THE RELATIVE COST OF OPERATING STEAM AND ELECTRIC LOCOMOTIVES

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ARMOUR INSTITUTE OF TECHNOLOGY

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THE RELATIVE COST OF OPERATING STEAM AND ELECTRIC LOCOMOTIVES FOR SWITCHING PURPOSES ON THE ST. PAUL RAILWAY INDUSTRY TRACKS

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A THESIS

PRESENTED BY

SPENSER N. HAVLICK AND JOHN P. SANGER

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

JUNE 2, 1921

APPROVED

Geo. F. Gebhardt
Professor of Mechanical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

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The industry switching service of which this thesis is a study is furnished to customers located along the C.M.&St. Paul Railroads right-of-way between Montrose Avenue and the northern terminus in Evanston. This right of way is leased to the Chicago Elevated Railways which company has recently installed electric locomotives for handling the freight business. This paper issa study of the relative costs and advantages of this electric operation compared to the former steam operation. All of the data on steam operation has been obtained from records of the C.M.& St.Pual R.R. The elctric locomotives were in operation for only five months, from Nov. 1,1921 to Mar. 31st,1921, before the figures here given had to be summarized, but it is the belief of the authors that the information gives a fair basis of comparison. The data on electrical operation was furnished by the Northwestern Elevated Railroad offices,

for these five months of service.

Freight and passenger service has been furnished over the line in question since the St Paul road acquired the right of way, about the year 1900. The original line was steam operated between Montrose Avenue and Evanston until the summer of 1907.

Prior to 1907, the Northwestern Elevated Railroad operated its trains as far north as Wilson Avenue only. But in 1907, when the C.M.& St. Paul R.R. was loosing heavily by operating heavy steam trains in the Evanston service, and the elevated desired such passenger service, the feasibility of an agreement became apparent. On Aug.22 the agreement became an actual fact whereby the Northwestern Elevated took over the passenger service for its electric line, and the St. Paul retained the operation of the freight service.

The expenses were to be met jointly by the two roads; the steam made to furnish the structure and the electric the rolling stock and electrical distribution system. The structure is now elevated as far as University Place, Evanston, and the Chicago Elevated R.R.Co., which incorporated the Northwestern Elevated R.R. Co., in 1911, is now satisfactorilly handling the passenger service. The right-of-way is still owned by C.M.& St.Paul R.R.

The freight service to the industries located along the right-of-way, was still handled by the St. Paul after 1907, that road taking the fréight revenue as its share of the profits.

The industries served ranged along a line approximately eight miles long extending from Montrose Avenue at the south to University Place on the north. At present there are fourteen separate sidings between these two points.The main service consists of delivering coal to these industries and returning the empties to the Montrose Yards. Some few

loaded cars are handled south, but these amount to but 5% of the total freight hauled.

Under steam operation the C.M.& St. Paul would deliver the loaded cars daily to the receiving yards at Montrose Avenue and would take away the empties. Here two 80 ton switching engines of the I-5 type would take the cars, sort them north, distribute and bring back the empties. Originally the engines alternated on day and night shifts, but because of complaints received from the residents along the right of way, the night work had to be abandoned.From then on both engines worked day shifts, the one operating north from the Montrose Yards and returning there at nights, and the other operating south from Central Str. Evanston and remaining at the water tank siding north of Howard Avenue when not in service.

This service was performed on the surface apart from the passenger line until

Jan.16,1915, when the elevation of the tracks was completed. This elevation had become necessary because of the rapid increase of population of the residential district through which the right-of-way passes. It was financed entirely by the C.M.& St.PaulR.R. From that time on the operation of the freight service presented serious difficulties.To begin with it is never advisable to operate steam locomotives over an electrified passenger division, as it requires very careful dispatching and slows up the entire work. In this particular case, the difficulty was augmented by the fact that the steam and electric crews reported to different superintendents and considered themselves as of different companies. As result many operating difficulties were confronted.

For these reasons, then, a change

from steam operation under the St. Paul supervision to electric operation under the Chicago Elevated Railroad came under consideration. The advisability of this change was strengthed by several other factors.

First, electric operation would eliminate the noise and dirt caused by the steam locomotives, which already caused many complaints from the residents adjoining the right-of-way.

Second, electric operation would be much speedier than steam, for a locomotive could be selected that would have a much greater average speed than that of the steam locomotive. While this did not mean that a proportionally greater amount of switching could be handled than before yet the greater speed presented many operating advantages. This was especially true for operation over the structure which required careful dispatching.

A third advantage lay in the fact that there was already installed over the structure a complete electric distributing system connected to a source of power adequate for any conceivable load demand without prohibitve voltage drop. This power is obtained from the Commonwealth Edison Co., of Chicago and is 600 volts Direct Current being furnished from C.E. substations located at suitable points along the line.

Fourth, it was generally conceded that the cost of electric operation would by no means exceed the cost of steam operation and might perhaps be much less.

The change from steam to electric operation was therefore considered on the above grounds prior to 1917, but because of the war the freight had dropped. In 1919 it was again taken up and a careful survey of the structure situation was made, and it was decided to purchase two fifty ton electric locomotives. It was found that one locomotive would handle the business 80% of the time but that the second was needed to help out on peak loads and to faciltitate

operation.

Accordingly the contracts were let, so that the Baldwin Locomotive Works would furnish the mechanical parts of the locomotive and the Westinghouse Electric Mfg.Co., should furnish the elctrical equipment. The first locomotive was finished and delivered by Nov.1st 1920 and the second arrived on the 15th of Nov. 1920. Train crews were picked from the employees of the Chicago Elevated R.R. Co.,and electric operation begun on Nov.1,1920.

II

THE SELECTION OF AN ELECTRIC LOCOMOTIVE

The data and calculations used in deciding upon the use of electric locomotives for switching on the St. Paul industry tracks, and the considerations for the selection of type and size are given here to make clear the nature of the service and the requirements. Included are the figures on the investigation of train loads and service demands, both minimum and maximum, and the averages; the data on the size of the locomotive as limited by the possibility of operation over the elevated structure; a study of the physical features of the track and line; the calculation of locomotive performance in accordance with these conditions; a discussion of speed requirements, suitable motor size, and number of locomotives necessary; and finally, the specifications on the locomotive actually selected.

FREIGHT TRAIN SERVICE

for Evanston Division Industry Tracks

(Figures compiled from the records of the Car Accountant, Chicago, Milwaukee, and St. Paul R.R.)

