Computer-Assisted Optimization of Train Crew Size for On-Board Fare Collection

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A personal computer–driven computer model that simulates the fare collection workload aboard passenger trains of the Metro-North Commuter Railroad is described. Three distinct formulas were developed to approximate most of the workloads experienced by the on-board train crews as they collect fares and fulfill train operating responsibilities. The recommendations produced by the output of these simulations provide vital guidance to Metro-North management seeking to provide the optimum level of on-board train staffing with regard to fare collection. In this manner, Metro-North initially reduced crew costs by lowering the number of conductors and assistant conductors required to cover all passenger trains. Since the initial use of these computer simulations in 1984, Metro-North has been able to provide an increased level of train service with more frequent and longer trains and to carry more than 20 percent more customers with a lower number of conductors and assistant conductor positions than required in 1984.

The Metro-North Commuter Railroad currently receives more than $231 million/year in fare revenues from its customers. The methods of payment for passage on the railroad include monthly or weekly passes, 10-trip tickets, one-way tickets, and on-board cash fare sales. All of these methods of payment require the train crew to check each customer to ensure that all customers have a valid ticket for their ride.

All Metro-North trains operate with a minimum crew of an engineer and a conductor. The deployment of assistant conductors depend on factors that include safety, train operation requirements, passenger loads, and fare collection. To minimize operating costs, the railroad strives to maximize the efficiency with which its assistant conductors are assigned to all passenger carrying trains. The railroad must provide a sufficient number of on-board train staff (conductor and assistant conductors) to properly collect fares from all of its customers. The number of staff required for each train is highly dependent on factors that include

- Maximum passenger load,
- Number of cash fares sold aboard,
- Distribution of total ridership during entire trip,
- Number of passengers boarding or disembarking at intermediate stations (also called intermediate or way riders),
- Period of operation (peak or off-peak service and fares),
- Operating schedule and station stopping pattern (local, express, or zone express service),
- Number of fare zones served,
- Length of time between passenger stops,
- Number of cars open for passenger occupancy,
- Station platform length and configuration (high or low level),
- Balancing the assignment of train crew personnel,
- Train operating procedures, and
- Other relevant factors in the expected work load (may or may not be related to fare collection needs).

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Metro-North has developed three train staffing formulas to simulate the fare collection workloads most often encountered by train crews. Each of these formulas specializes in a particular type of service pattern (e.g., multiple-stop locals, off-peak-period expresses, and peak-period zone expresses). These simulations provide the railroad with an important indicator as to the number of train crew members that each train requires. Altering the data inputs to these formulas can also enable management to assess the impact of schedule and ridership changes on train staffing. These three formulas and all input data reside on a Lotus 1-2-3 spreadsheet where each column of data represents a specific function or type of data. Arithmetic manipulation of the data in the columns generates outputs specific to each row of data.

Through the application of these train staffing formulas to all passenger-carrying trains, Metro-North has realized a considerable savings from reduced operating costs and improved its on-board fare collection efficiency. During 1984–1985, the initial year that this methodology served as a source of guidance in determining train crew size, the railroad was able to reduce the number of required conductor and assistant conductor positions to cover all passenger-carrying trains from 425 to 381. In the years since, Metro-North has used this formula to optimize continuously train crew size. A combination of physical plant, rail car, and service improvements as well as an aggressive marketing campaign has increased all categories of ridership on the Metro-North commuter rail system. With this increase in the number of total customers carried, an increase in the train staff requirements has been necessary to operate the higher number of trains.

The train staffing formulas have been an important tool in keeping the incremental crew costs associated with the ridership and service increases to a minimum. It should be noted that despite a growth in ridership of more than 20 percent and the operation of a greater number of passenger trains, the total number of conductors and assistant conductors required to cover the scheduled service in 1992 was 415, lower than the number needed in 1984.

It can be envisioned that a proof of payment system may be adopted in the future to make further economies in train crew costs. However, until such a policy decision is made, the continued use of these formulas will enable Metro-North to minimize and control its train crew costs by distributing and assigning them with maximum efficiency.

Metro-North's train staffing agreement with the labor unions representing the train crews is specific to the train and not based on the number of cars assigned to any one train. By agreement, the minimum required staffing for any Metro-North train is an engineer and a conductor. In determining the need for additional staffing, the agreement states that the management of the railroad reserves the right to determine the number of assistant conductors any train shall have assigned. A 60-day notification procedure for train crew size reductions is included in the labor agreement with the United Transportation Union, which represents the conductors and assistant conductors. A grievance and arbitration procedure is provided in the union contract for occasions on which the union has a dispute with the railroad on matters related to train staffing.

