40 TPH Without CBTC

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Is System Maxed Out?

Subway Ridership 1975-2015

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Introduction

Ridership on the New York City Subway has grown drastically in the last four decades, from 966 million in 1975 to 1.7 billion in 2015; at the Times Square subway station alone, rides increased by 29 million. This explosive growth in usage demonstrates the system's importance to both the city and region. New York City's 24-hour subway promotes a dynamic economy, livability, and connectivity giving residents access to economic opportunities and a quality of life that is unparalleled in most world cities.

Growth in subway ridership reflects the changes in New York City. The city's declining population in the 1970s, the high homicide rate in the late 1980s and early 1990s, the 2008 Financial Crisis, leading to an economic downturn and job losses, and the attacks of September 11, 2001 all influenced subway ridership. Several key events since 1975 have contributed to increased subway usage, including:

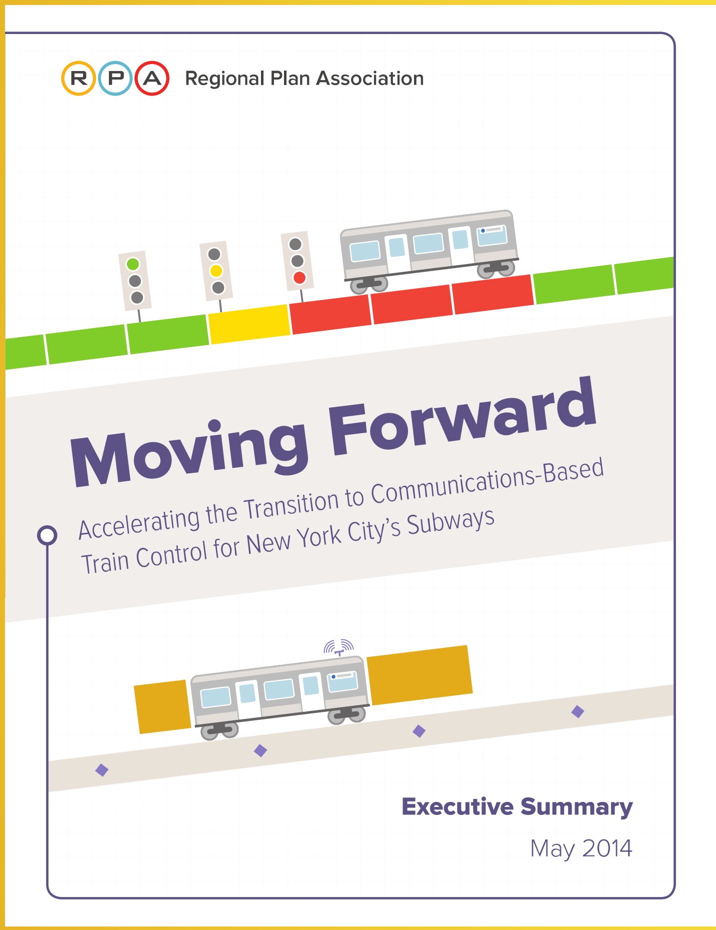
- Early 1980s: The massive, $7.6 billion capital investment in the New York City subway system in the form of new equipment and improved maintenance, plus graffiti removal, boosted ridership.
- 1998: The replacement of tokens with the MetroCard permitted unlimited 7- and 30-day trip options and to transfer between subways and buses without charge. Ridership increased in Brooklyn by 16% and the Bronx by 17% in the following year.
- 1995-2015: New York City's population grew significantly.
- 2010-2015: Tourism increased in New York City by nearly 10 million people to 58.5 million, increasing reliance on the subway.[1]

The health and continued growth of the subway system is critical to New York City's future. As such, the system must be improved to reflect New Yorkers' increasing reliance. Recommended system upgrades include:

1. System-wide implementation of advanced signaling technologies, such as Communications Based Train Control
2. Cellular and wifi access in all stations for an informed ridership
3. Improved information dissemination to riders through:
    a. Train tracking and countdown clocks, and
    b. Development of a weekend subway map to reflect construction and other planned diversions
    c. Continuation of investment in all equipment to achieve state of good repair across the system

[1] NYC & Company, NYC Visitation Statistics. http://www.nycandcompany.org/research/nyc-statistics-page

Is System Maxed Out



Executive Summary

The New York City subway system has made strides in recent years in upgrading stations, subway cars and passengers' experience. But in one crucial area – signaling - the subway system remains antiquated, relying primarily on century-old technology to keep trains running. While New York is in the early stages of converting to communications-based train control, the modern telecommunications system that many of the world's metro systems rely on today, the pace of change has been slow. At the current rate, a full transformation wouldn't occur for more than 50 years, putting the city decades behind its peers around the globe.

What are the consequences of going too slowly?

More delays, increased safety risk and an inefficient use of resources. Because the network relies on old technology, repairs and replacement parts are costly. As the system ages, that burden will only increase.

What is holding New York back?

Resources, certainly. While CBTC will save money in the long run, it requires a substantial upfront investment in new systems and equipment. Future capital plans need to significantly increase funding beyond current levels. Converting to CBTC also could be done sooner with modifications to procurement rules and more flexibility to work on the tracks throughout the day. These are hard decisions that involve changes to longstanding procedures, but could speed up other projects in addition to signal work.

This report will explain what CBTC is and how it works. It will discuss the status of CBTC in New York City's subway system, and make recommendations to implement it more quickly and efficiently.

What is Communications-Based Train Control?

Today, the New York City subway relies on a central nervous system made up of 15,000 signal blocks, 3,500 mainline switches and 339,000 signal relays. These components, which have hardly changed since the subway opened in 1904, let train operators know when it is safe for them to move trains forward.

The type of signaling system used by New York's subway, called fixed-block wayside signals, divides the subway tracks into blocks of around 1,000 feet and creates a buffer of one or more additional trailing blocks to ensure safe separation of train traffic. The buffers limit the number of trains that can flow through the tracks at any one time.

The effects of these constraints have increased as subway ridership has grown. In the last 20 years, the number of passengers has climbed to its highest level since 1950, with more growth expected in the coming years. During peak periods, trains are forced to wait in stations while crowds of passengers exit and enter the cars, causing delays that ricochet through the system. The result is fewer trains running per hour. In off-peak hours, where ridership growth has been greater, it has become increasingly difficult to find adequate time to inspect, maintain and replace the signal blocks, switches, relays and automatic train stops without major effects on service. Dispatchers can only determine so much now about train location, and lack the precision and ability to centrally monitor and manage the entire system.