MONTHLY TOTALS

	NORTH BOUND			SOUTH BOUND		
Month	Engines Operating	Cars Hauled Load	Cars Hauled Empty	Engines Operating	Cars Hauled Load	Cars Hauled Empty
Av.-1917	25	336	24	25	10	355
Jan. 1918	25	200	25	25	21	188
Feb. "	24	271	25	24	9	275
Mar. "	30	468	30	30	9	460
Apr. "	23	293	2	24	6	409
June "	24	208	-	26	-	242
Aug. "	28	270	-	26	-	257
Oct. "	28	304	-	31	24	283
Dec. "	24	202	-	25	10	191
June 1919	21	299	-	22	-	98
July "	30	342	-	30	--	288
Aug. "	24	231	-	24	-	246
Sep. "	23	331	-	23	-	328
Av. -1917	25	336	24	25	10	355
Av. -1918	26	277	10	26	10	288
Av. -1919	24	300	-	24	-	240

AVERAGE FREIGHT TRAFFIC PER DAY

Year	NORTH BOUND Engines Operating	NORTH BOUND Cars Hauled Loaded	NORTH BOUND Cars Hauled Empty	SOUTH BOUND Engines Operating	SOUTH BOUND Cars Hauled Loaded	SOUTH BOUND Cars Hauled Empty
1917	0.8	11.2	0.8	0.8	0.3	11.6
1918	0.9	9.2	0.3	0.9	0.3	9.6
1919 (4 mo.)	0.8	10.0	-	0.8	-	8.0

* * *

AVERAGE NO. CARS PER ENGINE OPERATED

Year	NORTH BOUND Loaded	NORTH BOUND Empty	SOUTH BOUND Loaded	SOUTH BOUND Empty
1917	14.0	1.0	0.4	15.0
1918	10.0	0.3	0.3	10.7
1919	12.5	-	-	10.0

* * *

DAILY SERVICE- NORTH and SOUTH

ENGINES

Av. Per Day	Number	Mileage Average	Mileage Total
May to Sept. (1919 incl)	1.6	7	11.9
June 20,22. 2 day av.	2.0	16.4	32.8

Cars

Loaded No. Cars	Loaded Mileage Av.	Loaded Mileage Total	Empty No. Cars	Empty Mileage Av.	Empty Mileage Total	Total No. Cars	Total Mileage Av.	Total Mileage Total
10.0	6.6	65.6	8.0	6.7	53.2	18	6.6	118.8
31.0			36.0			67		258.0

As an example of typical heavy work, the following data covering two days is given:

June 20th -Night Crew

Took north 10 loaded cars and spotted them.

Took out 13 empty cars from industry tracks.

June 21st -Day Crew.

Took north 7 loaded cars and spotted them.

Took out 4 loaded cars from industry track.

Took out 22 empty cars from industry track.

June 21st -Night Crew.

Took north 12 loaded cars and spotted them.

Took out 1 loaded car from industry track.

Took out 15 empty cars from industtry track.

June 22nd -Day Crew.

Took north 25 loaded cars and spotted them.

Took out 4 loaded cars from industry track.

Took out 22 empty cars from industry track.

Actual freight car miles on main track..516

Total car ton miles on main track.....21948

Average tons per car 42.5

Avearage switching per car placed 1.76

Average engine miles per shift 16.4

From the foregoing data, reasonable conclusions can be drawn concerning the load to be expected for the electric locomotives. The figures show that the average number of cars handled has not exceeded ten per day for any time since 1917. For 80% of the days of the year the maximum load is from 10 to 13 loaded cars per train and for12% of the days the maximum is 25 loaded cars per day. For the remaining 8% of the time a maximum of 30 to 35 loaded cars per day can be expected.

LIMITATION OF SIZE OF LOCOMOTIVES FOR MULTIPLE OPERATION OVER STRUCTURE.

For safe operation over the elevated structures, two locomotives operating in multiple must not overload the structure more than would two elevated cars coupled motor end to motor end. Two motor cars so coupled with a total load of 25 tons per truck give a maximum bending moment on a 50 foot span of 445.31 foot tons.

To make a standard fifty ton locomotive safe the specifications of both the General Electric and Westinghouse Engines must be changed as follows:

	Standard 50 ton W.H. Loco.	Relocating trucks of W.H. Loco.
Length over knuckles	36' 0" approx.	36' 0"
Center to center of trucks	17' 8"	18' 0"
Truck base	7' 2"	7' 2"
Overhang	8' 8"	9' 0"

	Standard 50 ton G.E. Loco.	Relocating trucks of G.E. Loco.
Length over knuckles	37'4"	37'4"
Center to center of trucks	19'6"	18'8"
Truck base	7'2"	7'2"
Overhang	8'5"	9'4"

MAXIMUM SAFE WEIGHT OF LOCOMOTIVE WHEN TWO ARE OPERATED TOGETHER.

WESTINGHOUSE		GENERAL ELECTRIC	
Standard 50 ton	REl ocating trucks	Standard 50 ton	Relocating trucks
47 tons	54.8 tons	46 tons	56 tons

Three fifty-ton locomotives operating together would overload one span twenty-three per cent over the present loads.

Fifty tons, then, it must be seen, is a conservative weight to place as the weight of an engine for use under these operating conditions

ions. A fifty ton locomotive can be operated on the stucture with any of the"Elevated" service cars, weighing with balanced load, not more than fifty tons, but not with a loaded standard freight car or any similar car on which the trucks are close to the end of the car.

A locomotive weighing fifty-six tons would have very little margin of safety when used with a fully loaded service car, or with another similar locomotive, but a fifty ton locomotive would be perfectly safe.

DETAILS OF LINE CONDITIONS AFFECTING OPERATION.

A map and a profile of the Evanston Branch of the Northwestern elevated are included with this study.The freight service is operated over approximately eight miles of this line, from the Montrose Avenue yards where the trains are received up the long grade to the elevation, and along the main line to the last industry tracks in Evanston. There are only three grades of importance along this route. These are: 1st the 800' 1½% grade from Montorse avenue up to the top of the elevated structure, 2nd the 690' 1½% grade just south of Calvary station and 3rd the 250' 2% grade north of the Howard avenue station. All of these grades are on tangent track , although there is a short 4 degree curve at the summit of the 800' grade north of Montrose Avenue. This curve and the others in the line are negligible in obtaining the maximum capacity of the locomotive, for, as curve resistance is usually

taken as one pound per degree of curvature, a four degree curve means but four pounds per ton train resistance. Grade resistance on the other hand, amounts to 20 pounds per ton per percent rise, G= 20 qW, so that a 1½% grade requires 30 pounds per ton tractive effort in itself. If the curve occurred on the grade, it would act to reduce the maximum capacity of the locomotive to a corresponding extent, but since in this case the grades are tangent the curves only enter into the matter as sources of power consumption.

Of the three important grades, the two shorter, the 690'- 1½% and 250'-2%, are compensated grades, so that the 800'-1½% grade, consuming the most power, becomes the ruling grade of the system.

The Northwestern Elevated intends reducing this grade in the next few years, so that the 690' -1½% grade will become the ruling grade, but for the present, the 800' grade must be considered the maximum.

CALCULATION OF LOCOMOTIVE CAPACITY.

We are now ready to proceed with the deter- of the capacity of a suitable electric locomotive. In the first place, the weight of such a loco- is limited to fifty tons, considering a standard 0-4-0 type with trucks spaced 18'-8" on centers by the consideration of desirability of operation over the structures. Such a locomotive ean be obtained from the large manufacturers as standard eqpipment. A fifty ton locomotive of this type will have the full weight, or 100,000 pounds on the drivers. When coupled to a heavy train, the adhesion of a locomotive starting on a grade is generally considered as 27%, through of overturning moments and friction, so the fifty ton locomotive will develop a tractive effort of 27,000 pounds when required.

