\ release} = t_8$

7. Model Solving

7.1. Plausible train routings

The first step in solving the model is to determine what the possible routings for every train type are. With 2 directions, 5 different train types, 15 different track changes and at least two tracks available anywhere along the corridor, there are more than 500,000 possible combinations for calculating run-times, which highlights the need to cut down the number of these combinations drastically. This will be ensured by considering which corridor segments are used by which train set and which are not (to ignore irrelevant track changes), by determining which tracks allow valid routings and which ones do not (to eliminate routing options which involve tracks which do not have a platform to serve station stops required for that train service) and by assigning individual tracks for one principle direction (which again cuts the number of potential routings down by half, while ensuring a much more efficient use of available track capacity[38]).

Concerning the Corridor segments used by every train type, Inter-City and Inter-Regional trains are the only train types to use the entire Kitchener Corridor, while Airport Shuttle trains part at Woodbine Junction, RER trains terminate at either Bramalea, Mount Pleasant or Georgetown and freight trains enter at Halwest Junction and exit at Silver Junction. Moving on to the valid routings, Liberty Village and St. Clair stations are only served by tracks K1 and K2 (as opposed to E1 and E2. This means that RER trains must use tracks K1 and K2 until at least Nickle, while only RER trains can use Track H0 in Georgetown[39].

[38] Just as with road lanes, track capacity is only a small fraction of that of uni-directional routing if the direction of traffic needs to be changed frequently and sharing for both directions is therefore best avoided as much as possible.

[39] In fact, Track H0 is the preferred track for those RER trains which originate/terminate at Georgetown, as it minimizes interference with through traffic and is located adjacent to GO Transit's layover facility.

Assigning a principle direction to the tracks is much more challenging, as there are no obvious right and wrong directions and the desire to minimize track routing conflicts (especially of trains running in opposite directions) as well as travel time losses forced by track changes often favors mutually exclusive directional assignments at different parts of the Corridor. A first hint when assigning principal directions to individual tracks is the narrowing of the Weston Subdivision from 4 to 3 tracks at Woodbine Junction, which favors that tracks K1 and E2 (i.e. the two centre tracks) are assigned for the same direction, so that the trains can merge onto or split from the same track (W2) without causing any conflicts with opposing traffic. The second hint is that when crossing opposing traffic cannot be avoided, it is better to have the conflict where trains merge than where they part tracks, as it is preferable to have trains waiting for a clear signal on tracks with less traffic, to minimize the risk of delaying subsequent train movements.

It could therefore be argued that using tracks E1/W3/H3 and K2/W1/H1 for westbound traffic would be preferable, as this allows westbound Airport Shuttle trains to leave the Kitchener Corridor at Woodbine Junction unhindered by opposing traffic, while other westbound passenger trains could wait on the (compared to Track W2/H2) lightly used Track W3/H3 for a gap to switch over to Track W1/H1 before the Halton Subdivision narrows down to two tracks at Peel. However, such a directional assignment would move the opposing traffic conflict for freight trains onto the Kitchener Corridor’s main tracks, as westbound freight trains would regularly have to wait in Georgetown for a signal to cross over opposing traffic at Silver Jct. while eastbound freight trains would do the same in Brampton for crossing over at Bramalea West.

Given that freight trains have much worse acceleration and braking capabilities than passenger trains, using tracks K2/W1/H1/G1 and E1/W3 for eastbound movements and tracks K1 and E2/W2/H2/G2 for westbound movements is the preferred choice. Coincidentally, this preference assigns the center track of the three-tracked section of the Weston Subdivision (i.e. between Woodbine and Halwest Junctions) to the direction where trains can be expected to be less delayed, as all westbound passenger trains start at Union Station, while eastbound trains may originate at stations which are as close as the Airport, Mount Pleasant or Georgetown or as far away as Cambridge, Kitchener and beyond[40] and are therefore more likely to benefit from the flexibility provided by assigning a second track for that direction.

As shown in more detail in Figure 23, westbound traffic will leave Toronto (Union Station) over the two center tracks (RER trains on Track K1, all other passenger trains on Track E2), which merge at Woodbine Junction into one single center track (W2), right after the Airport Shuttle trains have left the Kitchener Corridor onto the Airport Spur. Track W2 changes its name to Track H2 at Bramalea West, where it also begins to host freight traffic right before it becomes the southern mainline track of the Halton Subdivision at Peel. Westbound passenger trains will then use the center track of the three mainline tracks available between Brampton West and Silver Junction (H2) or switch like the freight trains onto the southernmost of these tracks (H3) if Track H2 is unavailable, with RER trains continuing beyond Bramalea terminating on Track H0 in Georgetown (or on Track H2 in Mount Pleasant). Freight trains split away with the Halton Subdivision at Silver Junction and all remaining passenger trains continue onto the southern mainline track of the Guelph Subdivision (G2). The retained westbound routings are therefore as listed below:

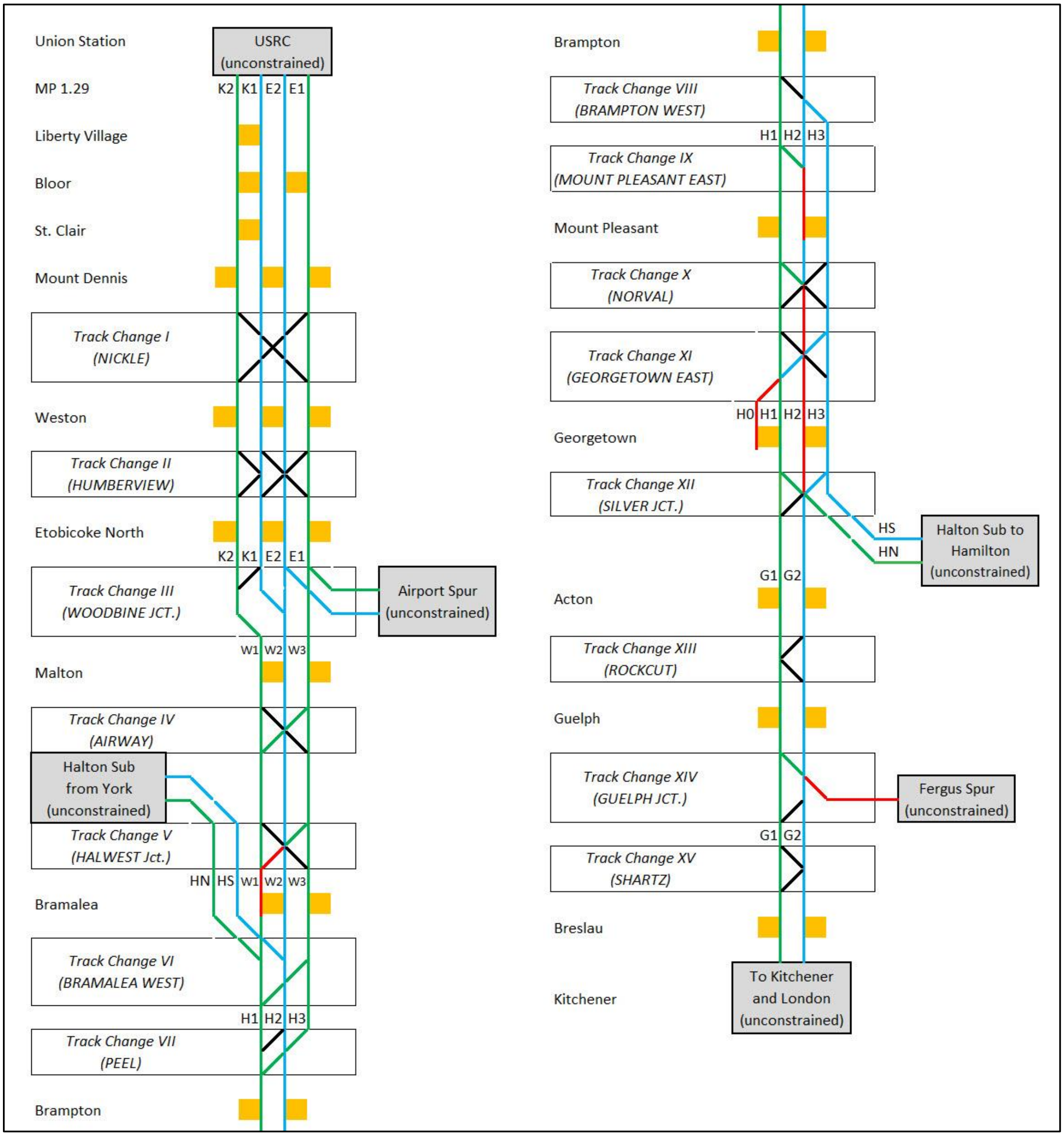
[40] Within the modelling process, it is assumed that Inter-City trains continue beyond Kitchener, thus vacating the track shortly after their scheduled arrival from Toronto or before departure towards Toronto, while Inter-Regional trains would be dwelling at Kitchener station between their scheduled arrival from Toronto and departure towards Toronto (Note that this has no effect on the Modelling process, as track availability is considered unconstrained within Kitchener Station). While the next logical terminus for the Inter-City trains would be London, it might be desirable to extend some trains beyond London to Windsor or Sarnia and potentially into the United States to Detroit or even Chicago.

- Inter-City: preferred routing (*IC-W1*) leaving Toronto on Track E2/H2/G2 (thus avoiding any track changes) with the following 3 alternative routings:
    - Routing *IC-W2*: Using Track H3 instead of H2 between Brampton West and Silver Junction, if the center track (H2) is needed for RER trains terminating or originating at Mount Pleasant or for any other train movement.
    - Routing *IC-W3F*: Identical to Routing IC-W1, but with additional dwell time in Guelph (to separate from the train portion continuing to Kitchener) and switching onto the Fergus Subdivision at Guelph Junction.
    - Routing *IC-W4F*: Identical to Routing IC-W2, but with additional dwell time in Guelph (to separate from the train portion continuing to Kitchener) and switching onto the Fergus Subdivision at Guelph Junction.
- Inter-Regional: preferred routing (*IR-W1*) leaving Toronto on Track E2/H2/G2 (thus avoiding any track changes) with the following alternative routing:
    - Routing *IR-W2*: Using Track H3 instead of H2 between Brampton West and Silver Junction (refer to: Routing IC-W2).
- Airport Shuttle: preferred routing (*AIR-W1*) leaving Toronto on Track E2 and crossing opposing traffic at Woodbine Junction to switch over onto the Airport Spur with no alternative routings.
- Regional Express Rail (*RER-W1*): preferred routing leaving Toronto on Track K1, switching over to Track W2/H2 at Woodbine Junction and at Georgetown East onto Track H0 with the following alternative routings:
    - Routing *RER-W2*: Using Track H3 instead of H2 between Brampton West and Georgetown East (refer to: routing IC-W2).

- Routing *RER-W3*: Same as Routing RER-W1, but with a scheduled signal stop at Georgetown East while waiting for the train path required for switching from Track H2 over H1 to H0 to be cleared.
- Routing *RER-W4*: Same as Routing RER-W2, but with a scheduled signal stop at Georgetown East while waiting for the train path required for switching from Track H3 over tracks H2 and H1 to H0 to be cleared.
- Routing *RER-W5MP*: Same as Routing RER-W2, but terminating at Mount-Pleasant on Track H2.
- Routing *RER-W6BL*: Same as Routing RER-W1, but terminating at Bramalea after switching over from Track W2 to W1 at Halwest Junction.
- Routing *RER-W7BL*: Same as Routing RER-W6BL, but with a scheduled signal stop just before switching over from Track H2 to H1 at Halwest Junction while waiting for track H1 to become clear.

- Freight: preferred routing (*F-W1*) merging onto Track H2 at Bramalea West, switching over to Track H3 at Brampton West and staying on the Halton Subdivision as it splits away from the Kitchener Corridor at Silver with no alternative routings.

Figure 23: Simplified track plan showing the directional routings through the Kitchener Corridor



Note: Tracks with primarily westbound (i.e. outbound) routings are shown in blue (mainly: Tracks K1, HS and E2/W2/H2/G2), while tracks with preliminarily eastbound (i.e. inbound) routings are shown in green (mainly: HN and K2/W1/H1/G1) and with bidirectional routings shown in red.
Source: own work.

In the opposite direction, eastbound Inter-City and Inter-Regional trains will use the northern mainline track of the Guelph Subdivision (G1) and use the northern-most of the three mainline tracks available between Silver and Brampton (H1), while freight trains join at Silver Jct. and use Track H1 whenever it is available. RER trains originate on either Track H0 in Georgetown, Track H2 in Mount Pleasant or Track W1 in Bramalea and primarily use the northern-most mainline track (H1/W1/K2). Freight trains split away with the Halton Subdivision at Bramalea, while RER trains continue on Track K1 and all other passenger trains switch over to Track W3 at either Peel, Bramalea West, Halwest Junction or Airway. Finally, Track W3 changes its name to Track E1 at Woodbine where the Airport Shuttle trains merge onto it, while Track W2 changes its name to Track K2 for the final miles before the USRC. The retained eastbound routings are therefore as listed below:

- Inter-City: preferred routing (*IC-E1*) leaving Kitchener on Track G1/H1 (later: W1) and switching over to Track H3/W3 at Peel with the following alternative routings:
  - Routing *IC-E2*: Switching over from Track H1/W1 to W3 at Bramalea West instead of Peel, if Track H2/W2 is blocked at Peel.
  - Routing *IC-E3*: Switching over from Track H1/W1 to W3 at Halwest Junction instead of Peel, if Track H2/W2 is blocked at Peel and Bramalea West.
  - Routing *IC-E4*: Switching over from Track H1/W1 to W3 at Airway instead of Peel, if Track H2/W2 is blocked at Peel, Bramalea West and Halwest Junction.
- Inter-Regional: preferred routing (*IR-E1*) leaving Kitchener on Track G1 and switching to Track H3/W3 at Peel with the following alternative routings:
  - Routing *IR-E2*: Switching over from Track H1/W1 to W3 at Bramalea West instead of Peel (refer to: Routing IC-E2).

- Routing *IR-E3*: Switching over from Track H1/W1 to W3 at Halwest Junction instead of Peel (refer to: Routing IC-E3).
- Routing *IR-E4*: Switching over from Track H1/W1 to W3 at Airway instead of Peel (refer to: Routing IC-E4).

- Airport Shuttle: preferred routing (*AIR-E1*) entering the Kitchener Corridor from the Airport Spur at Woodbine and entering Toronto on Track E2 with no alternative routings.
- Regional Express Rail (*RER-E1*): preferred routing leaving Georgetown on Track H0 and switching over to Track H1/W1 at Georgetown with the following alternative routing:
    - Routing *RER-E2MP*: Same as Routing RER-E1, but originating in Mount Pleasant from Track H2, switching over to Track H1 at Mount Pleasant East.
    - Routing *RER-E3BL*: Same as Routing RER-E1, but originating in Bramalea from Track W1.
- Freight: preferred routing (*F-E1*) merging onto Track H1 at Silver Junction and staying on the Halton Subdivision as it splits away from the Kitchener Corridor at Brampton with the following alternative routing:
    - Routing *F-E2*: Same as Routing F-E1, but using Track H2 (rather than Track H1) between Silver Junction and Norval.

7.2. Calculation of run-times per train type

Having determined the various train routings, we can now calculate the travel times for every identified train routing. As presented in Table 20, the travel times vary between 54 and 64 minutes for the entire Kitchener Corridor (69-70 minutes for trains terminating at Cambridge instead of Kitchener) and between 15 and 38 minutes for the train types which only use part of the Corridor. While the variance between the various train routings for the same train type was up to 80 seconds on westbound train routings, this maximum value was significantly lower with 46 seconds on eastbound train routings. This was to be expected, given that every track change requires a track speed limit of 45 mph and given that the difference in the track change count varied much more among westbound train routings of the same train type and route served (e.g. IC-W2 and IR-W2 involves 2 track changes more than IC-W1 and IR-W1) than among eastbound routings (where the number of track changes for different routings for the same train type and route served only varied for freight trains).

Similarly, the average increment by which variable-block timings exceed the respective fixed-block timings of the same train routing was higher for westbound than for eastbound routings (17 vs. 11 seconds). This was also to be expected, given that it’s the signals in the variable-block scenario variants which mark the start and end of the track speed limit and that the 45 mph speed limit therefore already applies from the last train-facing signal before the track change until the first signal (any signal) after the track change. Nevertheless, the by far highest gap between runtimes for fixed and variable signaling systems was found on the eastbound with Routing IC-E5F, but 88 out of the 101 seconds of gap can be explained by longer block lengths requiring the Inter-City portion from Cambridge to arrive earlier at Guelph station (before the train’s main portion from Kitchener may receive the signal to enter the station) than under the much shorter fixed blocks.

Table 20: Calculated travel times for all retained train routings

	WESTBOUND TRAVEL TIMES (Passenger: Toronto-Woodbine Jct./Bramalea/Mount Pleasant/Georgetown/Cambridge/Kitchener, Freight: Halwest Jct.-Silver Jct.)																	
Train type	INTER-CITY				INTER-REGIONAL		AIRPORT	REGIONAL EXPRESS RAIL (RER)							FREIGHT			
Train routing	IC-W1	IC-W2	IC-W3F	IC-W4F	IR-W1	IR-W2	AIR-W1	RER-W1	RER-W2	RER-W3	RER-W4	RER-W5MP	RER-W6BL	RER-W7BL	F-W1	MIN	AVG	MAX
Track change count	0	2	1	3	0	2	1	2	3	2	3	2	2	2	3	0	1.8	3
- vs. fastest routing	0	2	0	2	0	2	0	0	1	0	1	0	0	0	0	0	0.5	2
Travel time (fixed block)	0:55:08	0:56:05	1:09:06	1:10:04	1:02:55	1:03:35	0:16:06	0:36:54	0:37:14	0:37:22	0:37:42	0:31:42	0:25:02	0:25:30	0:16:43	0:16:06	00:41:05	1:10:04
- vs. fastest routing		0:00:58		0:00:58		0:00:40			0:00:20	0:00:28	0:00:48			0:00:28		0:00:20	00:00:37	0:00:58
Travel time (variable block)	0:55:08	0:56:27	1:09:06	1:10:26	1:02:55	1:03:56	0:16:16	0:37:17	0:37:43	0:37:45	0:38:11	0:32:05	0:25:24	0:25:52	0:17:02	0:16:16	00:41:22	1:10:26
- vs. fastest routing		0:01:20		0:01:20		0:01:01			0:00:26	0:00:28	0:00:54			0:00:28		0:00:26	00:00:48	0:01:20
- vs. fixed block	0:00:00	0:00:22	0:00:00	0:00:22	0:00:00	0:00:21	0:00:10	0:00:23	0:00:29	0:00:23	0:00:29	0:00:23	0:00:23	0:00:23	0:00:19	0:00:00	00:00:17	0:00:29
	EASTBOUND TRAVEL TIMES (Passenger: Kitchener/Cambridge/Georgetown/Mount Pleasant/Bramalea/Woodbine Jct.-Toronto, Freight: Silver Jct.-Halwest Jct.)																	
Train type	FREIGHT					INTER-REGIONAL				AIRPORT	REGIONAL EXPRESS RAIL (RER)			FREIGHT				
Train routing	IC-E1	IC-E2	IC-E3	IC-E4	IC-E5F	IR-E1	IR-E2	IR-E3	IR-E4	AIR-E1	RER-E1	RER-E2MP	RER-E3BL	F-E1	F-E2	MIN	AVG	MAX
Track change count	1	1	1	1	2	1	1	1	1	1	1	0	0	2	3	0	1.1	3
- vs. fastest routing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0.1	1
Travel time (fixed block)	0:54:38	0:55:01	0:55:11	0:55:15	1:08:58	1:02:19	1:02:00	1:02:15	1:02:35	0:15:24	0:35:16	0:30:25	0:22:55	0:16:49	0:17:03	0:15:24	00:43:13	1:08:58
- vs. fastest routing		0:00:22	0:00:32	0:00:37		0:00:19		0:00:16	0:00:35							0:00:16	00:00:25	0:00:37
Travel time (variable block)	0:54:44	0:55:03	0:55:16	0:55:29	1:10:39	1:02:24	1:02:02	1:02:15	1:02:48	0:15:33	0:35:16	0:30:35	0:22:55	0:16:49	0:17:05	0:15:33	00:43:24	1:10:39
- vs. fastest routing		0:00:20	0:00:32	0:00:45		0:00:22		0:00:13	0:00:46						0:00:16	0:00:13	00:00:26	0:00:46
- vs. fixed block	0:00:05	0:00:02	0:00:05	0:00:13	0:01:41	0:00:06	0:00:02	0:00:00	0:00:13	0:00:09	0:00:00	0:00:10	0:00:00	0:00:00	0:00:02	0:00:00	00:00:11	0:01:41

Note: Travel times shown for passenger trains are between Toronto Union and either Kitchener (Inter-City routings IC-W1/2 and IC-E1/2/3/4, as well as all Inter-Regional routings), Cambridge (train routings IC-W3F, IC-W4F and IC-E5F), Georgetown (RER routings RER-W1, RER-W2, RER-W3 and RER-E1), Mount Pleasant (RER routings RER-W5MP and RER-E3), Bramalea (all other RER routings) or Woodbine Junction (all Airport Shuttle routings), while the travel times shown for freight train routings refer to the travel time between Halwest and Silver Junctions.
Source: own work.

More detailed travel times can be found in Tables 21 and 22, where track changes requiring a track speed limit of 45 mph are indicated by highlighting the track number in yellow, while green track numbers indicate that no such change of track is required at this particular track change. Furthermore, station stops are highlighted and indicated with arrival and departure time, to distinguish them from passing times (i.e. the time a train is scheduled to pass through a location – such as a station or junction – without stopping).

Table 21: Calculated travel times for the various train types and routings (westbound, assuming fixed blocks)

Train service	INTER-CITY								INTER-REGIONAL				AIRPORT SHUTTLE		FREIGHT	
Routing	IC-W1		IC-W2		IC-W3F		IC-W4F		IR-W1		IR-W2		AIR-W1		F-W1	
Train path	IC		IC-VIII-XII		IC-XIV-Fergus		IC-VIII-XII-XIV-Fergus		IR		IR-VIII-XII		AIR-III		F-VI-XII	
Station dwell time [s]	60		60		60		60		40		40		40		n/a	
	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep
Toronto		0:00:00		0:00:00		0:00:00		0:00:00		0:00:00		0:00:00		0:00:00		
Track at USRC exit	E2		E2		E2		E2		E2		E2		E2			
Liberty Village		0:05:05		0:05:05		0:05:05		0:05:05		0:05:02		0:05:02		0:04:33		
Bloor		0:06:40		0:06:40		0:06:40		0:06:40	0:07:03	0:07:43	0:07:03	0:07:43	0:06:32	0:07:12		
St. Clair		0:07:28		0:07:28		0:07:28		0:07:28		0:09:04		0:09:04		0:08:33		
Mount Dennis	0:09:00	0:10:00	0:09:00	0:10:00	0:09:00	0:10:00	0:09:00	0:10:00	0:10:35	0:11:15	0:10:35	0:11:15	0:10:04	0:10:44		
Weston		0:12:05		0:12:05		0:12:05		0:12:05		0:12:49		0:12:49		0:12:18		
Etobicoke North		0:13:55		0:13:55		0:13:55		0:13:55		0:14:41		0:14:41		0:14:08		
Woodbine Jct.		0:15:20		0:15:20		0:15:20		0:15:20		0:16:14		0:16:14		0:16:06		
III: Woodbine Jct.	W2		W2		W2		W2		W2		W2		to: Airport		From: York	
Malton		0:16:06		0:16:06		0:16:06		0:16:06		0:17:04		0:17:04				
V: Halwest Jct.	W2		W2		W2		W2		W2		W2				HS	
Halwest Jct.		0:17:23		0:17:23		0:17:23		0:17:23		0:18:28		0:18:28				0:00:00
Bramalea		0:17:46		0:17:46		0:17:46		0:17:46	0:19:20	0:20:00	0:19:20	0:20:00				0:00:41
VI: Bramalea West	H2		H2		H2		H2		H2		H2				H2	
Brampton	0:20:37	0:21:37	0:20:37	0:21:37	0:20:37	0:21:37	0:20:37	0:21:37	0:23:30	0:24:10	0:23:30	0:24:10				0:05:41
VIII: Brampton West	H2		H3		H2		H3		H2		H3				H2	
Mount Pleasant		0:24:29		0:24:39		0:24:29		0:24:39	0:27:05	0:27:45	0:27:25	0:28:05				0:09:19
XI: Georgetown East	H2		H3		H2		H3		H2		H3				H2	
Georgetown		0:27:33		0:27:50		0:27:33		0:27:50	0:32:09	0:32:49	0:32:29	0:33:09				0:15:49
Silver Jct.		0:28:03		0:28:44		0:28:03		0:28:44		0:33:45		0:34:19				0:16:43
XII: Silver Jct.	G2		G2		G2		G2		G2		G2				To: HS	
Acton		0:32:22		0:33:19		0:32:22		0:33:19	0:38:34	0:39:14	0:39:14	0:39:54				
Guelph	0:42:07	0:44:07	0:43:04	0:45:04	0:42:07	0:46:07	0:43:04	0:47:04	0:49:35	0:50:15	0:50:15	0:50:55				
Guelph Jct.		0:45:46		0:46:44		0:47:59		0:48:56	0:50:53	0:51:33	0:51:33	0:52:13				
XIV: Guelph Jct.	G2		G2		Fergus Subdiv.		Fergus Subdiv.		G2		G1					
Breslau (new)		0:50:27		0:51:24					0:57:06	0:57:46	0:57:46	0:58:26				
Kitchener (new)	0:55:08		0:56:05						1:02:55		1:03:35					
Hespeler (reopened)					0:57:17	0:58:17	0:58:15	0:59:15								
Preston (new)					1:01:48	1:02:48	1:02:46	1:03:46								
Cambridge (new)					1:09:06		1:10:04									

Train service	REGIONAL EXPRESS RAIL													
Routing	RER-W1		RER-W2		RER-W3		RER-W4		RER-W5MP		RER-W6BL		RER-W7BL	
Train path	RER-III-XI		RER-III-VIII-XI		RER-III-Stop-XI		RER-III-VIII-Stop-XI		RER-III-MP		RER-III-V-BL		RER-III-Stop-V-BL	
Station dwell time [s]	20		20		20		20		20		20		20	
	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep
Toronto		0:00:00		0:00:00		0:00:00		0:00:00		0:00:00		0:00:00		0:00:00
Track at USRC exit	K1		K1		K1		K1		K1		K1		K1	
Liberty Village	0:05:16	0:05:36	0:05:16	0:05:36	0:05:16	0:05:36	0:05:16	0:05:36	0:05:16	0:05:36	0:05:16	0:05:36	0:05:16	0:05:36
Bloor	0:07:49	0:08:09	0:07:49	0:08:09	0:07:49	0:08:09	0:07:49	0:08:09	0:07:49	0:08:09	0:07:49	0:08:09	0:07:49	0:08:09
St. Clair	0:09:52	0:10:12	0:09:52	0:10:12	0:09:52	0:10:12	0:09:52	0:10:12	0:09:52	0:10:12	0:09:52	0:10:12	0:09:52	0:10:12
Mount Dennis	0:12:04	0:12:24	0:12:04	0:12:24	0:12:04	0:12:24	0:12:04	0:12:24	0:12:04	0:12:24	0:12:04	0:12:24	0:12:04	0:12:24
Weston	0:14:21	0:14:41	0:14:21	0:14:41	0:14:21	0:14:41	0:14:21	0:14:41	0:14:21	0:14:41	0:14:21	0:14:41	0:14:21	0:14:41
Etobicoke North	0:17:22	0:17:42	0:17:22	0:17:42	0:17:22	0:17:42	0:17:22	0:17:42	0:17:22	0:17:42	0:17:22	0:17:42	0:17:22	0:17:42
Woodbine Jct.		0:20:06		0:20:06		0:20:06		0:20:06		0:20:06		0:20:06		0:20:06
III: Woodbine Jct.	W2		W2		W2		W2		W2		W2		W2	
Malton	0:21:38	0:21:58	0:21:38	0:21:58	0:21:38	0:21:58	0:21:38	0:21:58	0:21:38	0:21:58	0:21:38	0:21:58	0:21:38	0:21:58
V: Halwest Jct.	W2		W2		W2		W2		W2		W1		W1 (after stop)	
Halwest Jct.		0:23:51		0:23:51		0:23:51		0:23:51		0:23:51		0:24:01		0:24:28
Bramalea	0:24:41	0:25:01	0:24:41	0:25:01	0:24:41	0:25:01	0:24:41	0:25:01	0:24:41	0:25:01	0:25:02		0:25:30	
VI: Bramalea West	H2		H2		H2		H2		H2					
Brampton	0:28:31	0:28:51	0:28:31	0:28:51	0:28:31	0:28:51	0:28:31	0:28:51	0:28:31	0:28:51				
VIII: Brampton West	H2		H3		H2		H3		H2					
Mount Pleasant	0:31:42	0:32:02	0:32:02	0:32:22	0:31:42	0:32:02	0:32:02	0:32:22	0:31:42					
XI: Georgetown East	H4		H4		H4 (after stop)		H4 (after stop)							
Georgetown	0:36:54		0:37:14		0:37:22		0:37:42							

Source: own work.

Table 22: Calculated travel times for the various train types and routings (eastbound, assuming fixed blocks)

Train service	INTER-CITY									
Routing	IC-E1		IC-E2		IC-E3		IC-E4		IC-E5F	
Train path	IC-VII		IC-VI		IC-V		IC-IV		IC-Fergus-XIV-IV	
Station dwell time [s]	60		60		60		60		60	
	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep
Cambridge (new)										0:00:00
Preston (new)									0:07:16	0:08:16
Hespeler (relocated)									0:11:47	0:12:47
Kitchener (new)		0:00:00		0:00:00		0:00:00		0:00:00		
At exit out of Kitchener:	G1		G1		G1		G1		From: Fergus Sub.	
Breslau (new)		0:05:04		0:05:04		0:05:04		0:05:04		
Kitchener station	G1		G1		G1		G1		G1	
Guelph Jct.		0:09:41		0:09:41		0:09:41		0:09:41		*0:22:04*
Guelph	0:12:03	0:13:03	0:12:03	0:13:03	0:12:03	0:13:03	0:12:03	0:13:03	0:23:32	*0:26:46*
Acton		0:23:10		0:23:10		0:23:10		0:23:10		*0:36:53*
XII: Silver	H1		H1		H1		H1		H1	
Silver Jct.		0:27:29		0:27:29		0:27:29		0:27:29		*0:41:12*
Georgetown		0:27:58		0:27:58		0:27:58		0:27:58		*0:41:41*
XI: Georgetown	H1		H1		H1		H1		H1	
Mount Pleasant		0:31:05		0:31:05		0:31:05		0:31:05		*0:44:48*
IX: Mount Pleasant	H1		H1		H1		H1		H1	
Brampton	0:33:23	0:34:23	0:33:23	0:34:23	0:33:23	0:34:23	0:33:23	0:34:23	*0:47:06*	*0:48:06*
VII: Peel	H3		H1		H1		H1		H1	
VI: Bramalea	W3		W3		W1		W1		W1	
Bramalea		0:38:15		0:38:21		0:37:53		0:37:47		*0:51:31*
V: Halwest	W3		W3		W3		W1		W1	
Halwest Jct.		0:38:37		0:38:55		0:38:38		0:38:10		*0:51:53*
IV: Airways	W3		W3		W3		W3		W3	
Malton		0:39:56		0:40:18		0:40:28		0:40:26		*0:54:09*
III: Woodbine	E1		E1		E1		E1		E1	
Woodbine Jct.		0:40:41		0:41:04		0:41:14		0:41:18		*0:55:01*
Etobicoke North		0:42:06		0:42:29		0:42:39		0:42:43		*0:56:26*
Weston		0:43:53		0:44:16		0:44:26		0:44:30		*0:58:13*
Mount Dennis	0:45:29	0:46:29	0:45:52	0:46:52	0:46:02	0:47:02	0:46:06	0:47:06	*0:59:49*	*1:00:49*
St. Clair		0:48:31		0:48:53		0:49:03		0:49:08		*1:02:51*
Bloor		0:49:18		0:49:41		0:49:51		0:49:55		*1:03:38*
Liberty Village		0:50:48		0:51:11		0:51:21		0:51:25		*1:05:08*
Track at USRC exit	E1		E1		E1		E1		E1	
Toronto (Union)	0:54:38		0:55:01		0:55:11		0:55:15		*1:08:58*	

Train service	INTER-REGIONAL							
Routing	IR-E1		IR-E2		IR-E3		IR-E4	
Train path	IR-XII-XI-VII		IR-XII-XI-VI		IR-XII-XI-V		IR-XII-XI-IV	
Station dwell time [s]	40		40		40		40	
	arr	dep	arr	dep	arr	dep	arr	dep
Cambridge (new)								
Preston (new)								
Hespeler (relocated)								
Kitchener (new)		0:00:00		0:00:00		0:00:00		0:00:00
At exit out of Kitchener:	G1		G1		G1		G1	
Breslau (new)	0:05:16	0:05:56	0:05:16	0:05:56	0:05:16	0:05:56	0:05:16	0:05:56
Kitchener station	G1		G1		G1		G1	
Guelph Jct.		0:11:27		0:11:27		0:11:27		0:11:27
Guelph	0:11:24	0:13:24	0:11:24	0:13:24	0:11:24	0:13:24	0:11:24	0:13:24
Acton	0:23:46	0:24:26	0:23:46	0:24:26	0:23:46	0:24:26	0:23:46	0:24:26
XII: Silver	H1		H1		H1		H1	
Silver Jct.		0:29:15		0:29:15		0:29:15		0:29:15
Georgetown	0:30:11	0:30:51	0:30:11	0:30:51	0:30:11	0:30:51	0:30:11	0:30:51
XI: Georgetown	H1		H1		H1		H1	
Mount Pleasant	0:35:15	0:35:55	0:35:15	0:35:55	0:35:15	0:35:55	0:35:15	0:35:55
IX: Mount Pleasant	H1		H1		H1		H1	
Brampton	0:38:50	0:39:30	0:38:50	0:39:30	0:38:50	0:39:30	0:38:50	0:39:30
VII: Peel	H3		H1		H1		H1	
VI: Bramalea	W3		W3		W1		W1	
Bramalea	0:43:33	0:44:13	0:43:14	0:43:54	0:43:00	0:43:40	0:43:00	0:43:40
V: Halwest	W3		W3		W3		W1	
Halwest Jct.		0:45:04		0:44:45		0:44:41		0:44:32
IV: Airways	W3		W3		W3		W3	
Malton		0:46:29		0:46:10		0:46:25		0:46:45
III: Woodbine	E1		E1		E1		E1	
Woodbine Jct.		0:47:19		0:47:00		0:47:16		0:47:35
Etobicoke North		0:48:52		0:48:33		0:48:49		0:49:08
Weston		0:50:43		0:50:24		0:50:39		0:50:59
Mount Dennis	0:52:17	0:52:57	0:51:58	0:52:38	0:52:14	0:52:54	0:52:33	0:53:13
St. Clair		0:54:28		0:54:09		0:54:25		0:54:44
Bloor	0:55:50	0:56:30	0:55:31	0:56:11	0:55:47	0:56:27	0:56:06	0:56:46
Liberty Village		0:58:29		0:58:10		0:58:25		0:58:45
Track at USRC exit	E1		E1		E1		E1	
Toronto (Union)	1:02:19		1:02:00		1:02:15		1:02:35	

Train service	AIRPORT SHUTTLE		REGIONAL EXPRESS RAIL						FREIGHT		FREIGHT	
Routing	AIR-E1		RER-E1		RER-E2MP		RER-E3BL		F-E1		F-E2	
Train path	AIR-III		RER-XI		RER-XI-X		RER-XI-X		F-XII-VI		F-XII-X-VI	
Station dwell time [s]	40		20		20		20		n/a		n/a	
	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep	arr	dep
XII: Silver			H4						From: HN		From: HN	
Silver Jct.										0:00:00		0:00:00
Georgetown				0:00:00						0:00:54		0:00:54
XI: Georgetown			H1		H2				H1		H2	
Mount Pleasant			0:05:00	0:05:20		0:00:00				0:07:35		0:07:43
IX: Mount Pleasant			H1		H1				H1		H1	
Brampton			0:08:11	0:08:31	0:03:20	0:03:40				0:11:13		0:11:27
VII: Peel			H1		H1				H1		H1	
VI: Bramalea			W1		W1		W1		HN		HN	
Bramalea			0:12:01	0:12:21	0:07:10	0:07:30		0:00:00		0:16:03		0:16:17
V: Halwest			W1		W1		W1		HN		HN	
Halwest Jct.				0:13:05		0:08:15		0:00:45		0:16:49		0:17:03
IV: Airways	From: Airport		W1		W1		W1		To: York		To: York	
Malton			0:15:04	0:15:24	0:10:13	0:10:33	0:02:43	0:03:03				
III: Woodbine	E1		K2		K2		K2		n/a		n/a	
Woodbine Jct.		0:00:00		0:16:40		0:11:50		0:04:19				
Etobicoke North		0:01:59	0:18:49	0:19:09	0:13:59	0:14:19	0:06:29	0:06:49				
Weston		0:03:49	0:21:50	0:22:10	0:17:00	0:17:20	0:09:29	0:09:49				
Mount Dennis	0:05:23	0:06:03	0:24:06	0:24:26	0:19:16	0:19:36	0:11:45	0:12:05				
St. Clair		0:07:34	0:26:18	0:26:38	0:21:28	0:21:48	0:13:57	0:14:17				
Bloor	0:08:56	0:09:36	0:28:22	0:28:42	0:23:31	0:23:51	0:16:01	0:16:21				
Liberty Village		0:11:34	0:30:53	0:31:13	0:26:02	0:26:22	0:18:32	0:18:52				
Track at USRC exit	E1		K2		K2		K2		n/a		n/a	
Toronto (Union)	0:15:24		0:35:16		0:30:25		0:22:55					

Source: own work.