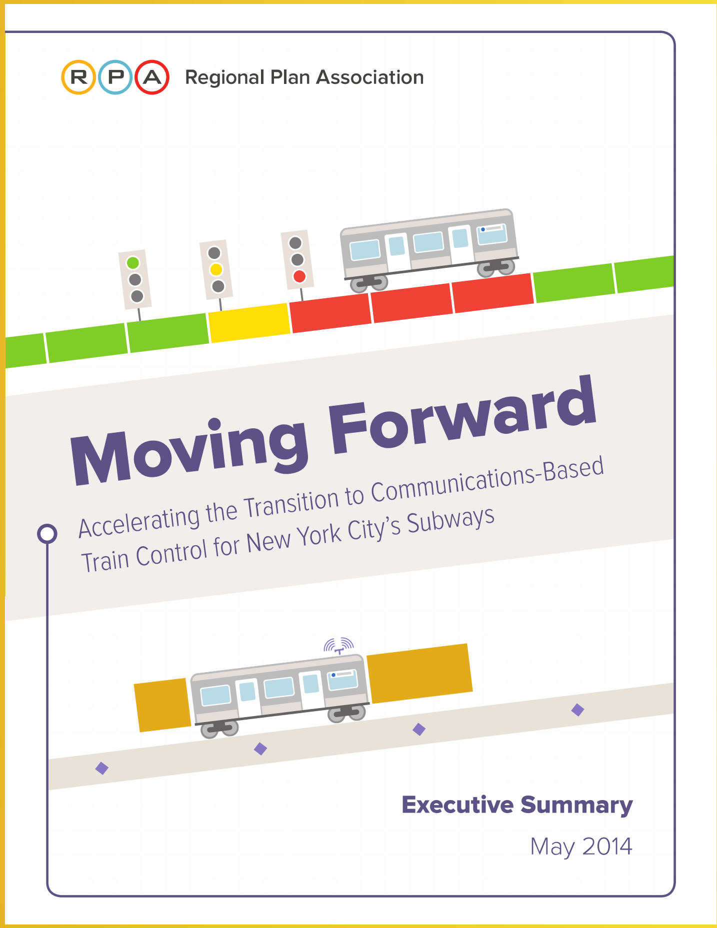
By contrast, CBTC combines the firepower of higher-speed computers and fiber-optic data communications to link tracks and vehicles into a seamless system. Computerized signal equipment installed along the tracks and on subway trains establishes precise knowledge about the location and speed of each vehicle, making it possible to centrally monitor and respond rapidly as conditions change.

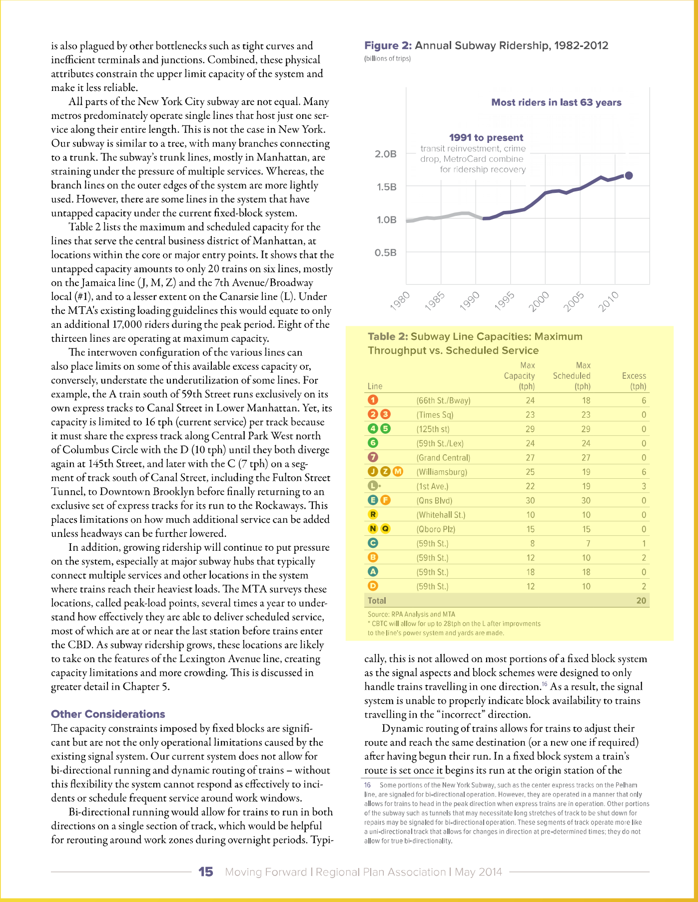
Benefits for riders, operators, businesses and the public

The benefits of CBTC flow from the greater efficiency, reliability and flexibility that it provides. Because trains can safely run closer together, they can circulate with greater frequency, reducing bunching and uneven service. Theoretically, CBTC can accommodate 40 or more trains an hour, compared with at most 30 using traditional signal systems. Although running at full CBTC capacity would require other improvements to the subway network, such as straightening curved track and expanding stations, passengers would see substantially less waiting and crowding with CBTC.

Instantaneous communications would improve reliability, allowing New York City Transit to work around and respond quickly to both rare and commonplace events such as stalled trains, accidents, flooding and police actions. Customers also would experience more accurate and timely countdown clocks and other important information. While the upfront capital costs are high, the annual savings from reduced energy, maintenance and operations would substantially reduce the costs of running the system. Energy would be saved by smoothing rates of acceleration and deceleration, which also would make for a more comfortable ride. Since signal maintenance would be much less labor-intensive, the MTA would be able to maintain CBTC for far less than the $106 million annual cost for the current sig-

What Is Current System Capacity





is also plagued by other bottlenecks such as tight curves and inefficient terminals and junctions. Combined, these physical attributes constrain the upper limit capacity of the system and make it less reliable.

All parts of the New York City subway are not equal. Many metros predominately operate single lines that host just one service along their entire length. This is not the case in New York. Our subway is similar to a tree, with many branches connecting to a trunk. The subway's trunk lines, mostly in Manhattan, are straining under the pressure of multiple services. Whereas, the branch lines on the outer edges of the system are more lightly used. However, there are some lines in the system that have untapped capacity under the current fixed-block system.

Table 2 lists the maximum and scheduled capacity for the lines that serve the central business district of Manhattan, at locations within the core or major entry points. It shows that the untapped capacity amounts to only 20 trains on six lines, mostly on the Jamaica line (J, M, Z) and the 7th Avenue/Broadway local (#1), and to a lesser extent on the Canarsie line (L). Under the MTA's existing loading guidelines this would equate to only an additional 17,000 riders during the peak period. Eight of the thirteen lines are operating at maximum capacity.