The ruling grade has been determined as the 800'-1½% grade north of Montrose Ave. The tractive effort required on this grade must, then be figured to include train resis-

tance, grade resistance, and effort necessary for acceleration. The train resistance of freight cars varies of course, with speed and conditions of the car and the weather, various authorities give averages of from three to seven pounds per ton for slowly moving trains. The usual value assumed is the mean of these,or five poundś per ton.

The grade resistance is twenty pounds per per ton percent rise, or thirty pounds per ton for a one and one half percent grade.

The acceleration of freight trains is generally considered as one tenth of a mile per hour per second, and this requires a tractive effort of 100 pounds per ton per each mile per hour per second acceleration, or 10 pounds per ton for this train(this is a liberal figure).

The total train resistance is , then 5 plus 30 plus 10 which equals 45 pounds per ton.With a maximum tractive effort of 27,000

pounds, the permissable train weight is 27,000 divided by 45 or 600 tons or 550 tons trailing load, which will be the weight of the average twelve car train.

Comparing the electric locomotive with the steam engine gives practically the same result. The steam locomotive used in this work was the type I-5, an eighty ton engine with 0-6-0 wheel arrangement, and 127200 pounds on drivers. This locomotive, under ordinary conditions, can accelerate a fifteen car train of approximatly 675 tons at the fequired rate up the one and one-half per cent grade, from standstill, and more with a running start.

The electric locomotive in comparison has seventy-nine per cent as much weight on drivers (100,000 pounds compared to 127,200 pounds). But because of the uniform application of torque the electric locomotive can develop ten to fifteen per cent more tractive effort in starting without spinning the wheels. A fifty ton electric locomotive should, then, be able to handle

considerably more than eighty per cent of the train weight hauled by an I-5 steam engine. This means a train of twelve or thirteen ordinary forty-five ton cars, and more when a running start is possible.

The average daily load has been computed to be in the neighborhood of ten loaded cars, hence a fifty ton electric locomotive with a capacity of twelve or thirteen, should be capable of performing the service required.

SPEED REQUIREMENTS

One of the objections to the steam locomotive in this industry service was the low operating speed of the engines used. Four to ten miles per hour was the normal range, with the average for heavy loads rather close to the lower figure. In order to work the locomotive and crew at maximum capacity, and at the same time to permit of operation over the elevated main line tracks without interfering with or delaying the regular service, the freight locomotive should have a much greater working speed.

A fair value of average operating speed to meet these conditions has been estimated at fifteen miles per hour, for full load. The electric locomotive, then, must be designed to operate at fifteen miles perhour with a trailing load of 550 tons, and at a voltage of 250 volts per motor as the minimum to be expected.

Although more power will be required for motors of the necessary size and rating than for smaller, slower, machines, the saving by expediting the work is expected to offset the

increase in investment and operating costs.

Locomotives equipped in this manner should be able to maintain a free running speed, light, of from thirty to thirty-five miles per hour. Light loads can, therefor, be hauled at a comparatively high rate of speed in emergency service.

SIZE OF MOTORS.

The Westinghouse people advise that the minimum equipment for their forty-seven ton locomotive be at least five hundred horsepower, or one hundred twenty-five horsepower per motor for an average operating speed of fourteen miles per hour on tangent level track. Similarly, the the fiftyton locomotive operating at sixteen miles per hour requires four - one hundred fifty horsepower motors.

But a 1½% grade in itself requires thirty pounds per ton tractive effort, or approximately twice as much as accelerating at 0.1 mile per hour per second on tangent level track. It is

apparent that the current taken for straight hauling would be much less than that required for operation on a grade.

However, all of the grades on the "Evanston line" are short, the time for which the maximum tractive effort (which might amount to 30% adhesion) would be required being always less than five minutes. It is usually considered that the one hour rating of a traction motor can be exceeded by sixty-five per cent for periods of five minutes or less without danger. In this particular case, the current corresponding to 30% adhesion would be that for a one hundred fifty horsepower motor, or approximately 238 amperes plus 65%.

Accordingly, any proposition for smaller motors than these would be of questionable advisability.

NO. OF ELECTRIC LOCOMOTIVES REQUIRED.

Two eighty ton steam locomotives were required to handle the maximum demands, one working from the north and one from the south end of the line,and each putting a maximum of ten or eleven hours a day, when the average operating speed was from four to ten miles per hour. All work had to be done in the day time.

The load handled ranges from ten to thirteen cars a day for eighty per cent of the time, to twenty-five cars on twelve percent of the days throughout the year, and a maximum of thirty-five cars the remaining time.

One electric locomotive can haul twelve or thirteen cars at an operating speed of fifteen to seventeen miles per hour, and being relatively noiseless, can work on night shifts. Hence one locomotive can handle the demand for eighty percent of the time, and by working two shifts, could handle the twenty-five car daily load, or, two locomotives could each work one shift to handle the twenty-five

cars. For the remaining eight percent of the time, three shifts would be necessary, for for this is largely special rush work at special prices.

It is also advisable to have two locomotives in case of the break down of one, and in an emergency, to operate in multiple on heavy loads. The decision, then must be to purchase two of the fifty ton locomotives secure an option on a third at the same price, to be exercised if made advisable by increased business.

SELECTION OF LOCOMOTIVES.

In accordance with the above considerations bids and specifications were called for and locomotives ordered. The locomotive finally selected as being the most satisfactory for the service was a Westinghouse special class, 0-4-0, double truck locomotive, with four 170 HP, type 567-R-I Motors, Gear ratio 17to 60, with 34" wheels. The data on this locomotive are as follows:

General Dimensions

Length inside of knuckles, about	37' 4"
Height over collecting devices in lowered position above top of running rail, not over	13ft. 8"
Height of center of drawbar above top of running rail	2' 10.5"
Width over side sheeting and bumpers	8' 6"
Distance center to center of trucks	18' 8"
Track gauge	4' 8.5"
Minimum radius of curvature of track locomotive alone	50' 0"

Clearance

Trucks, car body and fittings must conform to clearance diagrams shown on Metropolitan West Side Elevated Railway Co., Sheet No. 1594, as revised May 15th, 1917. It is desired to wear out steel wheels without any interference developing from trolley rail and guard rail on curves of 90 feet radius.

When the motors are in the lowest possible position, the clearance of any part above top of rail shall not be less than 2" with worn out wheels.

To facilitate operation around short curves, a side bearing clearance of 5/16" total is desired.

General Construction

The standard steeple type of cab is desired, arranged with two complete sets of motormans controlling apparatus, including brake valves, headlight switches,

etc., for operation in either direction.

Motors

Each locomotive will be equipped with four direct current motors of the field control commutating pole, box frame type, with heat treated gears and pinions.

The motors will be operated for the present without blowers and blowers may be omitted.