ON-BOARD WORKLOAD DETERMINATION

Metro-North performs on-board and station counts on all trains periodically with management personnel. A reliable data base is critical to the accuracy of this analysis.

Collectible Data

Collectible data include the following:

- Ridership counts: number of customers boarding or alighting
  - At origin/destination [the central business district (CBD), which in this case is Grand Central Terminal (GCT)], and
  - At intermediate stations along the line.
- Fare collection data: number of cash fares sold and prepaid tickets normally collected by the train crew.

Train Operation Data

Train operation data include the following:

- Number of cars in consist: number of cars open for passenger occupancy.
- Type of railcars (special characteristics): the oldest cars in the Metro-North fleet have manually operated doors. Additional train crew members are required for customer safety.
- Number of stops and total running time
  - Train crew is required to suspend fare collection tasks to perform station stop duties: door controls, safety checks, and so on;
  - Total time available to perform fare collection tasks; and
  - Longest nonstop run between stations providing an uninterrupted period when the train crew can perform a fare collection sweep.
- Type of station platforms
  - High-level platforms and automatic train doors increase the level of customer safety. These trains require less crew to operate;
  - Low-level platforms are served by trains with doors that are not automatic, requiring additional crew members for customer safety; and
  - Length of platform. This is especially important with high-level platforms where train consist length exceeds platform length. Additional crew members may be required to ensure that only the doors of platformed cars open at such stations.

Measurable Data

Measurable data include the following:

- Station dwell times
- Time required for a revenue collection sweep
- Walking time through the cars
- Time to sell cash fares, collect tickets, issue seat checks
- Time allowances for required on-board railroad operating procedures.

APPLICATION OF EQUATIONS TO DETERMINE OPTIMUM TRAIN STAFFING

The train staffing formulas and select examples of its outputs are given here in Appendixes A and B, Tables 1 and 2, and Figures 1 and 2. Characteristics follow:

- Peak period
  - Multiple-sweep formula on multizone local trains.
  - Concentrate on a single fare sweep on zone express trains.
- Off-peak and weekends (Saturdays and Sundays treated as different data sets)
  - Multiple-sweep formula on local portions of runs.
  - Adapted peak-period sweep formula for the nonstop express portion of runs to and from the main terminal in the CBD (GCT on the Metro-North Commuter Railroad System).

INPUTS FOR DECISION-MAKING PROCESS IN DETERMINING ACTUAL TRAIN STAFFING

The output of the train staffing is used as an indicator of ideal train staffing levels. Additional input is provided by observations and reports by transportation management and supervisory staff, train crews, customer service inspectors, supervisory conductors, planning department supervisors, and passenger revenue accounting department reports.

The revenue protection survey is conducted jointly by the internal audit and the planning departments of Metro-North. This survey is performed annually to identify any specific

TABLE 1 Off-Peak Train Staffing Formulas A and B: Sample Using Saturday Train 9018

Columns	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	TRAIN NUMBER	CASH FARE TIME (mins.)	# CASH FARES	NON-CASH FARE TIME (mins.)	# OF NON-CASH	TIME TO WALK CAR (mins.)	# OF CAR IN TRAIN	RUNNING TIME (mins.)	STA.STOP TIME LOSS (mins.)	# OF STOPS	RECC. CREW	CURRENT CREW	GCT COUNTS	# OF WAY RIDER	TOTAL ON'S
UPPER	9018	0.41	156	0.095	60	0.5	6	42	1	12	2.62	2	194	22	216
LOWER	9018	0.41	8	0.095	378	0.5	6	21	1	3	1.87	2	374	12	386

TABLE 2 Peak-Period Train Staffing Formula: Sample Using Train 526 (a.m. Peak Period)

Columns	A	G	L	h	J	N		M	C	E	t	K
	TRAIN NUMBER	# CARS IN TRAIN	CURRENT CREW	LONGEST NON-STOP RUN TIME	# STOPS ENROUTE	INT. RIDERS	STOP AT 125 ST	GCT COUNTS	# CASH FARES	# OF NON-CASH FARES	TIME REQUIRED TO SWEEP (mins.)	RECC. CREW GCT
	526	10 m-1	2	35	1	0	N	1189	21	1168	49.74	1.84

NOTE: Column Designations Have Been Adjusted to Conform to the Column Letters Used in the Off-Peak Analysis.