The interwoven configuration of the various lines can also place limits on some of this available excess capacity or, conversely, understate the underutilization of some lines. For example, the A train south of 59th Street runs exclusively on its own express tracks to Canal Street in Lower Manhattan. Yet, its capacity is limited to 16 tph (current service) per track because it must share the express track along Central Park West north of Columbus Circle with the D (10 tph) until they both diverge again at 145th Street, and later with the C (7 tph) on a segment of track south of Canal Street, including the Fulton Street Tunnel, to Downtown Brooklyn before finally returning to an exclusive set of express tracks for its run to the Rockaways. This places limitations on how much additional service can be added unless headways can be further lowered.

In addition, growing ridership will continue to put pressure on the system, especially at major subway hubs that typically connect multiple services and other locations in the system where trains reach their heaviest loads. The MTA surveys these locations, called peak-load points, several times a year to understand how effectively they are able to deliver scheduled service, most of which are at or near the last station before trains enter the CBD. As subway ridership grows, these locations are likely to take on the features of the Lexington Avenue line, creating capacity limitations and more crowding. This is discussed in greater detail in Chapter 5.

Other Considerations

The capacity constraints imposed by fixed blocks are significant but are not the only operational limitations caused by the existing signal system. Our current system does not allow for bi-directional running and dynamic routing of trains – without this flexibility the system cannot respond as effectively to incidents or schedule frequent service around work windows.

Bi-directional running would allow for trains to run in both directions on a single section of track, which would be helpful for rerouting around work zones during overnight periods. Typically, this is not allowed on most portions of a fixed block system as the signal aspects and block schemes were designed to only handle trains travelling in one direction.[16] As a result, the signal system is unable to properly indicate block availability to trains travelling in the "incorrect" direction.

Dynamic routing of trains allows for trains to adjust their route and reach the same destination (or a new one if required) after having begun their run. In a fixed block system a train's route is set once it begins its run at the origin station of the

Figure 2: Annual Subway Ridership, 1982-2012
(billions of trips)

Table 2: Subway Line Capacities: Maximum Throughput vs. Scheduled Service

Line		Max Capacity (tph)	Max Scheduled (tph)	Excess (tph)
1	(66th St./Bway)	24	18	6
2 3	(Times Sq)	23	23	0
4 5	(125th st)	29	29	0
6	(59th St./Lex)	24	24	0
7	(Grand Central)	27	27	0
J Z M	(Williamsburg)	25	19	6
L*	(1st Ave.)	22	19	3
E F	(Qns Blvd)	30	30	0
R	(Whitehall St.)	10	10	0
N Q	(Qboro Plz)	15	15	0
C	(59th St.)	8	7	1
B	(59th St.)	12	10	2
A	(59th St.)	18	18	0
D	(59th St.)	12	10	2
Total				20

Source: RPA Analysis and MTA
* CBTC will allow for up to 28tph on the L after improvments to the line's power system and yards are made.

16 Some portions of the New York Subway, such as the center express tracks on the Pelham line, are signaled for bi-directional operation. However, they are operated in a manner that only allows for trains to head in the peak direction when express trains are in operation. Other portions of the subway such as tunnels that may necessitate long stretches of track to be shut down for repairs may be signaled for bi-directional operation. These segments of track operate more like a uni-directional track that allows for changes in direction at pre-determined times; they do not allow for true bi-directionality.

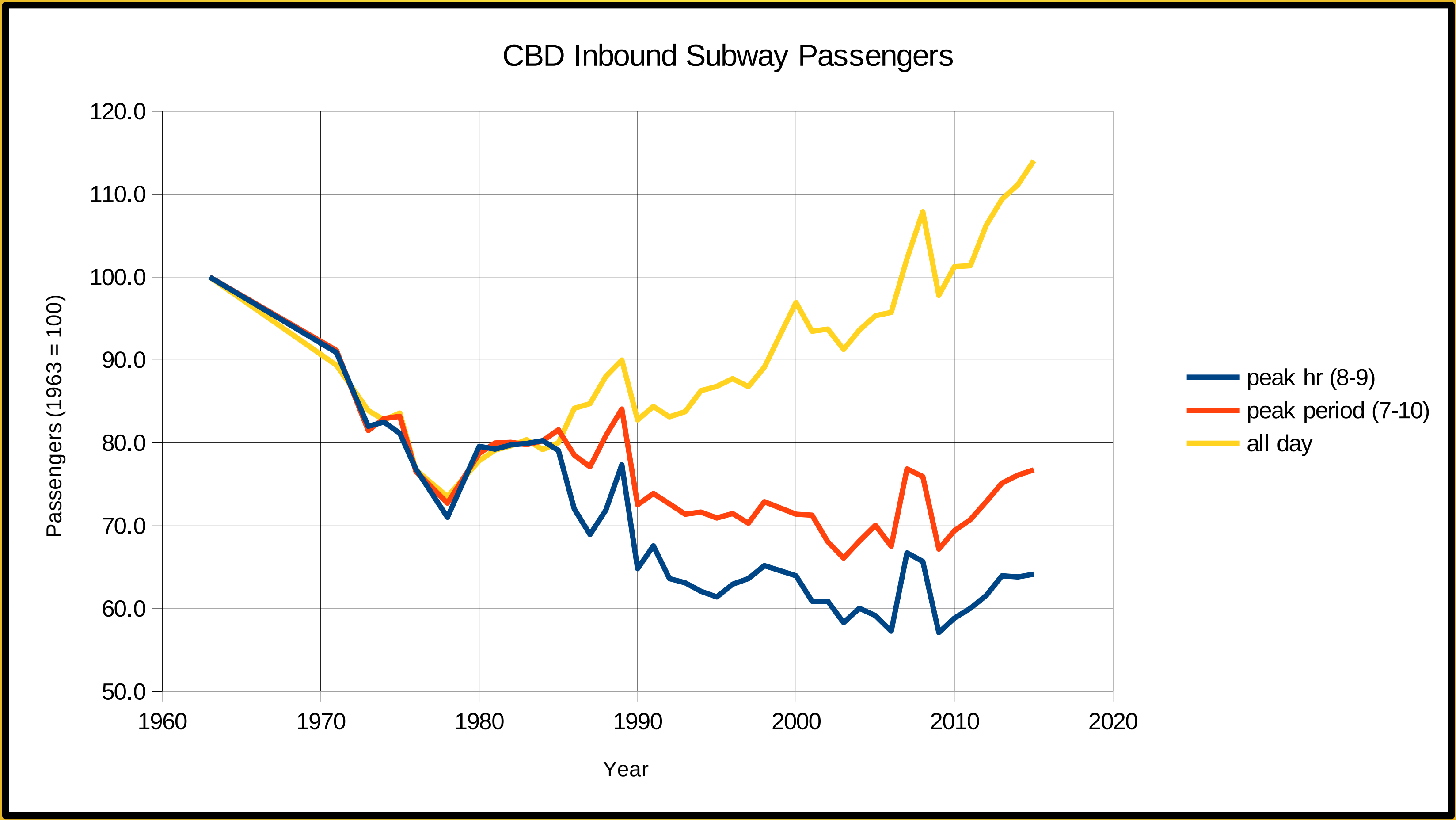
Current Wisdom

- System Ridership At All Time High
- Need Higher Service Levels (TPH) to Handle Demand
- Current Block Signal System Cannot Handle Higher Service Levels
- Ergo – CBTC Required
- And Quickly