The specifications for 567-R-1 the motor used are as follows:

Horsepower at 600 volts	180
Field control	yes
Series parallel switch	yes
One hour rating@ 300 & 600 volts	238 amps.
Corresponding tractive effort, S.F.	127000#
Corresponding speed, full series,	S.F.9MPH
Continuous capacity at 600 volts	S.F.140 amps
Corresponding tractive effort	5800#
Corresponding speed	25.3MPH
Cur. corresponding to 30% adhesion	405 amps
Time current is stood by motor	3 min.
Maximum safe speed	35 MPH
Free running speed light, full mult.	40MPH
Free running speed light, series mult.	20MPH

Size of wheels for above figures	34"
Size of Journal bearings	5" by 9"
Diameter of axle bearings	6.5"
Gear ratio	17-60
Gear face	5"

Control

No. of notches,series	8
No. of notches,series parallel	5
No. of notches,full parallel	4

Current Collecting Deivices

The locomotive builder will furnish and install on one end of the cab roof an air operated pantograph; and on the other end, a trolley pole so located that it can swing either way when the pantogranph is lowered. Locomotive builder will furnish and equip each end of locomotive with a Knutson No.5 trolley retriever and 22' of cord. The pantagraph and trolley pole must operate on overhead conductor varying from 14' to 22' above top of running rail. Trolley boards

will extend the length of the cab proper, extending also to a total width of 4' -6". The trolley base will be the type known a U.S. #13.

The locomotive builder will furnish four rail current collecting devices per per locomotive, in accordance with Railroad companys standard drawings, and will apply and connect one device on each side of each truck, installing the connecting cable in conduit on the trucks as directed.

A single-pole double-throw quick-break knife switch will be provided by the Locomotive Builder in order to connect in the main motor circuit, either the overhead or third rail current collecting devices, as desired.

Heating System

The Locomotive Builder will furnish and install in the center of the cab, a #149 "Estate" caboose stove, sold by the Estate Stove Company, of Chicago. Suitable

smoke jacket will be provided, and will be insulated from the steel roof by an #"Electro-bestos" stove pipe insulator, sold by the H.W.Johns-Mansville Co., of Chicago.

Air Brake System

Combined straight and automatic air brake system will be provided with separate straight and automatic brake valves. Two compressors, each with a continuous capacity of not less than 25 cu.ft. of free air per minute, will be provided by the Locomotive Builder and installed beneath the car body.

Weights.

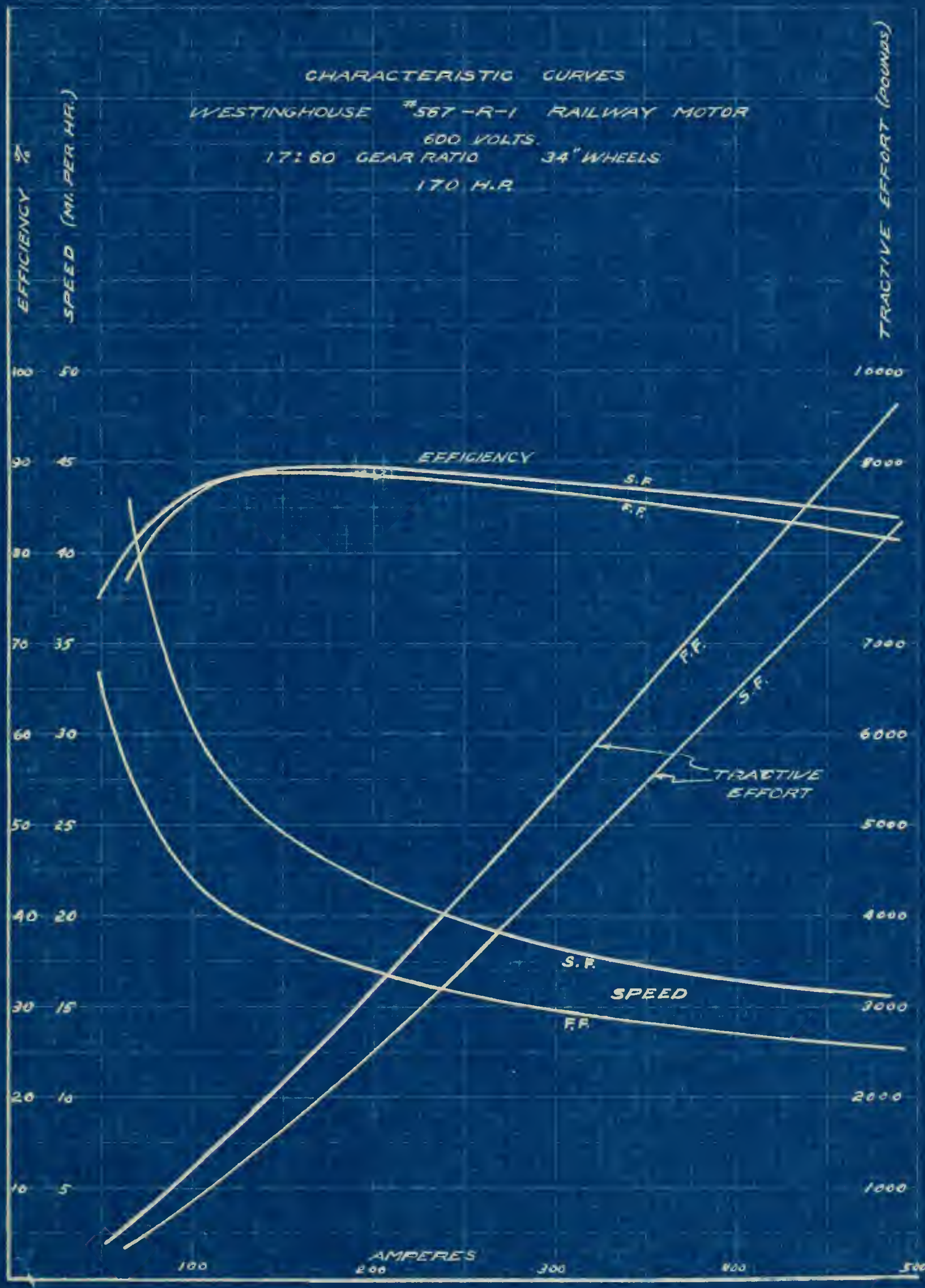
Total weight of Loco.#1-108100# incl.250# sand

Total weight of Loco.#2-107120# incl.250# sand

OPERATION OF THE ELECTRIC LOCOMOTIVES

The operating characteristics of the electric locomotives are shown by the accompanying curve sheets taken from the records and test data of the Westinghouse Company. The first of these gives the characteristics curves of the motors used, using both full field and short field. The short field winding is obtained by cutting out a portion of the regular winding. This decreases the field strength and the torque, but increases the speed of the motor. The short field is obtained thru special contacts on the controller,and can be reached only when the motors are in series, series parallel, without resistance. The curves shown are for 600 volts across each motor.

The speed surves and current curves are given to show the difference in operating characteristics for series, series parallel and for series parallel,parallel operation.