SATURDAY,

TO NEW YORK		9018	9518	9020	9520
		AM	AM	AM	PM
UPPER ZONE	Brewster North	10 10		11 10	
	Brewster	10 13		11 13	
	Croton Falls	10 18		11 18	
	Purdy's	10 21		11 21	
	Golden's Bridge	10 24		11 24	
	Katonah	10 28		11 28	
	Bedford Hills	10 32		11 32	
	Mount Kisco	10 36		11 36	
	Chappaqua	10 41		11 41	
	Pleasantville	10 44		11 44	
	Hawthorne	10 48		11 48	
	Mt. Pleasant	10 50			
	Valhalla	10 52		11 52	
LOWER ZONE	North White Plains	10 56	11 03	11 56	12 03
	White Plains	11 00	11 07	12 00	12 07
	Hartsdale		11 10		12 10
	Scarsdale		11 13		12 13
	Crestwood		11 16		12 16
	Tuckahoe		11 18		12 18
	Bronxville		11 20		12 20
	Fleetwood		11 23		12 23
	Mount Vernon West		11 26		12 26
	Wakefield				
	Woodlawn				12 28
	Williams Bridge				12 30
	Botanical Garden		11 31		12 32
	Fordham		11 33		12 34
	Tremont				
	Melrose				
	125th Street	D11 26	11 41	D12 26	12 43
	Grand Central Terminal	11 37 AM	11 53 AM	12 37 PM	12 55 PM

FIGURE 1 Timetable, Saturday Train 9018 to New York.

MONDAY-FRIDAY

TO NEW YORK	MORNING PEAK 526	528	928	930	328	632
	AM	AM	AM	AM	AM	AM
Brewster North			7 13	7 23		
Brewster			7 16	7 26		
Croton Falls			7 21	7 31		
Purdy's			7 25	7 35		
Golden's Bridge			7 28	7 38		
Katonah			7 32	7 42		
Bedford Hills			7 36	7 46		
Mount Kisco			7 40	7 50		
Chappaqua			7 47	7 56		
Pleasantville			7 50			
Hawthorne			7 54			
Valhalla			7 58			
North White Plains		7 59	8 02			
White Plains		8 03	8 06			
Hartsdale	7 58					
Scarsdale	8 02					
Crestwood						8 20
Tuckahoe						8 22
Bronxville						8 25
Fleetwood					8 13	
Mount Vernon West			D8 16		8 18	
Wakefield						
Woodlawn					8 21	
Williams Bridge					8 23	
Botanical Garden					8 25	
Fordham					8 27	
Tremont						
Melrose						
125th Street			D8 29		D8 35	D8 41
Grand Central Terminal	8 37 AM	8 39 AM	8 43 AM	8 47 AM	8 49 AM	8 54 AM

FIGURE 2 Timetable, a.m. peak-period Train 526 to New York.

patterns of passenger revenue losses through missed fares. The survey also serves as a way to validate the output of the train staffing formulas.

All feedback is used to calibrate the computer models and ensure accuracy.

ADDITIONAL APPLICATIONS OF TRAIN STAFFING SIMULATIONS

The simulations are also used to test the train staffing sensitivity to ridership increases or decreases: the cost impacts of marketing and promotional programs are determined, and 1-day variances (Monday mornings, Friday afternoons, holidays, and special events) are measured. Also measured are the on-board impacts of tariff changes, off-train ticket sales by ticket offices and ticket-vending machines, and the introduction of new ticketing or fare collection technologies.

OFF-PEAK TRAIN STAFFING FORMULAS

As mentioned before, staffing levels on off-peak trains are determined by many factors. Through the organization of information on each off-peak train into Columns A through O as given in Table 1, a formula can be assembled that enables the optimum train staffing level to be determined. This equation is Formula A.