7.3. Visual representation of train paths

One of the shortfalls of using being limited to using a mostly manual modelling process relying on Microsoft Excel rather than an optimisation approach which uses a professional timetabling software like OpenTrack is that conflicts (i.e. two overlapping train paths requiring the same track segment at the same time) are not automatically detected. Instead, the train paths will have to be drawn in charts which will then be used to visually detect any overlaps. Out of the 8 different time point series described in Section 6.4, the two relevant time point series relevant for defining the start and end of a train's blocking time are t_o and t_8, while t_5 provides the most relevant description of the train's movement. Every train movement on its allocated train path can therefore be sufficiently described with three different lines, which should be colour-coded by train type (RER in dark green, Airport Shuttle in dark red, Inter-Regional in light green, Inter-City in orange and Freight in purple) and have the train movement line (t_5) represented by a thicker line than the other two lines, in order to better identify which three lines represent the same train path. Unfortunately, Microsoft Excel 2013 does not support the simultaneous formatting of multiple lines in a chart, which would make it prohibitively time-consuming to change every line's formatting in every single timetable scenario. Instead, a template spreadsheet will need to be created where every train type has its fixed trios of lines and which visualises timetable scenarios automatically by entering a data set which defines the initial departure time at the first point where the train enters the Kitchener Corridor and the train routing for every line trio representing a train path.

With a maximum passenger train volume of 12 trains per hour and direction (RER: 4, Airport Shuttle: 4, Inter-Regional: 2 and Inter-City: 2), this would require 72 lines per hour for both directions combined. The need to also add freight trains and to cover multiple hours would quickly exhaust the limit of 256 lines which Microsoft Excel 2013 allows to include in the same chart and necessitates that the chart is split into three separate charts, as follows:

- Chart I: Shows the t_o, t_5 and t_8 time series (i.e. the movement of the train's head and the edges of the train's blocking time) for all passenger trains and allows to identify train path conflicts between them and to solve these conflicts by modifying the initial departure time and/or the train routing. Consequently, the scheduling of the passenger trains is the first step of creating a timetable scenario.
- Chart II: Shows the t_o and t_8 time series (i.e. the edges of the train's blocking time) for all non-airport trains (i.e. including the freight trains, but excluding the Airport Shuttles) and allows to identify train path conflicts between them and to solve these conflicts by modifying the initial departure time and/or the train routing[41]. Consequently, the scheduling of the freight trains is the second step of creating a timetable scenario.
- Chart III: Shows the t_5 time series of all trains (i.e. the movement of the train heads) and provides the best way to visualize the completed timetable scenarios.

In the end, a period of 3 hours was chosen for all three charts, which limits the number of freight slots which can be included into the graph to 10 trains per hour and direction (for a total of 24 trains per hour and direction) to not exceed 256 lines for Chart II. The resulting maximum freight train frequency translates into a minimum headway of 6 minutes, which is less than the minimum possible headway (i.e. the maximum spread between the t_o and t_8 values for any block of a particular train routing) for freight trains under a variable-block system (7 minutes), but twice the

[41] It should be noted that Airport Shuttles and Freight trains use different subdivisions along the Kitchener Corridor and that the train paths of the Airport Shuttles are therefore irrelevant when inserting the freight trains.

minimum possible headway under a fixed-block system (3 minutes) [42]. However, the inability to show all freight trains at the same time in the same chart (if the limit of 30 freight trains per direction gets exceeded for the 3-hour period chosen) does not impede the ability to schedule more than 30 freight train per direction, where needed. Finally, the ease of identifying train path conflicts was dramatically improved by designing the template spreadsheet in a way which allows to filter the train paths shown so that only the train path segments which use the selected track[43] are shown. Examples for all 3 of the chart types will be provided in the following section.

[42] The exact headway values are 6:17 and 2:31 minutes for variable and fixed block systems, respectively, but as discussed in the next Section, the initial departure times of freight trains will generally be set at a full minute (e.g. 15:22:00), just like in public schedules of passenger services.

[43] In reference to Table 19 and Figure 23, the various tracks were grouped as "Track A" (Tracks K2, W1, H1 and G1), "Track B" (Track K1), "Track C" (Tracks E2, W2, H2 and G2) and "Track D" (Tracks E1, W3 and G3) with all other tracks being grouped as "Other Tracks".

7.4. Testing of the model

In order to verify that the model works as intended, a test timetable scenario is developed assuming the variable-block system, where real-world data is entered into the template spreadsheet and the results are analysed. The initial departure data is entered for all westbound passenger trains which are currently scheduled to depart in Toronto between 15:00 and 17:59 (inclusively) or eastbound passenger trains which arrive in Toronto arrive between 16:00 and 18:59 (inclusively) on a typical business day, to cover all passenger train movements which operate on the Kitchener Corridor between 16:00 and 18:00. This results in a data set of 32 passenger train, divided as follows: 19 westbound trains (12 UPX, 1 VIA train and 6 GO trains, of which one trains terminates in Mount Pleasant, 2 in Georgetown and the remaining 3 trains travel all the way to Kitchener) and 13 eastbound trains (12 UPX and 1 GO train which originates in Mount Pleasant). The passenger trains are then assigned the train routings shown in Table 23 and subsequently plotted into the Chart I[44] shown in Figure 24, which are then filtered for the various tracks to confirm that there are no train path conflicts which need to be resolved. The freight trains are then entered using a Type II chart and by switching through the filters to avoid train path conflicts on any track, as shown in Figure 25, where the rail path segments are filtered to only show "Track C" (i.e. Track E2/W2/H2/G2, as explained in Footnote 43) and confirm that there is no additional westbound freight train slot available between Bramalea (BRML) and Brampton (BRMP).

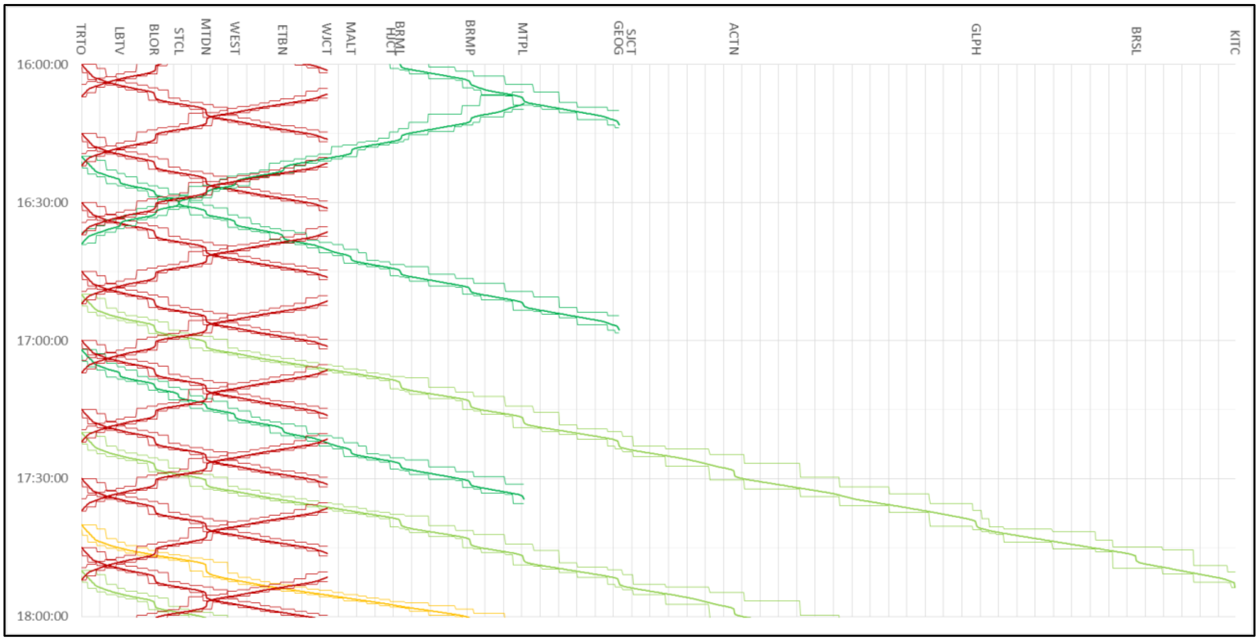
[44] A further explanation of these charts is provided in the author's thesis outreach video, which can be accessed at https://www.youtube.com/watch?v=6moFs9JHNBI.

Table 23: Overview of passenger trains comprising the data set for the test timetable scenario

Train	Origin/destination	Train count	Assumed train routing
Airport Shuttle	To: Pearson Airport	12	AIR-W1
VIA	To: Kitchener (and beyond)	1	IC-W1
GO	To: Mount Pleasant	1	RER-W1
GO	To: Georgetown	2	RER-W1
GO	To: Kitchener	3	IR-W1
Airport Shuttle	From: Pearson Airport	12	AIR-E1
GO	From: Mount Pleasant	1	RER-E2

Source: own work.

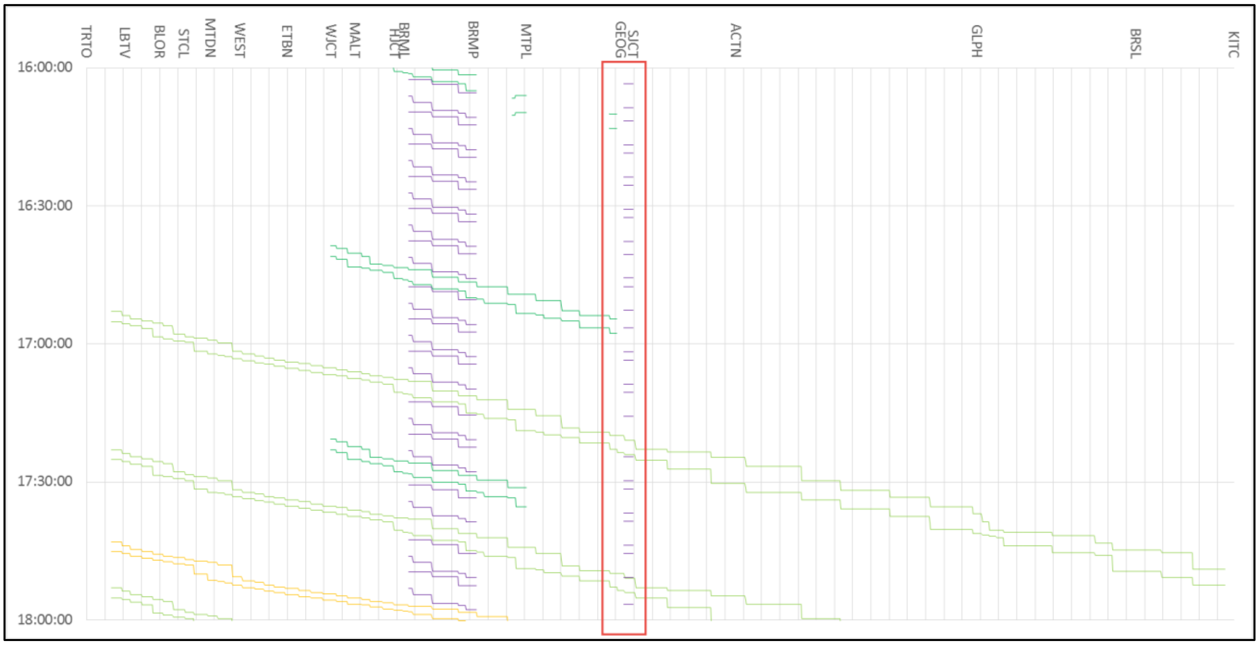
Figure 24: Chart I showing train blocking times for the test timetable scenario (assuming variable blocks)



Note: Every train path consists of three lines (with the outer lines representing the start and end of the blocking time and the center line representing the train head's movement), while the colour indicates the train type (orange for Inter-City, light green for Inter-Regional, dark green for RER and red for the Airport Shuttle). Station names are abbreviated as shown in Table 9 on page 49, while other location name abbreviations refer to Woodbine Jct. (WJCT), Halwest Jct. (HJCT) and Silver Jct. (SJCT).

Source: own work.

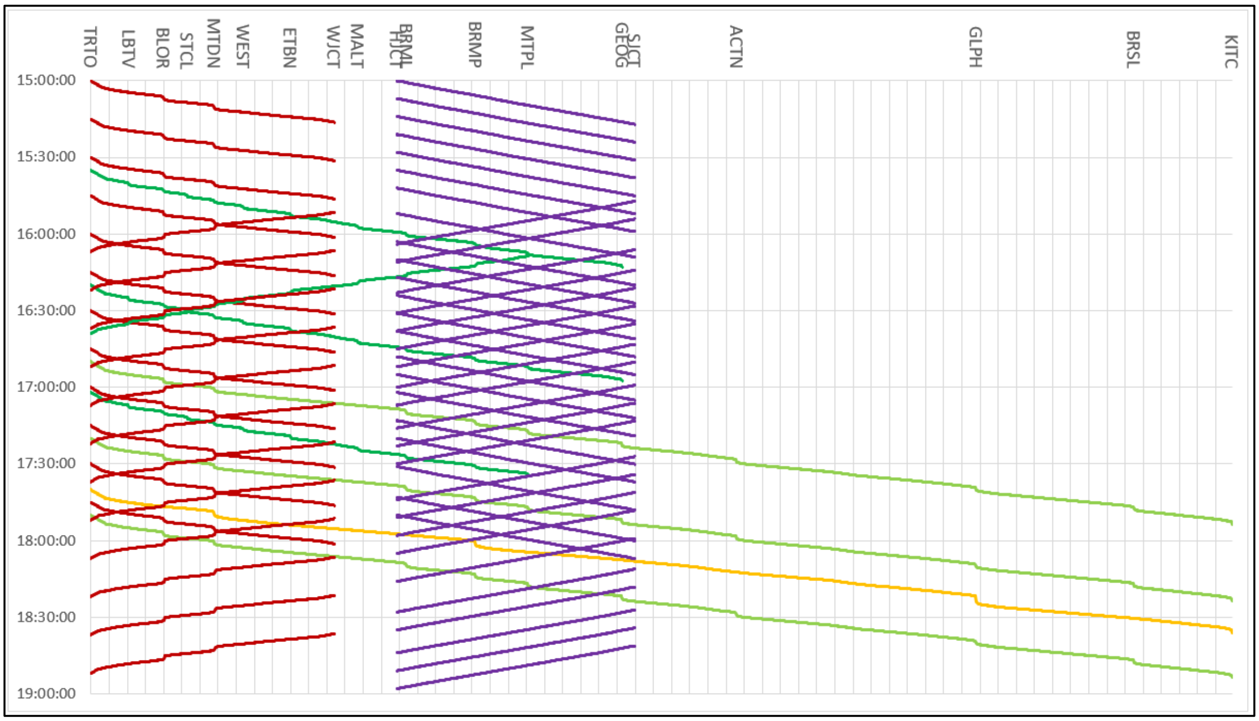
Figure 25: Chart II showing train blocking times of the test timetable scenario (filtered for Track E2/W2/H2/G2 and assuming variable blocks)



Note: This chart shows the train path segments for E2, W2, H2 and G2 (grouped collectively as "Track C", as explained in more detail in Footnote 43), where the line colours again correspond with the train type (orange for Inter-City, light green for Inter-Regional, dark green for RER and purple for freight trains). It is exclusively used by westbound trains, except for the small purple dots framed by the red box, which show eastbound freight trains merging into Track H2 at Silver Jct. and switching over onto Track H1 (i.e. "Track A") immediately afterwards.
Source: own work.

As indicated by the Chart III shown in Figure 26, the final test timetable scenario accommodates 22 freight train slots in either direction, for a total capacity of 41 westbound and 35 eastbound train movements or 28 westbound and 23 eastbound trains entering the shared Corridor segment between 15:00 and 18:00, thus excluding all Airport Shuttle (UPX) trains as well as the 17:50 departure from Toronto, which reaches Halwest Junction only shortly after 6pm. This means that 22 freight trains were the maximum number of freight trains which the author was able to insert to the timetable within that 3-hour window without causing any visible overlap with other trains on any of the tracks for which train movement lines can be filtered on Chart II. Compared to a theoretical freight slot capacity of 25 trains in the 3 hours period[45] (assuming the complete absence of any other trains in the shared corridor segment), this means that 3 freight slots (or one freight slot per hour) were lost due to the passenger trains and that the 3 westbound freight slots were replaced by 6 passenger trains (i.e. 2 passenger trains for every freight slot lost. In the opposite direction, however, Figure 27 shows that only one eastbound freight slots lost is caused by the only passenger train operating in that period, while the 2 remaining lost freight slots conflict at Silver Junction with two passenger trains operating in the opposite (i.e. westbound) direction.

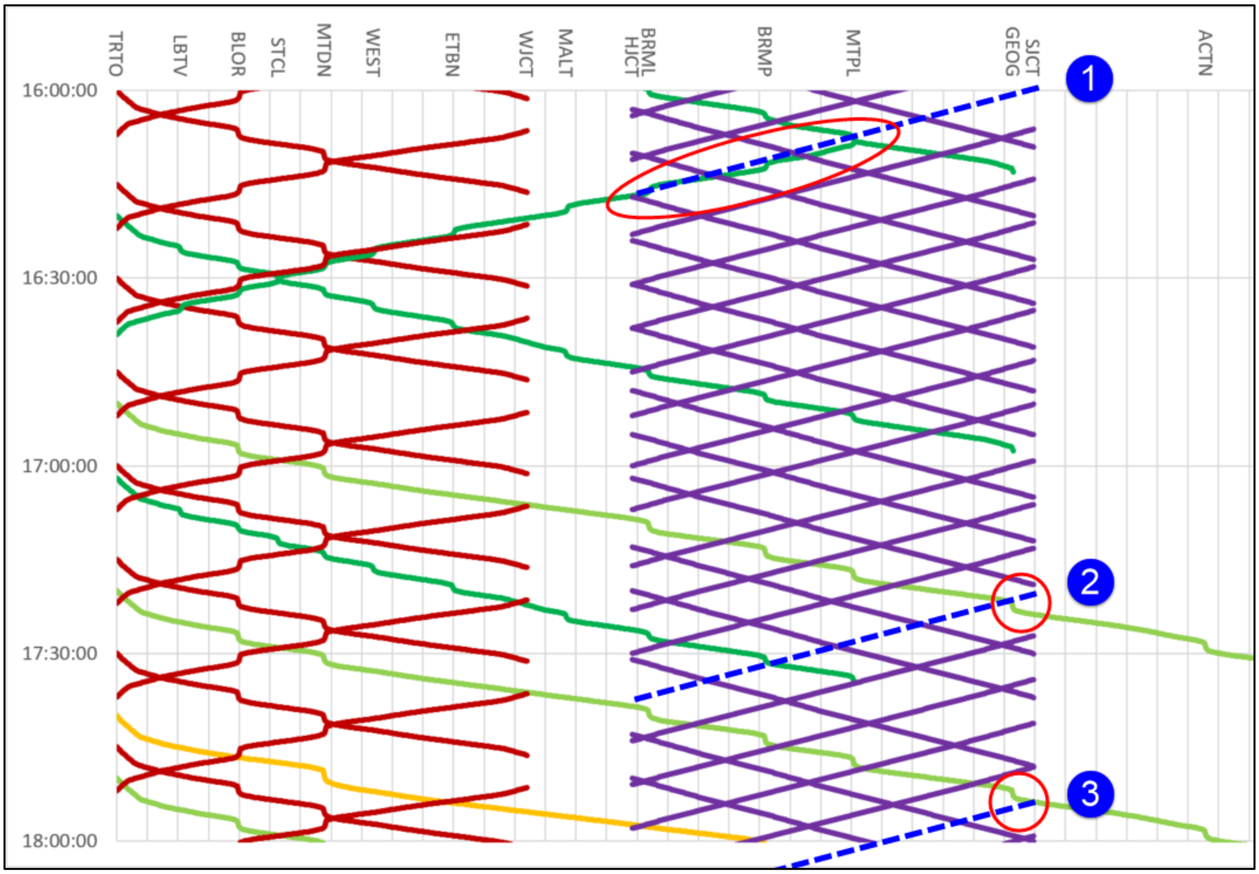
Figure 26: Chart III showing all scheduled train movements for the test timetable scenario (assuming variable blocks)



Note: as in the previous Figures, the line colour corresponds with the train type (orange for Inter-City, light green for Inter-Regional, dark green for RER, red for Airport Shuttle and purple for freight trains).
Source: own work.

[45] 180 minutes divided by the minimum 7-minute headway for freight trains operating under variable blocks.

Figure 27: eastbound freight slots lost due to passenger movements



Note: Freight slots lost due to passenger train movements are shown as a broken blue line with the conflicts with said passenger movements highlighted by a red circle.
Source: own work.

All departure times for westbound trains at Toronto Union (or passing times at Halwest Junction, in the case of freight trains) are provided in Table 24, which also shows the train routings for all train types, while Table 25 shows the same, but with the arrival times for eastbound trains.

Table 24: Westbound departure times for the test timetable scenario (assuming variable blocks)

Train type	Destination	Train routing	Departure time in Toronto
Airport Shuttle	To: Pearson Airport	AIR-W1	**15**:00/15/30/45 **16**:00/15/30/45 **17**:00/15/30/45
Regional Express Rail (RER)	To: Mount Pleasant	RER-W5MP	**17**:02
	To: Georgetown	*see departure times*	**15**:35 (RER-W2) **16**:20 (RER-W1)
Inter-Regional	To: Kitchener	IR-W1	**16**:50; **17**:20; **17**:50
Inter-City	To: Kitchener (and beyond)	IC-W1	**17**:40
Freight	From: York / To: Hamilton	F-W1	*Train passes Halwest Jct. at:* **15**:00/07/14/21/28/35/42/52 **16**:03/10/17/24/31/38/48/55 **17**:02/13/20/31/43/50

Source: own work.

Table 25: Eastbound arrival times for the test timetable scenario (assuming variable blocks)

Train type	Origin	Train routing	Arrival time in Toronto
Airport Shuttle	From: Pearson Airport	AIR-E1	**16**:07/22/37/52 **17**:07/22/37/52 **18**:07/22/37/52
Freight	From: Hamilton / To: York	F-E1	*Train passes Halwest Jct. at:* **16**:04/11/23/31/38/45/52 **17**:00/07/16/23/30/44/51/58 **18**:05/16/28/35/44/51/58

Source: own work.

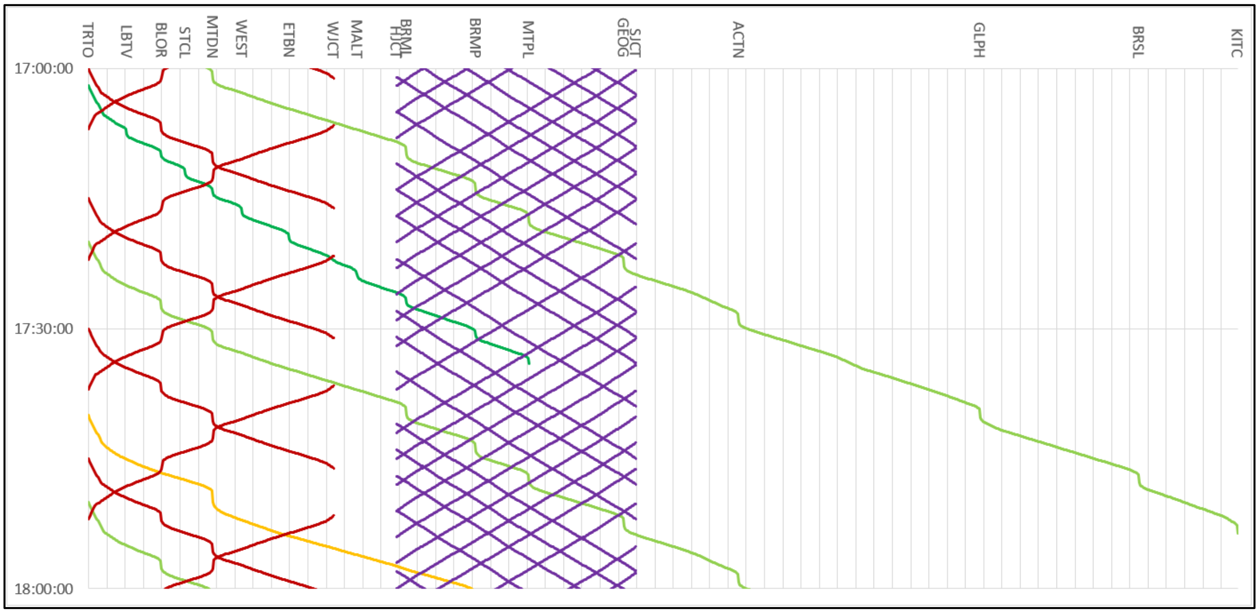
The freight train slots have therefore increased the train capacity from 32 to 76 trains (i.e. more than double their initial count), which is intuitive given the rather small number of scheduled passenger trains. The largest increase in capacity, however, was obtained by assuming a fixed-block signalling system, as shown in Table 26 and Figure 28, which increases the number of freight slots to 51 trains westbound and 53 trains eastbound, for a total capacity of 136 trains (of which 70 trains may operate westbound and 66 trains eastbound). This represents a more than four-fold increase in train capacity compared to the passenger train count and still more than twice the potential train count when assuming variable blocks. Whereas this massive increase can easily be explained with the observation made in the previous subsection that the minimum headway between two subsequent train movements is less than half under a fixed signalling system (for instance: 3 vs. 7 minutes between two subsequent freight train movements), obtaining a higher number of potential train movements for westbound than for eastbound trains appears much less intuitive. Indeed, the expectation would be that the lower degree of train heterogeneity would result in a higher train capacity in the eastbound direction, as all but one passenger trains sharing the Kitchener Corridor with freight traffic travel in the westbound direction. The distribution of available train slots between the westbound and eastbound direction will therefore need to be analysed when discussing the results obtained from the timetable scenarios developed and presented in the next chapter.

Table 26: Freight train passing times at Halwest Jct. for the test timetable scenario (assuming fixed blocks)

Train type	Origin and destination	Train routing	Passing time in Halwest Jct.
Freight	From: York / To: Hamilton (i.e. westbound)	F-W1	**15**:00/03/06/09/12/15/18/21/24/27 **15**:30/33/36/39/42/45/48/51/55 **16**:01/04/07/10/16/19/22/25/28 **16**:31/34/37/40/46/49/52/55/58 **17**:01/05/11/14/17/22/28 **17**:31/35/41/44/47/51/58
Freight	From: Hamilton / To: York (i.e. eastbound)	F-E1	**16**:00/03/06/09/12/15/18/23/29 **16**:32/35/38/41/44/47/50/53/56/59 **17**:02/05/08/14/17/20/23/26/29 **17**:32/37/42/45/48/51/54/57 **18**:00/03/07/12/15/18/21/27 **18**:30/33/37/42/45/48/51/54/57

Source: own work.

Figure 28: Chart III showing all scheduled train movements for the test timetable scenario (assuming fixed blocks)



Note: only a period of one hour shown, as the design of the spreadsheet in Excel 2013 only allows to display 30 freight slots per direction.
Source: own work.

8. Implementation

8.1. Timetable design

Before designing the actual timetables, some timetable design criteria need to be defined: First, RER trains terminate at either Bramalea, Mount Pleasant or Georgetown and must have left their turning track (tracks W1, H2 and H0, respectively) and head back towards Toronto before the track is needed by a subsequent train movement[46], while the turn-around time must be at least 5 minutes. Second, RER trains have alternating termini and therefore no 2 subsequent trains can terminate (eastbound trains: originate) at the same terminus. Third, all passenger trains must have their departure (eastbound trains: arrival) times at a fixed interval, except for the non-periodic "individual trips" scenario, where headway between two subsequent departures must not deviate by more than 10% from the average headway (i.e. 15 minutes for 4 trains per hour and 30 minutes for 2 trains per hour)[47]. Fourth, there must be no more than 30 minutes plus a 10% tolerance (i.e. a maximum permissible headway of 33 minutes) between two subsequent freight trains slots. Sixth, all patterns (even in the "individual trip" scenario) repeat themselves after 60 minutes.

[46] The exception for this is the partially periodic timetable, where the imbalance between trains originating and terminating in Bramalea, Mount Pleasant and Georgetown demands special solutions, which are discussed later in this Chapter.

[47] Valid headways between two subsequent departures are therefore 12-18 minutes for services operating at 4 trains per hour and 24-36 minutes for those operating at only 2 trains per hour.

8.2. Development of the timetable scenarios

The timetable scenarios will now be developed in accordance with the five timetable strategies selected in Section 5.4, starting with the most flexible (i.e. individual trips) and ending with the most restrictive (i.e. the integrated fixed interval timetable). For every individual scenario, the passenger trains will be inserted starting from the most interdependent[48] to the most independent train type (i.e. first Inter-City, then Inter-Regional, then RER and finally the Airport Shuttle) before the remaining gaps are filled with freight train slots. For practical reasons, westbound freight train slots are inserted before those in the opposite direction; however, westbound freight train slots may be replaced by eastbound freight train slots if both slots are mutually exclusive (i.e. conflicting each other) and if it narrows the gap in the number of freight slots and the maximum headway (between two subsequent slots) between the two directions. Furthermore, every timetable scenario will first be developed for the variable-block signalling system, because the resulting passenger timings are almost guaranteed to not cause any conflicts when re-using them for the fixed-block signalling system (where train paths consume much less track capacity).

Given that the run-times of the same train type differ by their routing, every train movement will be specified by its departure (eastbound trains: arrival) time in Toronto (freight trains: passing time at Halwest Jct.), the applicable train routing of that train movement and the signal waiting time for those westbound RER scenarios requiring a Signal Stop (i.e. RER-W3, RER-W4 and RER-W7BL)[49]. For passenger trains, that departure or arrival time in Toronto must be at a full minute

[48] The term "interdependence" refers to the degree to which operational constraints apply when scheduling the trains: For instance, Inter-City and Inter-Regional trains travel along the entire Kitchener Corridor and share tracks with all train types, while Airport Shuttle trains only use a small segment of that corridor and interact only with Inter-City and Inter-Regional trains. Also, short-haul trains with their frequent stops feed into more long-haul trains with more limited stops and it is infinitely more practical to plan multiple local feeder train routes in function of a few longer-distance routes than vice versa.

[49] This also means that all minimum or maximum headway requirements only apply to the arrival or departure timings at Toronto (passenger trains) or the passing time at Halwest Jct. (freight trains).

and can therefore only be changed in increments of one minute, while for freight trains, the passing time at Halwest Jct. may also be set to a half-minute (e.g. 10:12:30), provided that this is the only way to schedule a freight slot in-between two passenger train movements.

By default, all train movements are initially scheduled with the preferred routing of the respective train type and trying out different departure/arrival time in Toronto (freight: passing time at Halwest Junction) is the preferred way of finding a conflict-free slot for every train movement to be entered into the timetable. However, with every additional train movement slotted into the timetable, this becomes more difficult and changing the train routing of one of the conflicting slots may become the only way to resolve their conflicts.

A further objective is to minimize the maximum waiting time (between two consecutive train services serving the same station) as well as the travel time for a single ride (by using the fastest available routing where practical) and for connections between the different services modelled (by reducing the transfer time at a transfer station). The transfer time is the difference between the arrival time of train service A and the next departure time of train service B at the same transfer station at which changing from train service A to B is a logical transfer connection, which means that shortening the transfer time between two train services requires the adjustment of at least one of the two train services involved and may create new conflicts. In the case of certain transfers (e.g. a transfer in Guelph from an eastbound Inter-City arriving from Cambridge towards a westbound Inter-City or Inter-Regional train traveling towards Kitchener or at Mount Dennis for transfers between an eastbound Airport Shuttle and westbound Inter-City, Inter-Regional and RER trains), the coordination even involves train services traveling in opposite directions. As summarized in Table 27, there are 8 pairs of plausible transfer connections identified along the Kitchener Corridor, of which 3 are in the same direction (i.e. westbound-to-westbound or eastbound-to-eastbound) and the remaining 5 pairs in the opposing direction. Furthermore, a transfer time of 1 minute (i.e. 60 seconds) will be defined as minimum transfer time, whereas transfer times between 2 and 5 minutes (i.e. between 120 and 300 seconds) will be regarded as desirable.

Table 27: Transfer connections identified along the Kitchener Corridor

Transfer Station	Transfer connection (EB=eastbound, WB=westbound)	Remarks
Guelph	Arriving from: Cambridge (EB IC) Departing towards: Kitchener (WB IC/IR)	For passengers traveling between Hespeler and Kitchener (no direct connection with iON LRT)
	Arriving from: Kitchener (EB IC/IR) Departing towards: Cambridge (WB IC)	
	Arriving from: Cambridge (EB IC) Departing towards: Kitchener (WB IC/IR)	As above, but also for passengers traveling between Breslau and either Hespeler, Preston or Cambridge
	Arriving from: Kitchener (EB IC/IR) Departing towards: Cambridge (WB IC)	
Brampton	Arriving from: Kitchener/Cambridge (EB IC) Departing towards: Toronto (EB RER)	To reach stations not served by IC trains
	Arriving from: Toronto (WB RER) Departing towards: Kitchener/Cambridge (WB IC)	To leave from stations not served by IC trains
Bramalea	Arriving from: Kitchener/Cambridge (EB IR) Departing towards: Toronto (EB RER)	To reach stations not served by IR trains
	Arriving from: Toronto (WB RER) Departing towards: Kitchener/Cambridge (WB IR)	To leave from stations not served by IR trains
Mount Dennis	Arriving from: Kitchener/Cambridge (EB IC) Departing towards: Pearson Airport (WB AIR)	For passengers traveling to the Airport
	Arriving from: Pearson Airport (EB AIR) Departing towards: Kitchener/Cambridge (WB IC)	For passengers leaving from the Airport
	Arriving from: Kitchener/Cambridge (EB IR) Departing towards: Pearson Airport (WB AIR)	For passengers traveling to the Airport
	Arriving from: Pearson Airport (EB AIR) Departing towards: Kitchener/Cambridge (WB IR)	For passengers leaving from the Airport
	Arriving from: Georgetown (EB RER) Departing towards: Pearson Airport (WB AIR)	For passengers traveling to the Airport
	Arriving from: Pearson Airport (EB AIR) Departing towards: Georgetown (WB RER)	For passengers leaving from the Airport
	Arriving from: Toronto (WB RER) Departing towards: Pearson Airport (WB AIR)	For passengers traveling to the Airport from stations not served by the Airport Shuttle
	Arriving from: Pearson Airport (EB AIR) Departing towards: Toronto (EB RER)	For passengers leaving from the Airport from stations not served by the Airport Shuttle

Source: own work.