CHARACTERISTIC CURVES
WESTINGHOUSE #567-R-1 RAILWAY MOTOR
600 VOLTS.
17:60 GEAR RATIO 34" WHEELS
170 H.P.
EFFICIENCY %
SPEED (MI. PER HR.)
TRACTIVE EFFORT (POUNDS)
EFFICIENCY
S.F.
F.F.
TRACTIVE EFFORT
SPEED
AMPERES
100
200
300
400
500
10000
9000
8000
7000
6000
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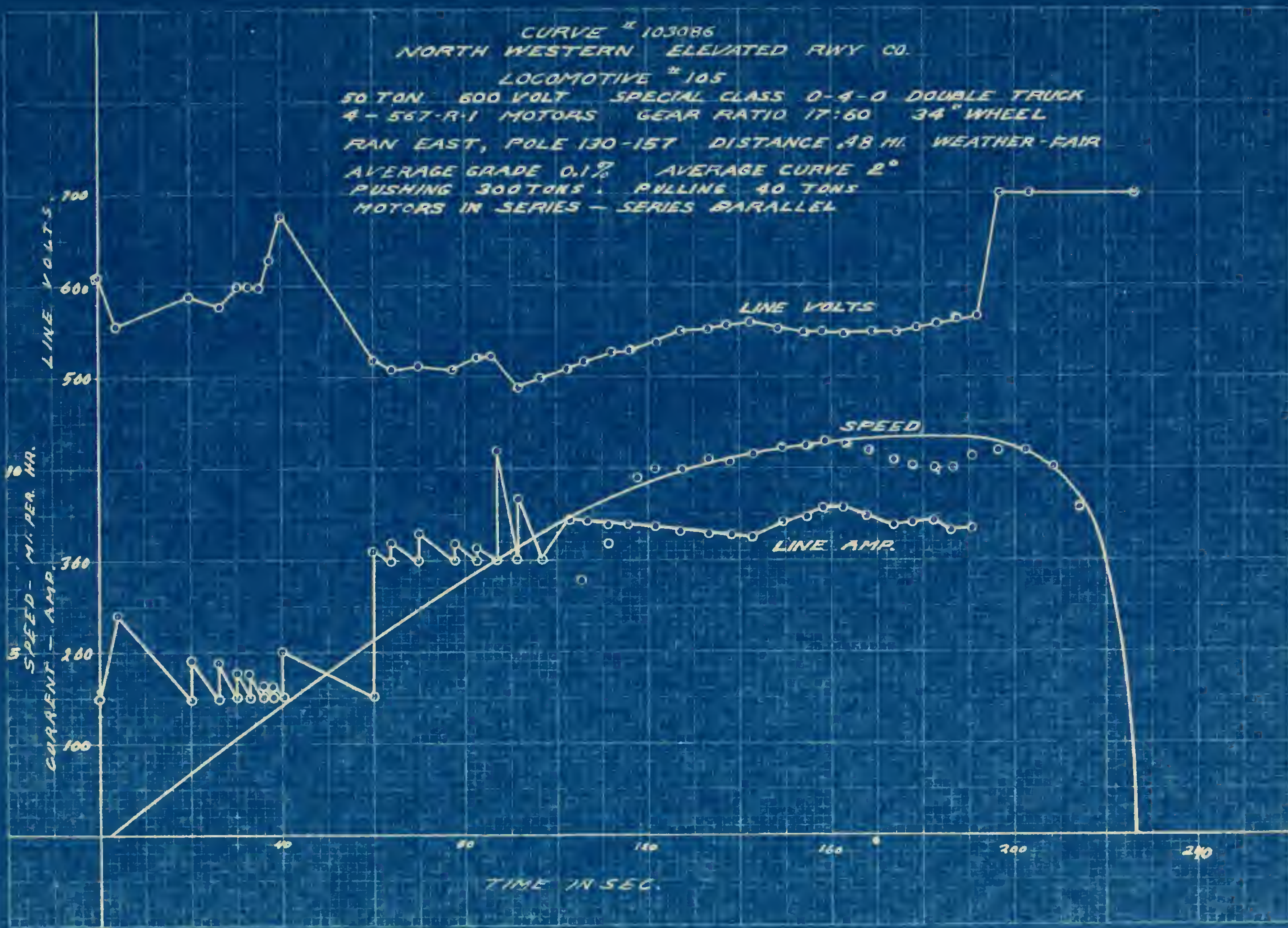
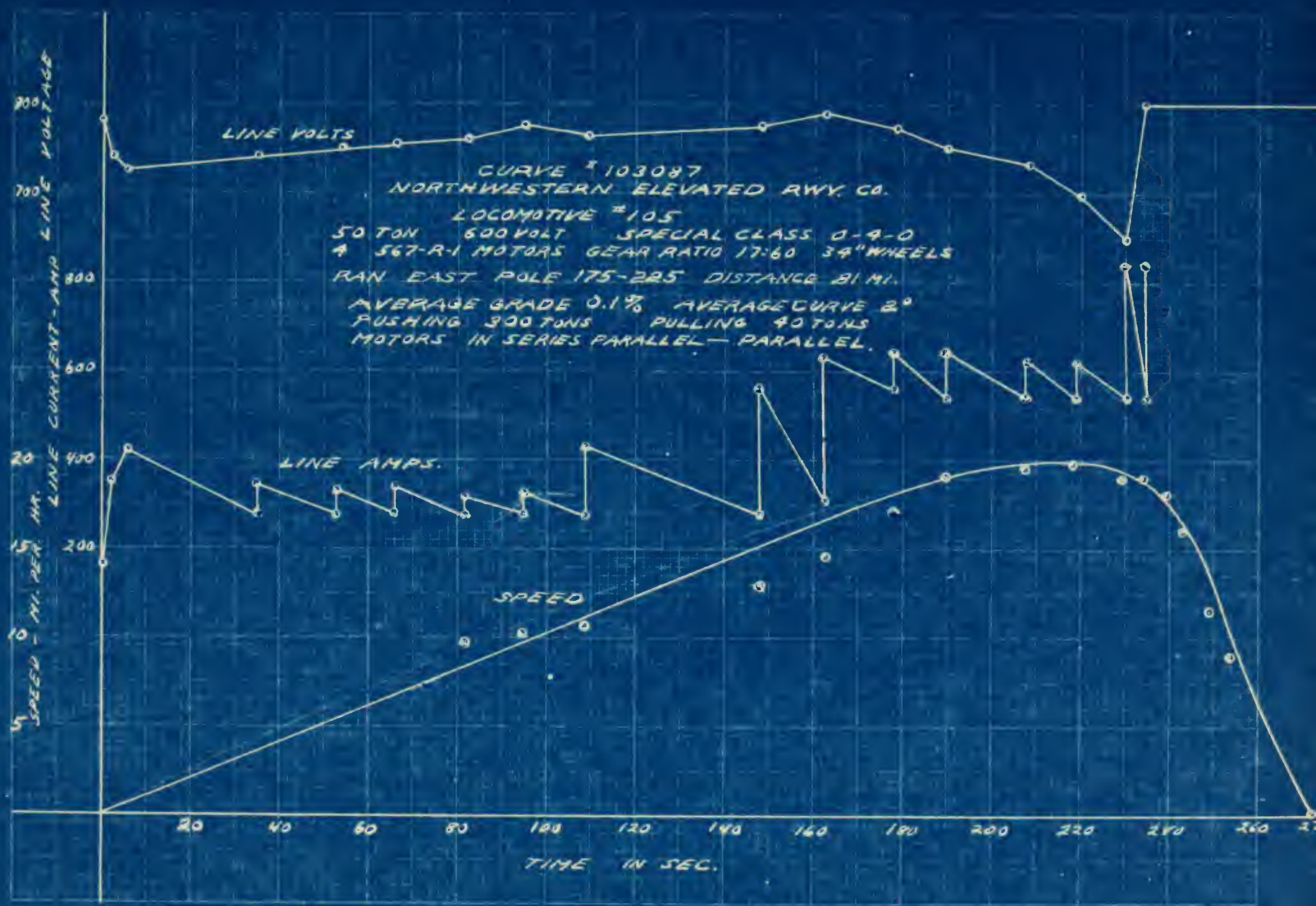