- Off-Peak Train Staffing Formula A

$$K = \frac{bc + de + 3fg}{h - ij}$$

where

- b = standard time to process a cash fare passenger, or 0.41 min;
- c = number of cash fares sold aboard train;
- d = standard time to process a noncash fare passenger, or 0.095 min;
- e = number of noncash fare passengers = $o - c$;
- 3 = standard of three fare collection sweeps by train crew;
- f = standard time for a crew member to walk one car length, or 0.5 min;
- g = number of cars in train;
- h = time allotted to crew for fare collection (running time);
- i = standard time loss by train crew at each station stop, or 1.0 min;

j = number of station stops made during fare collection;
K = recommended staffing for train;
l = current staffing levels;
m = ridership originating from or destined to GCT;
n = intermediate or way rider count; and
o = total number of passenger boardings (GCT and intermediate riders) = $m + n$.

Formula A is applicable for most off-peak trains that operate as multiple-stop locals for their entire runs. For the trains that operate as semiexpresses (making local stops over one portion of the line and operating as a nonstop express for the rest of the run to or from the CBD), a different formula is applied. The following equation reflects the one-time sweep manner in which train crews collect all remaining fares during the nonstop run to or from the CBD (GCT–New York).

- Off-Peak Train Staffing Formula B

$$K = \frac{bc + de}{h}$$

where variables are as given for Formula A.

Appendix A provides a sample calculation for Off-Peak Formulas A and B, and Table 1 provides a sample of the formula spreadsheet and output. The sample train used is Saturday Train 9018 from Brewster North to New York City; its timetable is shown in Figure 1. The upper zone refers to the local portion of the run between the outer terminus at Brewster North and an intermediate station at North White Plains, and the lower zone refers to the express run from North White Plains to GCT.

Many of the input requirements of Formulas A and B are met by data provided through the efforts of Metro-North's Planning Department and Passenger Revenue Accounting Department. The latter department provides the most recent cash fare volume data on a biannual basis. The Planning Department provides all passenger counts, train consist lengths, and timetable-related data. The Industrial Engineering Group of the Planning Department is responsible for developing the time standards used in the formulas.

Formula A is currently set so that the crew is able to perform three fare collection sweeps during the time allotted. Onboard observations of a select group of trains representative of all off-peak train schedule patterns revealed that the three-sweep rule for adequate revenue protection is valid on most off-peak, multiple fare zone, local trains. The only exceptions are some reverse-peak New Haven and Harlem Line local trains that stop at Fordham and Mount Vernon. On these trains, many riders that board at these two intermediate stations ride for only 10 to 20 min, making timely fare collection by the train crew more difficult than usual. As a result, reverse-peak trains are monitored closely via on-board observations to ensure that train staffing levels are adequate.

The running time (Column H) in Table 1 provides the total time available to the train crew to perform its fare collection sweeps. In general, it is set by the scheduled running time between specific station pairs that reflect where the formula expects the train crew to perform its fare collection sweeps.

The passenger count data in Columns M and N in Table 1 reflect the latest data collected by the Planning Department. For the relatively short-haul local trains on the Metro-North system from GCT–New York City to Croton-Harmon, North White Plains, and Stamford, the GCT passenger counts and intermediate ridership counts are directly applied to the staffing formula. Figure 3 provides a Metro-North system map to assist in reader orientation. GCT is the CBD, and the three aforementioned stations are intermediate stations on the Hudson, Harlem, and New Haven lines, respectively. A summary of this methodology is provided here:

- Inbound

Main count = number of passengers aboard at GCT

Way rider count = number getting off southward up to 125th Street

- Outbound

Main count = number of passengers aboard at GCT

Way rider count = number getting on from 125th Street and northward

For inbound trains from Brewster North and New Haven to New York, Formula A is used only for the outer portion of the run, where the train makes many local stops. To enable the formula to make the proper staffing recommendation for this part of the run, only data pertaining to the outer portion of the line are used.

For the nonstop express run as the train travels over the inner or lower portion of the line, Formula B is used to more accurately portray the one-sweep manner of fare collection by most train crews. Two separate staffing recommendations are made, one for the outer portion of the line and another for the inner zone portion of the trip. Through judicious use of step-on and step-off assistant conductors, additional crew cost savings can be realized as train crew sizes become tailored to meet the needs of specific line segments. The same methodology is applied in reverse for outbound trains from New York to Brewster or New Haven. It should be noted that this methodology cannot be applied in cases where the express portion of the run contains a few stops, as is the case with the Hudson Line.