Two Problems

- Peak Service Levels Determined by Peak Hour Demand – Not Daily Or Yearly Demand

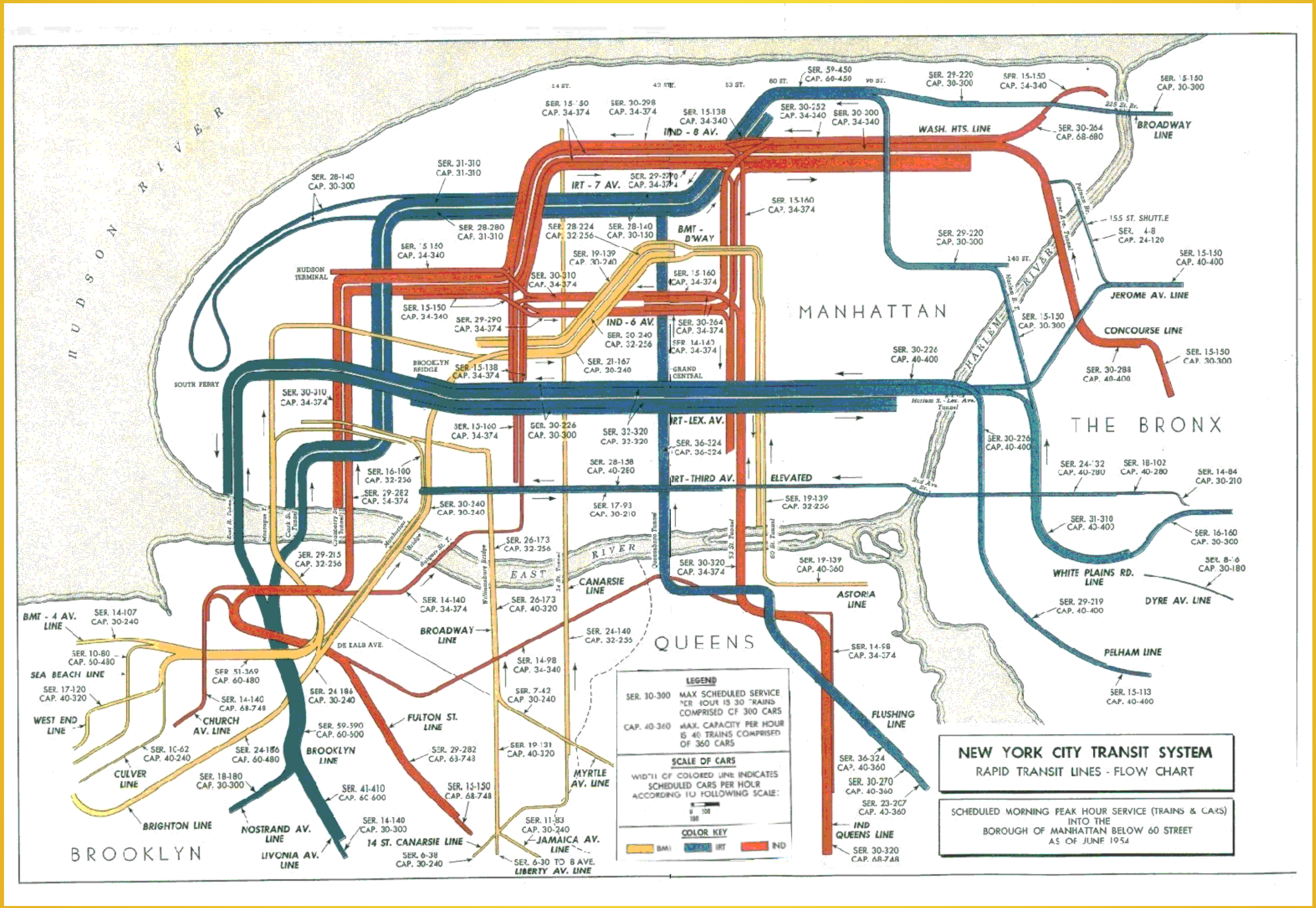
Peak Hour Demand Is Decreasing



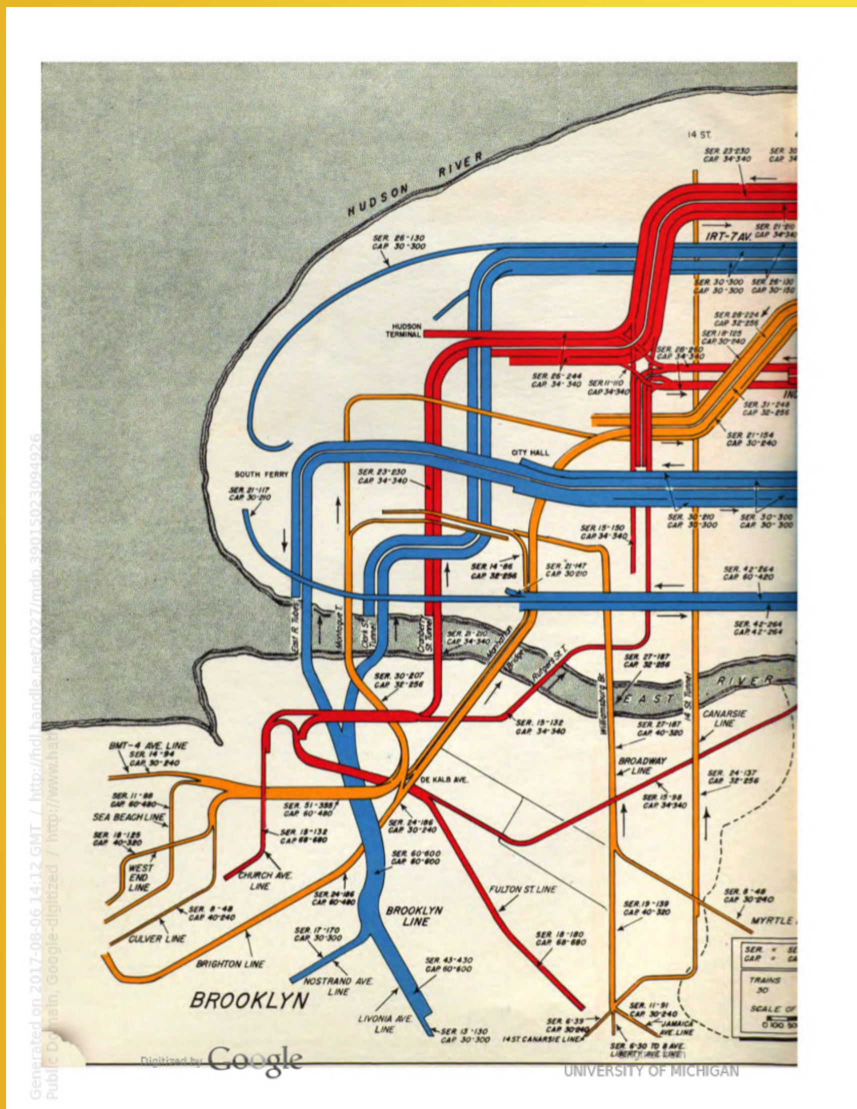
Two Problems

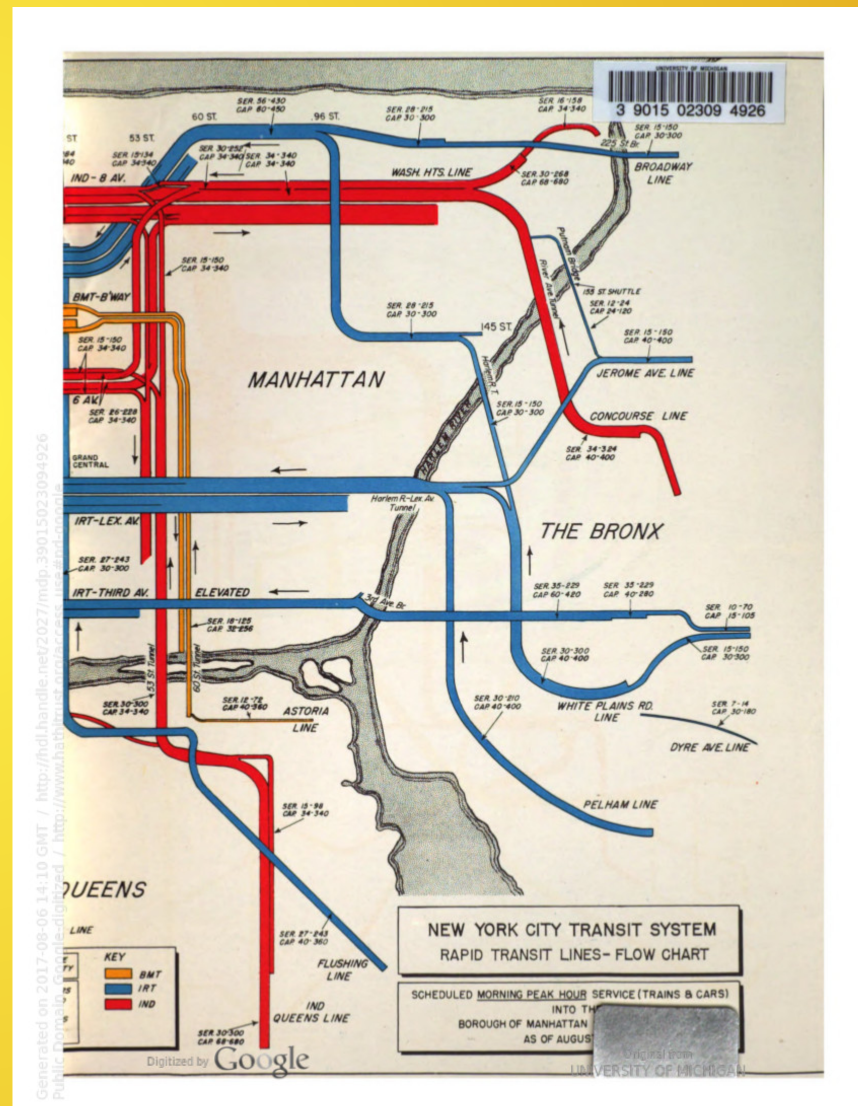
- Peak Service Levels Determined by Peak Hour Demand – Not Daily Or Yearly Demand
- How Did They Accommodate The Higher Demand In Previous Years – If Current System Cannot Handle Today's Reduced Demand?

They Ran More Trains (1954)



They Ran More Trains (1949)