CURVE # 103086
NORTH WESTERN ELEVATED RWY CO.
LOCOMOTIVE # 105
50 TON 600 VOLT SPECIAL CLASS 0-4-0 DOUBLE TRUCK
4 - 567-R-1 MOTORS GEAR RATIO 17:60 34" WHEEL
RAN EAST, POLE 130-157 DISTANCE .48 MI. WEATHER - FAIR
AVERAGE GRADE 0.1% AVERAGE CURVE 2°
PUSHING 300 TONS . PULLING 40 TONS
MOTORS IN SERIES — SERIES PARALLEL
LINE VOLTS
SPEED
LINE AMP.
700
600
500
300
200
100
10
5
LINE VOLTS.
SPEED - MI. PER. HR.
CURRENT - AMP.
40
80
120
160
200
240
TIME IN SEC.


CURVE # 103087
NORTHWESTERN ELEVATED RWY. CO.
LOCOMOTIVE # 105
50 TON 600 VOLT SPECIAL CLASS 0-4-0
4 567-R-1 MOTORS GEAR RATIO 17:60 34" WHEELS
RAN EAST POLE 175-225 DISTANCE .81 MI.
AVERAGE GRADE 0.1% AVERAGE CURVE 2°
PUSHING 300 TONS PULLING 40 TONS
MOTORS IN SERIES PARALLEL — PARALLEL.
LINE VOLTS
LINE AMPS.
SPEED
SPEED - MI. PER. HR.
LINE CURRENT - AMP LINE VOLTAGE
TIME IN SEC.
800
700
600
400
200
20
15
10
5
20
40
60
80
100
120
140
160
180
200
220
240
260

The speed obtainable in straight series is roughly twice that for series parallel but the current consumption is doubled, as is also the time required to reach maximum speed.

The speed curves as indicated are for a load of 340 tons-300 tons pushing and 40 tons trailing. These indicate very favorably speeds for the requirements of operating conditions.

The speeds to be expected when hauling a full load of 550 tons can be obtained approximately from the cahracteristic curves assuming uniform acceleration at 0.1 mile per hour per second until full voltage is applied to the motors and considering the train resistance as constant at 5 pounds per ton, the tractive effort required to accelerate a 600 ton train on the level is

750 plus 1500 = 2250#, and on a 1½% grade, 4500# more or 6750#. From the curves the current corresponding tothis tractive effort is 360 amperes per motor, whichis the maximum allowablefor periods of five

minutes or less. The maximum speed on the grade, full parallel is 15 miles per hour at 280 amperes per motor for full field, and 17.5 miles per hour at 340 amperes per motor for short field.

On tangent level track, the current during acceleration is reduced to 190 amperes and the limiting conditions are 25 miles per hour and 80 amperes full field and 30 miles per hour and 100 amperes short field.

Series-parallel operation practically halves the speed and the total current consumption. This corresponds to the operating requirements, since 15 miles per hour is the desired operating speed.

The maximum speed obtainable with the locomotive running light on short field is in the neighborhood of 40 miles per hour.

SERVICE AND PERFORMANCE OF ELECTRIC LOCOMOTIVES.

During the five months of operation, the electric locomotives have handled the heavy demands for winter soal deliveries in a very creditable manner. The work done during three months of the time was considerably above the expected average , as shown by the figures. Taken by months, the figures are as follows:

Month	Loco. Mi.	No. loaded cars handled	No. loaded cars/day	Loc.M.
Nov.		1015		
Nov.	968	1015	33.8	32.3
Dec.	831	1028	34.0	27.7
Jan.	667	797	26.6	22.2
Feb.	536	459	15.3	17.9
Mar.	511	564	18.5	17.0

The average number of loaded cars handled per day during Nov. and Dec. approximates the the figure considered in the calculation as a maximum value. Aheavy days work for the steam locomotive is given as 31 loaded cars

per day, handled in two shifts by an engine operating 32.8 miles. The Nov. figures for electricl operation show that an average for Nov. was 33.8 loaded cars were handled perday, with a locomotive mileage of 32.8

One electric locomotive it has been found, can take as many as 17 or 18 cars up the Montrose avenue grade. Occasionally it was necessary to double head the two locomotives to take a longer train up on to the structure, but it was seldom necessary to operate three shifts.

The cars are distributed to the industry tracks, in about the same manner and number per unit length of line with possibly a slight preponderance on the far or north end. As an example of the amount of work done, the records for each siding show in the following tables for the month of Mar. 1921, when 564 cars were distributed to the various industry tracks

The number of cars switched, and the location of each siding are noted.

Siding	No. Cars	Miles from Montrose Ave.
1. N.W.El.R.R.	16	.49
2. Ft. Dearborn storage W.H.	29	.81
3. Consumers yd. #37	46	1.16
4. Sanitary District	12	1.20
5. Consumers #35	3	1.62
6. G. Lill coal Co.,	61	1.90
7. Edgers Coal Co.	37	2.26
8. Ferguson Coal Co.	4	2.26
9. Best Coal Co.	91	2.80
10. Track Elevation	111	326
11. Consumers #17	22	4.83
12. Mars Slator Co.	16	4.89
13. Wis. Lumber Co.	9	4.92
14. North Shore Storage	2	4.93
15. Mainbstreet team track	10	5.65
16. Sinclair Oil	10	6.23
17. P.S. Company	18.	6.75
18. Church St. Team Track	34	7.40

19.	Armour and Company	18	7.45
20.	Consumers # 7	17	7.78
	Total	564	

The total number of carmiles of switching in March is given as 3596.34, and for the other four months, as follows:

Month	No. cars taken North	Total Mileage
Nov.	1037	6960.22
Dec.	975	6468.82
Jan. 77	770	5427.10
Feb.	459	3157.56
Mar.	564	3596.34

The cars taken north are mainly coal cars. The loads have been averaged with results that show that of the total number of cars taken from the receiving yards, 85% are 100,000 pounds capacity high side gondolas, ten percent are 80,000 pounds capacity low side gondolas, and five per cent are box cars or empties. The weight of an empty car average approximately twenty tons.

With due allowances, the average car weight on the north end haul can be taken as sixty-five tons, car and load, and the average south bound as 20 tons, since only one or two percent of the south bound cars loaded. This gives an average car weight on the round trip as forty two and one half tons. Then the miles hauled per month can be calculated.

Month	Car mileage	Ton Miles	Loco.miles
Nov.	6960.22	296,000	968
Dec.	6468.82	275000	831
Jan.	5427.10	230000	667
Feb.	3157.56	134000	536
Mar.	3596.34	153000	511

Month	Car mileage per loco. miles	Ton miles per loco. mile	Miles/car.
Nov.	7.20	306	6.72
Dec.	7.78	330	6.65
Jan.	8.14	340	7.04
Feb.	5.90	250	6.88
Mar.	7.04	300	6.40

These records permit of the calculation of monthly and daily averages of the first three items.