8.2.1. Scenario I (Individual trips)

For the individual trips, the first step was to come up with non-periodic departure/arrival times in Toronto, which still allow developing a conflict-free timetable adhering to the timetable design criteria outlined earlier in this section. Without the aid of an optimiser which could simply try out any possible combination of valid[50] departure/arrival times for the various train service types, this turned out to be far more challenging than with the periodic departure/arrival times in the other scenarios, as the absence of periodicity meant that a gap identified for a certain departure/arrival time would not automatically reoccur 15 or 30 minutes later. In order to avoid selecting the departure or arrival times in Toronto for the first train of a given train type and the headway to the subsequent departure completely arbitrarily, the selection of the corresponding values relied on the *Random* function built-into Microsoft Excel 2013, which produced a constant stream of random numbers which could be used to either determine the number of minutes after the full hour at which the first train of a certain train type departs (eastbound trains: arrives) in Toronto or the number of minutes which represents the headway between two subsequent departures. Furthermore, these random numbers could be used to replace inputs to resolve conflicts. As summarized in Table 28, the variable-block scenario variant results in 3 westbound and 2 eastbound freight slots, while the fixed-block scenario variant results in 10 westbound and 7 eastbound freight slots. This represents (when combining both directions) a total of 29 trains per hour with variable blocks (of which 20 use their preferred route) and 41 trains with fixed blocks (of which 35 trains use their preferred route).

[50] Recall from the previous section that headways between any two subsequent departures/arrivals of the same train service type in Toronto must not deviate by more than 10% from the average headway (15 or 30 minutes, depending on the train service type).

Table 28: Train count and headway variance for the "Individual Trips" scenario

Train type	Block type	Westbound			Eastbound		
		Train/Slot Count (preferred/ total)	Headway (in minutes)		Train/Slot Count (preferred/ total)	Headway (in minutes)	
			Min	Max		Min	Max
IC	Variable	1/2	24	36	0/2	29	31
	Fix				1/2		
IR	Variable	0/2	28	32	2/2	27	33
	Fix	2/2					
IC/IR	Variable	1/4	11	19	2/4	8	21
	Fix	3/4			3/4		
RER	Both	2/4	12	18	4/4	12	18
AIR	Both	4/4	12	17	4/4	13	17
Freight	Variable	3/3	13	24.5	0/2	29.5	30.5
	Fix	10/10	3	11	5/7	3	18
Total	Variable	10/15			10/14	Both directions:	20/29
	Fix	19/22			16/19		35/41

Source: own work.

8.2.2. Scenario II (Partially periodic timetable)

The main characteristic of the partially periodic timetable is that the peak frequencies are only offered in the peak direction, while lower (off-peak) frequencies are offered in the other (off-peak) direction. Therefore, not just two but four scenario variants need to be conducted for this scenario to cover the AM (peak direction: westbound) and the PM peak (peak direction: eastbound). Even though Regional Express Rail trains operate at the same frequency (i.e. 4 trains per hour) in both directions between Toronto and Bramalea, their operating frequencies differ beyond Bramalea (twice per hour to Georgetown in the peak direction, three times per hour in the off-peak direction to Mount Pleasant, of which one train continues to Georgetown).

This means that the inflow of terminating westbound RER trains and outflow of originating eastbound RER trains is imbalanced at all three termini (Bramalea, Mount Pleasant and Georgetown). Therefore, assumptions have to made as to what happens with the trainsets which terminate at one of these termini without any corresponding originating train (or originating at one of these termini without any corresponding terminating train): For Bramalea, it is assumed that surplus trainsets deadhead[51] from Toronto or back, while surplus vehicles in Mount Pleasant and Georgetown are assumed to be stored on Track H2 (between Norval and Georgetown East, in the case of Mount Pleasant, which means that this track becomes unavailable for routings like IC-W1, IR-W1, RER-W1 or F-E2) or at the layover facility next to Track H0 in Georgetown. Naturally, the number of trainsets which can be stored in either Mount Pleasant or Georgetown (and therefore the time over which such an imbalanced vehicle equipment can be maintained) is limited. However, the purpose of this scenario is to demonstrate the effect of having slightly less passenger

[51] "Deadheading" refers to a non-revenue move, which are motivated by operational requirements, such as the balancing of equipment and to reach layover or maintenance facilities.

trains in one direction[52] and this scenario is therefore included in the timetable scenarios developed for this thesis.

When starting with the AM scenario variants, the number of westbound Inter-Regional and Inter-City trains is only half their number as in the opposite direction, which makes it desirable to have them operate as close to 30 minutes apart as possible. As summarized in Table 29, the variable-block scenario variant results in 2 freight slots per direction, while the fixed-block scenario variant results in 7 westbound and 6 eastbound freight slots. This represents (when combining both directions) a total of 26 trains per hour with variable blocks (of which 21 use their preferred route) and 35 trains with fixed blocks (of which 30 trains use their preferred route).

Table 29: Train count and headway variance for the "Partially Periodic" scenario (AM peak)

Train type	Block type	Westbound			Eastbound		
		Train/Slot Count (preferred/ total)	Headway (in minutes)		Train/Slot Count (preferred/ total)	Headway (in minutes)	
			Min	Max		Min	Max
IC	Both	0/1	60		2/2	30	
IR	Both	0/1	60		2/2	30	
IC/IR	Both	0/2	26	34	2/4	11	19
RER	Both	3/4	15		4/4	15	
AIR	Both	4/4	15		4/4	15	
Freight	Variable	2/2	30		2/2	30	
	Fix	7/7	4.5	13	6/6	3	24
Total	Variable	9/12			12/14	Both directions:	21/26
	Fix	14/17			16/18		30/35

Source: own work.

52 The exact changes in frequencies are as follows: 10 instead of 12 between Toronto and Woodbine Jct., 6 instead of 8 between Woodbine Jct. and Bramalea, 5 instead of 6 trains between Bramalea and Mount Pleasant, 3 instead of 6 trains between Mount Pleasant and Georgetown, 2 instead of 4 trains between Georgetown and Kitchener and 1 instead of 2 trains between Guelph and Cambridge.

For the PM variants of Scenario II, the peak and the off-peak direction are swapped and minimizing the maximum gap between Inter-City and Inter-Regional services becomes desirable for the westbound direction. As summarized in

Table 30, the variable-block scenario variant results in 3 westbound and 2 eastbound freight slots, while the fixed-block scenario variant results in 7 freight slots per direction. This represents (when combining both directions) a total of 27 trains per hour with variable blocks (of which 20 use their preferred route) and 36 trains with fixed blocks (of which 29 trains use their preferred route).

Table 30: Train count and headway variance for the “Partially Periodic” scenario (PM peak)

Train type	Block type	Westbound			Eastbound		
		Train/Slot Count (preferred/ total)	Headway (in minutes)		Train/Slot Count (preferred/ total)	Headway (in minutes)	
			Min	Max		Min	Max
IC	Both	0/2	30		0/1	60	
IR	Variable	0/2	30		1/1	60	
	Fix				0/1		
IC/IR	Variable	0/4	9	21	1/2	26	34
	Fix				0/2		
RER	Both	3/4	15		4/4	15	
AIR	Both	4/4	15		4/4	15	
Freight	Variable	3/3	13.5	30	2/2	30	
	Fix	7/7	3.5	15	7/7	3	15.5
Total	Variable	10/15			10/12	Both directions:	20/27
	Fix	14/19			15/17		29/36

Source: own work.

8.2.3. Scenario III (Periodic timetable)

The periodic timetable scenario is basically a combination of the peak direction timetables of the partially periodic timetable scenarios shown above. As summarized in Table 31, the variable-block scenario variant results in 2 freight slots per direction, while the fixed-block scenario variant results in 10 freight slots per direction. This represents (when combining both directions) a total of 28 trains per hour with variable blocks (of which 20 use their preferred route) and 44 trains with fixed blocks (of which 38 trains use their preferred route).

Table 31: Train count and headway variance for the "Periodic Timetable" scenario

Train type	Block type	Westbound			Eastbound		
		Train/Slot Count (preferred/ total)	Headway (in minutes)		Train/Slot Count (preferred/ total)	Headway (in minutes)	
			Min	Max		Min	Max
IC	Variable	0/2	30		0/2	30	
	Fix	2/2					
IR	Variable	2/2	30		2/2	30	
	Fix				0/2		
IC/IR	Variable	2/4	11	19	2/4	11	19
	Fix	4/4			0/4		
RER	Variable	2/4	15		4/4	15	
	Fix	4/4					
AIR	Both	4/4	15		4/4	15	
Freight	Variable	2/2	30		2/2	30	
	Fix	10/10	3	12.5	8/10	4	7
Total	Variable	10/14			10/14	Both directions:	20/28
	Fix	22/22			16/22		38/44

Source: own work.

8.2.4. Scenario IV (Symmetric timetable)

The symmetric timetable is very similar to the periodic timetable, but with the added feature of all departures being symmetric to a certain recurring time point (in this case: every full hour). As summarized in Table 32, the variable-block scenario variant results in 2 freight slots per direction, while the fixed-block scenario variant results in 8 eastbound and 10 westbound freight slots. This represents (when combining both directions) a total of 28 trains per hour with variable blocks (of which 24 use their preferred route) and 42 trains with fixed blocks (of which 34 trains use their preferred route).

Table 32: Train count and headway variance for the "Symmetric Timetable" scenario

Train type	Block type	Westbound			Eastbound		
		Train/Slot Count (preferred/ total)	Headway (in minutes)		Train/Slot Count (preferred/ total)	Headway (in minutes)	
			Min	Max		Min	Max
IC	Both	2/2	30		2/2	30	
IR	Both	2/2	30		0/2	30	
IC/IR	Variable	4/4	11	19	2/4	11	19
	Fix				0/4		
RER	Both	2/4	15		4/4	15	
AIR	Both	4/4	15		4/4	15	
Freight	Variable	2/2	30		2/2	30	
	Fix	8/8	5	11	8/10	3	10
Total	Variable	12/14			12/14	Both directions:	24/28
	Fix	18/20			16/22		34/42

Source: own work.

8.2.5. Scenario V (Integrated fixed interval timetable)

Finally, the integrated fixed interval timetable is a special form of the periodic timetable, in which a number of trains arrive from various directions and stop simultaneously in the station for a few minutes at a so-called *integrated fixed interval timetable* (IFIT) hub before departing again in various directions, thus providing connections between these various trains and a multitude of reliable connections, while making the transfer connections nearly as convenient as direct connections. In the corresponding scenario developed for this thesis, the station of Guelph is chosen to act as an IFIT hub, where passengers transfer between Inter-City trains arriving from Cambridge and Inter-Regional trains departing towards Toronto or Kitchener and between Inter-Regional trains arriving from Toronto or Kitchener and Inter-City trains continuing towards Cambridge.

Unfortunately, the two tracks present in Guelph are not sufficient to have Inter-City and Inter-Regional traveling in all directions stop at the same time (even though Inter-City trains traveling from Cambridge and Kitchener can share the same track as they join and before they continue towards Toronto or Inter-City trains having arrived from Toronto and splitting before they either continue towards Kitchener or Cambridge can share the other track). Therefore, the IFIT hub is split in two subsequent parts, where first a same-platform connection is established for passengers transferring from Cambridge on to the Inter-Regional train towards Breslau and Kitchener and shortly afterwards a same-platform connection for passengers transferring from the Inter-Regional train arriving from Kitchener and Breslau towards Cambridge.

As summarized in Table 33, the variable-block scenario variant results in 2 freight slots per direction, while the fixed-block scenario variant results in 8 westbound and 10 eastbound freight slots per direction. This represents (when combining both directions) a total of 28 trains per hour with variable blocks (of which 26 use their preferred route) and 42 trains with fixed blocks (of which 38 trains use their preferred route).

Table 33: Train count and headway variance for the “Integrated Fixed Interval Timetable” scenario

Train type	Block type	Westbound			Eastbound		
		Train/Slot Count (preferred/ total)	Headway (in minutes)		Train/Slot Count (preferred/ total)	Headway (in minutes)	
			Min	Max		Min	Max
IC	Variable	2/2	30		2/2	30	
	Fix	0/2					
IR	Variable	2/2	30		0/2	30	
	Fix				2/2		
IC/IR	Variable	4/4	13	17	2/4	12	18
	Fix	2/4			4/4		
RER	Both	4/4	15		4/4	15	
AIR	Both	4/4	15		4/4	15	
Freight	Variable	2/2	30		2/2	30	
	Fix	8/8	6.5	9.5	8/10	3	14.5
Total	Variable	14/14			12/14	Both directions:	26/28
	Fix	18/20			20/22		38/42

Source: own work.

9. Results

9.1. Train capacity

One of the main goals of this thesis was to compare how applying different timetabling strategies onto the scheduling of passenger trains affects the number of total trains which can be scheduled (i.e. by complementing the slotted passenger trains with freight train slots until no additional slot can be inserted into the timetable). Given that the more advanced timetable strategies introduce constraints like periodicity (scenarios II-V), symmetry (scenarios IV-V) and coordinated transfers (Scenario V) and that every constraint reduces the solution space (i.e. the proportion of possible solutions which respects all applicable constraints and is therefore considered "feasible"), it appears as reasonable to expect that the total number of scheduled trains decreases as the underlying timetable strategy moves from the most flexible (i.e. Scenario I) to the least flexible (Scenario V).

However, the results presented in Table 34 do not indicate a significant difference in the number of trains which can be scheduled and even less so a trend that a more restrictive timetable strategy affects the number of trains which can be scheduled: When assuming variable blocks, scheduling passenger trains as individual trips (i.e. Scenario I) only yielded one additional train slot compared to scenarios III, IV and V (29 vs. 28 train slots), whereas assuming fixed blocks placed Scenario I only one slot (i.e. the smallest-possible increment) in front of Scenario V, while scenarios III and IV yielded 1-3 slots more (44 and 42 vs. 41 slots). The outliers are the two partially periodic scenarios, in which a significantly lower number of trains was slotted and explain 77% of the variance (as percentage of the respective averages) observed for both the variable and fixed blocks, as excluding these scenarios decreases the variance from 3.9% to 0.9% and from 30.9% to 7.0%, respectively.

Table 34: Number of slotted trains for the various scenarios

Signal System	Variable blocks			Fixed blocks				
Direction	West	East	Total	West	East	Total	vs. variable	
Scenario	Total slots							
I (individual trips)	15	14	29	22	19	41	12	29%
IIa (partially periodic, AM)	12	14	26	17	18	35	9	26%
IIb (partially periodic, PM)	15	12	27	19	17	36	9	25%
III (periodic)	14	14	28	22	22	44	16	36%
IV (symmetric)	14	14	28	20	22	42	14	33%
V (integrated fixed interval)	14	14	28	20	20	40	12	30%
Average	14.0	13.7	27.7	20.0	19.7	39.7	12.0	30%
Variance	1.2	0.7	1.1	3.6	4.3	12.3	7.6	62%
(in % of average)	8.6%	4.9%	3.9%	18.0%	21.7%	30.9%	63.3%	
Average (excluding Scenarios IIa and IIb)	14.3	14.0	28.3	21.0	20.8	41.8	13.5	32%
Variance (excluding Scenarios IIa and IIb)	0.3	0.0	0.3	1.3	2.3	2.9	3.7	126%
(in % of average)	1.8%	0.0%	0.9%	6.3%	10.8%	7.0%	27.2%	
Scenario	Of which: Preferred slots							
I (individual trips)	10	10	20	19	16	35	15	43%
IIa (partially periodic, AM)	9	12	21	14	16	30	9	30%
IIb (partially periodic, PM)	10	10	20	14	15	29	9	31%
III (periodic)	10	10	20	22	16	38	18	47%
IV (symmetric)	12	12	24	18	18	36	12	33%
V (integrated fixed interval)	14	12	26	18	18	36	10	28%
Average	10.8	11.0	21.8	17.5	16.5	34.0	12.2	36%
Variance	3.4	1.2	6.6	9.5	1.5	13.2	13.4	101%
(in % of average)	31.1%	10.9%	30.1%	54.3%	9.1%	38.8%	110%	
Average (excluding Scenarios IIa and IIb)	11.5	11.0	22.5	19.3	17.0	36.3	13.8	38%
Variance (excluding Scenarios IIa and IIb)	3.7	1.3	9.0	3.6	1.3	1.6	12.3	774%
(in % of average)	31.9%	12.1%	40.0%	18.6%	7.8%	4.4%	89.1%	

Source: own work.

When only looking at preferred slots, scheduling passenger trains while assuming variable blocks and following a symmetric or even integrated fixed interval strategy yielded between 3 and 6 more (not: less!) slotted trains than for the individual trips, partially periodic or periodic scenarios (24-26 vs. 20-21 train slots), while assuming fixed blocks led to 5-9 less slots for the partially periodic scenarios than for all other timetable scenarios (29-30 vs. 35-38 train slots). Therefore, the two partially periodic scenarios act as outliers for the fixed blocks, as they explain 89% of the variance (as percentage of the respective averages) observed, since excluding these scenarios decreases that metric from 38.8% to 4.4%. Conversely, for the variable blocks, excluding the partially periodic scenarios increased the observed variance from 30.1% to 40.0%, thus by 33%.

Table 35: Number of slotted trains on the mixed-operations segments for the various scenarios

Scenario		Variable blocks			Fixed blocks		
		Passenger	Freight	Combined	Passenger	Freight	Combined
Westbound	I (individual trips)	6	3	9	6	10	16
	IIa (partially periodic, AM)	5	2	7	5	7	12
	IIb (partially periodic, PM)	6	3	9	6	7	13
	III (periodic)	6	2	8	6	10	16
	IV (symmetric)	6	2	8	6	8	14
	V (integrated fixed interval)	6	2	8	6	8	14
Eastbound	I (individual trips)	6	2	8	6	7	13
	IIa (partially periodic, AM)	6	2	8	6	8	14
	IIb (partially periodic, PM)	5	2	7	5	9	14
	III (periodic)	6	2	8	6	10	16
	IV (symmetric)	6	2	8	6	10	16
	V (integrated fixed interval)	6	2	8	6	8	14
Combined	I (individual trips)	12	5	17	12	17	29
	IIa (partially periodic, AM)	11	4	15	11	15	26
	IIb (partially periodic, PM)	11	5	16	11	16	27
	III (periodic)	12	4	16	12	20	32
	IV (symmetric)	12	4	16	12	18	30
	V (integrated fixed interval)	12	4	16	12	16	28
Average	Westbound	5.8	2.3	8.2	5.8	8.3	14.2
	Eastbound	5.8	2.2	8.0	5.8	7.8	13.7
	Combined	11.7	4.3	16.0	11.7	17.0	28.7

Note: the frequencies are shown for the segment between Bramalea Jct. and Mount Pleasant (i.e. the only mixed-operations segment which includes a section with no more than two tracks – around Brampton station). Note that passenger (and thus also: combined) train volumes are lower west of Georgetown (and in the off-peak direction of scenarios IIa and IIb also: west of Mount Pleasant), due to RER trains terminating/originating in Georgetown (and Mount Pleasant, where applicable). Source: own work.

A breakdown of all slotted trains is provided in Table 35 for passenger and freight trains separately, which allows a more detailed analysis of the slotted train volumes. Unlike the previous table which showed the total number of trains scheduled anywhere on the Kitchener Corridor, this table only shows those trains which operate on the mixed-operation segment (i.e. between Bramalea Jct. and Silver Jct., thus excluding the Airport Shuttle trains) and confirms that the number of passenger trains is of course identical for all scenarios except the respective off-peak direction of scenarios IIa and IIb[53].

Concerning the variable blocks, the number of freight trains (highlighted in the table) slotted is always 2 per direction, except for the westbound directions of scenarios I and IIb, where a third freight train could be slotted. This additional westbound freight train pushes Scenario I to the top spot with 17 trains operating on the shared segment west of Bramalea and compensates in Scenario IIb for the loss of one passenger train between Bramalea and Mount Pleasant in the off-peak direction, while there is no additional freight slot to compensate for the passenger train lost in the off-peak direction of Scenario IIa. However, having been able to slot only one train (i.e. the smallest possible increment) more into Scenario I than into scenarios IIb, III, IV and V, this minimal difference hardly confirms the expected positive relation between the flexibility of the timetable strategy and the number of trains which can be slotted.

A different situation can be observed for the fixed blocks, where a maximum number of 10 freight trains could be slotted in the westbound direction of Scenario I, both directions of Scenario III and the eastbound direction of Scenario IV. Consequently, Scenario III has the highest number of slotted freight trains (20), followed by scenarios IV (18) and I (17), while Scenario IIa has the lowest (15), followed by scenarios IIb and V (16 each). These results seem to suggest that whereas there is no uniform impact of the timetable strategy's flexibility onto the train capacity under fixed blocks, *periodicity* might have a positive effect on train capacity (at least when comparing scenarios I and III), while a *numerical imbalance between westbound and eastbound passenger*

[53] Note, however, that RER trains traveling beyond Bramalea terminate in Georgetown (or Mount-Pleasant) and that the number of passenger trains decreases on the shared segment west of Georgetown (or Mount Pleasant).

trains (as in scenarios IIa and IIb), *symmetry* (as in Scenario IV) and the presence of *coordinated transfers* (as in Scenario V) all appear to have a negative effect on capacity.

Despite the results for the variable blocks not indicating any significant impact of the timetable strategy on train capacity, the findings for fixed blocks somewhat resonate with the author's observations (when determining valid timings for the different passenger train types in the various test scenarios) that whereas the intention for Scenario I was to choose headways between two subsequent departures of the same train type which make as much use of the 10% tolerance as possible, the insertion of additional passenger train became increasingly laborious for every additional train and often required to replace headway values with less heterogeneous values (i.e. closer to the average headway), while selecting feasible timings was clearly the easiest for Scenario III. Scenario IV was slightly more difficult, as any change of the westbound departure times of any train type in Toronto had to be mirrored by moving the corresponding eastbound arrival times into the opposite direction, while Scenario V required a delicate coordination of the respective arrival and departure times of Inter-City and Inter-Regional trains at Guelph station and scenarios IIa and IIb required to figure out by how many minutes the timings of the off-peak direction needed to be shifted, so that the gaps at either end of the mixed-use corridor segment matched to allow the slotting freight trains.

9.2. Benchmarking

9.2.1. Criteria

As discussed in Section 3.3, calculating the train capacity is not the only way to compare different operational scenarios. Given that the number of passenger trains offered is identical for all scenarios developed (except for the off-peak direction in the partially periodic scenario), other measures are needed to compare the relative attractiveness of the various timetable scenarios. Out of the determinants of timetable attractiveness identified by Schittenhelm (2010), the *scheduled travel time*, the presence or absence of *regular intervals between two consecutive departures* and the *length of the planned transfer time* seem to be the most applicable factors to be used for benchmarking the various scenarios, while the *number of departures*, the *number of transfers* and the *flexibility* (i.e. the operating hours) are (with the exception just mentioned) identical for all scenarios.

Concerning the scheduled travel time, the most relevant indicator appears to be the average scheduled travel speed, which shall be calculated by dividing the average travel time between Toronto Union and the arrival (for westbound trains) or departure time (for eastbound trains) of any given station for all trains which have a scheduled stop at that station. Even though the headways are calculated for every scenario and station separately just like with the travel speeds, using the average length of the headways would simply yield identical results for every scenario (except for Scenario II), as the sum of the headways between all consecutive departures always equal the length of the observation period (e.g. 60 minutes), a value which is then divided by the number of trains, which is identical for all scenarios (except the off-peak direction in Scenario II). Each headway is therefore squared before it is added up, as the least arbitrary way of ensuring that heterogenous headways get a different (in this case: higher) score than perfectly homogenous headways: for instance, a sequence of 10-20-10-20 minutes would reach a score of 1,000 (10^2+20^2+10^2+20^2), while a perfectly homogeneous sequence of 15-15-15-15 minutes would score 10% lower with 900 ($4*15^2$).

Unlike the previous two benchmark criteria, the transfer time is not a metric which is to either maximise (like the average speed) or minimise (like the perceived headway): whereas passengers naturally seek to avoid long transfer times, a short transfer time increases the risk of missing the outbound train on board which the passenger seeks to leave the transfer station (especially if the passenger's inbound train arrives late at the transfer station), which would suddenly add the entire headway (between the outbound train which was missed and the subsequent departure to the same station as desired by the passenger) onto the passenger's waiting time at the transfer station. Furthermore, the stress caused by fearing that the connection could be missed and by rushing to the platform of the outbound train may outweigh the perceived benefit of having a short waiting time, while seeing the outbound train depart without himself may add a certain frustration and thus further discomfort to the passenger. The optimal transfer time naturally depends on a variety of factors, including the length and ease of the transfer path, the passenger's walking speed and any mobility limitations (which might require the use of mobility aids like a lift) and the delay patterns typically experienced by the inbound and the outbound trains. Drawing from values identified in the literature[54], the optimal transfer time shall be set at 3 minutes. The perceived deviation from the optimal transfer time is therefore the actual transfer time (i.e. the difference between the scheduled arrival time of the inbound train and the scheduled departure train of the outbound train) minus the optimal transfer time of 3 minutes, while a negative value (i.e. when the scheduled

[54] For instance, Goverde (1998) provides an "optimum mean transfer waiting time" of 2.64 minutes, while Lee & Schonfeld (1991) compute an "optimal slack time" of 3.75 or 4 minutes, depending on the method used.

transfer time is less than the 3 minutes) shall be squared, in order to account for the additional stress (and in the case of a missed connection: unexpected waiting time) imposed on the passenger[55].

Finally, it might be useful to group the 18 stations into 3 different station classes before benchmarking the 5 scenarios against each other, as the average speed and perceived headway might vary between the various scenarios differently for major stops than for minor stops: Therefore, the 4 stops served by Inter-City trains along the Toronto-Kitchener (i.e. Mount Dennis, Brampton, Guelph and Kitchener) are grouped together with Cambridge (as the terminus of the Cambridge branch) into *Station Class 1* as “major stations”, while the 4 stations served by RER and Inter-Regional, but not Inter-City trains (i.e. Bloor, Bramalea, Mount Pleasant and Georgetown) are grouped together with Preston as “medium stations” into *Station Class 2* and the remaining 8 stations (i.e. Liberty Village, St. Clair, Weston, Etobicoke North, Malton, Acton, Breslau and Hespeler) are grouped as “minor stations” into *Station Class 3*.

[55] This means that a transfer time of 2 minutes (i.e. one minute less than the optimal transfer time) results in the same perceived deviation from the optimal transfer time as a transfer time of 4 minutes (i.e. 1 minute less than the optimal transfer time), while a transfer time of only 1 minute (i.e. 2 minutes less than the optimal transfer time) results in the same perceived deviation from the optimal transfer time as a transfer time of 7 minutes (i.e. 2^2=4 minutes more than the optimal transfer time).

9.2.2. Comparison

Two things catch the eye when comparing the results for the average scheduled travel speed as the first benchmarking criteria, which are shown in Table 36: First, the average speed seems to increase with the distance which lies between Toronto Union and the respective station. Second, the average speed seems to increase with the importance of said station, as Class 1 (i.e. "major") stations show a significantly higher average speed than Class 2 (i.e. "medium") stations, while Class 3 (i.e. "minor") stations show much lower average speeds. This may be explained by the fact that the station spacing increases outside of Toronto's greenbelt[56], while higher-order trains skip low-order stations to achieve superior travel speeds to passengers traveling from and to the higher-order stations.

Table 36: Average speed (in km/h) for travel between Toronto and the various stations

Distance (km)	Station Class	Station name	BY SCENARIO						OVERALL AVERAGE					
			I	IIa	IIb	III	IV	V	Variable	Fixed	West	East	Fixed vs. Var.	East vs. West
3.4	3	Liberty Village	43.6	43.6	43.6	43.6	43.6	43.6	43.6	43.6	38.6	50.1	-	11.5
6.4	2	Bloor	58.3	58.2	58.1	58.3	58.3	58.3	58.2	58.2	54.0	63.2	-	9.1
8.5	3	St. Clair	55.3	55.3	55.3	55.3	55.3	55.3	55.3	55.3	51.8	59.3	-	7.5
10.9	1	Mount Dennis	64.7	64.2	64.2	64.7	64.7	64.7	64.5	64.5	61.5	67.9	-	6.4
13.5	3	Weston	59.1	59.1	59.1	59.1	59.1	59.1	59.1	59.1	56.6	62.0	-	5.4
17.7	3	Etobicoke North	63.5	63.5	63.5	63.5	63.5	63.5	63.5	63.5	61.2	66.0	-	4.8
23.7	3	Malton	68.1	68.1	68.1	68.1	68.1	68.1	67.8	68.4	65.0	71.5	0.6	6.4
28.0	2	Bramalea	75.5	74.4	74.5	75.6	75.6	75.6	75.0	75.4	72.2	78.5	0.4	6.2
34.1	1	Brampton	85.7	83.0	83.5	85.6	86.2	86.2	84.9	85.2	83.3	86.8	0.3	3.5
38.8	2	Mount Pleasant	80.5	78.8	78.5	80.7	80.9	80.9	79.9	80.2	78.1	82.1	0.4	4.0
47.2	2	Georgetown	82.3	82.1	82.6	82.7	83.1	83.4	82.5	82.9	80.6	84.9	0.5	4.2
57.3	3	Acton	89.3	88.9	88.8	89.8	90.3	90.3	89.4	89.7	88.3	90.9	0.4	2.6
78.5	1	Guelph	102.5	102.3	102.1	102.6	103.6	103.3	102.5	102.9	101.6	103.8	0.4	2.2
92.5	3	Breslau (new)	97.4	97.1	97.1	97.8	98.1	98.1	97.4	97.7	96.6	98.5	0.3	1.9
101.2	1	Kitchener (new)	102.6	102.5	102.3	102.7	103.5	103.3	102.7	102.9	102.0	103.6	0.3	1.6
92.7	3	Hespeler	96.8	96.3	95.6	95.6	96.6	96.2	95.9	96.5	95.8	96.6	0.5	0.7
96.7	2	Preston	93.7	93.2	92.6	92.6	93.5	93.1	92.9	93.3	92.8	93.4	0.5	0.7
104.3	1	Cambridge	89.7	89.3	88.8	88.8	89.5	89.2	89.0	89.4	89.6	88.9	0.4	(0.7)
	ALL	**Average**	**78.3**	**77.8**	**77.7**	**78.2**	**78.5**	**78.5**	**78.1**	**78.4**	**76.1**	**80.4**	**0.3**	**4.3**
	1	- major stations	89.1	88.3	88.2	88.9	89.5	89.3	88.8	89.1	87.6	90.2	0.3	2.6
	2	- medium stations	78.1	77.4	77.3	78.0	78.3	78.3	77.8	78.2	75.6	80.4	0.4	4.9
	3	- minor stations	71.6	71.5	71.4	71.6	71.8	71.8	71.7	71.9	69.2	74.3	0.2	5.1
	ALL	**Vs. Scenario IIb**	0.74%	0.12%	0.00%	0.62%	**1.08%**	0.99%	0.59%	0.92%	-2.04%	3.55%	**0.35%**	**5.70%**
	1	- major stations	1.02%	0.10%	0.00%	0.79%	**1.52%**	1.34%	0.70%	1.00%	-0.61%	2.32%	0.31%	2.95%
	2	- medium stations	1.01%	0.11%	0.00%	0.91%	**1.30%**	1.28%	0.71%	1.15%	-2.21%	4.07%	0.46%	6.43%
	3	- minor stations	0.34%	0.14%	0.00%	0.29%	**0.60%**	0.53%	0.41%	0.71%	-3.01%	4.14%	0.31%	7.38%

Note: Calculated by dividing the average travel time (between Toronto Union and the indicated station) by the distance between Toronto Union and the indicated station.
Source: Own calculations.

[56] While the average distance between two subsequent stations along the Kitchener Corridor (with its assumed 18 stations plus Toronto Union) is 4.4 km, the value is much lower between Toronto and Mount Pleasant than beyond (2.4 vs. 6.9 km).

When comparing the different scenarios, Scenario IIb has the lowest average speed, followed narrowly by Scenario IIa. This is hardly surprising, given that the off-peak direction in Scenario II has only half the number of Inter-City and Inter-Regional trains compared to the peak-direction and all other scenarios, but the speed increment between the fastest Scenario (i.e. Scenario IV) and Scenario IIb is rather low with 0.8 km/h (or 1.08%). At the same time, the gap between fixed and variable blocks is even lower with only 0.3 km/h, which results from the fact that 45 mph limits for track changes are much shorter with fixed blocks than with variable blocks. Finally, the by far largest gap can be found between eastbound and westbound travel speeds, with overall eastbound travel speeds being 4.3 km/h faster than westbound. The reason for this large gap can be found in the fact that westbound trains are limited to the extremely low speed of 15 mph inside and around Toronto Union Station for one train-length longer, which means that they are required to crawl for up to 48 seconds longer at that speed than eastbound trains. Naturally, this absolute speed advantage of eastbound trains decreases the further west the respective station is and even turns negative for Cambridge, as it is now the eastbound trains which suffer from the low approach speed outside Cambridge station.

Moving on to the perceived headway scores, it is again the stations closer to Union Station which tend to reach the lowest values (even though with this metric, low values are superior to high values), as shown in Table 37. Unsurprisingly, Scenario II yields a significantly higher (i.e. worse) score than all the other scenarios with almost 31% more than Scenario III (i.e. the scenario with the lowest score), thanks to the lower number of trains in the respective off-peak direction. On the other hand, the differences between variable and fixed blocks are insignificant with a gap of only 0.04%, while those between westbound and eastbound trains still represent a rather low gap of only 0.73%.