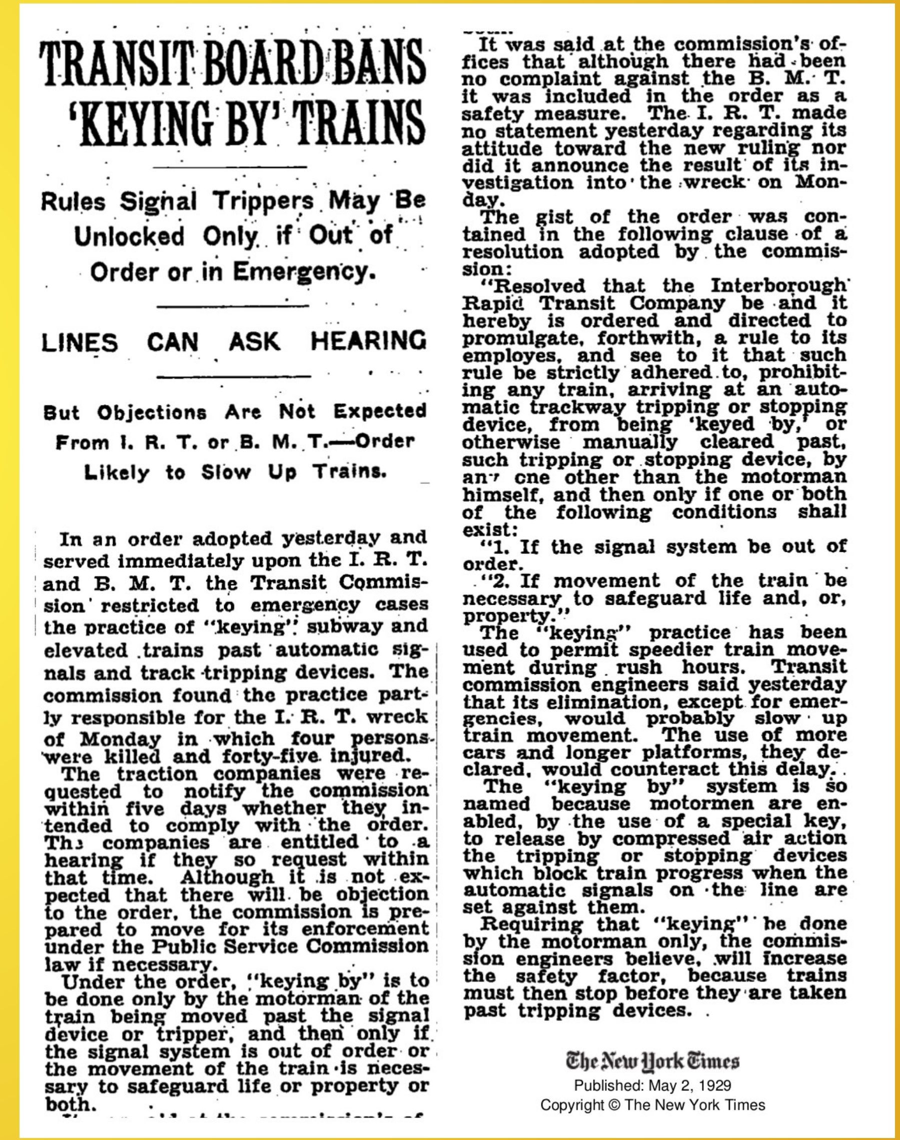


How Do Today's Service Levels Compare

Line	2017 Route	1949	1954	2015	Pct 49-54 Avg	Line	2017 Route	1949	1954	2015	Pct 49-54 Avg
Clark St Tunnel	N-2,3	30	28	17	59%	Lex Ave Local	S-6	30	30	23	77%
Joraloman St Tunnel	N-4,5	30	32	23	74%	Steinway Tunnel	S-7	27	36	27	86%
Cranberry St Tunnel	N-A,C	21	29	24	96%	8th Ave Exp	S-A,D	34	30	18	56%
Manhattan Br 6th Ave	N-B,D	0	0	20		8th Ave Local	S-B,C	30	30	13	43%
Rutgers St Tunnel	N-F	15	14	13	90%	53rd St Tunnel	S-E,M	30	30	23	77%
Williamsburg Br	N-J,M,Z	27	26	19	72%	63rd St Tunnel	S-F	0	0	15	
14th St Tunnel	N-L	24	24	20	83%	60th St Tunnel	S-N,Q,R	18	19	23	124%
Manhattan Br – Bway	N-N,Q	31	30	20	66%	Manhattan Br – Nassau		14	16	0	
Monague St Tun-Bway	N-R	21	21	10	48%	Montague St Tun-Nass		9	8	0	
West Side Local	S-1	26	28	19	70%	Third Ave El		42	28	0	
West Side Exp	S-2,3	30	31	19	62%	Total		519	522	373	72%
Lex Ave Exp	S-4,5	30	32	27	87%	Less Third Ave El		477	494	373	77%

How Did They Do It?

- They Did Not Key By Red Signals



TRANSIT BOARD BANS 'KEYING BY' TRAINS

Rules Signal Trippers May Be Unlocked Only if Out of Order or in Emergency.

LINES CAN ASK HEARING

But Objections Are Not Expected From I. R. T. or B. M. T.—Order Likely to Slow Up Trains.

In an order adopted yesterday and served immediately upon the I. R. T. and B. M. T. the Transit Commission restricted to emergency cases the practice of "keying" subway and elevated trains past automatic signals and track-tripping devices. The commission found the practice partly responsible for the I. R. T. wreck of Monday in which four persons were killed and forty-five injured.

The traction companies were requested to notify the commission within five days whether they intended to comply with the order. The companies are entitled to a hearing if they so request within that time. Although it is not expected that there will be objection to the order, the commission is prepared to move for its enforcement under the Public Service Commission law if necessary.

Under the order, "keying by" is to be done only by the motorman of the train being moved past the signal device or tripper, and then only if the signal system is out of order or the movement of the train is necessary to safeguard life or property or both.

It was said at the commission's offices that although there had been no complaint against the B. M. T. it was included in the order as a safety measure. The I. R. T. made no statement yesterday regarding its attitude toward the new ruling nor did it announce the result of its investigation into the wreck on Monday.

The gist of the order was contained in the following clause of a resolution adopted by the commission:

"Resolved that the Interborough Rapid Transit Company be and it hereby is ordered and directed to promulgate, forthwith, a rule to its employes, and see to it that such rule be strictly adhered to, prohibiting any train, arriving at an automatic trackway tripping or stopping device, from being 'keyed by,' or otherwise manually cleared past, such tripping or stopping device, by any one other than the motorman himself, and then only if one or both of the following conditions shall exist:

"1. If the signal system be out of order.

"2. If movement of the train be necessary to safeguard life and, or, property."

The "keying" practice has been used to permit speedier train movement during rush hours. Transit commission engineers said yesterday that its elimination, except for emergencies, would probably slow up train movement. The use of more cars and longer platforms, they declared, would counteract this delay.

The "keying by" system is so named because motormen are enabled, by the use of a special key, to release by compressed air action the tripping or stopping devices which block train progress when the automatic signals on the line are set against them.

Requiring that "keying" be done by the motorman only, the commission engineers believe, will increase the safety factor, because trains must then stop before they are taken past tripping devices.

The New York Times

Published: May 2, 1929

What Is Current System Max TPH

- Railway Signaling & Communications Sept 1949
- 90 Second Headway (40 TPH)
- 30 Second Station Dwell Time
- 605 Ft Trains
- 20 mph Operation
- 40 mph Max Train Speed Enforced by Grade Timers

General view of part of the interlocking layout and tower at Pitkin Avenue Yard

Signaling and Interlocking

On New Line of New York Subways

Fulton Street extension, in Brooklyn, includes modern entrance-exit controlled interlockings, and automatic signaling with the new rectifier-fed control circuits

THE Board of Transportation of the City of New York has recently placed in service an extension of the Fulton Street line in the borough of Brooklyn from the East New York express station to the Euclid avenue express station, including a large open air yard known as the Pitkin avenue yard. The total length of the extension is approximately 2.5 route miles of four-track main line and two lead tracks to the yard. On the 11 mi. of main tracks there are a total of 60 automatic block signals in addition to the interlocking signals.

The signal control is based on a single-block overlap, which means that the signal will not change from the red aspect until the rear end of the train has passed the second signal in advance. This provision is used in order to have braking distance protection from a danger signal (red) to the rear end of the preceding train.