Off-Peak Count Methodology for Trains To and From Brewster North

Harlem Line, Inbound

- Main count

upper = number getting on (Brewster North–Valhalla)

lower = number of passengers aboard at GCT

- Way rider count

upper = number getting off (Brewster–White Plains)

lower = number getting off (Hartsdale–125th Street)

METRO-NORTH'S SERVICE AREA

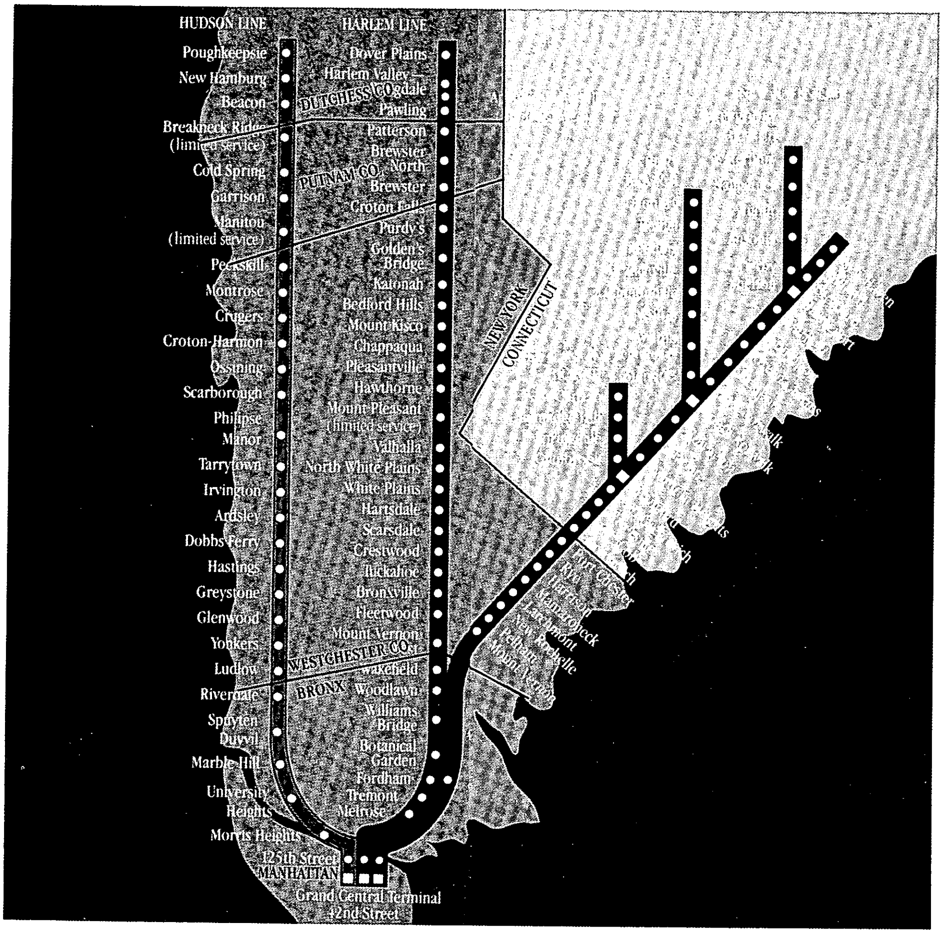

FIGURE 3 Map of Metro-North service area.

Harlem Line, Outbound

- Main count

lower = number of passengers aboard at GCT

- Way rider count

lower = number getting on (125th Street–Hartsdale)

upper = number getting on (White Plains–Brewster)

Off-Peak Count Methodology for Trains To and From New Haven

New Haven Line, Inbound

- Main count

outer = number getting on (New Haven–Noroton Heights)

inner = number of passengers at GCT

- Way rider count

outer = number getting off (Milford-Stamford)

inner = number getting off (Old Greenwich–125th Street)

New Haven Line, Outbound

- Main count

inner = number of passengers at GCT

- Way rider count

inner = number getting on (125th Street–Old Greenwich)

outer = number getting on (Stamford-Milford)

Off-Peak Count Methodology for Trains To and From Poughkeepsie

On the Hudson Line, Formula B cannot be applied to the through express trains in either direction to and from Poughkeepsie. This is because most of them are scheduled to make stops at Ossining, Tarrytown, Yonkers, and Marble Hill, providing an insufficient time for the single sweep assumed in Formula B. Therefore, two applications of Formula A are used to properly simulate the staffing requirements of both the upper and lower portions of the trip for all New York–Poughkeepsie trains.