Table 37: Perceived headway score for the various stations

Distance (km)	Station Class	Station name	BY SCENARIO I	IIa	IIb	III	IV	V	OVERALL AVERAGE Variable	Fixed	West	East	Var. vs. Fixed	West vs. East
3.4	3	Liberty Village	926	900	900	900	900	900	904	904	904	904	-	-
6.4	2	Bloor	502	453	453	429	472	472	464	464	485	442	-	43.3
8.5	3	St. Clair	926	900	900	900	900	900	904	904	904	904	-	-
10.9	1	Mount Dennis	390	389	402	333	359	442	386	386	401	370	-	30.9
13.5	3	Weston	926	900	900	900	900	900	904	904	904	904	-	-
17.7	3	Etobicoke North	926	900	900	900	900	900	904	904	904	904	-	-
23.7	3	Malton	926	900	900	900	900	900	904	904	904	904	-	-
28.0	2	Bramalea	792	789	791	753	738	779	775	772	770	777	2.8	(7.2)
34.1	1	Brampton	736	748	727	666	665	698	707	706	713	700	0.9	12.2
38.8	2	Mount Pleasant	1,249	962	950	973	988	927	1,008	1,008	1,014	1,002	(0.3)	11.7
47.2	2	Georgetown	1,190	1,395	1,396	957	974	926	1,138	1,141	1,135	1,145	(2.8)	(9.8)
57.3	3	Acton	1,813	2,700	2,700	1,800	1,800	1,800	2,102	2,102	2,101	2,103	-	(1.7)
78.5	1	Guelph	1,035	1,382	1,361	929	942	1,267	1,155	1,150	1,163	1,142	4.5	20.7
92.5	3	Breslau (new)	1,813	2,700	2,700	1,800	1,800	1,800	2,102	2,102	2,101	2,103	-	(1.7)
101.2	1	Kitchener (new)	1,048	1,389	1,365	937	951	1,294	1,166	1,162	1,175	1,153	4.5	21.1
92.7	3	Hespeler	1,825	2,700	2,700	1,800	1,800	1,800	2,104	2,104	2,108	2,100	(0.6)	7.5
96.7	2	Preston	1,825	2,700	2,700	1,800	1,800	1,800	2,104	2,104	2,108	2,100	(0.6)	7.5
104.3	1	Cambridge	1,825	2,700	2,700	1,800	1,800	1,800	2,104	2,104	2,108	2,100	(0.6)	7.5
	ALL	**Average**	**1,148**	**1,417**	**1,414**	**1,082**	**1,088**	**1,128**	**1,213**	**1,213**	**1,217**	**1,209**	**0.4**	**7.9**
	1	- major stations	1,007	1,322	1,311	933	943	1,100	1,104	1,102	1,112	1,093	1.8	18.5
	2	- medium stations	1,111	1,260	1,258	983	994	981	1,098	1,098	1,102	1,093	(0.2)	9.1
	3	- minor stations	1,260	1,575	1,575	1,238	1,238	1,238	1,354	1,354	1,354	1,354	(0.1)	0.5
	ALL	**Vs. Scenario IIa**	6.13%	**30.96%**	30.63%	0.00%	0.57%	4.25%	12.11%	12.07%	12.45%	11.72%	0.04%	0.73%
	1	- major stations	7.90%	**41.67%**	40.50%	0.00%	1.12%	17.94%	18.29%	18.09%	19.18%	17.20%	0.20%	1.98%
	2	- medium stations	13.34%	**28.46%**	28.28%	0.19%	1.40%	0.00%	11.94%	11.96%	12.41%	11.48%	-0.02%	0.93%
	3	- minor stations	1.82%	**27.27%**	27.27%	0.00%	0.00%	0.00%	9.39%	9.40%	9.42%	9.37%	-0.01%	0.04%

Note: Calculated by adding up the square-root of the headway values (in minute) of two consecutive arrivals (of westbound trains) and departures (of eastbound trains) stopping at the indicated station.
Source: Own calculations.

Finally, and as shown in Table 38, the perceived deviation from the optimal transfer time (assumed at 3 minutes) shows a slightly different picture, with Scenario II forming the midfield together with Scenario V and scenarios II and III having the lowest (i.e. best) score, while Scenario I has the by far worst score of all scenarios. Interestingly, Scenario V has the highest scores of any scenario at any transfer (at the transfer between Inter-City and RER in Brampton), but also the by-far lowest scores at eastbound-to-westbound, where it massively benefits from the optimisation of its transfers at its IFIT hub in Guelph, which demonstrates a key strength of IFIT timetabling.

Table 38: Perceived deviation (in minutes) from optimal transfer time

Transfer	Transfer from		Transfer to		Variable blocks						Fixed blocks						Average		
Station	Train	Origin	Train	Destination	I	IIa	IIb	III	IV	V	I	IIa	IIb	III	IV	V	Variable	Fixed	Diff.
Westbound to Westbound																			
Mount Dennis	AIR	Airport	RER	Toronto	2.94	1.19	1.19	1.19	0.19	5.19	2.94	1.19	1.19	1.19	0.19	5.19	**1.99**	**1.99**	-
Bramalea	IR	Kitchener	RER	Toronto	2.35	0.85	0.85	0.85	1.85	1.32	2.35	0.85	0.85	0.85	1.85	1.32	**1.35**	**1.35**	-
Brampton	IC	KITC/CMBR	RER	Toronto	9.35	3.60	3.92	4.35	4.60	24.60	8.82	3.51	3.88	4.05	4.51	24.51	**8.40**	**8.21**	**(0.19)**
Eastbound to Eastbound																			
Brampton	RER	Toronto	IC	KITC/CMBR	4.22	2.72	4.72	2.72	2.72	19.72	4.60	3.10	5.10	3.10	3.10	20.10	**6.14**	**6.51**	**0.38**
Bramalea	RER	Toronto	IR	Kitchener	3.36	0.60	0.60	0.60	0.60	8.94	3.74	0.98	0.98	0.98	0.98	9.32	**2.45**	**2.83**	**0.38**
Mount Dennis	RER	Toronto	AIR	Airport	1.06	1.67	1.67	1.67	0.11	0.67	1.06	1.67	1.67	1.67	0.11	0.67	**1.14**	**1.14**	-
Eastbound to Westbound																			
Guelph	IC	Kitchener	IC	Cambridge	14.38	13.12	15.45	1.27	1.46	4.79	15.00	12.66	15.04	3.09	1.68	5.66	**8.41**	**8.86**	**0.44**
Guelph	IR	Kitchener	IC	Cambridge	12.54	0.11	17.11	15.11	15.41	2.54	12.07	0.13	16.33	14.37	15.37	0.13	**10.47**	**9.73**	**(0.74)**
Guelph	IC	Cambridge	IC	Kitchener	9.80	14.56	16.56	0.20	0.22	6.22	9.40	12.50	14.50	2.12	2.12	5.50	**7.93**	**7.69**	**(0.23)**
Guelph	IC	Cambridge	IR	Kitchener	9.80	16.37	1.37	15.36	17.36	0.41	9.40	14.34	0.43	15.68	15.68	5.40	**10.11**	**10.15**	**0.04**
Mount Dennis	AIR	Airport	RER	Georgetown	8.19	0.33	0.33	0.33	0.33	3.42	8.19	0.33	0.33	0.33	0.33	3.42	**2.16**	**2.16**	-
Mount Dennis	AIR	Airport	IC	KITC/CMBR	6.51	10.01	12.01	10.01	10.01	1.01	6.51	10.01	12.01	10.01	10.01	1.01	**8.26**	**8.26**	-
Mount Dennis	AIR	Airport	IR	Kitchener	7.77	7.27	7.27	7.27	7.27	4.27	7.77	7.27	7.27	7.27	7.27	4.27	**6.86**	**6.86**	-
Mount Dennis	RER	Georgetown	AIR	Airport	7.89	0.01	0.01	0.01	1.22	1.22	7.89	0.01	0.01	0.01	1.22	1.22	**1.73**	**1.73**	-
Mount Dennis	IC	KITC/CMBR	AIR	Airport	5.22	9.22	9.89	9.22	9.22	0.60	5.22	9.22	9.89	9.22	9.22	0.60	**7.23**	**7.23**	-
Mount Dennis	IR	Kitchener	AIR	Airport	2.93	6.43	6.76	6.43	6.43	3.43	2.93	6.43	6.76	6.43	6.43	3.43	**5.40**	**5.40**	-
Median (Westbound to Westbound)					**2.94**	**1.19**	**1.19**	**1.19**	**1.85**	**5.19**	**2.94**	**1.19**	**1.19**	**1.19**	**1.85**	**5.19**	1.99	1.99	-
Median (Eastbound to Eastbound)					**3.36**	**1.67**	**1.67**	**1.67**	**0.60**	**8.94**	**3.74**	**1.67**	**1.67**	**1.67**	**0.98**	**9.32**	2.45	2.83	0.38
Median (Eastbound to Westbound)					**8.04**	**8.25**	**8.58**	**6.85**	**6.85**	**2.98**	**8.04**	**8.25**	**8.58**	**6.85**	**6.85**	**3.43**	7.58	7.46	(0.12)
Median (overall)					**7.14**	**3.16**	**4.32**	**2.19**	**2.29**	**3.43**	**7.14**	**3.30**	**4.49**	**3.09**	**2.61**	**3.85**	6.50	6.69	0.19

Note: Calculated by subtracting 3 minutes from the actual transfer time (i.e. departure time of the train onto which the passenger transfers minus arrival time of the train from which he transferred), while forming the square root for all negative values (i.e. less than 3 minutes of transfer time).
Source: Own calculations.

10. Discussion

10.1. Train capacity and timetable quality

The results observed in the benchmarking process described in the previous chapter are summarized in Table 39, which indicates that scenarios III, IV and V have the highest count of slots, while scenarios IIa and IIb can accommodate significantly less slots and Scenario I ends up somewhere in between. These results would contradict the hypothesis that with every added timetable constraint imposed by a timetable strategy (such as periodicity, symmetry and coordinated transfers), the number of trains which can be slotted decreases. Nevertheless, and as discussed in the previous Chapter, the results do not negate that the choice of timetable strategy may have a significant impact on train capacity: instead, it appears like whereas a *numerical imbalance between westbound and eastbound passenger trains of the same type*, *timetable symmetry* and *coordinated transfers* may all be indeed negatively related to train capacity, periodicity may have the opposite (i.e. positive) effect, thus obscuring what would otherwise look like a clear negative relationship between the number of timetable constraints and train capacity.

Table 39: Summary of results from benchmarking process

Benchmark criteria	I	IIa	IIb	III	IV	V	MIN	MAX	Average
Slotted trains	35.0	30.5	31.5	36.0	35.0	34.0	30.5	36.0	33.7
- of which: preferred slots	27.5	25.5	24.5	29.0	30.0	31.0	24.5	31.0	27.9
- of which: freight trains	11.0	9.5	10.5	12.0	11.0	10.0	9.5	12.0	10.7
Average Speed (km/h)	78.4	77.9	77.8	78.3	78.6	78.6	77.8	78.6	78.3
Perceived headway score	1111	1362	1361	1043	1050	1094	1043	1362	1170
Perceived deviation from optimal transfer time	9.8	6.2	7.4	5.3	5.4	6.4	5.3	9.8	6.8

Note: Figures represent the average of the respective figures for variable and fixed blocks.
Source: Own calculations.

One possible explanation for the inability of the partially periodic timetable scenarios (IIa and IIb) to compensate for the lower count in passenger trains would be that one additional freight slot might consume more track capacity than one passenger train traveling on the same track (due to its longer length and slower speed). Another possible explanation would be that the necessity to cross the opposing traffic of passenger trains before merging with the passenger trains traveling in the same direction makes it much more difficult to slot in a freight train than a passenger train, as a gap must not only exist in the flow of passenger trains traveling in the same direction, but also for those traveling in the opposite direction and, even worse, these gaps must align in order to create a valid path for a freight slot. This means that whereas westbound and eastbound trains operate mostly independently from each other on a multiple-tracked line, the presence of two separate streams of trains (i.e. passenger and freight trains), which cross each other at-grade and share the same corridor for a certain distance, introduces a significant level of interferences between westbound and eastbound movements.

Consequently, the insertion of any freight train requires an overlap of gaps in the flow of westbound and eastbound train movements at the point where passenger and freight trains merge into the shared segment (i.e. Bramalea Jct. for westbound and Silver Jct. for eastbound movements). At the same time, further interferences are introduced by imposing timetable symmetry (as the move of the westbound timings of any train type needs to be mirrored by moving the eastbound train timings of the same train type by the same number of minutes in the opposite direction) or coordinated transfers (which create a direct dependency between multiple train types and train directions[57]) and the resulting reduction in the solution space may therefore explain the observed negative relationship of these two factors and train capacity.

The positive relationship between periodicity and train capacity may look counter-intuitive at first sight, but the requirement for regular headways is not more of a constraint limiting the solution space than the requirement for irregular headways. As mentioned in the previous Chapter, this

[57] In the case of Scenario V, these dependencies comprise two train types – Inter-City and Inter-Regional – and three directions: westbound to Kitchener, westbound to Cambridge and eastbound to Toronto.

became clear when determining valid headways for Scenario I, which progressively slipped from as heterogeneous as permittable to more homogeneous headways while manually inserting the various passenger trains (and the obligatory 2 freight train slots per hour). This may be explained by the fact that resolving a conflict between two different train movements in a periodic timetable solves any conflict between all scheduled trips of the corresponding train services in that area, thanks to the nature of ever-repeating timetable pattern.

Moving on to the qualitative measures, the results suggest that while altering the ratio of fast passenger trains (like Inter-City and Inter-Regional) to slower passenger trains (like RER and the Airport Shuttle) has a significant impact on average train speeds (as demonstrated by comparing scenarios IIa and IIb to the other scenarios), the differences in the other scenarios (which are caused by trains using non-preferred slots requiring additional track changes) are marginal at best. A very similar observation can be made for altering the number of passenger trains (at least in one direction) on perceived headways. However, decreasing the number of operated trains in one direction in scenarios IIa and IIb for certain train types (i.e. Inter-Regional and Inter-City trains by 50%) without increasing the number of these train types by the same margin in the opposite direction makes it impossible to isolate the effect of having an westbound-eastbound imbalance from the effect of having altered the number and composition of passenger trains in the system and therefore obscures any comparison of scenarios IIa and IIb with other scenarios.

The picture is slightly different for the perceived deviation from the optimal transfer time, as the presence of coordinated transfers (at the IFIT hub in Guelph in Scenario V) seems to cause less optimal transfer times at other transfer points, while the variability in the headways (in Scenario I) severely obstructs the ability to ensure good transfers between two services with headways which are neither identical nor a divisor or multiple of each other. However, this observation leads towards the question to which extent the favorable performance of the fully periodic timetable strategies (III, IV and V) compared to their non-periodic or partially periodic peers (scenarios I, IIa and IIb) can really be attributed to periodicity *per se*, as opposed to the fact that all frequencies used for any train type are a multiple of 15 (15, 30 or 60) minutes. It is therefore thinkable that travel times arranged as a non-periodic (but possibly symmetric) timetable, where all trains operate with the same rotation of headways (e.g. 11-19-13-17 minutes), would yield more favorable transfer times than having certain services operate at intervals of 15 (or 30) minutes and others at 10 (or 20) minutes.

In summary, periodicity seems to have a positive effect on train capacity, while the effect of timetable symmetry and coordinated transfers appears as negative (except for the number of preferred slots, where it also appears as positive). This seems to suggest that the presence of uniform headways increases capacity, while imposing heterogeneous headways, timetable symmetry or coordinated transfers decreases the solution space and thus constrains the ability to complement the scheduled passenger trains by slotting additional freight trains. However, these effects are marginal compared to the strong negative effect of reducing the number of passenger trains in one direction, as the "missing" passenger trains are not substituted by any additional freight slots. In the case of the qualitative measures, the lower number of fast trains (in scenarios IIa and IIb) has a slightly negative effect on average speed, while the overall lower number of trains (in the off-peak direction) has a strong positive effect on the perceived length of the headway and the absence of periodic timings exacerbates the perceived transfer times. That said, the insights gained by this research neither allow to isolate the effect of an imbalance of westbound and eastbound trains from the effects of an overall lower number and composition of scheduled passenger trains nor to isolate the effect of scheduling exclusively with periodic headways which are either a multiple or divisor of each other from scheduling with any periodic headways in general.

10.2. Variable vs. fixed blocks

As summarized in Table 40, the choice of block length has the by far largest impact on train capacity, with fixed blocks allowing the insertion of between 3 and 5 times as many freight slots as with the variable blocks. This appears as highly plausible, given that the assumed length of the variable blocks (i.e. the distance between two consecutive signals) modelled in this Thesis is on average almost 1 mile long[58] or 20 times the assumed length of a fixed block (0.05 miles) and that every train therefore consumes less track capacity when scheduled under fixed blocks. At the same time, this increases the size of gaps between train movements and facilitates therefore the insertion of additional slots.

Table 40: Breakdown of results from benchmarking process by assumed signalling system

	Variable blocks						Fixed blocks						MIN	MAX	Average		
	I	IIa	IIb	III	IV	V	I	IIa	IIb	III	IV	V			var.	fix.	comb.
Slotted trains	29	26	27	28	28	28	41	35	36	44	42	40	26	44	27.7	39.7	33.7
- of which: preferred slots	20	21	20	20	24	26	35	30	29	38	36	36	20	38	21.8	34.0	27.9
- of which: freight trains	5	4	5	4	4	4	17	15	16	20	18	16	4	20	4.3	17.0	10.7
Average Speed (km/h)	78.1	77.7	77.7	78.2	78.6	78.6	78.7	78.2	77.9	78.4	78.7	78.5	77.7	78.7	78.1	78.4	78.3
Perceived headway score	1112	1362	1361	1042	1050	1091	1110	1362	1360	1044	1050	1098	1042	1362	1169	1171	1170
Perceived deviation from optimal transfer time	9.8	6.2	7.3	5.2	5.3	6.4	9.8	6.3	7.5	5.4	5.5	6.4	5.2	9.8	6.7	6.8	6.8

Source: Own calculations.

Concerning the measures of timetable quality, average speed seems to be slightly higher for fixed blocks, which appears as intuitive, given that fixed blocks allow a much higher granularity when assigning local speed limits for using track changes. Conversely, there is no discernable difference for perceived headways and transfer times, which corresponds with the fact that the departure or

[58] There are approximately 65 signal locations listed in Table 15, which cover the 62.9 miles between Toronto and Kitchener.

arrival timings of all passenger trains are identical in Toronto for either choice of block lengths, which naturally yields at any given station very similar gaps between two consecutive departures or between two connecting trains.

10.3. Implications for other rail bottlenecks

As discussed in the previous subsections, the results suggest that timetable periodicity is positively related to train capacity, while the presence of timetable symmetry and coordinated transfers seem to have a negative effect. Given that the results were obtained from a case study using the Kitchener Corridor, these observations might be most applicable to urban multi-use corridors which have similar characteristics: For instance, whereas the absence of grade separations at any of the junctions outside the USRC (e.g. Woodbine Jct., Bramalea Jct., Silver Jct. and Guelph Jct.) seemed to have placed the periodical schedule at an advantage (as coordinating frequent services operating on conflicting routings is facilitated by these services operating at headways which are either identical or a multiple or fraction of each other), periodicity might just act as a capacity-limiting constraint on corridors where traffic flows in both directions are completely grade separated. Conversely, the presence of timetable symmetry and coordinated transfers will probably pose a limiting effect on capacity on almost any thinkable infrastructure setting, due to the drastic reduction of timetabling flexibility these timetable design characteristics impose.

That said, the by far largest impact on train capacity has been identified in the choice of blocking method with fixed blocks increasing train capacity in the case study by approximately one-half (compared to the much longer variable blocks). Given that a decrease in block length reduces the "footprint" (i.e. the track capacity consumed by each train) regardless of whether traffic flows are fully grade-separated or not, a significant improvement in dispatching efficiency should yield comparable track capacity gains on any multi-tracked corridor. However, it should be noted that interference between any two rail services increases with the corridor length over which these heterogeneous services share the same tracks and with their speed differential (i.e. the difference in the respective services' average speed while traveling on the shared section). Whereas the shared section was comparatively short in this case study (approximately 20 km or one-fifth of the total corridor length) and while the speed differential was already considerable[59], some corridors might have mixed traffic for much longer sections or operating at even higher speed differentials, which could lead to significantly different results.

Concerning timetable quality, the most substantial result in the case study was that the periodic timetables had a significantly shorter perceived transfer time than those constructed as individual trips. Even though scenarios III and IV (i.e. the regular periodic and the symmetric timetable) scored the highest in the case study, the IFIT timetable might outperform all other strategies tested in this thesis on corridors where the IFIT hub(s) accounts for most transfers, given its strength to optimise the transfer times at such hubs. This observation is mirrored by the Swiss Federal Railways' (SBB) decision to focus its infrastructure upgrades mainly on the segments where they may bring the travel times of the major trains to just under any multiple of half their headway[60] rather than simply where the travel time savings were the highest. Following the Swiss dictum of "as swift as necessary, not as fast as possible!"[61], the targeted reduction of travel times at strategic segments has allowed the creation of coordinated transfers at as many hubs as possible and the

[59] Freight trains as the train type with the longest transit time pass through the shared section with an average speed of approximately 45 mph (75 km/h), while Inter-City trains as the fastest train type pass with an average speed of approximately 75 mph (120 km/h), thus 60% higher than freight trains.

[60] Staying just under any multiple of half their headway makes sure that the trains of the major train service can stop at the same time at the hubs and have enough dwell time to allow passengers to transfer between the various connections.

[61] In German: "*so rasch wie nötig, nicht so schnell wie möglich!*"

resulting ease of connecting between different train types (and other modes of transport – from the city bus over the ferry to the rack railway) certainly contributed to positioning Switzerland as the country with the highest per-capita ridership in Europe (and possibly: the world)[62]. (Tyler, 2003)

[62]According to the European Commission (2017), per-capita rail ridership in Switzerland was 2,466 km in 2015 and therefore approximately twice the corresponding values in France (1,340 km), Germany (1,124 km) and the United Kingdom (1,023 km) and almost three times the average value across the European Union (896 km).

10.4. Limitations

As acknowledged throughout this thesis, the main challenge of this research was to model train movements without access to professional timetabling software, which required all train movements to be approximated by assuming constant acceleration. Consequently, several factors influencing the train movements were ignored, such as the trains' tractive effort, weight, moment of inertia, horsepower-to-weight ratio and the gradients present along the corridor. Nevertheless, the modelling process still assumed different acceleration, deceleration, maximum speed and train length values and stopping patterns for each train type, while the focus of this research was to make observations about the relative differences in the impact of the individual timetable strategies on various timetable capacity and quality measures rather than comparing their absolute values with other studies or corridors.

Probably the most severe drawback of using Microsoft Excel instead of a professional timetabling software solution was that this research had to rely on a mostly manual timetabling process without using any optimiser, which made any attempt of timetable simulation impractical and thus precluded the consideration of timetable reliability and stability. This means that an optimizer might have been able to schedule more freight trains into one or all the different scenarios (especially into Scenario 1, where the scheduling process was much more complex and the chosen arrival/departure times even more arbitrary than in the other scenarios), which might have altered (and in the worst case: even reversed) some of the relationships observed.

Another element which had to be simplified in the modelling process was the signalling system: even though the variable-block signalling system was based on the Centralized Traffic Control (CTC) signalling system installed along the Kitchener Corridor, the complexity of its functionality had to be significantly reduced. Likewise, the lack of professional software forced the decision to model a fixed-block train control system based on the German LZB system instead of a moving-block train control system like Communications Based Train Control (CBTC), which Metrolinx (2015) states as its preferred choice for its future RER network. Again, this limitation does not appear likely to severely alter the results from the research aspects this research focused on, given that both, LZB and CBTC rely on in-cab signalling rather than stationary signals and a train traveling at the assumed top speed of 110 mph will traverse one block length (0.05 miles or 80 meters) in less than 2 seconds, while if anything, a moving-block signalling system should perform at lest as good as the assumed fixed-block signalling system.

Considering the design process of the timetable strategies, the train frequencies were chosen in a way that all headways were not only a divisor of 60 minutes but also either a multiple or divisor of each other. The obtained results therefore does not allow to distinguish between the impact of periodicity *per se* and of ensuring that all headways are either a multiple or divisor of each other. Similarly, the inclusion of a non-periodic symmetric timetable in the train timetable strategies selected in Section 5.4 would have allowed to investigate the impact of symmetry independently from periodicity. However, the 5 timetable strategies implemented in this research already resulted in 12 different scenarios, due to the partially periodic timetable requiring two different scenarios (for the morning and afternoon peak) and all scenarios needing to be prepared for both assumed blocking systems. Given the computational constraints applicable to this research, it was not practical to include more (let alone: all) of the 24 timetable strategies identified by Schittenhelm (2013) and mentioned in Section 3.3 into this research.

Concerning the outcomes of this research, the choice and design of timetable strategies does not allow to isolate the effect of an imbalance of westbound and eastbound trains from the effects of an overall lower number and composition of scheduled passenger trains. Consequently, the results from scenarios IIa and IIb might not be directly comparable to the other scenarios given that their assumed number of passenger trains (both directions combined) is lower than for the other scenarios. This is especially the case for the timetable quality measures, which might have shown different results for a timetable scenario which decreased the number of trains by a certain proportion (e.g. 50%) in one direction and increased it by the same figure in the other direction, but such an additional timetable scenario would have further increased the number of timetable scenarios to be modelled. Similarly, certain results from the various scenarios (such as the number of preferred slots and all the timetable quality measures) might have been different if they had also been measured before inserting the freight train slots (rather than just afterwards), as their variation in the number of freight train slots which could be slotted into the individual scenarios may affect these measures.

In the end, this research could touch the subject of timetable quality and other pertinent aspects concerning the timetabling on a capacity-constrained railway corridor only somewhat superficially. As a result, the timetable quality measures used in this research to assess the timetable scenarios were rather improvised and elementary. However, one should recall that the focus of this research was on train capacity and this is indeed reflected by the many compromises which had to be made in order to not exceed the scope and timeframe expected from a master thesis.

11. Conclusions

11.1. Conclusions for rail infrastructure and transportation planners

The simultaneous trends towards the globalization of goods flows and the suburbanization of people has led to increased traffic on rails and roads alike, while fierce intra- and intermodal competition has pressured railways to rationalise their infrastructure. This has exacerbated the rail congestion on many busy corridors and highlights the need to utilise existing tracks more efficiently, especially on urban corridors, as these tend to have the highest train volumes and are the most expensive to expand by inserting additional tracks thanks to dense urban developments around them, which drives property prices the closer one gets to an urban or metropolitan core. This thesis has therefore aimed at expanding the understanding of how the scheduling of passenger trains affects train capacity, which refers to the ability to maximize the number of passenger and freight trains operating over the same corridor segment in a certain period (e.g. 1 hour). The Kitchener corridor in the Greater Toronto and Hamilton Area (GTHA) was chosen to quantify the impact of various timetable strategies (which are applied when scheduling passenger trains) on overall train capacity.

The results suggest that train capacity is the highest on a mixed-use rail corridor if each type of passenger trains is scheduled with periodic (i.e. constant) headways which are either identical or a multiple or fraction of each other. This implies that scheduling passenger trains with a "clock-face" timetable does not only provide passengers with a more predictable schedule, but also increases train capacity while allowing for shorter transfer times. Even though the creation of integrated fixed-interval hubs (IFIT) allows to minimize transfer times at these IFIT hubs, the case study has shown that average transfer times may still end up higher than with other periodic timetables. Nevertheless, the Swiss experience discussed in Section 10.3 demonstrates that this trade-off can be overcome by targeting infrastructure upgrades in a way which guarantees that the resulting travel times permit the highest-order train services to stop at the various hubs in both directions at the same time and allow to form an IFIT hub by coordinate these stops with lower-order trains and bus services available at these stations.

However, the results mentioned above will require more extensive and rigorous research than what was possible in this Master Thesis before their applicability to other rail corridors can be validated. Nevertheless, the observation that the move from variable-length blocks with stationary signals to a fixed-block in-cab signalling system results in a substantial increase in train capacity should hold true on any multi-tracked corridor.

11.2. Areas for future research

Considering the results in the context of this thesis' purpose as outlined in Section 1.4, it seems that future research should include a higher number of timetable strategies than the 5 strategies investigated in this thesis, in order to better isolate the impact of different variables, such as differentiating the effect of symmetry from that of periodicity. The resulting computational effort, of course, requires the use of professional timetabling software, which will also open the possibilities of assessing the timetable stability or robustness by simulating rather than just modelling the train movements. Furthermore, the limitations acknowledged in the previous chapter and throughout this thesis should be addressed by verifying the reported results and relationships through the use of an optimiser. Finally, these timetable scenarios should be applied on different rail corridors, to explore how different infrastructure features affect the train capacity and timetable quality.

Concerning the indicators of train capacity, future research would benefit from modelling the blocking systems closer to the signalling systems typically used on urban shared-use rail corridors, which should include moving-block systems like CBTC or ETCS (European Train Control System), as the future unified train control standard in Europe). Furthermore, future research should exploit the capabilities of professional timetabling software by modelling train movements much closer to typical train types and without the simplifying the complexities of changes in train speed through the simplistic assumption of constant acceleration.

Moving on to the indicators of timetable quality, future research would certainly benefit from a much deeper focus on the underlying concepts of this topic, in order to provide a more rigorous way of benchmarking the timetable concepts produced by the various timetable strategies from the passenger's perspective. These qualitative indicators should already be measured after inserting the passenger trains and repeated after each additional freight slot, so that the incremental impact of inserting an additional freight train can be assessed. Furthermore, a measure should be developed which regards the access of freight trains with some sort of level-of-service model by calculating and analysing the delay suffered by a freight train arriving at random times while waiting for the next available freight train slot.

A different, but closely related research field would be to investigate ways of how the locomotive engineers of freight trains can be instructed to reduce their speed in a way so that they avoid having to got to standstill at the merging point (while waiting for the tracks ahead on the shared section to clear), which would inevitably cause delay on dense passenger traffic, given their (compared to passenger trains) much lower acceleration capabilities (especially at lower speeds). This issue had been solved by the former Eastern German state railway Deutsche Reichsbahn (DR) with two disks showing either the letter "K" (known as "Signal Zp 10", instructing the locomotive engineer to "cut travel time"[63] by traveling at its applicable speed limit until the next siding) or "L" (known as "Signal Zp 11", instructing the locomotive engineer to "drive slower"[64] by reducing its speed to approximately half its applicable speed limit until the next siding, in order to avoid having to stop in front of a subsequent signal) (Deutsche Reichsbahn, 1971) – a practice which is now known as *pacing* in the railway literature (Harker, 1990). However, modern technology and especially in-cab signalling should allow much smoother and more accurate ways to predict and adjust the freight train's movement so that it inserts itself into the shared segment in a way which closely resembles the "just in time" philosophy which has become commonplace in modern supply chains.

[63] In German: "Fahrzeit kürzen!"
[64] In German: "Langsamer fahren!"

Bibliography

Abril, M., Barber, F., Ingolotti, L., Salido, M., Tormos, P., & Lova, A. (2008). An assessment of railway capacity. *Transportation Research Part E*, 774-806.

Albrecht, T. (2014). Energy-Efficient Railway Operation. In I. A. Hansen, & J. Pachl, *Railway Timetabling & Operations (2nd revised and extended edition)* (pp. 91-116). Hamburg: Eurailpress.

Bellemare, A. (2014). *Ontario high-speed rail study was rushed ahead of election*. Retrieved from CBC News - Kitchener-Waterloo: http://www.cbc.ca/news/canada/kitchener-waterloo/ontario-high-speed-rail-study-was-rushed-ahead-of-election-1.2866591

Brünger, O., & Dahlhaus, E. (2014). Running Time Estimation. In I. A. Hansen, & J. Pachl, *Railway Timetabling & Operations (2nd revised and extended edition)* (pp. 65-90). Hamburg: Eurailpress.

Caimi, G., Kroon, L., & Liebchen, C. (2017). Models for railway timetable optimization: Applicability and applications in practice. *Journal of Rail Transport Planning & Management, 6*(4), 285-312.

Caltrain. (2011). *Caltrain Design Criteria - Chapter 2: Track.* Retrieved from Caltrain: http://www.caltrain.com/assets/_engineering/engineering-standards-2/criteria/CHAPTER2.pdf

Calvert, J. B. (2004). *Degree of Curvature.* Retrieved from University of Denver: https://mysite.du.edu/~jcalvert/railway/degcurv.htm

Canadian Electric Railway Map Collection. (2016). *Canadian Electric Railway Map Collection (Release Mark: Alpha 28).* Retrieved from Canadian Electric Railway Map Collection.

Caprara, A., Monaci, M., Totha, P., & Guidac, P. L. (2006). A Lagrangian heuristic algorithm for a real-world train timetabling problem. *Discrete Applied Mathematics*, 738-753.

CBC News. (2016, February 11). *Kitchener, Toronto mayors pitch 2 city innovation corridor*. Retrieved from CBC News - Kitchener-Waterloo: http://www.cbc.ca/news/canada/kitchener-waterloo/john-tory-berry-vrbanovic-toronto-kitchener-innovation-corridor-1.3444007

Chen, B., & Harker, P. T. (1990). Two Moments Estimation of the Delay on Single-Track Rail Lines with Scheduled Traffic. *Transportation Science*, 261-275.

City of Toronto. (2017). *IBI Group Phase 1 Interim Report - Land Use Study: Development in Proximity to Rail Operations - Appendix B: Database and Maps*. Retrieved February 11, 2018, from https://www.toronto.ca/wp-content/uploads/2017/10/8682-3-TTR_CityWideLandUse_APPENDIX-B-DATABASE-AND-KEY-MAP_2017-08-30.pdf

CN. (1964a). *Canadian National Railways - system time table (effective April 26, 1964).* Montreal: Canadian National Railways.

CN. (1964b). *Canadian National Railways - system time table (effective October 25, 1964).* Montreal: Canadian National Railways.

CN. (1970). *System Time Table (effective January 7, 1970).* Montreal: Canadian National Railways.

CN. (1971). *System Time Table (effective February 1, 1971).* Montreal: Canadian National Railways.

CN. (1975). *System Timetable (effective October 26, 1975 - April 24, 1976).* Montreal: Canadian National.

CNR. (1937). *Local Time Tables (Central Region - effective April 25th, 1937).* Montreal: Canadian National Railway.

CNR. (1939). *Local Time Tables (Central Region - effective December, 3rd 1939).* Montreal: Canadian National Railways.

CNR. (1941). *Canadian National Railways - System Timetable (effective June 22, 1941).* Montreal: Canadian National Railways.

CNR. (1943). *Canadian National Railways - System Timetable (effective June 27, 1943).* Montreal: Canadian National.

CNR. (1945). *Rail Timetables (effective April 29, 1945).* Montreal: Canadian National Railways.

CNR. (1953). *Canadian National Railways - System Time Tables (effective November 29, 1953).* Montreal: Canadian National Railways.

CNR. (1954). *Canadian National Railways - System Time Tables (effective April 25, 1954).* Montreal: Canadian National Railways.

CNR. (1956). *Canadian National Railways - Time Tables (effective Sept. 30, 1956 to April 27, 1957).* Montreal: Canadian National Railways.

CNR. (1957). *Canadian National Railways - Time Tables (effective October 27, 1957).* Montreal: Canadian National Railways.

CNR. (1958). *Canadian National Railways - Time Tables (effective April 27, 1958).* Montreal: Canadian National Railways.

CNR. (1959). *Time Tables (effective April 26, 1959).* Montreal.

Collenette, D. (2016). *Special Advisor for High Speed Rail: Final Report.* Retrieved February 27, 2018, from http://www.mto.gov.on.ca/english/publications/high-speed-rail-in-ontario-final-report/pdfs/high-speed-rail-in-ontario-final-report.pdf

Cordeau, J.-F., Toth, P., & Vigo, D. (1998). A Survey of Optimization Models for Train Routing and Scheduling. *Transportation Science*, 380-404.

CP. (1954). *Canadian Pacific Time Table - Folder A (System Folder, effective September 26, 1954).* Montreal: Canadian Pacific.

CP. (1955). *Canadian Pacific Time Table - Folder A (System Folder, effective April 24, 1955).* Montreal: Canadian Pacific.

CP Rail. (1971a). *Timetable (effective April 25, 1971).* Montreal: CP Rail.

CP Rail. (1971b). *Timetable (effective October 31, 1971).* Montreal: Canadian Pacific.

D'Amato, L. (2018, June 12). *What's in a future under Ford?* Retrieved from The Record - Waterloo Region Record - Opinion: https://www.therecord.com/opinion-story/8665536-what-s-in-a-future-under-ford-/

Davis, B. (2018, May 3). *GO train service to Cambridge to be studied*. Retrieved from The Record - Waterloo Region Record: https://www.therecord.com/news-story/8587290-go-train-service-to-cambridge-to-be-studied/

de Fabris, S., Longo, G., Medeossi, G., & Pesenti, R. (2014). Automatic generation of railway timetables based on a mesoscopic infrastructure model. *Journal of Rail Transport Planning & Management, 4*(1-2), 2-13.

Deutsche Reichsbahn. (1971). *Die Signale der Deutschen Reichsbahn - Signalbuch (SB) DV 301 - gültig vom 1. Oktober 1971 (in German).* Retrieved from Bahn Statistik: http://www.bahnstatistik.de/Signale_pdf/SB-DR.pdf

Dicembre, A., & Ricci, S. (2011). Railway traffic on high density urban corridors: Capacity, signalling and timetable. *Journal of Rail Transport Planning & Management, 1*(2), 59-68.