Item	Av. per month	Av. per day
Car miles	5122	170.7
Ton miles	217700	7256
Locomotive miles	703	23.4

For the other three items, average car miles per locomotive mile is 7.21, which means that each locomotive handles an average load of 7.21 cars, or an average tonnage load of 306 tons. The maximum may be expected to be about twice this value.

The average miles per car works out to be 6.74 miles, or, the switching service out and back is equivalent to 6.74 miles of operation for each car.

BASIS OF COMPARISON OF COSTS

When it is desired to make an accurate comparison of the relative costs of two, different methods of doing the same thing certain fundamentals relations should exist between the various detailed cost items. To eliminate the possiblility of more or less serious errors, these five conditions should be fulfilled.

First: the nature and amount of service performed, and the operating conditions where these affect the cost(as in this case; weather conditions of right of way, efficiency of train crew, etc.) should be similar to all practical purposes.

Second: all costs for both methods of operation should be averaged over the same period of time, or reduced to such an average, because of the rapidly varying unit prices.

Third:the total cost of each service

should contain the same or corresponding factors in both estimates. That is, if the figures on one method neglect maintainance of way, the other should not include it.

Fourth: the same degree of accuracy should prevail in all figures. It is unfair to use an accurately measured figure for some one item of the cost of one syatem an only a rough estimate for the corresponding item in the other system.

Fifth: the cost of each service should be reduced to as fundamental units as possible, to do justice to each method of service.

When it is impossible for any reason to comply with these requirements, the results obtainable can be considered only as more or less close approximations. A study of the relations of steam and electric locomotives on the St. Paul industry service shows that all of these conditions cannot be properly fullfilled.

In the first place, the steam locomotives formerly used on this work were pooled by the C.M.& St.Paul Chicago Terminal division with more than a hundred others. No one locomotive spent a great amount of time in the Evanston Line service, and from the nature of the cost accounting system, this fact makes it extremely difficult to properly apportion the cost of the Evanston line. WHile the general nature of the service over the Evanston line is the same as that over the whole Chicago Division, great care must be taken in determining the ratio of average service on this line to the total service performed, to arrive at a fair unit cost.

On the other hand, the electric locomotives are used only in this specific service, and careful cost records have been made making it possible to absolutely determine the exact cost of operation.

The operating conditions with similar

but not exactly the same, for the electric crew, being under the direction of a Yardmaster at Buena Park, could be worked the more efficiently. As to climatic conditions, and conditions of right of way no practical difference exists.

, The second condition can be met with a reasonable degree of accuracy. Factors are available for reducing all costs to a present day basis, and operating expenses can be average over similar periods of time.

It is also possible to compute corresponding costs for both steam and electric operation. These have been classed under three headings: fixed charges, operating expenses and maintainance and damage charges. In both cases maintanance of right of way is neglected, as the freight service forms but a small proportion of the traffic over the line so the difference with steam and electric freight charges is negligible.

The condition requiring similar accuracy of results for the two costs charges has proved absolutely impossible to fulfill, for, as stated above, the cost of steam operation must be estimated from the operating expenses ofa whole division while exact figures are available for the engine. An attempt was made to follow through the charges against the identical locomotives used in the Evanston line service for a period prior to the introduotio of electric operation, but the because of the many arbitrary assumptions necessary in so doing it becam evident that the results would not justify the great amount of time and labor required in so doing. Hence, while exact data were available for some few items, the majority of the costs were figured as an average for the class I-5 locomotives.

The most arbitrary assumptions had to be made in selecting the unit cost basis of omparison. For this type of service, three units might be used. The most fundamental of these is

the gross ton-mile, which, for operating expenses, is practically independent of quantity of service, length of trains, size of locomotives, or similar items. Somewhat similar to this is the cost per loaded car handled. This basis assumes that the operating conditions are similar, and that the average mile per car is the same in each case. But no records could be obtained from C.M.&St.P R.R. of the number of cars handled over periods for which locomotive costs could be computed. These units are therefore not available.

This leaves the locomotive-mile as the only possible unit with which to work, and even this is unsatisfactory for the steam operation because an assumption must be made of the average operating speed of the engines, and miles figured from the hours in service.

This is not at all satisfactory. the average operating cost per mile can be figured on this basis for the locomotives as a class, but this figure may not hold for the Evanston

line, because of the possibility of a limited amount of service, less than the average, being required during a shift, with a resulting c cost per mile much higher than the average.

In considering fixed charges, the locomotive-mile basis is unfair to the locomotive operating at less than full capacity, or hauling the longer trains. In the absence of other data, the most satisfactory method of computing fixed charges per locomotive-mile is to assume the same mileage per year for the steam as for the electric- i.e.,assume the same service for each, which may or may not be near the truth.

I t is evident that the comparative figures cannot be relied upon as better than a rough estimate of the relative cost of steam and electric operation. The figures on electric costs can be depended upon as fairly accurate, but too many arbitrary assumptions and approximations are necessary to permit of accuracy with the steam computations.

COST OF OPERATION OF ELECTRIC LOCOMOTIVES.

To arrive at a fair basis of comparison of the relative costs of steam and electric locomotives, the figures must be obtained for some unit of work performed. Before such unit costs can be calculated, however, the total cost of operation over a definite period must be arrived at. In obtaining these amounts for the electric locomotives for five months of operation, the cost is separated into some twenty-eight items, for convenience in determining the total expenses, and in studying the distribution of cost with variation in amount of service. The following items are those considered by the Engineer Accountant of the Northwestern Elevated R.R. in his investigation of cost changes.

Train Crew Labor.

The employees necessary for freight operation include motormen, switchmen, trolley men and a yard master. These men are paid an

hourly rate, and time cards, made out each day for each man, are handled by the regular routine of the elevated roads. The exact amount paid for labor can be obtained from these cards.

Inspection and Repairs to Electric Locomotives.

Each locomotive is inspected every second week and any necessary minor repairs made as required. The labor for such inspection is shown on the shop time sheets, and the material required is recorded by the store-keeper.

Time of General Office Clerks devoted to freight purposes.

This item covers the labor of the time-keeper force in making up the entries for labor for freight purposes, making out the payroll, etc. The time of all other clerks and officials is not included.

Sand

The cost of sand includes the actual price paid for the sand plus the actual labor costs for handling it into bins. The cost of drying it and placing it on the locomotives is taken care of under item 2.

Stationery

This includes all stationery supplies furnished by the elevated road to the Freight Crews, such as reports cards, time cards etc. Actual costs as shown by the storekeepers requisitions and the purchasing department are used.

Interest on Captial invested.

The toatl amount invested in the two electric locomotives is covered by an application for expenses #432 amounting to $63,872.28 Interest on this is figured at 7½%, the rate allowed by the Illinois Public Utility Commission in the 1919 valuation of the Elevated Companies, as shown on page 61

of the Final Order of the Commission; dated Jan. 4,1921. The interest at this rate amounts to $ 4,790.42 a year, or $399.20 per month.