Hudson Line, Inbound

- Main count

upper = number getting on (Poughkeepsie-Crugers)

lower = number of passengers aboard at GCT

- Way rider count

upper = number getting off (New Hamburg–Croton-Harmon)

lower = number getting off (Ossining–125th Street)

Hudson Line, Outbound

- Main count

lower = number of passengers aboard at GCT

- Way rider count

lower = number getting on (125th Street–Ossining)
upper = number getting on (Croton-Harmon–New Hamburg)

The Planning Department continuously updates the data used for the train staffing formula. The time standards used are periodically evaluated so that they are representative of actual conditions aboard the trains. When necessary, the formulas are reviewed to ensure that the staffing levels they recommend are indeed the actual staffing levels required to properly collect all fares.

PEAK-PERIOD TRAIN STAFFING FORMULA

For peak-period trains, the train staffing formula is much different. The criteria that directly affect the staffing recommendations made by the formula are GCT counts, number of cash fares, total time required for one fare collection sweep, and the longest nonstop running time near the CBD. Table 2 provides a sample of the formula worksheet and output. Again, information required for this study is organized in columns similar to those used for the off-peak period. For inbound peak-period trains, Metro-North requires that all ticket collection tasks be completed before a train's entry into the Park Avenue Tunnel. This is unique to this railroad as safety requirements dictate that a member of the train crew be present at each end of the train as it travels through this tunnel. The formula automatically adjusts the nonstop running time allotted to the crew so that they are finished with their fare collection sweep before the train's entry into the tunnel (8 min) if no stop is made at 125th Street. If a stop is scheduled at 125th Street, the formula calls for the train crew to complete the fare collection task 2 min before arrival at this station, where many customers disembark. For all outbound trains, the formula calls for the crew to be finished 2 min before arriving at its first stop.

This peak-period staffing formula portrays limited-stop zone expresses. It can only approximate the staffing requirements of multiple-stop local trains, and on-board observations supplement the recommendations of the formula.

The peak-period methodology for staffing trains is described:

1. Determine t, the amount of time required for a fare collection sweep.

$$t = \frac{\text{number of noncash fares}}{28.4} + (0.41 \times \text{number of cash fares})$$

2. Determine the staffing level K, by comparing t against h, the total available time for the fare collection sweep.

–All outbound and inbound trains stopping at 125th Street:

$$K = \frac{t}{h - 2\text{ min}}$$

–Inbound trains not stopping at 125th Street:

$$K = \frac{t}{h - 8\text{ min}}$$

Appendix B provides a sample calculation using a.m. peak-period Train 526.

APPENDIX A
Sample Calculation for Off-Peak Period

The following sample uses Train 9018, the Saturday inbound train from Brewster North to GCT (timetable displayed in Figure 1).

UPPER ZONE: OFF-PEAK FORMULA A

$$K = \frac{bc + de + 3fg}{h - ij}$$

$$= \frac{(0.41)(156) + (0.095)(60) + 3(0.5)(6)}{42 - (1)(12)} = 2.62$$

where

$b = 0.41$,
$c = 156$,
$d = 0.095$,
$e = 60$,
$f = 0.5$,
$g = 6$,

h = 42,
i = 1,
j = 12, and
K = recommended crew for upper zone of Train 9018.

LOWER ZONE: OFF-PEAK FORMULA B

$$K = \frac{0.095e + 0.41c}{h} = \frac{(0.095)(378) + (0.41)(8)}{21} = 1.87$$

where

c = 8,
e = 378,
h = 21, and
K = recommended crew for lower zone of Train 9018.

APPENDIX B
Sample Calculation for Peak Period

Train 526, the morning peak-period zone express from Hartsdale/Scarsdale to New York City, is used for this sample. This train does not stop at 125th Street (timetable displayed in Figure 2).

1. Determine the value of t, the time required for a fare collection sweep.

$$t = \frac{\text{number of noncash fares}}{28.4} + (0.41 \times \text{number of cash fares})$$

$$= \frac{1189 - 21}{28.4} + (0.41)(21)$$

$$= \frac{1168}{28.4} + 8.61$$

$$= 41.13 + 8.61 = 49.74 \text{ min}$$

2. Determine the train crew size required.

$$K = \frac{t}{\text{longest nonstop running time} - 8 \text{ min}}$$

$$= \frac{49.74 \text{ min}}{35 - 8 \text{ min}} = 1.84$$

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