Dillon Consulting & Hatch Mott MacDonald. (2014). *Cambridge to Milton Passenger Rail Business Case and Implementation Strategy - Final Report.* Retrieved from https://www.cambridge.ca/en/learn-about/resources/Cambridge-Milton-Passenger-Rail_-Final-Report--October-2014.pdf

Dingler, M. H., Lai, Y.-C., & Barkan, C. P. (2009). Impact of Operational Practices on Rail Line Capacity - A Simulation Analysis. 2009 Annual AREMA Conference.

Edwards, J. R. (2010). *Train Energy, Power and Traffic Control.* Retrieved from https://web.engr.uky.edu/~jrose/RailwayIntro/Modules/Module%203%20Train%20Energy,%20Power%20and%20Traffic%20Control%20REES%202010.pdf

European Commission. (2017). *EU Transport in Figures: Statistical Pocketbook 2017.* Retrieved from European Commission - Legal acts on transport statistics: https://ec.europa.eu/transport/sites/transport/files/pocketbook2017.pdf

ExcelFunctions. (2018). *Built-In Excel Functions List*. Retrieved from ExcelFunctions.net: https://www.excelfunctions.net/excel-functions-list.html

Federal Railroad Administration. (2008). *Background on Federal Track Safety Standards.* Retrieved from Passenger Rail Oklahoma: http://passengerrailok.org/memberfiles/Track%20Standards%20fact%20sheet%20FINAL.pdf

Gerson, J. (2018). *Kathleen Wynne's pledge to spend billions on a bullet train makes zero sense*. Retrieved from MacLeans - Opinion: https://www.macleans.ca/politics/kathleen-wynnes-crazy-train/

Ghaviha, N., Bohlin, M., Wallin, F., & Dahlquist, E. (2015). Optimal Control of an EMU Using Dynamic Programming and Tractive Effort as the Control Variable. *Proceedings of the 56th SIMS* (pp. 377-382). Linköping (Sweden): Research Gate.

Gibson, S., Cooper, G., & Ball, B. (2002). The Evolution of Capacity Charges on the UK Rail. *Journal of Transport Economics and Policy, 36*(2), 341-352.

GO Transit. (2017). *Train Map - Plan du réseau de train.* Retrieved April 14, 2018, from GO Transit: https://www.gotransit.com/file_source/gotransit/assets/img/maps/train-map-large.png

GO Transit. (2018). *Kitchener - GO Train and Bus Schedule (Table 31 - effective June 23, 2018).* Retrieved November 18, 2018, from GO Transit: https://www.gotransit.com/static_files/gotransit/assets/pdf/TripPlanning/FullSchedules/Table31.pdf

Goverde. (2008). Timetable Stability Analysis. In I. A. Hansen, & J. Pachl, *Railway Timetable & Traffic* (pp. 118-134). Hamburg: Eurailpress.

Goverde, R. M. (1998). *Optimal Scheduling of Connections in Railway Systems.* Retrieved from Semantic Scholar: https://pdfs.semanticscholar.org/ee83/7b619a18c792aeda99faa2cff062446e0653.pdf

Government of Canada. (2018). *Grade Crossings Regulations.* Retrieved from Justice Laws Website: http://laws-lois.justice.gc.ca/PDF/SOR-2014-275.pdf

GrandLinq. (2018, June 17). *Central Station - Innovation District*. Retrieved from http://www.rideion.ca/central-station.html

Harker, P. T. (1990). Use of Advanced Train Control Systems in Scheduling and Operating Railroads: Models, Algorithms, and Applications. *Transportation Research Record 1263*, 101-110.

Harker, P. T. (1995). Services and Technology: Reeingineering the Railroads. *Interfaces*, 72-80.

Harker, P. T., & Hong, S. (1990). Two moments estimation of the delay on a partially double-track rail line with scheduled traffic. *Journal of the Transportation Research Forum*, 38-49.

Hynes, R. (2011). *Implementing High Speed Rail in the United States - Development of US High Speed Rail Safety Requirements.* Retrieved from American Public Transportation Association (APTA): http://www.apta.com/mc/hsr/previous/2011/presentations/Presentations/Implementing-High-Speed-Rail-in-the-United-States.pdf

Jovanovic, D., & Harker, P. (1991). Tactical scheduling of rail operations: the SCAN I system. *Transportation Science*, 46-64.

Kalinowski, T. (2014). *GO buys Kitchener track west of Georgetown*. Retrieved February 11, 2018, from https://www.thestar.com/news/gta/transportation/2014/09/29/go_buys_kitchener_track_west_of_georgetown.html

Keay, B. (2014?). *Making Sense of Canadian Railroad Signals.* Retrieved from The Calgary Model Railway Society: http://www.mikeroque.com/railroad-signals/

Keevill, D. (2016). *Increasing Levels of Automation with CBTC.* Retrieved from Institution of Railway Signal Engineers: http://www.irse.org/knowledge/publicdocuments/IRSE%20CBTC%20Conference%20%20-%202016%20Toronto%20-%20%20Dave_Keevill_Increasing_GoA_rev2.pdf

Kraay, D., Harker, P. T., & Chen, B. (1991). Optimal Pacing of Trains in Freight Railroads: Model Formulation and Solution. *Operations Research*, 82-99.

Lai, Y.-C., & Barkan, C. P. (2009). Enhanced Parametric Railway Capacity Evaluation Tool. *Transportation Research Record: Journal of the Transportation Research Board*, 33-40.

Landex, A. (2009). *The Potential for Regional Express Trains when Introducing High-Speed Operation.* Retrieved July 16, 2017, from http://orbit.dtu.dk/files/4034136/H%C3%B8jhastighedstogs%20potentiale%20for%20hurtigere%20regionaltogstrafik.pdf

Langan, P. (2001). *Remembering Glen Christie.* Retrieved from Paul Langan - My Books: https://www.paullangan.com/p/mtybiiks.html

Lee, K. K., & Schonfeld, P. (1991). Optimal Slack Time for Timed Transfers at a Transit Terminal. *Journal of Advanced Transportation*, 281-308.

Liebchen, C. (2006). *Periodic Timetable Optimization in Public Transport - PhD Thesis.* Retrieved March 27, 2018, from Semantic Scholar: https://pdfs.semanticscholar.org/63aa/a9434081105f71ed215d3bebe5a15f093aa9.pdf

Liebchen, C., & Möhring, R. H. (2007). The Modeling Power of the Periodic Event Scheduling Problem: Railway Timetables — and Beyond. In G. Frank, L. Kroon, A. Schoebel, D. Wagner, & C. D. Zaroliagis, *Algorithmic methods for railway optimization* (pp. 3-40). Berlin, Heidelberg: Springer.

Lusby, R. M., Larsen, J., Ehrgott, M., & Ryan, D. (2011). Railway track allocation - models and methods. *OR Spectrum*(33), 843–883.

Martin, U. (2014). Railway Timetabling & Operations: Analysis - Modelling - Optimisation - Simulation - Performance Evaluation, 2nd Revised and Extended Edition. In I. A. Hansen, & J. Pachl, *Railway Timetabling & Operations* (pp. 275-293). Hamburg: Eurailpress.

Meirich, C., & Nießen, N. (2016). Calculating the maximal number of additional freight trains in a railway network. *Journal of Rail Transport Planning & Management, 6*(3), 200-217.

Metrolinx. (2015). *GO Regional Express Rail Initial Business Case .* Retrieved February 26, 2018, from http://www.metrolinx.com/en/regionalplanning/projectevaluation/benefitscases/GO_RER_Initial_Business_Case_EN.pdf

Metrolinx. (2015a). *GO Regional Express Rail Initial Business Case - Appendix A-J.* Retrieved April 15, 2018, from http://www.metrolinx.com/en/regionalplanning/projectevaluation/benefitscases/GO_RER_Initial_Business_Case_Appendix_A-J_EN.pdf

Metrolinx. (2016). *The Eglinton Crosstown Light Rail Transit Project - Mount Dennis Station.* Retrieved from The Crosstown - The Project - Station and Stops: http://www.thecrosstown.ca/the-project/stations-and-stops/mount-dennis-station

Metrolinx. (2018a). *Kitchener GO line*. Retrieved February 26, 2018, from http://www.metrolinx.com/en/regionalplanning/rer/rer_kitchener.aspx

Metrolinx. (2018b). *New Stations*. Retrieved from Metrolinx - Regional Planning: http://www.metrolinx.com/en/regionalplanning/newstations/default.aspx

Mokkapati, C. (2011). *A Simple and Efficient Train Braking Algorithm for PTC Systems.* Retrieved from American Railway Engineering and Maintenance-of-Way Association - Conference proceedings: https://www.arema.org/files/library/2011_Conference_Proceedings/Simple_and_Efficient_Train_Braking_Algorithm_for_PTC_Systems.pdf

Morrison Hershfield Ltd. (2012). Report - Vertical and Horizontal Clearance Measurements Taken Along The USRC West and the USRC East Excluding Union Station Train Shed. In Parsons Brinckerhoff, *Metrolinx Electrification Project - Conceputal Design Report - Part 5 - Union Station Rail Corridor - Version 04.*

Morrison Hershfield Ltd. (2012a). Vertical and Horizontal Clearance Measurements Taken Along the Kitchener Rail Corridor KI1 Strachan Ave to Hwy 427, KI2 Hwy 427 Weston Sub to Mount Pleasant Station Halton Sub & KI3 Mount Pleasant Station to Silver Junction. In Parsons Brinckerhoff, *Metrolinx Electrification Project - Conceptual Design Report - Part 3 - Kitchener Corridor - Version 03.*

Ontario Railway Map Collection. (2017). *Ontario Railway Map Collection (Release Mark: Alpha 15).* Retrieved from The Ontario Railway Map Collection: http://ontariomap.webs.com//Ontario%20Railway%20Map%20Collection.kmz

OpenStreetMap. (2018). *OpenStreetMap*. Retrieved from https://www.openstreetmap.org/#map=13/43.4049/-80.3343&layers=T

OpenTrack Railway Technology Ltd. (2018). *OpenTrack Railway Technology*. Retrieved from Railway Simulation: http://www.opentrack.ch/opentrack/opentrack_e/opentrack_e.html

Outhit, J. (2016). *The Record - Via Rail calls on old trains for new service to Kitchener.* Retrieved February 27, 2018, from https://www.therecord.com/news-story/6377051-via-rail-calls-on-old-trains-for-new-service-to-kitchener/

Pachl, J. (2014). Timetable Design Principles (2nd revised and extended edition). In I. A. Hansen, & J. Pachl, *Railway Timetabling & Operations* (pp. 13-46). Hamburg: Eurailpress.

Parks Canada. (2018, June 3). *Former Canadian National Railways (VIA Rail/GO Transit) Station*. Retrieved from Directory of Federal Heritage Designations > Heritage Railway Stations: http://www.pc.gc.ca/apps/dfhd/page_hrs_eng.aspx?id=2100

Parsons Brinckerhoff. (2014). *Metrolinx Electrification Project - Conceptual Design Report - Part 1 - Lakeshore, Kitchener & Union Station Rail Corridors - Network - Version 06.*

Parsons Brinckerhoff. (2014a). *Metrolinx Electrification Project - Conceptual Design Report - Part 2 - Lakeshore West Corridor - Version 04.* Toronto: Metrolinx.

Parsons Brinckerhoff. (2014b). *Metrolinx Electrification Project - Conceptual Design Report - Part 3 - Kitchener Corridor - Version 03.* Toronto: Metrolinx.

Parsons Brinckerhoff. (2014c). *Metrolinx Electrification Project - Conceptual Design Report - Part 4 - Lakeshore East Corridor - Version 04.* Toronto: Metrolinx.

Parsons Brinckerhoff. (2014d). *Metrolinx Electrification Project - Conceptual Design Report - Part 5 - Union Station Rail Corridor - Version 04.* Toronto: Metrolinx.

Parsons Brinckerhoff. (2014e). *Metrolinx Electrification Project - Conceptual Design Report - Part 6 - Maintenance Facilities - Version 01.* Toronto: Metrolinx.

Pouryousef, H., Lautala, P., & White, T. (2015). Railroad capacity tools and methodologies in the U.S. and Europe. *Journal of Modern Transportation, 23*(1), 30-42.

Powell, J., & Palacin, R. (2015). Passenger Stability Within Moving Railway Vehicles: Limits on Maximum Longitudinal Acceleration. *Urban Rail Transit*, 95-103.

Preston, J., Armstrong, J., Sameni, M. K., Potts, C., Bektas, T., & Khosravi, B. (2011). *Overcoming the Constraints caused by Nodes on the Rail Network.* Retrieved September 26, 2017, from http://www.railway-research.org/IMG/pdf/f3_preston_john.pdf

Radtke, A. (2008). Infrastructure Modelling. In I. A. Hansen, & J. Pachl, *Railway Timetable & Traffic* (pp. 43-57). Hamburg: Eurailpress.

Railway Association of Canada. (2012). *Canadian Rail Atlas.* Ottawa: Railway Association of Canada.

Region of Waterloo. (2017). *ION Stage 1 Bus Rapid Transit and Stage 2 Light Rail Transit Map: (Cambridge to Kitchener).* Retrieved from Home - ION Information - Maps - System: http://rapidtransit.regionofwaterloo.ca/en/resourcesGeneral/RouteMapRevised-MAR2017.jpg

Region of Waterloo. (2018). *Next Steps*. Retrieved from Home - ION Information - Timelines: http://rapidtransit.regionofwaterloo.ca/en/projectinformation/nextsteps.asp

Roberts, E. W., & Stremes, D. P. (2015). *Canadian Trackside Guide 2015.* Ottawa: Bytown Railway Society.

Schittenhelm, B. (2010). Timetable Attractiveness Parameters. *WIT Transactions on The Built Environment, 114*, 975-984.

Schittenhelm, B. (2011). *Planning With Timetable Supplements in Railway Timetables.* Retrieved April 15, 2018, from Trafikdage på Aalborg Universitet: http://www.trafikdage.dk/papers_2011/63_BerndSchittenhelm.pdf

Schittenhelm, B. (2013). *Quantitative Methods for Assessments of Railway Timetables - PhD Thesis.* Kongens Lyngby: DTU Transport.

Smith, J. P. (2017). *C.N.Rys. Brampton Subdivision.* Retrieved January 21, 2018, from http://www.cnr-in-ontario.com/Subdivisions/Brampton.html

Thomas, D. (2017). *VIA High Frequency Rail: Details emerge*. Retrieved April 15, 2018, from Railway Age: https://www.railwayage.com/freight/class-i/via-high-frequency-rail-details-emerge/

Transit Toronto. (2017). *GO TRANSIT'S KITCHENER LINE*. Retrieved February 11, 2018, from https://transit.toronto.on.ca/regional/2102.shtml

Transport Canada. (2018). *Subpart A - Classes of Track*. Retrieved from Government of Canada - Transport Canada: https://www.tc.gc.ca/eng/railsafety/rules-tce54-832.htm

Triplinx. (2018). *Schedules By Route.* Retrieved February 25, 2018, from https://www.triplinx.ca/en/route-schedules/6/RouteSchedules/union-pearson-express/904/up-express-pearson-airport/1?Date=2%2F26%2F2018&Hour=3&Minute=55&Meridian=AM

Tyler, J. (2003). *The philosophy and practice of Taktfahrplan: a case-study of the East Coast Main Line.* Retrieved March 30, 2018, from White Rose Research Online: http://eprints.whiterose.ac.uk/2058/

UIC. (2004). *UIC Code 406 - 1st edition.* Retrieved April 15, 2018, from Banverket: http://banportalen.banverket.se/Banportalen/upload/1753/HandbokUIC406.pdf

Vansteenwegen, P., & Oudheusden, D. V. (2007). Decreasing the passenger waiting time for an intercity rail network. *Transportation Research Part B*, 478-492.

VIA Rail. (1976). *VIA - CN - CP Rail - System Timetable (effective October 31, 1976).* Montreal: VIA Rail.

VIA Rail. (1977). *VIA - System Timetable (effective April 24, 1977).* Montreal: VIA Rail.

VIA Rail. (1988). *National Timetable (effective October 30, 1988).* Montreal: VIA Rail.

VIA Rail. (1989). *National Timetable (effective April 30, 1989).* Montreal: VIA Rail.

VIA Rail. (2016). *2016 Annual Public Meeting: Questions and Answers.* Retrieved February 27, 2018, from http://www.viarail.ca/sites/all/files/media/pdfs/About_VIA/Question_Final_EN.pdf

VIA Rail. (2016a). *Summary of the 2016-2020 Corporate Plan and 2016 Operating and Capital Budgets.* Retrieved March 4, 2018, from http://www.viarail.ca/sites/all/files/media/pdfs/About_VIA/our-company/corporate-plan/Summary%20of%20the%202016-2020%20Corporate%20Plan.pdf

VIA Rail. (2017). *2017 Annual Public Meeting: Questions and Answers.* Retrieved February 27, 2018, from http://www.viarail.ca/sites/all/files/media/pdfs/About_VIA/APM_2017_QA_FINAL_EN.pdf

VIA Rail. (2018a). *Summary of the 2017-2021 Corporate Plan and 2017 Operations and Capital Budgets.* Retrieved March 30, 2018, from http://www.viarail.ca/sites/all/files/media/pdfs/About_VIA/our-company/corporate-plan/CorporatePlan_2017_2021.pdf

VIA Rail. (2018b). *Timetable - Effective June 17, 2018.* Retrieved October 25, 2018, from https://www.viarail.ca/sites/all/files/media/pdfs/schedules/VIARail_Timetable-2018_Juin-v2.pdf

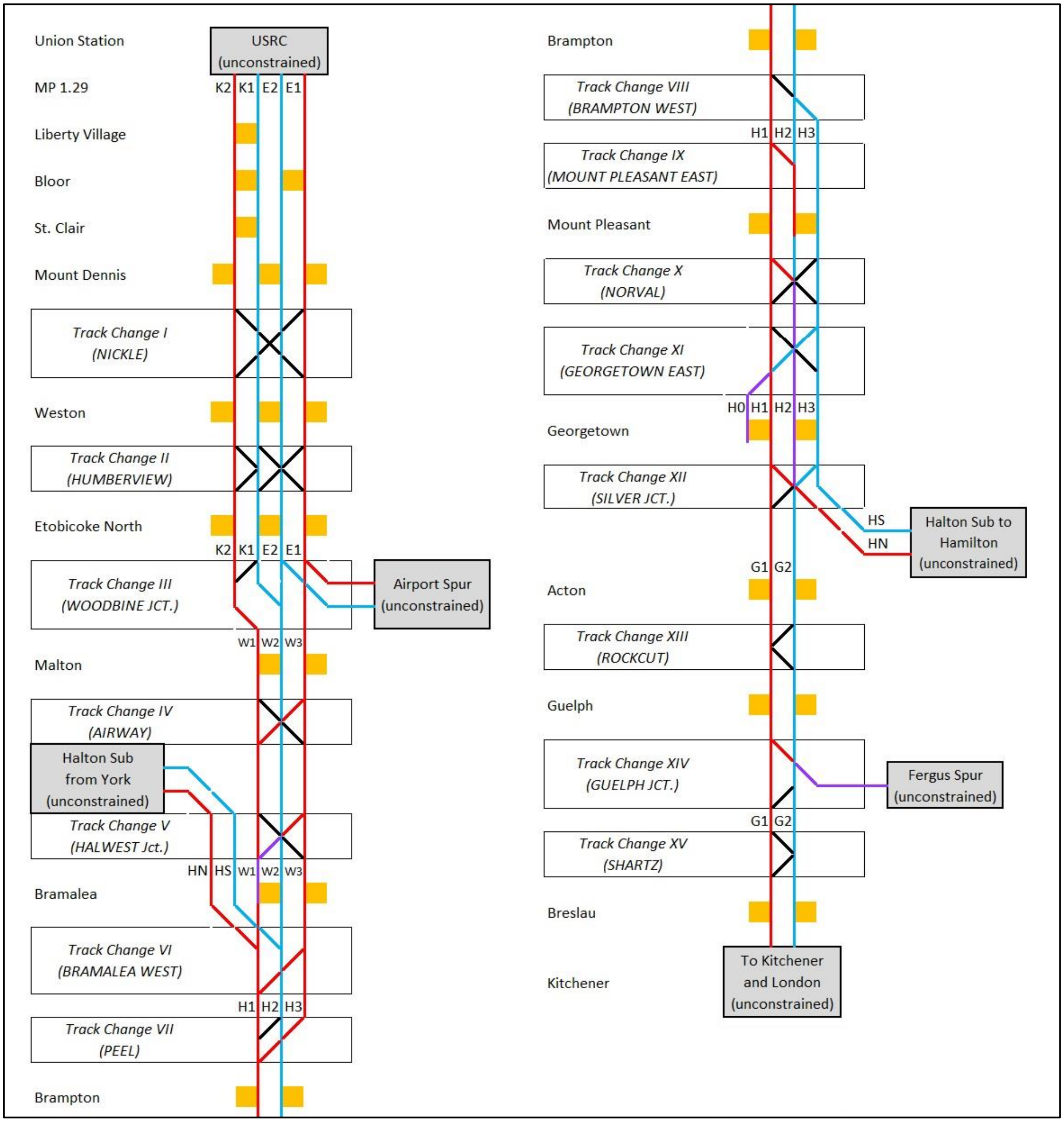
VIA Rail. (2018c). *2018 Annual Public Meeting: Questions and Answers (Part 3).* Retrieved November 18, 2018, from VIA Rail - Governance and Reports: https://www.viarail.ca/sites/all/files/media/pdfs/About_VIA/our-company/annual-public-meeting/2018%20ANNUAL%20PUBLIC%20MEETING-PART3.pdf

Walker, M. (2008). *SPV's Comprehensive Railroad Atlas of North America - Ontario.* Canterbury (England): SPV.

Waterloo Region Record. (2012). *Via Rail is cutting service to and from Kitchener*. Retrieved February 11, 2018, from https://www.therecord.com/news-story/2606278-via-rail-is-cutting-service-to-and-from-kitchener/

Wegener, M. (2010). *Linienzugbeeinflussung (LZB) [in German]*. Retrieved from Indusi.de - Informationen und Diskussionsbeiträge zum Schienenverkehr: http://www.marco-wegener.de/technik/lzb.htm

Appendix I: Assumed track plan



Note: Tracks are represented by a line which is coloured according to the principal direction of traffic, with red lines indicating tracks used for eastbound movements (i.e. towards Toronto Union), blue lines indicating tracks used for westbound movements (i.e. away from Toronto Union) and purple lines (to be found between Halwest Jct. and Bramalea station, between Norval and Silver Jct. and on the Fergus Spur) indicating tracks used by eastbound and westbound movements alike, while orange squares represent platforms serving any adjacent tracks and the term "unconstrained" refers to any network areas where capacity is assumed to be unconstrained and the exact track layout therefore does not need to be defined.

Appendix II: Timetable concepts with all timings

Scenario I (Individual trips): Variable-block signaling system

Train service		IR	RER	AIR	Freight	IC	Freight	RER	AIR	IR	RER	AIR	IC	Freight	AIR	RER
Station dwell time [s]		40	20	40	n/a	60	n/a	20	40	40	20	40	60	n/a	40	20
Routing		IR-W2	RER-W1	AIR-W1	F-W1	IC-W1	F-W1	RER-W6BL	AIR-W1	IR-W2	RER-W3a	AIR-W1	IC-W2	F-W1	AIR-W1	RER-W7BLa
Toronto		16:03:00	16:03:00	16:07:00		16:20:00		16:20:00	16:23:00	16:31:00	16:32:00	16:38:00	16:44:00		16:55:00	16:50:00
Liberty Village		16:08:02	16:08:36	16:11:33		16:25:05		16:25:36	16:27:33	16:36:02	16:37:36	16:42:33	16:49:05		16:59:33	16:55:36
Bloor		16:10:43	16:11:09	16:14:12		16:26:40		16:28:09	16:30:12	16:38:43	16:40:09	16:45:12	16:50:40		17:02:12	16:58:09
St. Clair		16:12:04	16:13:12	16:15:33		16:27:28		16:30:12	16:31:33	16:40:04	16:42:12	16:46:33	16:51:28		17:03:33	17:00:12
Mount Dennis	arr	16:13:35	16:15:04	16:17:04		16:29:00		16:32:04	16:33:04	16:41:35	16:44:04	16:48:04	16:53:00		17:05:04	17:02:04
Mount Dennis		16:14:15	16:15:24	16:17:44		16:30:00		16:32:24	16:33:44	16:42:15	16:44:24	16:48:44	16:54:00		17:05:44	17:02:24
Weston		16:15:49	16:17:41	16:19:18		16:32:05		16:34:41	16:35:18	16:43:49	16:46:41	16:50:18	16:56:05		17:07:18	17:04:41
Etobicoke North		16:17:41	16:20:42	16:21:08		16:33:55		16:37:42	16:37:08	16:45:41	16:49:42	16:52:08	16:57:55		17:09:08	17:07:42
Woodbine Jct.		16:19:14	16:23:15	16:23:16		16:35:20		16:40:15	16:39:16	16:47:14	16:52:15	16:54:16	16:59:20		17:11:16	17:10:15
Malton		16:20:04	16:25:21			16:36:06		16:42:21		16:48:04	16:54:21		17:00:06			17:12:21
Halwest Jct.		16:21:28	16:27:13		16:30:30	16:37:23	16:43:00	16:44:24		16:49:28	16:56:13		17:01:23	17:06:00		17:14:51
Bramalea	arr	16:22:20	16:28:04		16:31:13	16:37:46	16:43:43	16:45:24		16:50:20	16:57:04		17:01:46	17:06:43		17:15:52
Bramalea		16:23:00	16:28:24		16:31:13	16:37:46	16:43:43			16:51:00	16:57:24		17:01:46	17:06:43		signal stop
Brampton	arr	16:26:30	16:31:53		16:36:14	16:40:37	16:48:44			16:54:30	17:00:53		17:04:37	17:11:44		(0 minutes)
Brampton		16:27:10	16:32:13		16:36:14	16:41:37	16:48:44			16:55:10	17:01:13		17:05:37	17:11:44		before
Mount Pleasant		16:31:12	16:35:25		16:40:07	16:44:29	16:52:37			16:59:12	17:04:25		17:08:47	17:15:37		entering
Georgetown	arr	16:35:36	16:40:17		16:46:38	16:47:33	16:59:08			17:03:36	17:11:45		17:11:58	17:22:08		Halwest Jct.
Georgetown		16:36:16			16:46:38	16:47:33	16:59:08			17:04:16	signal stop		17:11:58	17:22:08		
Silver Jct.		16:37:25			16:47:32	16:48:03	17:00:02			17:05:25	(2 minutes)		17:12:52	17:23:02		
Acton		16:43:15				16:52:22				17:11:15	before		17:17:41			
Guelph	arr	16:53:35				17:02:07				17:21:35	entering		17:27:26			
Guelph		16:54:15				17:04:07				17:22:15	Georgetown		17:29:26			
Guelph Jct.		16:55:34				17:05:46				17:23:34			17:31:06			
Breslau		17:01:46				17:10:27				17:29:46			17:35:47			
Kitchener	arr	17:06:56				17:15:08				17:34:56			17:40:27			
Routing						IC-W3F							IC-W4F			
Guelph						17:06:07							17:31:26			
Guelph Jct.						17:07:59							17:33:19			
Hespeler						17:18:17							17:43:37			
Preston						17:22:48							17:48:08			
Cambridge	arr					17:29:06							17:54:26			
Travel time		01:03:56	00:37:17	00:16:16	00:17:02	00:55:08	00:17:02	00:25:24	00:16:16	01:03:56	00:39:45	00:16:16	00:56:27	00:17:02	00:16:16	00:25:52

Train service		RER	IR	AIR	RER	IC	Freight	AIR	RER	IR	AIR	RER	IC	Freight	AIR	
Station dwell time [s]		20	40	40	20	60	n/a	40	20	40	40	20	60	n/a	40	
Routing						IC-E5F							IC-E5F			
Cambridge						16:08:21							16:37:21			
Preston						16:16:36							16:45:36			
Hespeler						16:21:08							16:50:08			
Guelph Jct.						16:30:24							16:59:24			
Guelph	arr					16:31:53							17:00:53			
Routing		RER-E1	IR-E1	AIR-E1	RER-E3BL	IC-E4	F-E2	AIR-E1	RER-E1	IR-E1	AIR-E1	RER-E3BL	IC-E4	F-E2	AIR-E1	
Kitchener			16:04:36			16:23:31				16:37:36			16:52:31			
Breslau			16:10:31			16:28:36				16:43:31			16:57:36			
Guelph Jct.			16:16:02			16:33:13				16:49:02			17:02:13			
Guelph	arr		16:17:20			16:34:34				16:50:20			17:03:34			
Guelph			16:18:00			16:36:34				16:51:00			17:05:34			
Acton			16:29:02			16:46:41				17:02:02			17:15:41			
Silver Jct.			16:33:50			16:51:00	16:50:55			17:06:50			17:20:00	17:20:25		
Georgetown	arr		16:34:47			16:51:30	16:51:49			17:07:47			17:20:30	17:21:19		
Georgetown		16:29:44	16:35:27			16:51:30	16:51:49		17:00:44	17:08:27			17:20:30	17:21:19		
Mount Pleasant		16:35:04	16:40:31			16:54:37	16:58:39		17:06:04	17:13:31			17:23:37	17:28:09		
Brampton	arr	16:37:55	16:43:26			16:56:55	17:02:24		17:08:55	17:16:26			17:25:55	17:31:54		
Brampton		16:38:15	16:44:06			16:57:55	17:02:24		17:09:15	17:17:06			17:26:55	17:31:54		
Bramalea	arr	16:41:45	16:48:14			17:01:19	17:07:14		17:12:45	17:21:14			17:30:19	17:36:44		
Bramalea		16:42:05	16:48:54		16:55:05	17:01:19	17:07:14		17:13:05	17:21:54		17:25:05	17:30:19	17:36:44		
Halwest Jct.		16:42:50	16:49:46		16:55:50	17:01:41	17:08:00		17:13:50	17:22:46		17:25:50	17:30:41	17:37:30		
Malton		16:45:08	16:51:10		16:58:08	17:04:11			17:16:08	17:24:10		17:28:08	17:33:11			
Woodbine Jct.		16:46:25	16:52:00	16:55:27	16:59:25	17:05:03		17:12:27	17:17:25	17:25:00	17:28:27	17:29:25	17:34:03		17:41:27	
Etobicoke North		16:48:54	16:53:34	16:57:35	17:01:54	17:06:28		17:14:35	17:19:54	17:26:34	17:30:35	17:31:54	17:35:28		17:43:35	
Weston		16:51:54	16:55:24	16:59:25	17:04:54	17:08:15		17:16:25	17:22:54	17:28:24	17:32:25	17:34:54	17:37:15		17:45:25	
Mount Dennis	arr	16:53:51	16:56:59	17:00:59	17:06:51	17:09:51		17:17:59	17:24:51	17:29:59	17:33:59	17:36:51	17:38:51		17:46:59	
Mount Dennis		16:54:11	16:57:39	17:01:39	17:07:11	17:10:51		17:18:39	17:25:11	17:30:39	17:34:39	17:37:11	17:39:51		17:47:39	
St. Clair		16:56:23	16:59:10	17:03:10	17:09:23	17:12:52		17:20:10	17:27:23	17:32:10	17:36:10	17:39:23	17:41:52		17:49:10	
Bloor		16:58:26	17:01:12	17:05:12	17:11:26	17:13:40		17:22:12	17:29:26	17:34:12	17:38:12	17:41:26	17:42:40		17:51:12	
Liberty Village		17:00:57	17:03:10	17:07:10	17:13:57	17:15:10		17:24:10	17:31:57	17:36:10	17:40:10	17:43:57	17:44:10		17:53:10	
Toronto	arr	17:05:00	17:07:00	17:11:00	17:18:00	17:19:00		17:28:00	17:36:00	17:40:00	17:44:00	17:48:00	17:48:00		17:57:00	
Travel time		00:35:16	01:02:24	00:15:33	00:22:55	00:55:29	00:17:05	00:15:33	00:35:16	01:02:24	00:15:33	00:22:55	00:55:29	00:17:05	00:15:33	

Scenario I (Individual trips): Fixed-block signaling system

Train service	Freight	IR	RER	AIR	Freight	Freight	IC	Freight	Freight	RER	AIR	IR	Freight	RER	AIR	IC	Freight	Freight	Freight	AIR	RER	Freight
Station dwell time [s]	n/a	40	20	40	n/a	n/a	60	n/a	n/a	20	40	40	n/a	20	40	60	n/a	n/a	n/a	40	20	n/a
Routing	F-W1	IR-W1	RER-W1	AIR-W1	F-W1	F-W1	IC-W1	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W1	F-W1	RER-W3a	AIR-W1	IC-W2	F-W1	F-W1	F-W1	AIR-W1	RER-W7BLa	F-W1
Toronto		16:03:00	16:03:00	16:07:00			16:20:00			16:20:00	16:23:00	16:31:00		16:32:00	16:38:00	16:44:00				16:55:00	16:50:00	
Liberty Village		16:08:02	16:08:36	16:11:33			16:25:05			16:25:36	16:27:33	16:36:02		16:37:36	16:42:33	16:49:05				16:59:33	16:55:36	
Bloor		16:10:43	16:11:09	16:14:12			16:26:40			16:28:09	16:30:12	16:38:43		16:40:09	16:45:12	16:50:40				17:02:12	16:58:09	
St. Clair		16:12:04	16:13:12	16:15:33			16:27:28			16:30:12	16:31:33	16:40:04		16:42:12	16:46:33	16:51:28				17:03:33	17:00:12	
Mount Dennis arr		16:13:35	16:15:04	16:17:04			16:29:00			16:32:04	16:33:04	16:41:35		16:44:04	16:48:04	16:53:00				17:05:04	17:02:04	
Mount Dennis		16:14:15	16:15:24	16:17:44			16:30:00			16:32:24	16:33:44	16:42:15		16:44:24	16:48:44	16:54:00				17:05:44	17:02:24	
Weston		16:15:49	16:17:41	16:19:18			16:32:05			16:34:41	16:35:18	16:43:49		16:46:41	16:50:18	16:56:05				17:07:18	17:04:41	
Etobicoke North		16:17:41	16:20:42	16:21:08			16:33:55			16:37:42	16:37:08	16:45:41		16:49:42	16:52:08	16:57:55				17:09:08	17:07:42	
Woodbine Jct.		16:19:14	16:23:06	16:23:06			16:35:20			16:40:06	16:39:06	16:47:14		16:52:06	16:54:06	16:59:20				17:11:06	17:10:06	
Malton		16:20:04	16:24:58				16:36:06			16:41:58		16:48:04		16:53:58		17:00:06					17:11:58	
Halwest Jct.	16:18:00	16:21:28	16:26:51		16:29:00	16:32:00	16:37:23	16:42:00	16:46:00	16:44:01		16:49:28	16:52:00	16:55:51		17:01:23	17:02:00	17:05:00	17:08:00		17:14:28	17:15:00
Bramalea arr	16:18:41	16:22:20	16:27:41		16:29:41	16:32:41	16:37:46	16:42:41	16:46:41	16:45:02		16:50:20	16:52:41	16:56:41		17:01:46	17:02:41	17:05:41	17:08:41		17:15:30	17:15:41
Bramalea	16:18:41	16:23:00	16:28:01		16:29:41	16:32:41	16:37:46	16:42:41	16:46:41			16:51:00	16:52:41	16:57:01		17:01:46	17:02:41	17:05:41	17:08:41		signal stop	17:15:41
Brampton arr	16:23:41	16:26:30	16:31:31		16:34:41	16:37:41	16:40:37	16:47:41	16:51:41			16:54:30	16:57:41	17:00:31		17:04:37	17:07:41	17:10:41	17:13:41		(0 minutes)	17:20:41
Brampton	16:23:41	16:27:10	16:31:51		16:34:41	16:37:41	16:41:37	16:47:41	16:51:41			16:55:10	16:57:41	17:00:51		17:05:37	17:07:41	17:10:41	17:13:41		before	17:20:41
Mount Pleasant	16:27:33	16:30:45	16:35:02		16:38:33	16:41:33	16:44:29	16:51:33	16:55:33			16:58:45	17:01:33	17:04:02		17:08:39	17:11:33	17:14:33	17:17:33		entering	17:24:33
Georgetown arr	16:34:04	16:35:09	16:39:54		16:45:04	16:48:04	16:47:33	16:58:04	17:02:04			17:03:09	17:08:04	17:11:22		17:11:50	17:18:04	17:21:04	17:24:04		Halwest Jct.	17:31:04
Georgetown	16:34:04	16:35:49			16:45:04	16:48:04	16:47:33	16:58:04	17:02:04			17:03:49	17:08:04	signal stop		17:11:50	17:18:04	17:21:04	17:24:04			17:31:04
Silver Jct.	16:34:57	16:36:45			16:45:57	16:48:57	16:48:03	16:58:57	17:02:57			17:04:45	17:08:57	(2 minutes)		17:12:44	17:18:57	17:21:57	17:24:57			17:31:57
Acton		16:42:14					16:52:22					17:10:14		before		17:17:19						
Guelph arr		16:52:35					17:02:07					17:20:35		entering		17:27:04						
Guelph		16:53:15					17:04:07					17:21:15		Georgetown		17:29:04						
Guelph Jct.		16:54:33					17:05:46					17:22:33				17:30:44						
Breslau		17:00:46					17:10:27					17:28:46				17:35:24						
Kitchener arr		17:05:55					17:15:08					17:33:55				17:40:05						
Routing							IC-W3F									IC-W4F						
Guelph							17:06:07									17:31:04						
Guelph Jct.							17:07:59									17:32:56						
Hespeler							17:18:17									17:43:15						
Preston							17:22:48									17:47:46						
Cambridge arr							17:29:06									17:54:04						
Travel time	00:16:57	01:02:55	00:36:54	00:16:06	00:16:57	00:16:57	00:55:08	00:16:57	00:16:57	00:25:02	00:16:06	01:02:55	00:16:57	00:39:22	00:16:06	00:56:05	00:16:57	00:16:57	00:16:57	00:16:06	00:25:30	00:16:57