The obedience of stopping at a red signal, and therefore the protection indicated above, is obtained by using a power-operated automatic train stop or "trip" at each signal. When the signal is at danger, the automatic stop arm is in the raised or tripping position. If the motorman does not observe or obey the restricted aspect of the red signal, the arm of the automatic stop comes in contact with the trip cock on the cars of the train, thereby making an emergency brake application, and the train is brought to a stop before it reaches the rear end of the preceding train.

The signal system is laid out for a 90-second headway with 30-second station stops at local platforms and 45-second station stops at express platforms. The average operating speed for the signal layout is taken at 20 miles per hour for rush hour operation, but the signals are so located and spaced as to give maximum protection for the maximum speed obtainable for any run. The maximum train length is 605 ft. for the 10-car train.

The close headway and the fairly long station stops produce a "block" or track circuit which is relatively short, the average being approximately 17 track circuits per mile of track.

Grade-Time Signals

The maximum speed *obtainable* by a train in this section of subway is 52 m.p.h. However, a maximum *permis-*

What Is Current System Max TPH

- 1999 Manhattan East Side Alternatives Major Investment Study/Draft Environmental Impact Statement (MIS/DEIS)
- Lexington Avenue Line
- 90 Second Headways including 30 Second Station Dwell Time

Manhattan East Side Transit Alternatives MIS/DEIS

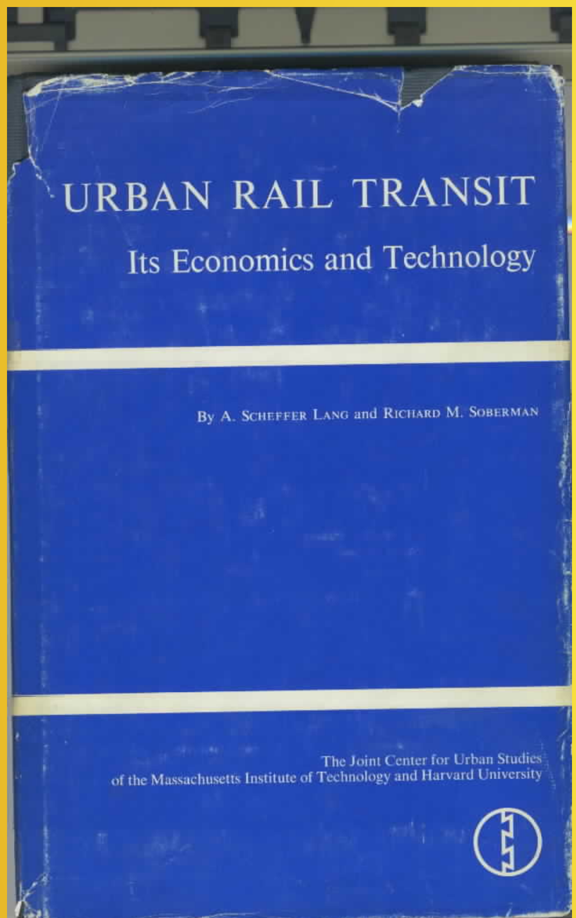
and station "dwell" times (the time a train sits in a station). Based on safety and signal constraints and allowing for a dwell time of 30 seconds, trains on the Lexington Avenue and Broadway lines can theoretically be operated at 120-second headways (i.e., one train every 120 seconds) for a total train throughput of 30 trains per hour. However, due to congestion and slower exiting and boarding times at certain stations, scheduled headways often tend to be slightly longer.

NYCT defines station dwell time as the time from when a train is fully stopped within a station to when it starts to move again. Scheduled dwell times are dependent on ridership levels, signalization, and transfer opportunities. Actual dwell times can vary significantly from those scheduled because of incidents such as train queuing, door holding, and especially heavy passenger boarding and exiting volumes. On a typical business day, the station dwell time tends to be the longest during peak periods, when passenger volumes are greatest and service is most frequent. When the passenger demand is high, more trains are needed to provide enough capacity. In addition, because of this higher demand, the actual time for passengers to load and unload a train increases. As a result, actual dwell times are likely to exceed scheduled dwell times. The longer the schedule "violation" becomes or the more frequently the violations occur, the fewer the number of trains can serve that line segment. Longer dwell times increase headways between trains, so that the maximum number of trains per hour cannot be processed. The fewer the trains serving the segment, the more crowded the trains and stations on that segment can become. As crowding increases in trains and on station platforms, the time needed for boarding and exiting increases, further contributing to the violation in scheduled headways. All of the above are part of a cyclical downward pattern that contributes to reduced throughput during peak travel periods.

Lexington Avenue Line. The current NYCT signal system on the Lexington Avenue line is designed to allow 90-second headways, including a 30-second allowance for station dwell times, with operating headways of 120 seconds. The additional 30 seconds in the operating headway is meant to allow trains to move far enough ahead of the following trains, so the following trains generally can run on green signals. Ideally, 30 trains per hour can be scheduled along this line. The system can absorb occasional dwell time aberrations, but if dwell times at more than a few stations along the line are 45 seconds or more, the train throughput is reduced. Along the heavily used Lexington Avenue line, the 120-second headways cannot be maintained during peak periods because of the excessive dwell times at stations. Field observations of weekday peak period headways and dwell times were made at a number of stations along the Lexington Avenue line during the AM peak period. Within short time intervals, headways deviated, sometimes significantly, from those scheduled. This was mainly attributed to delays in service and long station dwell times. Excessive dwell times were often the result of high exiting and boarding volumes, transfers across the platform, and train bunching. For example, when a train is delayed by more than 3 or 4 minutes, the next few trains upstream queue up at the approach to a station and arrive at the station at short headways. This phenomenon is the main reason why scheduled throughput could be met over a sufficiently long period of time, while falling short during heavily traveled peak periods. The data showed that actual arrival headways were as low as 1.5 minutes and as high as 10 or more minutes during the AM peak period. Actual dwell times varied from 15 seconds to more than 3 minutes. At 42nd Street-Grand Central station, the average headways were observed to average about 2.5 minutes for the express trains and 2.8 minutes for the local trains. These gaps translate to about 24 express and 21 local trains during the AM peak hour, when 27 express and 25 local trains are scheduled. Dwell times were observed to cluster in the 50- to 60-second range. Table 9D-7 shows the average headways and median dwell times (the median value is