Train service	Freight	RER	IR	AIR	RER	Freight	Freight	IC	Freight	AIR	Freight	RER	Freight	IR	AIR	RER	IC	Freight	AIR			
Station dwell time [s]	n/a	20	40	40	20	n/a	n/a	60	n/a	40	n/a	20	n/a	40	40	20	60	n/a	40			
Routing								IC-E5F									IC-E5F					
Cambridge								16:10:02									16:39:02					
Preston								16:18:17									16:47:17					
Hespeler								16:22:48									16:51:48					
Guelph Jct.								16:32:05									17:01:05					
Guelph arr								16:33:34									17:02:34					
Routing	F-E1	RER-E1	IR-E1	AIR-E1	RER-E3BL	F-E1	F-E1	IC-E4	F-E2	AIR-E1	F-E1	RER-E1	F-E1	IR-E1	AIR-E1	RER-E3BL	IC-E1	F-E2	AIR-E1			
Kitchener			16:04:41					16:23:45						16:37:41			16:53:22					
Breslau			16:10:37					16:28:49						16:43:37			16:58:26					
Guelph Jct.			16:16:08					16:33:26						16:49:08			17:03:03					
Guelph arr			16:17:25					16:34:48						16:50:25			17:04:24					
Guelph			16:18:05					16:36:48						16:51:05			17:06:24					
Acton			16:29:07					16:46:55						17:02:07			17:16:32					
Silver Jct.	16:23:11		16:33:56			16:39:41	16:42:41	16:51:13	16:48:57		16:54:11		17:01:11	17:06:56			17:20:50	17:18:57				
Georgetown arr	16:24:06		16:34:52			16:40:36	16:43:36	16:51:43	16:49:52		16:55:06		17:02:06	17:07:52			17:21:20	17:19:52				
Georgetown	16:24:06	16:29:44	16:35:32			16:40:36	16:43:36	16:51:43	16:49:52		16:55:06	17:00:44	17:02:06	17:08:32			17:21:20	17:19:52				
Mount Pleasant	16:30:47	16:35:04	16:40:37			16:47:17	16:50:17	16:54:50	16:56:40		17:01:47	17:06:04	17:08:47	17:13:37			17:24:27	17:26:40				
Brampton arr	16:34:25	16:37:55	16:43:32			16:50:55	16:53:55	16:57:08	17:00:25		17:05:25	17:08:55	17:12:25	17:16:32			17:26:45	17:30:25				
Brampton	16:34:25	16:38:15	16:44:12			16:50:55	16:53:55	16:58:08	17:00:25		17:05:25	17:09:15	17:12:25	17:17:12			17:27:45	17:30:25				
Bramalea arr	16:39:14	16:41:45	16:48:14			16:55:44	16:58:44	17:01:32	17:05:14		17:10:14	17:12:45	17:17:14	17:21:14			17:31:37	17:35:14				
Bramalea	16:39:14	16:42:05	16:48:54		16:55:05	16:55:44	16:58:44	17:01:32	17:05:14		17:10:14	17:13:05	17:17:14	17:21:54		17:25:05	17:31:37	17:35:14				
Halwest Jct.	16:40:00	16:42:50	16:49:46		16:55:50	16:56:30	16:59:30	17:01:55	17:06:00		17:11:00	17:13:50	17:18:00	17:22:46		17:25:50	17:31:59	17:36:00				
Malton		16:45:08	16:51:10		16:58:08			17:04:11				17:16:08		17:24:10		17:28:08	17:33:17					
Woodbine Jct.		16:46:25	16:52:00	16:55:36	16:59:25			17:05:03		17:12:36		17:17:25		17:25:00	17:28:36	17:29:25	17:34:03		17:41:36			
Etobicoke North		16:48:54	16:53:34	16:57:35	17:01:54			17:06:28		17:14:35		17:19:54		17:26:34	17:30:35	17:31:54	17:35:28		17:43:35			
Weston		16:51:54	16:55:24	16:59:25	17:04:54			17:08:15		17:16:25		17:22:54		17:28:24	17:32:25	17:34:54	17:37:15		17:45:25			
Mount Dennis arr		16:53:51	16:56:59	17:00:59	17:06:51			17:09:51		17:17:59		17:24:51		17:29:59	17:33:59	17:36:51	17:38:51		17:46:59			
Mount Dennis		16:54:11	16:57:39	17:01:39	17:07:11			17:10:51		17:18:39		17:25:11		17:30:39	17:34:39	17:37:11	17:39:51		17:47:39			
St. Clair		16:56:23	16:59:10	17:03:10	17:09:23			17:12:52		17:20:10		17:27:23		17:32:10	17:36:10	17:39:23	17:41:52		17:49:10			
Bloor		16:58:26	17:01:12	17:05:12	17:11:26			17:13:40		17:22:12		17:29:26		17:34:12	17:38:12	17:41:26	17:42:40		17:51:12			
Liberty Village		17:00:57	17:03:10	17:07:10	17:13:57			17:15:10		17:24:10		17:31:57		17:36:10	17:40:10	17:43:57	17:44:10		17:53:10			
Toronto arr		17:05:00	17:07:00	17:11:00	17:18:00			17:19:00		17:28:00		17:36:00		17:40:00	17:44:00	17:48:00	17:48:00		17:57:00			
Travel time	00:16:49	00:35:16	01:02:19	00:15:24	00:22:55	00:16:49	00:16:49	00:55:15	00:17:03	00:15:24	00:16:49	00:35:16	00:16:49	01:02:19	00:15:24	00:22:55	00:54:38	00:17:03	00:15:24			

Scenario IIa (partially periodic timetable, morning peak pattern): Variable-block signaling system

Train service		IC	RER	AIR	Freight	RER	AIR	IR	RER	AIR	Freight	RER	AIR		
Station dwell time [s]		60	20	40	n/a	20	40	40	20	40	n/a	20	40		
Routing		IC-W2	RER-W5MP	AIR-W1	F-W1	RER-W6BL	AIR-W1	IR-W2	RER-W5MP	AIR-W1	F-W1	RER-W4a	AIR-W1		
Toronto		16:00:00	16:02:00	16:08:00		16:17:00	16:23:00	16:26:00	16:32:00	16:38:00		16:47:00	16:53:00		
Liberty Village		16:05:05	16:07:36	16:12:33		16:22:36	16:27:33	16:31:02	16:37:36	16:42:33		16:52:36	16:57:33		
Bloor		16:06:40	16:10:09	16:15:12		16:25:09	16:30:12	16:33:43	16:40:09	16:45:12		16:55:09	17:00:12		
St. Clair		16:07:28	16:12:12	16:16:33		16:27:12	16:31:33	16:35:04	16:42:12	16:46:33		16:57:12	17:01:33		
Mount Dennis	arr	16:09:00	16:14:04	16:18:04		16:29:04	16:33:04	16:36:35	16:44:04	16:48:04		16:59:04	17:03:04		
Mount Dennis		16:10:00	16:14:24	16:18:44		16:29:24	16:33:44	16:37:15	16:44:24	16:48:44		16:59:24	17:03:44		
Weston		16:12:05	16:16:41	16:20:18		16:31:41	16:35:18	16:38:49	16:46:41	16:50:18		17:01:41	17:05:18		
Etobicoke North		16:13:55	16:19:42	16:22:08		16:34:42	16:37:08	16:40:41	16:49:42	16:52:08		17:04:42	17:07:08		
Woodbine Jct.		16:15:20	16:22:15	16:24:16		16:37:15	16:39:16	16:42:14	16:52:15	16:54:16		17:07:15	17:09:16		
Malton		16:16:06	16:24:21			16:39:21		16:43:04	16:54:21			17:09:21			
Halwest Jct.		16:17:23	16:26:13		16:29:30	16:41:24		16:44:28	16:56:13		16:59:30	17:11:13			
Bramalea	arr	16:17:46	16:27:04		16:30:13	16:42:24		16:45:20	16:57:04		17:00:13	17:12:04			
Bramalea		16:17:46	16:27:24		16:30:13			16:46:00	16:57:24		17:00:13	17:12:24			
Brampton	arr	16:20:37	16:30:53		16:35:14			16:49:30	17:00:53		17:05:14	17:15:53			
Brampton		16:21:37	16:31:13		16:35:14			16:50:10	17:01:13		17:05:14	17:16:13			
Mount Pleasant	arr	16:24:47	16:34:05		16:39:07			16:53:32	17:04:05		17:09:07	17:19:31			
Mount Pleasant		16:24:47			16:39:07			16:54:12			17:09:07	17:19:51			
Georgetown	arr	16:27:58			16:45:38			16:58:36			17:15:38	17:25:45			
Georgetown		16:27:58			16:45:38			16:59:16			17:15:38	signal stop			
Silver Jct.		16:28:52			16:46:32			17:00:25			17:16:32	(1 minute)			
Acton		16:33:41						17:06:15				before			
Guelph	arr	16:43:26						17:16:35				entering			
Guelph		16:45:26						17:17:15				Georgetown			
Guelph Jct.		16:47:06						17:18:34							
Breslau		16:51:47						17:24:46							
Kitchener	arr	16:56:27						17:29:56							
Routing		IC-W4F													
Guelph		16:47:26													
Guelph Jct.		16:49:19													
Hespeler		16:59:37													
Preston		17:04:08													
Cambridge	arr	17:10:26													
Travel time		00:56:27	00:32:05	00:16:16	00:17:02	00:25:24	00:16:16	01:03:56	00:32:05	00:16:16	00:17:02	00:38:45	00:16:16		

Train service		IR	AIR	RER	Freight	IC	AIR	RER	IR	AIR	RER	Freight	IC	AIR	RER
Station dwell time [s]		40	40	20	n/a	60	40	20	40	40	20	n/a	60	40	20
Routing						IC-E5F							IC-E5F		
Cambridge						16:04:21							16:34:21		
Preston						16:12:36							16:42:36		
Hespeler						16:17:08							16:47:08		
Guelph Jct.						16:26:24							16:56:24		
Guelph	arr					16:27:53							16:57:53		
Routing		IR-E1	AIR-E1	RER-E3BL	F-E1	IC-E1	AIR-E1	RER-E1	IR-E1	AIR-E1	RER-E3BL	F-E1	IC-E1	AIR-E1	RER-E1
Kitchener		16:01:36				16:20:16			16:31:36				16:50:16		
Breslau		16:07:31				16:25:21			16:37:31				16:55:21		
Guelph Jct.		16:13:02				16:29:58			16:43:02				16:59:58		
Guelph	arr	16:14:20				16:31:19			16:44:20				17:01:19		
Guelph		16:15:00				16:33:19			16:45:00				17:03:19		
Acton		16:26:02				16:43:26			16:56:02				17:13:26		
Silver Jct.		16:30:50			16:37:11	16:47:45			17:00:50			17:07:11	17:17:45		
Georgetown	arr	16:31:47			16:38:05	16:48:14			17:01:47			17:08:05	17:18:14		
Georgetown		16:32:27			16:38:05	16:48:14		16:51:44	17:02:27			17:08:05	17:18:14		17:21:44
Mount Pleasant		16:37:31			16:44:46	16:51:22		16:57:04	17:07:31			17:14:46	17:21:22		17:27:04
Brampton	arr	16:40:26			16:48:24	16:53:39		16:59:55	17:10:26			17:18:24	17:23:39		17:29:55
Brampton		16:41:06			16:48:24	16:54:39		17:00:15	17:11:06			17:18:24	17:24:39		17:30:15
Bramalea	arr	16:45:14			16:53:14	16:58:37		17:03:45	17:15:14			17:23:14	17:28:37		17:33:45
Bramalea		16:45:54		16:49:05	16:53:14	16:58:37		17:04:05	17:15:54		17:19:05	17:23:14	17:28:37		17:34:05
Halwest Jct.		16:46:46		16:49:50	16:54:00	16:58:59		17:04:50	17:16:46		17:19:50	17:24:00	17:28:59		17:34:50
Malton		16:48:10		16:52:08		17:00:17		17:07:08	17:18:10		17:22:08		17:30:17		17:37:08
Woodbine Jct.		16:49:00	16:51:27	16:53:25		17:01:03	17:06:27	17:08:25	17:19:00	17:21:27	17:23:25		17:31:03	17:36:27	17:38:25
Etobicoke North		16:50:34	16:53:35	16:55:54		17:02:28	17:08:35	17:10:54	17:20:34	17:23:35	17:25:54		17:32:28	17:38:35	17:40:54
Weston		16:52:24	16:55:25	16:58:54		17:04:15	17:10:25	17:13:54	17:22:24	17:25:25	17:28:54		17:34:15	17:40:25	17:43:54
Mount Dennis	arr	16:53:59	16:56:59	17:00:51		17:05:51	17:11:59	17:15:51	17:23:59	17:26:59	17:30:51		17:35:51	17:41:59	17:45:51
Mount Dennis		16:54:39	16:57:39	17:01:11		17:06:51	17:12:39	17:16:11	17:24:39	17:27:39	17:31:11		17:36:51	17:42:39	17:46:11
St. Clair		16:56:10	16:59:10	17:03:23		17:08:52	17:14:10	17:18:23	17:26:10	17:29:10	17:33:23		17:38:52	17:44:10	17:48:23
Bloor		16:58:12	17:01:12	17:05:26		17:09:40	17:16:12	17:20:26	17:28:12	17:31:12	17:35:26		17:39:40	17:46:12	17:50:26
Liberty Village		17:00:10	17:03:10	17:07:57		17:11:10	17:18:10	17:22:57	17:30:10	17:33:10	17:37:57		17:41:10	17:48:10	17:52:57
Toronto	arr	17:04:00	17:07:00	17:12:00		17:15:00	17:22:00	17:27:00	17:34:00	17:37:00	17:42:00		17:45:00	17:52:00	17:57:00
Travel time		01:02:24	00:15:33	00:22:55	00:16:49	00:54:44	00:15:33	00:35:16	01:02:24	00:15:33	00:22:55	00:16:49	00:54:44	00:15:33	00:35:16

Scenario IIa (partially periodic timetable, morning peak pattern): Fixed-block signaling system

Train service		IC	Freight	RER	AIR	Freight	Freight	Freight	RER	AIR	IR	Freight	RER	AIR	Freight	Freight	RER	AIR			
Station dwell time [s]		60	n/a	20	40	n/a	n/a	n/a	20	40	40	n/a	20	40	n/a	n/a	20	40			
Routing		IC-W2	F-W1	RER-W5MP	AIR-W1	F-W1	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W2	F-W1	RER-W5MP	AIR-W1	F-W1	F-W1	RER-W4a	AIR-W1			
Toronto		16:00:00		16:02:00	16:08:00				16:17:00	16:23:00	16:26:00		16:32:00	16:38:00			16:47:00	16:53:00			
Liberty Village		16:05:05		16:07:36	16:12:33				16:22:36	16:27:33	16:31:02		16:37:36	16:42:33			16:52:36	16:57:33			
Bloor		16:06:40		16:10:09	16:15:12				16:25:09	16:30:12	16:33:43		16:40:09	16:45:12			16:55:09	17:00:12			
St. Clair		16:07:28		16:12:12	16:16:33				16:27:12	16:31:33	16:35:04		16:42:12	16:46:33			16:57:12	17:01:33			
Mount Dennis	arr	16:09:00		16:14:04	16:18:04				16:29:04	16:33:04	16:36:35		16:44:04	16:48:04			16:59:04	17:03:04			
Mount Dennis		16:10:00		16:14:24	16:18:44				16:29:24	16:33:44	16:37:15		16:44:24	16:48:44			16:59:24	17:03:44			
Weston		16:12:05		16:16:41	16:20:18				16:31:41	16:35:18	16:38:49		16:46:41	16:50:18			17:01:41	17:05:18			
Etobicoke North		16:13:55		16:19:42	16:22:08				16:34:42	16:37:08	16:40:41		16:49:42	16:52:08			17:04:42	17:07:08			
Woodbine Jct.		16:15:20		16:22:06	16:24:06				16:37:06	16:39:06	16:42:14		16:52:06	16:54:06			17:07:06	17:09:06			
Malton		16:16:06		16:23:58					16:38:58		16:43:04		16:53:58				17:08:58				
Halwest Jct.		16:17:23	16:18:00	16:25:51		16:28:00	16:35:00	16:39:30	16:41:01		16:44:28	16:49:00	16:55:51		16:58:00	17:05:00	17:10:51				
Bramalea	arr	16:17:46	16:18:41	16:26:41		16:28:41	16:35:41	16:40:11	16:42:02		16:45:20	16:49:41	16:56:41		16:58:41	17:05:41	17:11:41				
Bramalea		16:17:46	16:18:41	16:27:01		16:28:41	16:35:41	16:40:11			16:46:00	16:49:41	16:57:01		16:58:41	17:05:41	17:12:01				
Brampton	arr	16:20:37	16:23:41	16:30:31		16:33:41	16:40:41	16:45:11			16:49:30	16:54:41	17:00:31		17:03:41	17:10:41	17:15:31				
Brampton		16:21:37	16:23:41	16:30:51		16:33:41	16:40:41	16:45:11			16:50:10	16:54:41	17:00:51		17:03:41	17:10:41	17:15:51				
Mount Pleasant	arr	16:24:39	16:27:33	16:33:42		16:37:33	16:44:33	16:49:03			16:53:25	16:58:33	17:03:42		17:07:33	17:14:33	17:19:02				
Mount Pleasant		16:24:39	16:27:33			16:37:33	16:44:33	16:49:03			16:54:05	16:58:33			17:07:33	17:14:33	17:19:22				
Georgetown	arr	16:27:50	16:34:04			16:44:04	16:51:04	16:55:34			16:58:29	17:05:04			17:14:04	17:21:04	17:25:22				
Georgetown		16:27:50	16:34:04			16:44:04	16:51:04	16:55:34			16:59:09	17:05:04			17:14:04	17:21:04	signal stop				
Silver Jct.		16:28:44	16:34:57			16:44:57	16:51:57	16:56:27			17:00:19	17:05:57			17:14:57	17:21:57	(1 minute)				
Acton		16:33:19									17:05:54						before				
Guelph	arr	16:43:04									17:16:15						entering				
Guelph		16:45:04									17:16:55						Georgetown				
Guelph Jct.		16:46:44									17:18:13										
Breslau		16:51:24									17:24:26										
Kitchener	arr	16:56:05									17:29:35										
Routing		IC-W4F																			
Guelph		16:47:04																			
Guelph Jct.		16:48:56																			
Hespeler		16:59:15																			
Preston		17:03:46																			
Cambridge	arr	17:10:04																			
Travel time		00:56:05	00:16:57	00:31:42	00:16:06	00:16:57	00:16:57	00:16:57	00:25:02	00:16:06	01:03:35	00:16:57	00:31:42	00:16:06	00:16:57	00:16:57	00:38:22	00:16:06			

Train service		IR	AIR	RER	Freight	Freight	Freight	IC	AIR	RER	Freight	Freight	IR	AIR	RER	Freight	Freight	Freight	IC	AIR	RER
Station dwell time [s]		40	40	20	n/a	n/a	n/a	60	40	20	n/a	n/a	40	40	20	n/a	n/a	n/a	60	40	20
Routing								IC-E5F											IC-E5F		
Cambridge								16:06:02											16:36:02		
Preston								16:14:17											16:44:17		
Hespeler								16:18:48											16:48:48		
Guelph Jct.								16:28:05											16:58:05		
Guelph	arr							16:29:34											16:59:34		
Routing		IR-E1	AIR-E1	RER-E3BL	F-E1	F-E1	F-E1	IC-E1	AIR-E1	RER-E1	F-E1	F-E1	IR-E1	AIR-E1	RER-E3BL	F-E1	F-E1	F-E1	IC-E1	AIR-E1	RER-E1
Kitchener		16:01:41						16:20:22					16:31:41						16:50:22		
Breslau		16:07:37						16:25:26					16:37:37						16:55:26		
Guelph Jct.		16:13:08						16:30:03					16:43:08						17:00:03		
Guelph	arr	16:14:25						16:31:24					16:44:25						17:01:24		
Guelph		16:15:05						16:33:24					16:45:05						17:03:24		
Acton		16:26:07						16:43:32					16:56:07						17:13:32		
Silver Jct.		16:30:56			16:33:11	16:36:11	16:39:11	16:47:50			16:53:11	16:56:11	17:00:56			17:03:11	17:06:11	17:09:11	17:17:50		
Georgetown	arr	16:31:52			16:34:06	16:37:06	16:40:06	16:48:20			16:54:06	16:57:06	17:01:52			17:04:06	17:07:06	17:10:06	17:18:20		
Georgetown		16:32:32			16:34:06	16:37:06	16:40:06	16:48:20		16:51:44	16:54:06	16:57:06	17:02:32			17:04:06	17:07:06	17:10:06	17:18:20		17:21:44
Mount Pleasant		16:37:37			16:40:47	16:43:47	16:46:47	16:51:27		16:57:04	17:00:47	17:03:47	17:07:37			17:10:47	17:13:47	17:16:47	17:21:27		17:27:04
Brampton	arr	16:40:32			16:44:25	16:47:25	16:50:25	16:53:45		16:59:55	17:04:25	17:07:25	17:10:32			17:14:25	17:17:25	17:20:25	17:23:45		17:29:55
Brampton		16:41:12			16:44:25	16:47:25	16:50:25	16:54:45		17:00:15	17:04:25	17:07:25	17:11:12			17:14:25	17:17:25	17:20:25	17:24:45		17:30:15
Bramalea	arr	16:45:14			16:49:14	16:52:14	16:55:14	16:58:37		17:03:45	17:09:14	17:12:14	17:15:14			17:19:14	17:22:14	17:25:14	17:28:37		17:33:45
Bramalea		16:45:54		16:49:05	16:49:14	16:52:14	16:55:14	16:58:37		17:04:05	17:09:14	17:12:14	17:15:54		17:19:05	17:19:14	17:22:14	17:25:14	17:28:37		17:34:05
Halwest Jct.		16:46:46		16:49:50	16:50:00	16:53:00	16:56:00	16:58:59		17:04:50	17:10:00	17:13:00	17:16:46		17:19:50	17:20:00	17:23:00	17:26:00	17:28:59		17:34:50
Malton		16:48:10		16:52:08				17:00:17		17:07:08			17:18:10		17:22:08				17:30:17		17:37:08
Woodbine Jct.		16:49:00	16:51:36	16:53:25				17:01:03	17:06:36	17:08:25			17:19:00	17:21:36	17:23:25				17:31:03	17:36:36	17:38:25
Etobicoke North		16:50:34	16:53:35	16:55:54				17:02:28	17:08:35	17:10:54			17:20:34	17:23:35	17:25:54				17:32:28	17:38:35	17:40:54
Weston		16:52:24	16:55:25	16:58:54				17:04:15	17:10:25	17:13:54			17:22:24	17:25:25	17:28:54				17:34:15	17:40:25	17:43:54
Mount Dennis	arr	16:53:59	16:56:59	17:00:51				17:05:51	17:11:59	17:15:51			17:23:59	17:26:59	17:30:51				17:35:51	17:41:59	17:45:51
Mount Dennis		16:54:39	16:57:39	17:01:11				17:06:51	17:12:39	17:16:11			17:24:39	17:27:39	17:31:11				17:36:51	17:42:39	17:46:11
St. Clair		16:56:10	16:59:10	17:03:23				17:08:52	17:14:10	17:18:23			17:26:10	17:29:10	17:33:23				17:38:52	17:44:10	17:48:23
Bloor		16:58:12	17:01:12	17:05:26				17:09:40	17:16:12	17:20:26			17:28:12	17:31:12	17:35:26				17:39:40	17:46:12	17:50:26
Liberty Village		17:00:10	17:03:10	17:07:57				17:11:10	17:18:10	17:22:57			17:30:10	17:33:10	17:37:57				17:41:10	17:48:10	17:52:57
Toronto	arr	17:04:00	17:07:00	17:12:00				17:15:00	17:22:00	17:27:00			17:34:00	17:37:00	17:42:00				17:45:00	17:52:00	17:57:00
Travel time		01:02:19	00:15:24	00:22:55	00:16:49	00:16:49	00:16:49	00:54:38	00:15:24	00:35:16	00:16:49	00:16:49	01:02:19	00:15:24	00:22:55	00:16:49	00:16:49	00:16:49	00:54:38	00:15:24	00:35:16

Scenario IIb (partially periodic timetable, afternoon peak pattern): Variable-block signaling system

Train service	RER	AIR	IC	RER	AIR	IR	Freight	RER	AIR	IC	Freight	RER	AIR	IR	Freight
Station dwell time [s]	20	40	60	20	40	40	n/a	20	40	60	n/a	20	40	40	n/a
Routing	RER-W2	AIR-W1	IC-W2	RER-W6BL	AIR-W1	IR-W2	F-W1	RER-W4a	AIR-W1	IC-W2	F-W1	RER-W6BL	AIR-W1	IR-W2	F-W1
Toronto	16:02:00	16:08:00	16:17:00	16:17:00	16:23:00	16:26:00		16:32:00	16:38:00	16:47:00		16:47:00	16:53:00	16:56:00	
Liberty Village	16:07:36	16:12:33	16:22:05	16:22:36	16:27:33	16:31:02		16:37:36	16:42:33	16:52:05		16:52:36	16:57:33	17:01:02	
Bloor	16:10:09	16:15:12	16:23:40	16:25:09	16:30:12	16:33:43		16:40:09	16:45:12	16:53:40		16:55:09	17:00:12	17:03:43	
St. Clair	16:12:12	16:16:33	16:24:28	16:27:12	16:31:33	16:35:04		16:42:12	16:46:33	16:54:28		16:57:12	17:01:33	17:05:04	
Mount Dennis arr	16:14:04	16:18:04	16:26:00	16:29:04	16:33:04	16:36:35		16:44:04	16:48:04	16:56:00		16:59:04	17:03:04	17:06:35	
Mount Dennis	16:14:24	16:18:44	16:27:00	16:29:24	16:33:44	16:37:15		16:44:24	16:48:44	16:57:00		16:59:24	17:03:44	17:07:15	
Weston	16:16:41	16:20:18	16:29:05	16:31:41	16:35:18	16:38:49		16:46:41	16:50:18	16:59:05		17:01:41	17:05:18	17:08:49	
Etobicoke North	16:19:42	16:22:08	16:30:55	16:34:42	16:37:08	16:40:41		16:49:42	16:52:08	17:00:55		17:04:42	17:07:08	17:10:41	
Woodbine Jct.	16:22:15	16:24:16	16:32:20		16:39:16	16:42:14		16:52:15	16:54:16	17:02:20		17:07:15	17:09:16	17:12:14	
Malton	16:24:21		16:33:06	16:39:21		16:43:04		16:54:21		17:03:06		17:09:21		17:13:04	
Halwest Jct.	16:26:13		16:34:23	16:41:24		16:44:28	16:49:30	16:56:13		17:04:23	17:06:00	17:11:24		17:14:28	17:19:30
Bramalea arr	16:27:04		16:34:46	16:42:24		16:45:20	16:50:13	16:57:04		17:04:46	17:06:43	17:12:24		17:15:20	17:20:13
Bramalea	16:27:24		16:34:46			16:46:00	16:50:13	16:57:24		17:04:46	17:06:43			17:16:00	17:20:13
Brampton arr	16:30:53		16:37:37			16:49:30	16:55:14	17:00:53		17:07:37	17:11:44			17:19:30	17:25:14
Brampton	16:31:13		16:38:37			16:50:10	16:55:14	17:01:13		17:08:37	17:11:44			17:20:10	17:25:14
Mount Pleasant	16:34:51		16:41:47			16:54:12	16:59:07	17:04:51		17:11:47	17:15:37			17:24:12	17:29:07
Georgetown arr	16:39:43		16:44:58			16:58:36	17:05:38	17:10:11		17:14:58	17:22:08			17:28:36	17:35:38
Georgetown			16:44:58			16:59:16	17:05:38	signal stop		17:14:58	17:22:08			17:29:16	17:35:38
Silver Jct.			16:45:52			17:00:25	17:06:32	(0 minutes)		17:15:52	17:23:02			17:30:25	17:36:32
Acton			16:50:41			17:06:15		before		17:20:41				17:36:15	
Guelph arr			17:00:26			17:16:35		entering		17:30:26				17:46:35	
Guelph			17:02:26			17:17:15		Georgetown		17:32:26				17:47:15	
Guelph Jct.			17:04:06			17:18:34				17:34:06				17:48:34	
Breslau			17:08:47			17:24:46				17:38:47				17:54:46	
Kitchener arr			17:13:27			17:29:56				17:43:27				17:59:56	
Routing			IC-W4F							IC-W4F					
Guelph			17:04:26							17:34:26					
Guelph Jct.			17:06:19							17:36:19					
Hespeler			17:16:37							17:46:37					
Preston			17:21:08							17:51:08					
Cambridge arr			17:27:26							17:57:26					
Travel time	00:37:43	00:16:16	00:56:27	00:25:24	00:16:16	01:03:56	00:17:02	00:38:11	00:16:16	00:56:27	00:17:02	00:25:24	00:16:16	01:03:56	00:17:02

Train service	IR	AIR	RER	Freight	AIR	RER	IC	AIR	RER	Freight	AIR	RER			
Station dwell time [s]	40	40	20	n/a	40	20	60	40	20	n/a	40	20			
Routing							IC-E5F								
Cambridge							16:19:21								
Preston							16:27:36								
Hespeler							16:32:08								
Guelph Jct.							16:41:24								
Guelph arr							16:42:53								
Routing	IR-E1	AIR-E1	RER-E3BL	F-E1	AIR-E1	RER-E2MP	IC-E2	AIR-E1	RER-E1	F-E1	AIR-E1	RER-E2MP			
Kitchener	16:01:36						16:34:57								
Breslau	16:07:31						16:40:01								
Guelph Jct.	16:13:02						16:44:38								
Guelph arr	16:14:20						16:46:00								
Guelph	16:15:00						16:48:00								
Acton	16:26:02						16:58:07								
Silver Jct.	16:30:50			16:41:11			17:02:25			17:11:11					
Georgetown arr	16:31:47			16:42:05			17:02:55			17:12:05					
Georgetown	16:32:27			16:42:05			17:02:55		17:06:44	17:12:05					
Mount Pleasant	16:37:31			16:48:46		16:56:25	17:06:02		17:12:04	17:18:46		17:26:25			
Brampton arr	16:40:26			16:52:24		16:59:55	17:08:20		17:14:55	17:22:24		17:29:55			
Brampton	16:41:06			16:52:24		17:00:15	17:09:20		17:15:15	17:22:24		17:30:15			
Bramalea arr	16:45:14			16:57:14		17:03:45	17:13:20		17:18:45	17:27:14		17:33:45			
Bramalea	16:45:54		16:49:05	16:57:14		17:04:05	17:13:20		17:19:05	17:27:14		17:34:05			
Halwest Jct.	16:46:46		16:49:50	16:58:00		17:04:50	17:13:54		17:19:50	17:28:00		17:34:50			
Malton	16:48:10		16:52:08			17:07:08	17:15:17		17:22:08			17:37:08			
Woodbine Jct.	16:49:00	16:51:27	16:53:25		17:06:27	17:08:25	17:16:03	17:21:27	17:23:25		17:36:27	17:38:25			
Etobicoke North	16:50:34	16:53:35	16:55:54		17:08:35	17:10:54	17:17:28	17:23:35	17:25:54		17:38:35	17:40:54			
Weston	16:52:24	16:55:25	16:58:54		17:10:25	17:13:54	17:19:15	17:25:25	17:28:54		17:40:25	17:43:54			
Mount Dennis arr	16:53:59	16:56:59	17:00:51		17:11:59	17:15:51	17:20:51	17:26:59	17:30:51		17:41:59	17:45:51			
Mount Dennis	16:54:39	16:57:39	17:01:11		17:12:39	17:16:11	17:21:51	17:27:39	17:31:11		17:42:39	17:46:11			
St. Clair	16:56:10	16:59:10	17:03:23		17:14:10	17:18:23	17:23:52	17:29:10	17:33:23		17:44:10	17:48:23			
Bloor	16:58:12	17:01:12	17:05:26		17:16:12	17:20:26	17:24:40	17:31:12	17:35:26		17:46:12	17:50:26			
Liberty Village	17:00:10	17:03:10	17:07:57		17:18:10	17:22:57	17:26:10	17:33:10	17:37:57		17:48:10	17:52:57			
Toronto arr	17:04:00	17:07:00	17:12:00		17:22:00	17:27:00	17:30:00	17:37:00	17:42:00		17:52:00	17:57:00			
Travel time	01:02:24	00:15:33	00:22:55	00:16:49	00:15:33	00:30:35	00:55:03	00:15:33	00:35:16	00:16:49	00:15:33	00:30:35			

Scenario IIb (partially periodic timetable, afternoon peak pattern): Fixed-block signaling system

Train service	Freight	RER	AIR	IC	Freight	Freight	RER	AIR	IR	Freight	Freight	RER	AIR	IC	Freight	Freight	RER	AIR	IR
Station dwell time [s]	n/a	20	40	60	n/a	n/a	20	40	40	n/a	n/a	20	40	60	n/a	n/a	20	40	40
Routing	F-W1	RER-W2	AIR-W1	IC-W2	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W2	F-W1	F-W1	RER-W4a	AIR-W1	IC-W2	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W2
Toronto		**16:02:00**	**16:08:00**	**16:17:00**			**16:17:00**	**16:23:00**	**16:26:00**			**16:32:00**	**16:38:00**	**16:47:00**			**16:47:00**	**16:53:00**	**16:56:00**
Liberty Village		**16:07:36**	16:12:33	16:22:05			**16:22:36**	16:27:33	16:31:02			**16:37:36**	16:42:33	16:52:05			**16:52:36**	16:57:33	17:01:02
Bloor		**16:10:09**	**16:15:12**	16:23:40			**16:25:09**	**16:30:12**	**16:33:43**			**16:40:09**	**16:45:12**	16:53:40			**16:55:09**	**17:00:12**	**17:03:43**
St. Clair		**16:12:12**	16:16:33	16:24:28			**16:27:12**	16:31:33	16:35:04			**16:42:12**	16:46:33	16:54:28			**16:57:12**	17:01:33	17:05:04
Mount Dennis arr		**16:14:04**	**16:18:04**	**16:26:00**			**16:29:04**	**16:33:04**	**16:36:35**			**16:44:04**	**16:48:04**	**16:56:00**			**16:59:04**	**17:03:04**	**17:06:35**
Mount Dennis		**16:14:24**	**16:18:44**	**16:27:00**			**16:29:24**	**16:33:44**	**16:37:15**			**16:44:24**	**16:48:44**	**16:57:00**			**16:59:24**	**17:03:44**	**17:07:15**
Weston		**16:16:41**	16:20:18	16:29:05			**16:31:41**	16:35:18	16:38:49			**16:46:41**	16:50:18	16:59:05			**17:01:41**	17:05:18	17:08:49
Etobicoke North		**16:19:42**	16:22:08	16:30:55			**16:34:42**	16:37:08	16:40:41			**16:49:42**	16:52:08	17:00:55			**17:04:42**	17:07:08	17:10:41
Woodbine Jct.		16:22:06	16:24:06	16:32:20			16:37:06	16:39:06	16:42:14			16:52:06	16:54:06	17:02:20			17:07:06	17:09:06	17:12:14
Malton		**16:23:58**		16:33:06			**16:38:58**		16:43:04			**16:53:58**		17:03:06			**17:08:58**		17:13:04
Halwest Jct.	16:20:00	16:25:51		16:34:23	16:35:00	16:39:30	16:41:01		16:44:28	16:46:30	16:50:00	16:55:51		17:04:23	17:05:00	17:08:30	17:11:01		17:14:28
Bramalea arr	16:20:41	**16:26:41**		16:34:46	16:35:41	16:40:11	**16:42:02**		**16:45:20**	16:47:11	16:50:41	**16:56:41**		17:04:46	17:05:41	17:09:11	**17:12:02**		**17:15:20**
Bramalea	16:20:41	**16:27:01**		16:34:46	16:35:41	16:40:11			**16:46:00**	16:47:11	16:50:41	**16:57:01**		17:04:46	17:05:41	17:09:11			**17:16:00**
Brampton arr	16:25:41	**16:30:31**		**16:37:37**	16:40:41	16:45:11			**16:49:30**	16:52:11	16:55:41	**17:00:31**		**17:07:37**	17:10:41	17:14:11			**17:19:30**
Brampton	16:25:41	**16:30:51**		**16:38:37**	16:40:41	16:45:11			**16:50:10**	16:52:11	16:55:41	**17:00:51**		**17:08:37**	17:10:41	17:14:11			**17:20:10**
Mount Pleasant	16:29:33	**16:34:22**		16:41:39	16:44:33	16:49:03			**16:54:05**	16:56:03	16:59:33	**17:04:22**		17:11:39	17:14:33	17:18:03			**17:24:05**
Georgetown arr	16:36:04	**16:39:14**		16:44:50	16:51:04	16:55:34			**16:58:29**	17:02:34	17:06:04	**17:09:42**		17:14:50	17:21:04	17:24:34			**17:28:29**
Georgetown	16:36:04			16:44:50	16:51:04	16:55:34			**16:59:09**	17:02:34	17:06:04			17:14:50	17:21:04	17:24:34			**17:29:09**
Silver Jct.	16:36:57			16:45:44	16:51:57	16:56:27			17:00:19	17:03:27	17:06:57			17:15:44	17:21:57	17:25:27			17:30:19
Acton				16:50:19					**17:05:54**					17:20:19					**17:35:54**
Guelph arr				**17:00:04**					**17:16:15**					**17:30:04**					**17:46:15**
Guelph				**17:02:04**					**17:16:55**					**17:32:04**					**17:46:55**
Guelph Jct.				17:03:44					17:18:13					17:33:44					17:48:13
Breslau				17:08:24					**17:24:26**					17:38:24					**17:54:26**
Kitchener arr				**17:13:05**					**17:29:35**					**17:43:05**					**17:59:35**
Routing				IC-W4F										IC-W4F					
Guelph				**17:04:04**										**17:34:04**					
Guelph Jct.				17:05:56										17:35:56					
Hespeler				**17:16:15**										**17:46:15**					
Preston				**17:20:46**										**17:50:46**					
Cambridge arr				**17:27:04**										**17:57:04**					
Travel time	00:16:57	00:37:14	00:16:06	00:56:05	00:16:57	00:16:57	00:25:02	00:16:06	01:03:35	00:16:57	00:16:57	00:37:42	00:16:06	00:56:05	00:16:57	00:16:57	00:25:02	00:16:06	01:03:35

Train service	Freight	IR	AIR	RER	Freight	AIR	RER	Freight	Freight	IC	AIR	RER	Freight	AIR	RER	Freight	Freight	Freight	Freight
Station dwell time [s]	n/a	40	40	20	n/a	40	20	n/a	n/a	60	40	20	n/a	40	20	n/a	n/a	n/a	n/a
Routing										IC-E5F									
Cambridge										**16:21:02**									
Preston										**16:29:17**									
Hespeler										**16:33:48**									
Guelph Jct.										16:43:05									
Guelph arr										**16:44:34**									
Routing	F-E1	IR-E2	AIR-E1	RER-E3BL	F-E1	AIR-E1	RER-E2MP	F-E1	F-E1	IC-E2	AIR-E1	RER-E1	F-E1	AIR-E1	RER-E2MP	F-E1	F-E1	F-E1	F-E1
Kitchener		**16:02:00**								**16:34:59**									
Breslau		**16:07:56**								16:40:04									
Guelph Jct.		16:13:27								16:44:41									
Guelph arr		**16:14:44**								**16:46:02**									
Guelph		**16:15:24**								**16:48:02**									
Acton		**16:26:26**								16:58:09									
Silver Jct.	16:26:11	16:31:15			16:39:41			16:50:41	16:54:11	17:02:28			17:09:41			17:20:11	17:23:11	17:20:11	17:23:11
Georgetown arr	16:27:06	**16:32:11**			16:40:36			16:51:36	16:55:06	17:02:57			17:10:36			17:21:06	17:24:06	17:21:06	17:24:06
Georgetown	16:27:06	**16:32:51**			16:40:36			16:51:36	16:55:06	17:02:57		**17:06:44**	17:10:36			17:21:06	17:24:06	17:21:06	17:24:06
Mount Pleasant arr	16:33:47	**16:37:15**			16:47:17			16:58:17	17:01:47	17:06:05		**17:11:44**	17:17:17			17:27:47	17:30:47	17:27:47	17:30:47
Mount Pleasant	16:33:47	**16:37:55**			16:47:17		**16:56:35**	16:58:17	17:01:47	17:06:05		**17:12:04**	17:17:17		**17:26:35**	17:27:47	17:30:47	17:27:47	17:30:47
Brampton arr	16:37:25	**16:40:51**			16:50:55		**16:59:55**	17:01:55	17:05:25	17:08:22		**17:14:55**	17:20:55		**17:29:55**	17:31:25	17:34:25	17:31:25	17:34:25
Brampton	16:37:25	**16:41:31**			16:50:55		**17:00:15**	17:01:55	17:05:25	**17:09:22**		**17:15:15**	17:20:55		**17:30:15**	17:31:25	17:34:25	17:31:25	17:34:25
Bramalea arr	16:42:14	**16:45:14**			16:55:44		**17:03:45**	17:06:44	17:10:14	**17:13:20**		**17:18:45**	17:25:44		**17:33:45**	17:36:14	17:39:14	17:36:14	17:39:14
Bramalea	16:42:14	**16:45:54**		**16:49:05**	16:55:44		**17:04:05**	17:06:44	17:10:14	17:13:20		**17:19:05**	17:25:44		**17:34:05**	17:36:14	17:39:14	17:36:14	17:39:14
Halwest Jct.	16:43:00	16:46:46		16:49:50	16:56:30		17:04:50	17:07:30	17:11:00	17:13:54		17:19:50	17:26:30		17:34:50	17:37:00	17:40:00	17:37:00	17:40:00
Malton		16:48:10		**16:52:08**			**17:07:08**			17:15:17		**17:22:08**			**17:37:08**				
Woodbine Jct.		16:49:00	16:51:36	16:53:25		17:06:36	17:08:25			17:16:03	17:21:36	17:23:25		17:36:36	17:38:25				
Etobicoke North		16:50:34	16:53:35	**16:55:54**		17:08:35	**17:10:54**			17:17:28	17:23:35	**17:25:54**		17:38:35	**17:40:54**				
Weston		16:52:24	16:55:25	**16:58:54**		17:10:25	**17:13:54**			17:19:15	17:25:25	**17:28:54**		17:40:25	**17:43:54**				
Mount Dennis arr		**16:53:59**	**16:56:59**	**17:00:51**		**17:11:59**	**17:15:51**			**17:20:51**	**17:26:59**	**17:30:51**		**17:41:59**	**17:45:51**				
Mount Dennis arr		**16:54:39**	**16:57:39**	**17:01:11**		**17:12:39**	**17:16:11**			**17:21:51**	**17:27:39**	**17:31:11**		**17:42:39**	**17:46:11**				
St. Clair		16:56:10	16:59:10	**17:03:23**		17:14:10	**17:18:23**			17:23:52	17:29:10	**17:33:23**		17:44:10	**17:48:23**				
Bloor		**16:58:12**	**17:01:12**	**17:05:26**		**17:16:12**	**17:20:26**			17:24:40	**17:31:12**	**17:35:26**		**17:46:12**	**17:50:26**				
Liberty Village		17:00:10	17:03:10	**17:07:57**		17:18:10	**17:22:57**			17:26:10	17:33:10	**17:37:57**		17:48:10	**17:52:57**				
Toronto arr		**17:04:00**	**17:07:00**	**17:12:00**		**17:22:00**	**17:27:00**			**17:30:00**	**17:37:00**	**17:42:00**		**17:52:00**	**17:57:00**				
Travel time	00:16:49	01:02:00	00:15:24	00:22:55	00:16:49	00:15:24	00:30:25	00:16:49	00:16:49	00:55:01	00:15:24	00:35:16	00:16:49	00:15:24	00:30:25	00:16:49	00:16:49	00:16:49	00:16:49

Scenario III (periodic timetable): Variable-block signaling system

Train service		Freight	RER	AIR	IC	RER	AIR	IR	Freight	RER	AIR	IC	RER	AIR	IR
Station dwell time [s]		n/a	20	40	60	20	40	40	n/a	20	40	60	20	40	40
Routing		F-W1	RER-W3a	AIR-W1	IC-W2	RER-W6BL	AIR-W1	IR-W1	F-W1	RER-W3a	AIR-W1	IC-W2	RER-W6BL	AIR-W1	IR-W1
Toronto			16:02:00	16:08:00	16:15:00	16:17:00	16:23:00	16:26:00		16:32:00	16:38:00	16:45:00	16:47:00	16:53:00	16:56:00
Liberty Village			16:07:36	16:12:33	16:20:05	16:22:36	16:27:33	16:31:02		16:37:36	16:42:33	16:50:05	16:52:36	16:57:33	17:01:02
Bloor			16:10:09	16:15:12	16:21:40	16:25:09	16:30:12	16:33:43		16:40:09	16:45:12	16:51:40	16:55:09	17:00:12	17:03:43
St. Clair			16:12:12	16:16:33	16:22:28	16:27:12	16:31:33	16:35:04		16:42:12	16:46:33	16:52:28	16:57:12	17:01:33	17:05:04
Mount Dennis	arr		16:14:04	16:18:04	16:24:00	16:29:04	16:33:04	16:36:35		16:44:04	16:48:04	16:54:00	16:59:04	17:03:04	17:06:35
Mount Dennis			16:14:24	16:18:44	16:25:00	16:29:24	16:33:44	16:37:15		16:44:24	16:48:44	16:55:00	16:59:24	17:03:44	17:07:15
Weston			16:16:41	16:20:18	16:27:05	16:31:41	16:35:18	16:38:49		16:46:41	16:50:18	16:57:05	17:01:41	17:05:18	17:08:49
Etobicoke North			16:19:42	16:22:08	16:28:55	16:34:42	16:37:08	16:40:41		16:49:42	16:52:08	16:58:55	17:04:42	17:07:08	17:10:41
Woodbine Jct.			16:22:15	16:24:16	16:30:20	16:37:15	16:39:16	16:42:14		16:52:15	16:54:16	17:00:20	17:07:15	17:09:16	17:12:14
Malton			16:24:21		16:31:06	16:39:21		16:43:04		16:54:21		17:01:06	17:09:21		17:13:04
Halwest Jct.		16:19:00	16:26:13		16:32:23	16:41:24		16:44:28	16:49:00	16:56:13		17:02:23	17:11:24		17:14:28
Bramalea	arr	16:19:43	16:27:04		16:32:46	16:42:24		16:45:20	16:49:43	16:57:04		17:02:46	17:12:24		17:15:20
Bramalea		16:19:43	16:27:24		16:32:46			16:46:00	16:49:43	16:57:24		17:02:46			17:16:00
Brampton	arr	16:24:44	16:30:53		16:35:37			16:49:30	16:54:44	17:00:53		17:05:37			17:19:30
Brampton		16:24:44	16:31:13		16:36:37			16:50:10	16:54:44	17:01:13		17:06:37			17:20:10
Mount Pleasant		16:28:37	16:34:25		16:39:47			16:53:45	16:58:37	17:04:25		17:09:47			17:23:45
Georgetown	arr	16:35:08	16:40:45		16:42:58			16:58:09	17:05:08	17:10:45		17:12:58			17:28:09
Georgetown		16:35:08	signal stop		16:42:58			16:58:49	17:05:08	signal stop		17:12:58			17:28:49
Silver Jct.		16:36:02	(1 minute)		16:43:52			16:59:45	17:06:02	(1 minute)		17:13:52			17:29:45
Acton			before		16:48:41			17:05:14		before		17:18:41			17:35:14
Guelph	arr		entering		16:58:26			17:15:35		entering		17:28:26			17:45:35
Guelph			Georgetown		17:00:26			17:16:15		Georgetown		17:30:26			17:46:15
Guelph Jct.					17:02:06			17:17:33				17:32:06			17:47:33
Breslau					17:06:47			17:23:46				17:36:47			17:53:46
Kitchener	arr				17:11:27			17:28:55				17:41:27			17:58:55
Routing					IC-W5F							IC-W5F			
Guelph					17:02:26							17:32:26			
Guelph Jct.					17:04:19							17:34:19			
Hespeler					17:14:37							17:44:37			
Preston					17:19:08							17:49:08			
Cambridge	arr				17:25:26							17:55:26			
Travel time		00:17:02	00:38:45	00:16:16	00:56:27	00:25:24	00:16:16	01:02:55	00:17:02	00:38:45	00:16:16	00:56:27	00:25:24	00:16:16	01:02:55

Train service		IR	AIR	RER	Freight	IC	AIR	RER	IR	AIR	RER	Freight	IC	AIR	RER
Station dwell time [s]		40	40	20	n/a	60	40	20	40	40	20	n/a	60	40	20
Routing						IC-E5F							IC-E5F		
Cambridge						16:04:21							16:34:21		
Preston						16:12:36							16:42:36		
Hespeler						16:17:08							16:47:08		
Guelph Jct.						16:26:24							16:56:24		
Guelph	arr					16:27:53							16:57:53		
Routing		IR-E1	AIR-E1	RER-E3BL	F-E1	IC-E4	AIR-E1	RER-E1	IR-E1	AIR-E1	RER-E3BL	F-E1	IC-E4	AIR-E1	RER-E1
Kitchener		16:01:36				16:19:31			16:31:36				16:49:31		
Breslau		16:07:31				16:24:36			16:37:31				16:54:36		
Guelph Jct.		16:13:02				16:29:13			16:43:02				16:59:13		
Guelph	arr	16:14:20				16:30:34			16:44:20				17:00:34		
Guelph		16:15:00				16:32:34			16:45:00				17:02:34		
Acton		16:26:02				16:42:41			16:56:02				17:12:41		
Silver Jct.		16:30:50			16:35:41	16:47:00			17:00:50			17:05:41	17:17:00		
Georgetown	arr	16:31:47			16:36:35	16:47:30			17:01:47			17:06:35	17:17:30		
Georgetown		16:32:27			16:36:35	16:47:30		16:51:44	17:02:27			17:06:35	17:17:30		17:21:44
Mount Pleasant		16:37:31			16:43:16	16:50:37		16:57:04	17:07:31			17:13:16	17:20:37		17:27:04
Brampton	arr	16:40:26			16:46:54	16:52:55		16:59:55	17:10:26			17:16:54	17:22:55		17:29:55
Brampton		16:41:06			16:46:54	16:53:55		17:00:15	17:11:06			17:16:54	17:23:55		17:30:15
Bramalea	arr	16:45:14			16:51:44	16:57:19		17:03:45	17:15:14			17:21:44	17:27:19		17:33:45
Bramalea		16:45:54		16:49:05	16:51:44	16:57:19		17:04:05	17:15:54		17:19:05	17:21:44	17:27:19		17:34:05
Halwest Jct.		16:46:46		16:49:50	16:52:30	16:57:41		17:04:50	17:16:46		17:19:50	17:22:30	17:27:41		17:34:50
Malton		16:48:10		16:52:08		17:00:11		17:07:08	17:18:10		17:22:08		17:30:11		17:37:08
Woodbine Jct.		16:49:00	16:51:27	16:53:25		17:01:03	17:06:27	17:08:25	17:19:00	17:21:27	17:23:25		17:31:03	17:36:27	17:38:25
Etobicoke North		16:50:34	16:53:35	16:55:54		17:02:28	17:08:35	17:10:54	17:20:34	17:23:35	17:25:54		17:32:28	17:38:35	17:40:54
Weston		16:52:24	16:55:25	16:58:54		17:04:15	17:10:25	17:13:54	17:22:24	17:25:25	17:28:54		17:34:15	17:40:25	17:43:54
Mount Dennis	arr	16:53:59	16:56:59	17:00:51		17:05:51	17:11:59	17:15:51	17:23:59	17:26:59	17:30:51		17:35:51	17:41:59	17:45:51
Mount Dennis		16:54:39	16:57:39	17:01:11		17:06:51	17:12:39	17:16:11	17:24:39	17:27:39	17:31:11		17:36:51	17:42:39	17:46:11
St. Clair		16:56:10	16:59:10	17:03:23		17:08:52	17:14:10	17:18:23	17:26:10	17:29:10	17:33:23		17:38:52	17:44:10	17:48:23
Bloor		16:58:12	17:01:12	17:05:26		17:09:40	17:16:12	17:20:26	17:28:12	17:31:12	17:35:26		17:39:40	17:46:12	17:50:26
Liberty Village		17:00:10	17:03:10	17:07:57		17:11:10	17:18:10	17:22:57	17:30:10	17:33:10	17:37:57		17:41:10	17:48:10	17:52:57
Toronto	arr	17:04:00	17:07:00	17:12:00		17:15:00	17:22:00	17:27:00	17:34:00	17:37:00	17:42:00		17:45:00	17:52:00	17:57:00
Travel time		01:02:24	00:15:33	00:22:55	00:16:49	00:55:29	00:15:33	00:35:16	01:02:24	00:15:33	00:22:55	00:16:49	00:55:29	00:15:33	00:35:16

Scenario III (periodic timetable): Fixed-block signaling system

Train service	Freight	RER	AIR	IC	Freight	Freight	Freight	RER	AIR	IR	Freight	Freight	RER	AIR	IC	Freight	Freight	Freight	RER	AIR	IR	Freight
Station dwell time [s]	n/a	20	40	60	n/a	n/a	n/a	20	40	40	n/a	n/a	20	40	60	n/a	n/a	n/a	20	40	40	n/a
Routing	F-W1	RER-W1	AIR-W1	IC-W1	F-W1	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W1	F-W1	F-W1	RER-W1	AIR-W1	IC-W1	F-W1	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W1	F-W1
Toronto		16:02:00	16:08:00	16:15:00				16:17:00	16:23:00	16:26:00			16:32:00	16:38:00	16:45:00				16:47:00	16:53:00	16:56:00	
Liberty Village		16:07:36	16:12:33	16:20:05				16:22:36	16:27:33	16:31:02			16:37:36	16:42:33	16:50:05				16:52:36	16:57:33	17:01:02	
Bloor		16:10:09	16:15:12	16:21:40				16:25:09	16:30:12	16:33:43			16:40:09	16:45:12	16:51:40				16:55:09	17:00:12	17:03:43	
St. Clair		16:12:12	16:16:33	16:22:28				16:27:12	16:31:33	16:35:04			16:42:12	16:46:33	16:52:28				16:57:12	17:01:33	17:05:04	
Mount Dennis arr		16:14:04	16:18:04	16:24:00				16:29:04	16:33:04	16:36:35			16:44:04	16:48:04	16:54:00				16:59:04	17:03:04	17:06:35	
Mount Dennis		16:14:24	16:18:44	16:25:00				16:29:24	16:33:44	16:37:15			16:44:24	16:48:44	16:55:00				16:59:24	17:03:44	17:07:15	
Weston		16:16:41	16:20:18	16:27:05				16:31:41	16:35:18	16:38:49			16:46:41	16:50:18	16:57:05				17:01:41	17:05:18	17:08:49	
Etobicoke North		16:19:42	16:22:08	16:28:55				16:34:42	16:37:08	16:40:41			16:49:42	16:52:08	16:58:55				17:04:42	17:07:08	17:10:41	
Woodbine Jct.		16:22:06	16:24:06	16:30:20				16:37:06	16:39:06	16:42:14			16:52:06	16:54:06	17:00:20				17:07:06	17:09:06	17:12:14	
Malton		16:23:58		16:31:06				16:38:58		16:43:04			16:53:58		17:01:06				17:08:58		17:13:04	
Halwest Jct.	16:22:00	16:25:51		16:32:23	16:34:30	16:37:30	16:40:30	16:41:01		16:44:28	16:47:00	16:52:00	16:55:51		17:02:23	17:04:30	17:07:30	17:10:30	17:11:01		17:14:28	17:17:00
Bramalea arr	16:22:41	16:26:41		16:32:46	16:35:11	16:38:11	16:41:11	16:42:02		16:45:20	16:47:41	16:52:41	16:56:41		17:02:46	17:05:11	17:08:11	17:11:11	17:12:02		17:15:20	17:17:41
Bramalea	16:22:41	16:27:01		16:32:46	16:35:11	16:38:11	16:41:11			16:46:00	16:47:41	16:52:41	16:57:01		17:02:46	17:05:11	17:08:11	17:11:11			17:16:00	17:17:41
Brampton arr	16:27:41	16:30:31		16:35:37	16:40:11	16:43:11	16:46:11			16:49:30	16:52:41	16:57:41	17:00:31		17:05:37	17:10:11	17:13:11	17:16:11			17:19:30	17:22:41
Brampton	16:27:41	16:30:51		16:36:37	16:40:11	16:43:11	16:46:11			16:50:10	16:52:41	16:57:41	17:00:51		17:06:37	17:10:11	17:13:11	17:16:11			17:20:10	17:22:41
Mount Pleasant	16:31:33	16:34:02		16:39:29	16:44:03	16:47:03	16:50:03			16:53:45	16:56:33	17:01:33	17:04:02		17:09:29	17:14:03	17:17:03	17:20:03			17:23:45	17:26:33
Georgetown arr	16:38:04	16:38:54		16:42:33	16:50:34	16:53:34	16:56:34			16:58:09	17:03:04	17:08:04	17:08:54		17:12:33	17:20:34	17:23:34	17:26:34			17:28:09	17:33:04
Georgetown	16:38:04	16:39:14		16:42:33	16:50:34	16:53:34	16:56:34			16:58:49	17:03:04	17:08:04	17:09:14		17:12:33	17:20:34	17:23:34	17:26:34			17:28:49	17:33:04
Silver Jct.	16:38:57			16:43:03	16:51:27	16:54:27	16:57:27			16:59:45	17:03:57	17:08:57			17:13:03	17:21:27	17:24:27	17:27:27			17:29:45	17:33:57
Acton				16:47:22						17:05:14					17:17:22						17:35:14	
Guelph arr				16:57:07						17:15:35					17:27:07						17:45:35	
Guelph				16:59:07						17:16:15					17:29:07						17:46:15	
Guelph Jct.				17:00:46						17:17:33					17:30:46						17:47:33	
Breslau				17:05:27						17:23:46					17:35:27						17:53:46	
Kitchener arr				17:10:08						17:28:55					17:40:08						17:58:55	
Routing				IC-W3F											IC-W3F							
Guelph				17:02:07											17:32:07							
Guelph Jct.				17:03:59											17:33:59							
Hespeler				17:14:17											17:44:17							
Preston				17:18:48											17:48:48							
Cambridge arr				17:25:06											17:55:06							
Travel time	00:16:57	00:37:14	00:16:06	00:55:08	00:16:57	00:16:57	00:16:57	00:25:02	00:16:06	01:02:55	00:16:57	00:16:57	00:37:14	00:16:06	00:55:08	00:16:57	00:16:57	00:16:57	00:25:02	00:16:06	01:02:55	00:16:57

Train service	Freight	IR	AIR	RER	Freight	Freight	IC	Freight	AIR	RER	Freight	Freight	IR	AIR	RER	Freight	Freight	IC	Freight	AIR	RER	Freight
Station dwell time [s]	n/a	40	40	20	n/a	n/a	60	n/a	40	20	n/a	n/a	40	40	20	n/a	n/a	60	n/a	40	20	n/a
Routing							IC-E5F											IC-E5F				
Cambridge							16:04:02											16:34:02				
Preston							16:12:17											16:42:17				
Hespeler							16:16:48											16:46:48				
Guelph Jct.							16:26:05											16:56:05				
Guelph arr							16:27:34											16:57:34				
Routing	F-E1	IR-E2	AIR-E1	RER-E3BL	F-E1	F-E1	IC-E3	F-E2	AIR-E1	RER-E1	F-E1	F-E1	IR-E2	AIR-E1	RER-E3BL	F-E1	F-E1	IC-E3	F-E2	AIR-E1	RER-E1	F-E1
Kitchener		16:02:00					16:19:49						16:32:00					16:49:49				
Breslau		16:07:56					16:24:54						16:37:56					16:54:54				
Guelph Jct.		16:13:27					16:29:31						16:43:27					16:59:31				
Guelph arr		16:14:44					16:30:52						16:44:44					17:00:52				
Guelph		16:15:24					16:32:52						16:45:24					17:02:52				
Acton		16:26:26					16:42:59						16:56:26					17:12:59				
Silver Jct.	16:26:11	16:31:15			16:33:11	16:38:41	16:47:18	16:44:57			16:52:11	16:56:11	17:01:15			17:03:11	17:08:41	17:17:18	17:14:57			17:22:11
Georgetown arr	16:27:06	16:32:11			16:34:06	16:39:36	16:47:47	16:45:52			16:53:06	16:57:06	17:02:11			17:04:06	17:09:36	17:17:47	17:15:52			17:23:06
Georgetown	16:27:06	16:32:51			16:34:06	16:39:36	16:47:47	16:45:52		16:51:44	16:53:06	16:57:06	17:02:51			17:04:06	17:09:36	17:17:47	17:15:52		17:21:44	17:23:06
Mount Pleasant	16:33:47	16:37:55			16:40:47	16:46:17	16:50:55	16:52:40		16:57:04	16:59:47	17:03:47	17:07:55			17:10:47	17:16:17	17:20:55	17:22:40		17:27:04	17:29:47
Brampton arr	16:37:25	16:40:51			16:44:25	16:49:55	16:53:12	16:56:25		16:59:55	17:03:25	17:07:25	17:10:51			17:14:25	17:19:55	17:23:12	17:26:25		17:29:55	17:33:25
Brampton	16:37:25	16:41:31			16:44:25	16:49:55	16:54:12	16:56:25		17:00:15	17:03:25	17:07:25	17:11:31			17:14:25	17:19:55	17:24:12	17:26:25		17:30:15	17:33:25
Bramalea arr	16:42:14	16:45:14			16:49:14	16:54:44	16:57:42	17:01:14		17:03:45	17:08:14	17:12:14	17:15:14			17:19:14	17:24:44	17:27:42	17:31:14		17:33:45	17:38:14
Bramalea	16:42:14	16:45:54		16:49:05	16:49:14	16:54:44	16:57:42	17:01:14		17:04:05	17:08:14	17:12:14	17:15:54		17:19:05	17:19:14	17:24:44	17:27:42	17:31:14		17:34:05	17:38:14
Halwest Jct.	16:43:00	16:46:46		16:49:50	16:50:00	16:55:30	16:58:27	17:02:00		17:04:50	17:09:00	17:13:00	17:16:46		17:19:50	17:20:00	17:25:30	17:28:27	17:32:00		17:34:50	17:39:00
Malton		16:48:10		16:52:08			17:00:17			17:07:08			17:18:10		17:22:08			17:30:17			17:37:08	
Woodbine Jct.		16:49:00	16:51:36	16:53:25			17:01:03		17:06:36	17:08:25			17:19:00	17:21:36	17:23:25			17:31:03		17:36:36	17:38:25	
Etobicoke North		16:50:34	16:53:35	16:55:54			17:02:28		17:08:35	17:10:54			17:20:34	17:23:35	17:25:54			17:32:28		17:38:35	17:40:54	
Weston		16:52:24	16:55:25	16:58:54			17:04:15		17:10:25	17:13:54			17:22:24	17:25:25	17:28:54			17:34:15		17:40:25	17:43:54	
Mount Dennis arr		16:53:59	16:56:59	17:00:51			17:05:51		17:11:59	17:15:51			17:23:59	17:26:59	17:30:51			17:35:51		17:41:59	17:45:51	
Mount Dennis		16:54:39	16:57:39	17:01:11			17:06:51		17:12:39	17:16:11			17:24:39	17:27:39	17:31:11			17:36:51		17:42:39	17:46:11	
St. Clair		16:56:10	16:59:10	17:03:23			17:08:52		17:14:10	17:18:23			17:26:10	17:29:10	17:33:23			17:38:52		17:44:10	17:48:23	
Bloor		16:58:12	17:01:12	17:05:26			17:09:40		17:16:12	17:20:26			17:28:12	17:31:12	17:35:26			17:39:40		17:46:12	17:50:26	
Liberty Village		17:00:10	17:03:10	17:07:57			17:11:10		17:18:10	17:22:57			17:30:10	17:33:10	17:37:57			17:41:10		17:48:10	17:52:57	
Toronto arr		17:04:00	17:07:00	17:12:00			17:15:00		17:22:00	17:27:00			17:34:00	17:37:00	17:42:00			17:45:00		17:52:00	17:57:00	
Travel time	00:16:49	01:02:00	00:15:24	17:12:00	00:16:49	00:16:49	00:55:11	00:17:03	00:15:24	00:29:56	00:16:49	00:16:49	01:02:00	00:15:24	17:42:00	00:16:49	00:16:49	00:55:11	00:17:03	00:15:24	00:29:56	00:16:49

Scenario IV (symmetric timetable): Variable-block signaling system

Train service	RER	AIR	IC	Freight	RER	AIR	IR	RER	AIR	IC	Freight	RER	AIR	IR
Station dwell time [s]	20	40	60	n/a	20	40	40	20	40	60	n/a	20	40	40
Routing	RER-W3a	AIR-W1	IC-W1	F-W1	RER-W6BL	AIR-W1	IR-W1	RER-W3a	AIR-W1	IC-W1	F-W1	RER-W6BL	AIR-W1	IR-W1
Toronto	16:03:00	16:07:00	16:16:00		16:18:00	16:22:00	16:27:00	16:33:00	16:37:00	16:46:00		16:48:00	16:52:00	16:57:00
Liberty Village	16:08:36	16:11:33	16:21:05		16:23:36	16:26:33	16:32:02	16:38:36	16:41:33	16:51:05		16:53:36	16:56:33	17:02:02
Bloor	16:11:09	16:14:12	16:22:40		16:26:09	16:29:12	16:34:43	16:41:09	16:44:12	16:52:40		16:56:09	16:59:12	17:04:43
St. Clair	16:13:12	16:15:33	16:23:28		16:28:12	16:30:33	16:36:04	16:43:12	16:45:33	16:53:28		16:58:12	17:00:33	17:06:04
Mount Dennis arr	16:15:04	16:17:04	16:25:00		16:30:04	16:32:04	16:37:35	16:45:04	16:47:04	16:55:00		17:00:04	17:02:04	17:07:35
Mount Dennis	16:15:24	16:17:44	16:26:00		16:30:24	16:32:44	16:38:15	16:45:24	16:47:44	16:56:00		17:00:24	17:02:44	17:08:15
Weston	16:17:41	16:19:18	16:28:05		16:32:41	16:34:18	16:39:49	16:47:41	16:49:18	16:58:05		17:02:41	17:04:18	17:09:49
Etobicoke North	16:20:42	16:21:08	16:29:55		16:35:42	16:36:08	16:41:41	16:50:42	16:51:08	16:59:55		17:05:42	17:06:08	17:11:41
Woodbine Jct.	16:23:15	16:23:16	16:31:20		16:38:15	16:38:16	16:43:14	16:53:15	16:53:16	17:01:20		17:08:15	17:08:16	17:13:14
Malton	16:25:21		16:32:06		16:40:21		16:44:04	16:55:21		17:02:06		17:10:21		17:14:04
Halwest Jct.	16:27:13		16:33:23	16:36:30	16:42:24		16:45:28	16:57:13		17:03:23	17:06:30	17:12:24		17:15:28
Bramalea arr	16:28:04		16:33:46	16:37:13	16:43:24		16:46:20	16:58:04		17:03:46	17:07:13	17:13:24		17:16:20
Bramalea	16:28:24		16:33:46	16:37:13			16:47:00	16:58:24		17:03:46	17:07:13			17:17:00
Brampton arr	16:31:53		16:36:37	16:42:14			16:50:30	17:01:53		17:06:37	17:12:14			17:20:30
Brampton	16:32:13		16:37:37	16:42:14			16:51:10	17:02:13		17:07:37	17:12:14			17:21:10
Mount Pleasant	16:35:25		16:40:29	16:46:07			16:54:45	17:05:25		17:10:29	17:16:07			17:24:45
Georgetown arr	16:40:45		16:43:33	16:52:38			16:59:09	17:10:45		17:13:33	17:22:38			17:29:09
Georgetown	signal stop		16:43:33	16:52:38			16:59:49	signal stop		17:13:33	17:22:38			17:29:49
Silver Jct.	(0 minutes)		16:44:03	16:53:32			17:00:45	(0 minutes)		17:14:03	17:23:32			17:30:45
Acton	before		16:48:22				17:06:14	before		17:18:22				17:36:14
Guelph arr	entering		16:58:07				17:16:35	entering		17:28:07				17:46:35
Guelph	Georgetown		17:00:07				17:17:15	Georgetown		17:30:07				17:47:15
Guelph Jct.			17:01:46				17:18:33			17:31:46				17:48:33
Breslau			17:06:27				17:24:46			17:36:27				17:54:46
Kitchener arr			17:11:08				17:29:55			17:41:08				17:59:55
Routing			IC-W3F							IC-W3F				
Guelph			17:02:07							17:32:07				
Guelph Jct.			17:03:59							17:33:59				
Hespeler			17:14:17							17:44:17				
Preston			17:18:48							17:48:48				
Cambridge arr			17:25:06							17:55:06				
Travel time	00:37:45	00:16:16	00:55:08	00:17:02	00:25:24	00:16:16	01:02:55	00:37:45	00:16:16	00:55:08	00:17:02	00:25:24	00:16:16	01:02:55