9D-12

What Does Theory Tell Say



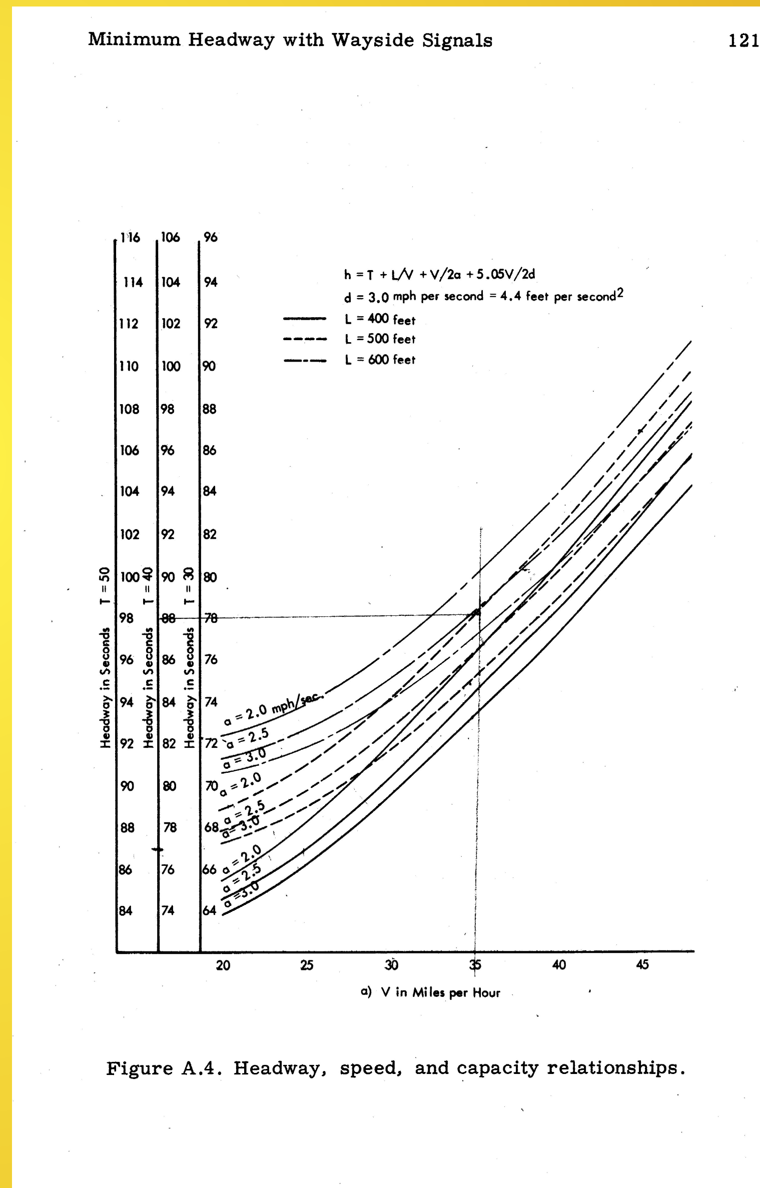

Minimum Headway with Wayside Signals 121

Figure A.4. Headway, speed, and capacity relationships.

What Does Theory Tell Us

- Limit possibilities of the subway as a transport system,V. A. Mnatsakanov, Cand.Tech.Sci.,"Metro and Tunnels" No. 3, 2002.
- Available On Web In Russion
- www.metro.ru.library/analytics/145

In Table 1 and in Fig. 3 shows the dependence of the station's capacity on the acceleration (deceleration) of the metro train.

Table 1.

a (b), m / s^2	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
P, train / hour	21.9	32.3	39	43.8	47.3	50.5	52.9	54.8	56.5

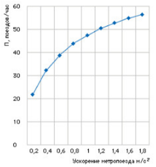


Fig. 3. Dependence of the station's capacity from the acceleration (deceleration) of the metro train.

In the presented dependence there is a saturation effect: when the acceleration is increased from 0.2 m / s^2 to 1.2 m / s^2, the capacity increases almost in proportion to the growth of accelerations (decelerations), and with the further growth of accelerations (decelerations) ability is markedly reduced.

The meteorological trains currently in operation are characterized by the following average acceleration during acceleration to speeds of 60-70 km / h and average decelerations in the speed range of 70-0 km / h (Table 2).

table 2

Car model	**Average acceleration, m / s^2**	**Average deceleration, m / s^2**
Maud. 81.717 / 714	0.98	1.28
Maud. 81.720 / 721 (Yauza)	0.79	1.11

Substituting in the formula (6) the values of the accelerations (decelerations) from Table 2, we get that the capacity of the metro stations is:

- for metro trains from mod cars. 81.717 / 714 - 47 trains / hour
- for metro trains from mod cars. 81.720 / 721 (Yauza) - 43 trains / hour.

On the Moscow Metro metro trains operate today with a frequency of 40 trains / hour and a speed of 41 km / h. But the technical characteristics of the cars allow them to operate at a frequency of 47 trains / hour and a speed of about 48 km / h.

On each radial line of the Moscow subway there are 5-6 of the busiest hours in the "peak" hours. The teams following each other, pass these stages in 15-20 minutes. At this time, their cars

Graphical Approach

- Probably What Our Grandparents Used
  - They Did Not Use Computers
    - If It Works – It's Not Sophisticated
- Need Only a Spreadsheet and a Vector Drawing Application
- Use Open Source – Low Cost
  - Spreadsheet – LibreOffice Calc
  - Vector Graphics - Inkscape

Tokyo’s Approach

- Extensive Operator Training
  - Youtube Clip

Other Approaches

- Use of Feedback to Make a Bad Process Good – At Much Less Cost
- Moscow’s Approach
  - Count Up Clock At Each Station
    - Zero’s Out As Train Leaves Station
    - Keeps Spacing Between Trains Down To Second

Other Approaches

- Paris Has Les Pendules de Régulation
  - Crew Needs Remember Only Departure Time

L'horaire

Comme pour tous les chemins de fer de France et de Navarre les rames de métro ont aussi des horaires. Vous avez déjà peut être remarqué ces pendules en bout de quai avec des heures un peu bizarres. Ce sont des pendules de régulation.
exemple: au terminus de Nation, le chef de départ donne au conducteur de la rame 16h32 min 30 secondes. Lorsque le conducteur rencontrera une pendule de régulation (à la station place d'italie par exemple) indiquant 33.00, c'est qu'il aura pris 30 secondes de retard . Si à une autre station il rencontre à nouveau une pendule de régulation (La Motte Picquet par exemple) indiquant 32.00, c'est qu'il aura pris 30 secondes d'avance. Donc on se réfère toujours à l 'heure de départ du terminus et non à l'horaire de passage. Sur ces pendules seront juste indiquées les minutes et les secondes.
Voici la bête (ici 4 horaires diffèrents mais lorsque le train arrivera en station seul celui qui lui correspond reste allumé).

La lettre A correspond aux heures de pointe du soir,
la lettre B correspond aux heures de pointe du matin,
la lettre C aux heures creuses,
et la lettre D à la nuit

40 TPH Without CBTC

Questions?
Comments?

Thanks For Listening.