Train service	IR	AIR	RER	Freight	IC	AIR	RER	IR	AIR	RER	Freight	IC	AIR	RER
Station dwell time [s]	40	40	20	n/a	60	40	20	40	40	20	n/a	60	40	20
Routing					IC-E5F							IC-E5F		
Cambridge					16:03:21							16:33:21		
Preston					16:11:36							16:41:36		
Hespeler					16:16:08							16:46:08		
Guelph Jct.					16:25:24							16:55:24		
Guelph arr					16:26:53							16:56:53		
Routing	IR-E2	AIR-E1	RER-E3BL	F-E1	IC-E1	AIR-E1	RER-E1	IR-E2	AIR-E1	RER-E3BL	F-E1	IC-E1	AIR-E1	RER-E1
Kitchener	16:00:58				16:19:16			16:30:58				16:49:16		
Breslau	16:06:54				16:24:21			16:36:54				16:54:21		
Guelph Jct.	16:12:25				16:28:58			16:42:25				16:58:58		
Guelph arr	16:13:42				16:30:19			16:43:42				17:00:19		
Guelph	16:14:22				16:32:19			16:44:22				17:02:19		
Acton	16:25:24				16:42:26			16:55:24				17:12:26		
Silver Jct.	16:30:13			16:35:41	16:46:45			17:00:13			17:05:41	17:16:45		
Georgetown arr	16:31:09			16:36:35	16:47:14			17:01:09			17:06:35	17:17:14		
Georgetown	16:31:49			16:36:35	16:47:14		16:51:44	17:01:49			17:06:35	17:17:14		17:21:44
Mount Pleasant	16:36:53			16:43:16	16:50:22		16:57:04	17:06:53			17:13:16	17:20:22		17:27:04
Brampton arr	16:39:48			16:46:54	16:52:39		16:59:55	17:09:48			17:16:54	17:22:39		17:29:55
Brampton	16:40:28			16:46:54	16:53:39		17:00:15	17:10:28			17:16:54	17:23:39		17:30:15
Bramalea arr	16:44:14			16:51:44	16:57:37		17:03:45	17:14:14			17:21:44	17:27:37		17:33:45
Bramalea	16:44:54		16:49:05	16:51:44	16:57:37		17:04:05	17:14:54		17:19:05	17:21:44	17:27:37		17:34:05
Halwest Jct.	16:45:46		16:49:50	16:52:30	16:57:59		17:04:50	17:15:46		17:19:50	17:22:30	17:27:59		17:34:50
Malton	16:47:10		16:52:08		16:59:17		17:07:08	17:17:10		17:22:08		17:29:17		17:37:08
Woodbine Jct.	16:48:00	16:52:27	16:53:25		17:00:03	17:07:27	17:08:25	17:18:00	17:22:27	17:23:25		17:30:03	17:37:27	17:38:25
Etobicoke North	16:49:34	16:54:35	16:55:54		17:01:28	17:09:35	17:10:54	17:19:34	17:24:35	17:25:54		17:31:28	17:39:35	17:40:54
Weston	16:51:24	16:56:25	16:58:54		17:03:15	17:11:25	17:13:54	17:21:24	17:26:25	17:28:54		17:33:15	17:41:25	17:43:54
Mount Dennis arr	16:52:59	16:57:59	17:00:51		17:04:51	17:12:59	17:15:51	17:22:59	17:27:59	17:30:51		17:34:51	17:42:59	17:45:51
Mount Dennis	16:53:39	16:58:39	17:01:11		17:05:51	17:13:39	17:16:11	17:23:39	17:28:39	17:31:11		17:35:51	17:43:39	17:46:11
St. Clair	16:55:10	17:00:10	17:03:23		17:07:52	17:15:10	17:18:23	17:25:10	17:30:10	17:33:23		17:37:52	17:45:10	17:48:23
Bloor	16:57:12	17:02:12	17:05:26		17:08:40	17:17:12	17:20:26	17:27:12	17:32:12	17:35:26		17:38:40	17:47:12	17:50:26
Liberty Village	16:59:10	17:04:10	17:07:57		17:10:10	17:19:10	17:22:57	17:29:10	17:34:10	17:37:57		17:40:10	17:49:10	17:52:57
Toronto arr	17:03:00	17:08:00	17:12:00		17:14:00	17:23:00	17:27:00	17:33:00	17:38:00	17:42:00		17:44:00	17:53:00	17:57:00
Travel time	01:02:02	00:15:33	00:22:55	00:16:49	00:54:44	00:15:33	00:35:16	01:02:02	00:15:33	00:22:55	00:16:49	00:54:44	00:15:33	00:35:16

Scenario IV (symmetric timetable): Fixed-block signaling system

Train service	Freight	RER	AIR	IC	Freight	Freight	RER	AIR	IR	Freight	Freight	RER	AIR	IC	Freight	Freight	RER	AIR	IR	Freight		
Station dwell time [s]	n/a	20	40	60	n/a	n/a	20	40	40	n/a	n/a	20	40	60	n/a	n/a	20	40	40	n/a		
Routing	F-W1	RER-W3a	AIR-W1	IC-W1	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W1	F-W1	F-W1	RER-W3a	AIR-W1	IC-W1	F-W1	F-W1	RER-W6BL	AIR-W1	IR-W1	F-W1		
Toronto		16:03:00	16:07:00	16:16:00			16:18:00	16:22:00	16:27:00			16:33:00	16:37:00	16:46:00			16:48:00	16:52:00	16:57:00			
Liberty Village		16:08:36	16:11:33	16:21:05			16:23:36	16:26:33	16:32:02			16:38:36	16:41:33	16:51:05			16:53:36	16:56:33	17:02:02			
Bloor		16:11:09	16:14:12	16:22:40			16:26:09	16:29:12	16:34:43			16:41:09	16:44:12	16:52:40			16:56:09	16:59:12	17:04:43			
St. Clair		16:13:12	16:15:33	16:23:28			16:28:12	16:30:33	16:36:04			16:43:12	16:45:33	16:53:28			16:58:12	17:00:33	17:06:04			
Mount Dennis arr		16:15:04	16:17:04	16:25:00			16:30:04	16:32:04	16:37:35			16:45:04	16:47:04	16:55:00			17:00:04	17:02:04	17:07:35			
Mount Dennis		16:15:24	16:17:44	16:26:00			16:30:24	16:32:44	16:38:15			16:45:24	16:47:44	16:56:00			17:00:24	17:02:44	17:08:15			
Weston		16:17:41	16:19:18	16:28:05			16:32:41	16:34:18	16:39:49			16:47:41	16:49:18	16:58:05			17:02:41	17:04:18	17:09:49			
Etobicoke North		16:20:42	16:21:08	16:29:55			16:35:42	16:36:08	16:41:41			16:50:42	16:51:08	16:59:55			17:05:42	17:06:08	17:11:41			
Woodbine Jct.		16:23:06	16:23:06	16:31:20			16:38:06	16:38:06	16:43:14			16:53:06	16:53:06	17:01:20			17:08:06	17:08:06	17:13:14			
Malton		16:24:58		16:32:06			16:39:58		16:44:04			16:54:58		17:02:06			17:09:58		17:14:04			
Halwest Jct.	16:23:00	16:26:51		16:33:23	16:34:00	16:39:00	16:42:01		16:45:28	16:47:30	16:53:00	16:56:51		17:03:23	17:04:00	17:09:00	17:12:01		17:15:28	17:17:30		
Bramalea arr	16:23:41	16:27:41		16:33:46	16:34:41	16:39:41	16:43:02		16:46:20	16:48:11	16:53:41	16:57:41		17:03:46	17:04:41	17:09:41	17:13:02		17:16:20	17:18:11		
Bramalea	16:23:41	16:28:01		16:33:46	16:34:41	16:39:41			16:47:00	16:48:11	16:53:41	16:58:01		17:03:46	17:04:41	17:09:41			17:17:00	17:18:11		
Brampton arr	16:28:41	16:31:31		16:36:37	16:39:41	16:44:41			16:50:30	16:53:11	16:58:41	17:01:31		17:06:37	17:09:41	17:14:41			17:20:30	17:23:11		
Brampton	16:28:41	16:31:51		16:37:37	16:39:41	16:44:41			16:51:10	16:53:11	16:58:41	17:01:51		17:07:37	17:09:41	17:14:41			17:21:10	17:23:11		
Mount Pleasant	16:32:33	16:35:02		16:40:29	16:43:33	16:48:33			16:54:45	16:57:03	17:02:33	17:05:02		17:10:29	17:13:33	17:18:33			17:24:45	17:27:03		
Georgetown arr	16:39:04	16:40:22		16:43:33	16:50:04	16:55:04			16:59:09	17:03:34	17:09:04	17:10:22		17:13:33	17:20:04	17:25:04			17:29:09	17:33:34		
Georgetown	16:39:04	signal stop		16:43:33	16:50:04	16:55:04			16:59:49	17:03:34	17:09:04	signal stop		17:13:33	17:20:04	17:25:04			17:29:49	17:33:34		
Silver Jct.	16:39:57	(0 minutes)		16:44:03	16:50:57	16:55:57			17:00:45	17:04:27	17:09:57	(0 minutes)		17:14:03	17:20:57	17:25:57			17:30:45	17:34:27		
Acton		before		16:48:22					17:06:14			before		17:18:22					17:36:14			
Guelph arr		entering		16:58:07					17:16:35			entering		17:28:07					17:46:35			
Guelph		Georgetown		17:00:07					17:17:15			Georgetown		17:30:07					17:47:15			
Guelph Jct.				17:01:46					17:18:33					17:31:46					17:48:33			
Breslau				17:06:27					17:24:46					17:36:27					17:54:46			
Kitchener arr				17:11:08					17:29:55					17:41:08					17:59:55			
Routing				IC-W3F										IC-W3F								
Guelph				17:02:07										17:32:07								
Guelph Jct.				17:03:59										17:33:59								
Hespeler				17:14:17										17:44:17								
Preston				17:18:48										17:48:48								
Cambridge arr				17:25:06										17:55:06								
Travel time	00:16:57	00:37:22	00:16:06	00:55:08	00:16:57	00:16:57	00:25:02	00:16:06	01:02:55	00:16:57	00:16:57	00:37:22	00:16:06	00:55:08	00:16:57	00:16:57	00:25:02	00:16:06	01:02:55	00:16:57		

Train service	Freight	IR	Freight	AIR	RER	Freight	IC	Freight	AIR	RER	Freight	Freight	IR	Freight	AIR	RER	Freight	IC	Freight	AIR	RER	Freight
Station dwell time [s]	n/a	40	n/a	40	20	n/a	60	n/a	40	20	n/a	n/a	40	n/a	40	20	n/a	60	n/a	40	20	n/a
Routing							IC-E5F											IC-E5F				
Cambridge							16:05:02											16:35:02				
Preston							16:13:17											16:43:17				
Hespeler							16:17:48											16:47:48				
Guelph Jct.							16:27:05											16:57:05				
Guelph arr							16:28:34											16:58:34				
Routing	F-E1	IR-E2	F-E1	AIR-E1	RER-E3BL	F-E1	IC-E1	F-E2	AIR-E1	RER-E1	F-E1	F-E1	IR-E2	F-E1	AIR-E1	RER-E3BL	F-E1	IC-E1	F-E2	AIR-E1	RER-E1	F-E1
Kitchener		16:01:00					16:19:22						16:31:00					16:49:22				
Breslau		16:06:56					16:24:26						16:36:56					16:54:26				
Guelph Jct.		16:12:27					16:29:03						16:42:27					16:59:03				
Guelph arr		16:13:44					16:30:24						16:43:44					17:00:24				
Guelph		16:14:24					16:32:24						16:44:24					17:02:24				
Acton		16:25:26					16:42:32						16:55:26					17:12:32				
Silver Jct.	16:25:11	16:30:15	16:32:11			16:35:11	16:46:50	16:44:57			16:52:11	16:55:11	17:00:15	17:02:11			17:05:11	17:16:50	17:14:57			17:22:11
Georgetown arr	16:26:06	16:31:11	16:33:06			16:36:06	16:47:20	16:45:52			16:53:06	16:56:06	17:01:11	17:03:06			17:06:06	17:17:20	17:15:52			17:23:06
Georgetown	16:26:06	16:31:51	16:33:06			16:36:06	16:47:20	16:45:52		16:51:44	16:53:06	16:56:06	17:01:51	17:03:06			17:06:06	17:17:20	17:15:52		17:21:44	17:23:06
Mount Pleasant	16:32:47	16:36:55	16:39:47			16:42:47	16:50:27	16:52:40		16:57:04	16:59:47	17:02:47	17:06:55	17:09:47			17:12:47	17:20:27	17:22:40		17:27:04	17:29:47
Brampton arr	16:36:25	16:39:51	16:43:25			16:46:25	16:52:45	16:56:25		16:59:55	17:03:25	17:06:25	17:09:51	17:13:25			17:16:25	17:22:45	17:26:25		17:29:55	17:33:25
Brampton	16:36:25	16:40:31	16:43:25			16:46:25	16:53:45	16:56:25		17:00:15	17:03:25	17:06:25	17:10:31	17:13:25			17:16:25	17:23:45	17:26:25		17:30:15	17:33:25
Bramalea arr	16:41:14	16:44:14	16:48:14			16:51:14	16:57:37	17:01:14		17:03:45	17:08:14	17:11:14	17:14:14	17:18:14			17:21:14	17:27:37	17:31:14		17:33:45	17:38:14
Bramalea	16:41:14	16:44:54	16:48:14		16:49:05	16:51:14	16:57:37	17:01:14		17:04:05	17:08:14	17:11:14	17:14:54	17:18:14		17:19:05	17:21:14	17:27:37	17:31:14		17:34:05	17:38:14
Halwest Jct.	16:42:00	16:45:46	16:49:00		16:49:50	16:52:00	16:57:59	17:02:00		17:04:50	17:09:00	17:12:00	17:15:46	17:19:00		17:19:50	17:22:00	17:27:59	17:32:00		17:34:50	17:39:00
Malton		16:47:10			16:52:08		16:59:17			17:07:08			17:17:10			17:22:08		17:29:17			17:37:08	
Woodbine Jct.		16:48:00		16:52:36	16:53:25		17:00:03		17:07:36	17:08:25			17:18:00		17:22:36	17:23:25		17:30:03		17:37:36	17:38:25	
Etobicoke North		16:49:34		16:54:35	16:55:54		17:01:28		17:09:35	17:10:54			17:19:34		17:24:35	17:25:54		17:31:28		17:39:35	17:40:54	
Weston		16:51:24		16:56:25	16:58:54		17:03:15		17:11:25	17:13:54			17:21:24		17:26:25	17:28:54		17:33:15		17:41:25	17:43:54	
Mount Dennis arr		16:52:59		16:57:59	17:00:51		17:04:51		17:12:59	17:15:51			17:22:59		17:27:59	17:30:51		17:34:51		17:42:59	17:45:51	
Mount Dennis		16:53:39		16:58:39	17:01:11		17:05:51		17:13:39	17:16:11			17:23:39		17:28:39	17:31:11		17:35:51		17:43:39	17:46:11	
St. Clair		16:55:10		17:00:10	17:03:23		17:07:52		17:15:10	17:18:23			17:25:10		17:30:10	17:33:23		17:37:52		17:45:10	17:48:23	
Bloor		16:57:12		17:02:12	17:05:26		17:08:40		17:17:12	17:20:26			17:27:12		17:32:12	17:35:26		17:38:40		17:47:12	17:50:26	
Liberty Village		16:59:10		17:04:10	17:07:57		17:10:10		17:19:10	17:22:57			17:29:10		17:34:10	17:37:57		17:40:10		17:49:10	17:52:57	
Toronto arr		17:03:00		17:08:00	17:12:00		17:14:00		17:23:00	17:27:00			17:33:00		17:38:00	17:42:00		17:44:00		17:53:00	17:57:00	
Travel time	00:16:49	01:02:00	00:16:49	00:15:24	00:22:55	00:16:49	00:54:38	00:17:03	00:15:24	00:35:16	00:16:49	00:16:49	01:02:00	00:16:49	00:15:24	00:22:55	00:16:49	00:54:38	00:17:03	00:15:24	00:35:16	00:16:49

Scenario V (integrated fixed-interval timetable): Variable-block signaling system

Train service	RER	IR	AIR	Freight	IC	RER	AIR	RER	IR	AIR	Freight	IC	RER	AIR
Station dwell time [s]	20	40	40	n/a	60	20	40	20	40	40	n/a	60	20	40
Routing	RER-W6BL	IR-W1	AIR-W1	F-W1	IC-W1	RER-W1	AIR-W1	RER-W6BL	IR-W1	AIR-W1	F-W1	IC-W1	RER-W1	AIR-W1
Toronto	16:04:00	16:06:00	16:09:00		16:19:00	16:19:00	16:24:00	16:34:00	16:36:00	16:39:00		16:49:00	16:49:00	16:54:00
Liberty Village	16:09:36	16:11:02	16:13:33		16:24:05	16:24:36	16:28:33	16:39:36	16:41:02	16:43:33		16:54:05	16:54:36	16:58:33
Bloor	16:12:09	16:13:43	16:16:12		16:25:40	16:27:09	16:31:12	16:42:09	16:43:43	16:46:12		16:55:40	16:57:09	17:01:12
St. Clair	16:14:12	16:15:04	16:17:33		16:26:28	16:29:12	16:32:33	16:44:12	16:45:04	16:47:33		16:56:28	16:59:12	17:02:33
Mount Dennis arr	16:16:04	16:16:35	16:19:04		16:28:00	16:31:04	16:34:04	16:46:04	16:46:35	16:49:04		16:58:00	17:01:04	17:04:04
Mount Dennis	16:16:24	16:17:15	16:19:44		16:29:00	16:31:24	16:34:44	16:46:24	16:47:15	16:49:44		16:59:00	17:01:24	17:04:44
Weston	16:18:41	16:18:49	16:21:18		16:31:05	16:33:41	16:36:18	16:48:41	16:48:49	16:51:18		17:01:05	17:03:41	17:06:18
Etobicoke North	16:21:42	16:20:41	16:23:08		16:32:55	16:36:42	16:38:08	16:51:42	16:50:41	16:53:08		17:02:55	17:06:42	17:08:08
Woodbine Jct.	16:24:15	16:22:14	16:25:16		16:34:20	16:39:15	16:40:16	16:54:15	16:52:14	16:55:16		17:04:20	17:09:15	17:10:16
Malton	16:26:21	16:23:04			16:35:06	16:41:21		16:56:21	16:53:04			17:05:06	17:11:21	
Halwest Jct.	16:28:24	16:24:28		16:28:30	16:36:23	16:43:13		16:58:24	16:54:28		16:58:30	17:06:23	17:13:13	
Bramalea arr	16:29:24	16:25:20		16:29:13	16:36:46	16:44:04		16:59:24	16:55:20		16:59:13	17:06:46	17:14:04	
Bramalea		16:26:00		16:29:13	16:36:46	16:44:24			16:56:00		16:59:13	17:06:46	17:14:24	
Brampton arr		16:29:30		16:34:14	16:39:37	16:47:53			16:59:30		17:04:14	17:09:37	17:17:53	
Brampton		16:30:10		16:34:14	16:40:37	16:48:13			17:00:10		17:04:14	17:10:37	17:18:13	
Mount Pleasant		16:33:45		16:38:07	16:43:29	16:51:25			17:03:45		17:08:07	17:13:29	17:21:25	
Georgetown arr		16:38:09		16:44:38	16:46:33	16:56:17			17:08:09		17:14:38	17:16:33	17:26:17	
Georgetown		16:38:49		16:44:38	16:46:33				17:08:49		17:14:38	17:16:33		
Silver Jct.		16:39:45		16:45:32	16:47:03				17:09:45		17:15:32	17:17:03		
Acton		16:45:14			16:51:22				17:15:14			17:21:22		
Guelph arr		16:55:35			17:01:07				17:25:35			17:31:07		
Guelph		16:56:15			17:03:07				17:26:15			17:33:07		
Guelph Jct.		16:57:33			17:04:46				17:27:33			17:34:46		
Breslau		17:03:46			17:09:27				17:33:46			17:39:27		
Kitchener arr		17:08:55			17:14:08				17:38:55			17:44:08		
Routing					IC-W3F							IC-W3F		
Guelph					17:05:07							17:35:07		
Guelph Jct.					17:06:59							17:36:59		
Hespeler					17:17:17							17:47:17		
Preston					17:21:48							17:51:48		
Cambridge arr					17:28:06							17:58:06		
Travel time	00:25:24	01:02:55	00:16:16	00:17:02	00:55:08	00:37:17	00:16:16	00:25:24	01:02:55	00:16:16	00:17:02	00:55:08	00:37:17	00:16:16

Train service	Freight	AIR	RER	IC	AIR	IR	RER	Freight	AIR	IC	RER	AIR	IR	RER
Station dwell time [s]	n/a	40	20	60	40	40	20	n/a	40	60	20	40	40	20
Routing				IC-E5F						IC-E5F				
Cambridge				16:00:21						16:30:21				
Preston				16:08:36						16:38:36				
Hespeler				16:13:08						16:43:08				
Guelph Jct.				16:22:24						16:52:24				
Guelph arr				16:23:53						16:53:53				
Routing	F-E1	AIR-E1	RER-E1	IC-E1	AIR-E1	IR-E2	RER-E3BL	F-E1	AIR-E1	IC-E1	RER-E1	AIR-E1	IR-E2	RER-E3BL
Kitchener				16:16:16		16:20:58				16:46:16			16:50:58	
Breslau				16:21:21		16:26:54				16:51:21			16:56:54	
Guelph Jct.				16:25:58		16:32:25				16:55:58			17:02:25	
Guelph arr				16:27:19		16:33:42				16:57:19			17:03:42	
Guelph				16:29:19		16:34:22				16:59:19			17:04:22	
Acton				16:39:26		16:45:24				17:09:26			17:15:24	
Silver Jct.	16:27:11			16:43:45		16:50:13		16:57:11		17:13:45			17:20:13	
Georgetown arr	16:28:05			16:44:14		16:51:09		16:58:05		17:14:14			17:21:09	
Georgetown	16:28:05		16:38:44	16:44:14		16:51:49		16:58:05		17:14:14	17:08:44		17:21:49	
Mount Pleasant	16:34:46		16:44:04	16:47:22		16:56:53		17:04:46		17:17:22	17:14:04		17:26:53	
Brampton arr	16:38:24		16:46:55	16:49:39		16:59:48		17:08:24		17:19:39	17:16:55		17:29:48	
Brampton	16:38:24		16:47:15	16:50:39		17:00:28		17:08:24		17:20:39	17:17:15		17:30:28	
Bramalea arr	16:43:14		16:50:45	16:54:37		17:04:14		17:13:14		17:24:37	17:20:45		17:34:14	
Bramalea	16:43:14		16:51:05	16:54:37		17:04:54	17:06:05	17:13:14		17:24:37	17:21:05		17:34:54	17:36:05
Halwest Jct.	16:44:00		16:51:50	16:54:59		17:05:46	17:06:50	17:14:00		17:24:59	17:21:50		17:35:46	17:36:50
Malton			16:54:08	16:56:17		17:07:10	17:09:08			17:26:17	17:24:08		17:37:10	17:39:08
Woodbine Jct.		16:49:27	16:55:25	16:57:03	17:04:27	17:08:00	17:10:25		17:19:27	17:27:03	17:25:25	17:34:27	17:38:00	17:40:25
Etobicoke North		16:51:35	16:57:54	16:58:28	17:06:35	17:09:34	17:12:54		17:21:35	17:28:28	17:27:54	17:36:35	17:39:34	17:42:54
Weston		16:53:25	17:00:54	17:00:15	17:08:25	17:11:24	17:15:54		17:23:25	17:30:15	17:30:54	17:38:25	17:41:24	17:45:54
Mount Dennis arr		16:54:59	17:02:51	17:01:51	17:09:59	17:12:59	17:17:51		17:24:59	17:31:51	17:32:51	17:39:59	17:42:59	17:47:51
Mount Dennis		16:55:39	17:03:11	17:02:51	17:10:39	17:13:39	17:18:11		17:25:39	17:32:51	17:33:11	17:40:39	17:43:39	17:48:11
St. Clair		16:57:10	17:05:23	17:04:52	17:12:10	17:15:10	17:20:23		17:27:10	17:34:52	17:35:23	17:42:10	17:45:10	17:50:23
Bloor		16:59:12	17:07:26	17:05:40	17:14:12	17:17:12	17:22:26		17:29:12	17:35:40	17:37:26	17:44:12	17:47:12	17:52:26
Liberty Village		17:01:10	17:09:57	17:07:10	17:16:10	17:19:10	17:24:57		17:31:10	17:37:10	17:39:57	17:46:10	17:49:10	17:54:57
Toronto arr		17:05:00	17:14:00	17:11:00	17:20:00	17:23:00	17:29:00		17:35:00	17:41:00	17:44:00	17:50:00	17:53:00	17:59:00
Travel time	00:16:49	00:15:33	00:35:16	00:54:44	00:15:33	01:02:02	00:22:55	00:16:49	00:15:33	00:54:44	00:35:16	00:15:33	01:02:02	00:22:55

Scenario V (integrated fixed-interval timetable): Fixed-block signaling system

Train service	Freight	RER	IR	AIR	Freight	IC	Freight	RER	AIR	Freight	Freight	RER	IR	AIR	Freight	IC	Freight	RER	AIR	Freight
Station dwell time [s]	n/a	20	40	40	n/a	60	n/a	20	40	n/a	n/a	20	40	40	n/a	60	n/a	20	40	n/a
Routing	F-W1	RER-W6BL	IR-W1	AIR-W1	F-W1	IC-W2	F-W1	RER-W1	AIR-W1	F-W1	F-W1	RER-W6BL	IR-W1	AIR-W1	F-W1	IC-W2	F-W1	RER-W1	AIR-W1	F-W1
Toronto		16:04:00	16:06:00	16:09:00		16:19:00		16:19:00	16:24:00			16:34:00	16:36:00	16:39:00		16:49:00		16:49:00	16:54:00	
Liberty Village		16:09:36	16:11:02	16:13:33		16:24:05		16:24:36	16:28:33			16:39:36	16:41:02	16:43:33		16:54:05		16:54:36	16:58:33	
Bloor		16:12:09	16:13:43	16:16:12		16:25:40		16:27:09	16:31:12			16:42:09	16:43:43	16:46:12		16:55:40		16:57:09	17:01:12	
St. Clair		16:14:12	16:15:04	16:17:33		16:26:28		16:29:12	16:32:33			16:44:12	16:45:04	16:47:33		16:56:28		16:59:12	17:02:33	
Mount Dennis arr		16:16:04	16:16:35	16:19:04		16:28:00		16:31:04	16:34:04			16:46:04	16:46:35	16:49:04		16:58:00		17:01:04	17:04:04	
Mount Dennis		16:16:24	16:17:15	16:19:44		16:29:00		16:31:24	16:34:44			16:46:24	16:47:15	16:49:44		16:59:00		17:01:24	17:04:44	
Weston		16:18:41	16:18:49	16:21:18		16:31:05		16:33:41	16:36:18			16:48:41	16:48:49	16:51:18		17:01:05		17:03:41	17:06:18	
Etobicoke North		16:21:42	16:20:41	16:23:08		16:32:55		16:36:42	16:38:08			16:51:42	16:50:41	16:53:08		17:02:55		17:06:42	17:08:08	
Woodbine Jct.		16:24:06	16:22:14	16:25:06		16:34:20		16:39:06	16:40:06			16:54:06	16:52:14	16:55:06		17:04:20		17:09:06	17:10:06	
Malton		16:25:58	16:23:04			16:35:06		16:40:58				16:55:58	16:53:04			17:05:06		17:10:58		
Halwest Jct.	16:21:00	16:28:01	16:24:28		16:28:00	16:36:23	16:37:30	16:42:51		16:44:30	16:51:00	16:58:01	16:54:28		16:58:00	17:06:23	17:07:30	17:12:51		17:14:30
Bramalea arr	16:21:41	16:29:02	16:25:20		16:28:41	16:36:46	16:38:11	16:43:41		16:45:11	16:51:41	16:59:02	16:55:20		16:58:41	17:06:46	17:08:11	17:13:41		17:15:11
Bramalea	16:21:41		16:26:00		16:28:41	16:36:46	16:38:11	16:44:01		16:45:11	16:51:41		16:56:00		16:58:41	17:06:46	17:08:11	17:14:01		17:15:11
Brampton arr	16:26:41		16:29:30		16:33:41	16:39:37	16:43:11	16:47:31		16:50:11	16:56:41		16:59:30		17:03:41	17:09:37	17:13:11	17:17:31		17:20:11
Brampton	16:26:41		16:30:10		16:33:41	16:40:37	16:43:11	16:47:51		16:50:11	16:56:41		17:00:10		17:03:41	17:10:37	17:13:11	17:17:51		17:20:11
Mount Pleasant	16:30:33		16:33:45		16:37:33	16:43:39	16:47:03	16:51:02		16:54:03	17:00:33		17:03:45		17:07:33	17:13:39	17:17:03	17:21:02		17:24:03
Georgetown arr	16:37:04		16:38:09		16:44:04	16:46:50	16:53:34	16:55:54		17:00:34	17:07:04		17:08:09		17:14:04	17:16:50	17:23:34	17:25:54		17:30:34
Georgetown	16:37:04		16:38:49		16:44:04	16:46:50	16:53:34			17:00:34	17:07:04		17:08:49		17:14:04	17:16:50	17:23:34			17:30:34
Silver Jct.	16:37:57		16:39:45		16:44:57	16:47:44	16:54:27			17:01:27	17:07:57		17:09:45		17:14:57	17:17:44	17:24:27			17:31:27
Acton			16:45:14			16:52:19							17:15:14			17:22:19				
Guelph arr			16:55:35			17:02:04							17:25:35			17:32:04				
Guelph			16:56:15			17:04:04							17:26:15			17:34:04				
Guelph Jct.			16:57:33			17:05:44							17:27:33			17:35:44				
Breslau			17:03:46			17:10:24							17:33:46			17:40:24				
Kitchener arr			17:08:55			17:15:05							17:38:55			17:45:05				
Routing						IC-W3F										IC-W3F				
Guelph						17:06:04										17:36:04				
Guelph Jct.						17:07:56										17:37:56				
Hespeler						17:18:15										17:48:15				
Preston						17:22:46										17:52:46				
Cambridge arr						17:29:04										17:59:04				
Travel time	00:16:57	00:25:02	01:02:55	00:16:06	00:16:57	00:56:05	00:16:57	00:36:54	00:16:06	00:16:57	00:16:57	00:25:02	01:02:55	00:16:06	00:16:57	00:56:05	00:16:57	00:36:54	00:16:06	00:16:57

Train service	Freight	Freight	AIR	Freight	RER	IC	Freight	AIR	IR	RER	Freight	Freight	AIR	Freight	RER	IC	Freight	AIR	IR	RER
Station dwell time [s]	n/a	n/a	40	n/a	20	60	n/a	40	40	20	n/a	n/a	40	n/a	20	60	n/a	40	40	20
Routing						IC-E5F										IC-E5F				
Cambridge						16:02:02										16:32:02				
Preston						16:10:17										16:40:17				
Hespeler						16:14:48										16:44:48				
Guelph Jct.						16:24:05										16:54:05				
Guelph arr						16:25:34										16:55:34				
Routing	F-E1	F-E1	AIR-E1	F-E1	RER-E1	IC-E1	F-E2	AIR-E1	IR-E1	RER-E3BL	F-E1	F-E1	AIR-E1	F-E1	RER-E1	IC-E1	F-E2	AIR-E1	IR-E1	RER-E3BL
Kitchener						16:16:22			16:20:41							16:46:22			16:50:41	
Breslau						16:21:26			16:26:37							16:51:26			16:56:37	
Guelph Jct.						16:26:03			16:32:08							16:56:03			17:02:08	
Guelph arr						16:27:24			16:33:25							16:57:24			17:03:25	
Guelph						16:29:24			16:34:05							16:59:24			17:04:05	
Acton						16:39:32			16:45:07							17:09:32			17:15:07	
Silver Jct.	16:26:11	16:29:11		16:32:11		16:43:50	16:41:27		16:49:56		16:56:11	16:59:11		17:02:11		17:13:50	17:11:27		17:19:56	
Georgetown arr	16:27:06	16:30:06		16:33:06		16:44:20	16:42:22		16:50:52		16:57:06	17:00:06		17:03:06		17:14:20	17:12:22		17:20:52	
Georgetown	16:27:06	16:30:06		16:33:06	16:38:44	16:44:20	16:42:22		16:51:32		16:57:06	17:00:06		17:03:06	17:08:44	17:14:20	17:12:22		17:21:32	
Mount Pleasant	16:33:47	16:36:47		16:39:47	16:44:04	16:47:27	16:49:10		16:56:37		17:03:47	17:06:47		17:09:47	17:14:04	17:17:27	17:19:10		17:26:37	
Brampton arr	16:37:25	16:40:25		16:43:25	16:46:55	16:49:45	16:52:55		16:59:32		17:07:25	17:10:25		17:13:25	17:16:55	17:19:45	17:22:55		17:29:32	
Brampton	16:37:25	16:40:25		16:43:25	16:47:15	16:50:45	16:52:55		17:00:12		17:07:25	17:10:25		17:13:25	17:17:15	17:20:45	17:22:55		17:30:12	
Bramalea arr	16:42:14	16:45:14		16:48:14	16:50:45	16:54:37	16:57:44		17:04:14		17:12:14	17:15:14		17:18:14	17:20:45	17:24:37	17:27:44		17:34:14	
Bramalea	16:42:14	16:45:14		16:48:14	16:51:05	16:54:37	16:57:44		17:04:54	17:06:05	17:12:14	17:15:14		17:18:14	17:21:05	17:24:37	17:27:44		17:34:54	17:36:05
Halwest Jct.	16:43:00	16:46:00		16:49:00	16:51:50	16:54:59	16:58:30		17:05:46	17:06:50	17:13:00	17:16:00		17:19:00	17:21:50	17:24:59	17:28:30		17:35:46	17:36:50
Malton					16:54:08	16:56:17			17:07:10	17:09:08					17:24:08	17:26:17			17:37:10	17:39:08
Woodbine Jct.			16:49:36		16:55:25	16:57:03		17:04:36	17:08:00	17:10:25			17:19:36		17:25:25	17:27:03		17:34:36	17:38:00	17:40:25
Etobicoke North			16:51:35		16:57:54	16:58:28		17:06:35	17:09:34	17:12:54			17:21:35		17:27:54	17:28:28		17:36:35	17:39:34	17:42:54
Weston			16:53:25		17:00:54	17:00:15		17:08:25	17:11:24	17:15:54			17:23:25		17:30:54	17:30:15		17:38:25	17:41:24	17:45:54
Mount Dennis arr			16:54:59		17:02:51	17:01:51		17:09:59	17:12:59	17:17:51			17:24:59		17:32:51	17:31:51		17:39:59	17:42:59	17:47:51
Mount Dennis			16:55:39		17:03:11	17:02:51		17:10:39	17:13:39	17:18:11			17:25:39		17:33:11	17:32:51		17:40:39	17:43:39	17:48:11
St. Clair			16:57:10		17:05:23	17:04:52		17:12:10	17:15:10	17:20:23			17:27:10		17:35:23	17:34:52		17:42:10	17:45:10	17:50:23
Bloor			16:59:12		17:07:26	17:05:40		17:14:12	17:17:12	17:22:26			17:29:12		17:37:26	17:35:40		17:44:12	17:47:12	17:52:26
Liberty Village			17:01:10		17:09:57	17:07:10		17:16:10	17:19:10	17:24:57			17:31:10		17:39:57	17:37:10		17:46:10	17:49:10	17:54:57
Toronto arr			17:05:00		17:14:00	17:11:00		17:20:00	17:23:00	17:29:00			17:35:00		17:44:00	17:41:00		17:50:00	17:53:00	17:59:00
Travel time	00:16:49	00:16:49	00:15:24	00:16:49	00:35:16	00:54:38	00:17:03	00:15:24	01:02:19	00:22:55	00:16:49	00:16:49	00:15:24	00:16:49	00:35:16	00:54:38	00:17:03	00:15:24	01:02:19	00:22:55