Depreciation of Electric Locomotives

An attempt was made by the Engineer Accountant of the Elevated Roads to determine the life of the electric locomotives from the experience of the other roads with similar service conditions. An extensive correspondence on this subject, with engineers skilled in valuation an estimating, tends to prove that the life of the locomotives will average from twenty to thirty years with a ten percent scrap value. A typical reply is that of Sidney Withington, Electrical Engineer for the New York New Haven and Hartford Railroad who says,

" It seems to me that maintainance is not always 100% as it might be economical to allow locomotives to deteriorate and replace them with new ones after a period of years.

"Furthermore it seems to me that obsolescence should be considered, as the development of electrification is rapid and it is not impossible that improvement will be made within the next twenty years which will permit the use of equipment so much more efficient than equipement at present available as to make general replacement economically advisable.

" All things considered therefore, it would be my opinion that 20 years would be a reasonable assumption as to the length of life."

As a fair average of the estimates a life of 25 years is assumed, with a scrap value of ten percent. The original cost is 63,872.28 so the salvage value is estimated at $6,387.23, and, assuming straight line depreciation, the annual depreciation is $57,485.05 divided by 25, or $ 2,299,40 The monthly charge is then $191.62.

Insurance on Elec. Locomotive.

The actual cost of insurance, as submitted by Mr Love, Ass't Auditor, is $171.16 per year or $14.27 a month.

Sand Dryer Interest

The sand dryer was purchased for use in freight service exclusively, at a cost of$270. Allowing interest at 7½% as above, this amounts to $20.25 a year, or $1.69 a month.

Sand Dryer Depreciation.

The estimated life of the sand dryer is 10 years, with practically no scrap value at the end of this period. This gives a depreciation charge of $ 27.00 per year of$2.25 per month.

Lubrication of Locomotives

In spection of the records of the Shop Department shows that the average amounts of lubricants used per month were as follows:

Electric car oil	10 gals.
Compressor Oil	2 gals.
Gear Grease	37 lbs.
Woolen Packing Waste	5 lbs.

The resulting cost then for the five month operation pertaining lubricants totaled $40.90

Locomotive Brake Shoes

The cost of Brake Shoes is governed by a contract per 1000 car miles which works out as follows:

Month	Mileage	COntraotnPrice	Cost per mo.
Nov.	968	.9293	.90
Dec.	831	.9293	.77
Jan.	667	.8579	.57
Feb.	536	.8579	.46
Mar.	511	.8579	.44

Other Supplies for Freight Service.

This item includes such supplies as cannot be allowed to any particular phase of service, such as tank car covers, coal for heating locomotives etc.

Yardmasters Office Telephones

There are two phones in the yard masters office. One is a company phone for which a proper proportion of the switching operation cost is $2.50 per month.

The Illinois Bell Telephone is an extension of the one in the main office at Buena. The charge for this phone is 75¢ per month for the extension plus one half of the regular phone cost of this telephone. The total cost for the operation of these telephones over the five month period amounted to $70.55.

Yardmaster's Office Rent

The portion of the Buena Station owned by the St. Paul and leased to the Northwestern is used by the freight department as an office and storehouse. The area of this part is about 557 square feet.

Based on the 1919 valuation of the whole building, and at 7½%, the rental value of the part used by the freight business would be approximately $900.00 per year or $75.00 per month, according to Mr. Helton, Real Estate Agent of the Elevated.

Yardmaster's Office Electric Light

The Yardmaster reports a total of 1401 hours of electric light. There are five 23 watt Mazada lamps used and this would give a total of 161.1 KW. which at 5¢ per KWH would make the total cost of the five months operation amount to $8.055

The total cost of heating the Yardmasters office for the same five month period amounted to $71.10

Taxes on Locomotive.

$500.00 per year or 41.67 per month.

Electric Energy used by Locomotive

This is actual cost, as shown by meter reading in locomotives, multiplied by the rate paid by the elevated company for electrical energy.

Repairs to Bldg. used exclusively for freight purposes.

This item is the labor and material cost for repairs to freight buildings as shown by labor

time sheets and requisitions.

Repairs to freight track trolley equipement

This item covers only repairs on trolley equipment used for freight purposes and is shown by labor time sheets and storehouse requisitions.

Repairs to station and platforms

Repairs to stations and platforms by freight cars and is covered by labor time sheets and storehouse requisitions.

Damage to Freight Cars.

Cost of repairs to freight cars is actual cost as shown by labo time sheets and requisitions.

Damage to contents of freight cars.

This is the actual amount paid to claimant for damage to contents of the car.

Personal damage on account of freight accidents.

This includes actual amount paid to claimant plus any costs accruing.

Maintainance of freight trolley equipment.

This is the actual cost of maintainance of overhead trolley equipment on freight racks.

OtherExpenses

This item carries the actual cost of items not allocated to any other itam, such costs as switch light oil, matches, coal for flagman's shanty and various other small items due to freight operation.

Tax on freight business.

The 1919 Tax bill from the St. Paul Co. gives the tax on freight business at $ 7,240.50

Owing to the large increase in freight rates in 1920, and the exceptionally large business done in 1920, it is estimated that the receipts for 1920 would be approximately $9000 per year of $7.50 per month.

Rent of C.N.S.&MR.R. Locomotives.

While one electric locomotive was delivered prior to Nov. 1st 1920, the other was not put into service until Nov. 15th. In the interim an electric locomotive was rented from the

Chicago North Shore & Milwaukee Railroad and the rental price was paid during the month of December.

This is the actual cost of repairs to the North Shore Locomotive while in our possession.

Cost Of Electric Operation.

By the methods outlined in the preceding section, the cost per month for each item can be calculated, and the total expense of electric operation can be computed for each month.

Since the basis of comparison must be on the locomotive mile as a unit, the cost of each item is given as total for the month, and as dollars per locomotive mile.

	November 1920.	Cost/ Loco.Mile.
Train Crew	$3,336.00	$3.445
Insp. & repairs to	148.03	0.153
Gen. office exp.	15.00	0.0155
Elect. Loc. Int. @7½%	399.20	0.413
Elect. Loc. Depreciation	191.62	0.198
Elect. Loc. Insurance	14.27	0.0147
Sand Dryer. Int. @7½%	1.69	0.00175
Sand Dryer Depreciation	2.25	0.00233
Lubrication	8.80	0.0091
Brake Shoes 968 Miles @	.9293	0.00093
Other supplies	7.63	0.0079
Yardmaster telephone	13.63	0.0141
" office rent	75.00	0.0775
" E light	1.34	0.0014
" " heat	14.22	0.0147
Taxes on Locomotive	41.67	0.043

Elect. Power	322.24	0.3333
Any other expenses	109.10	0.113
Tax on freight	750.00	0.775
	$5452.59	$5.59

December 1920.

Train Crew	$ 2841.78	3.425
Insp. & repairs to	398,84	.470
General Office Clerks	15.00	0.0181
Elec.Loc. Int.@ 7½%	399.20	0.472
" " Depreciation	191.62	0.2305
" " Insurance	14.27	0.0172
Sand Dryer Int. @7½%	1.69	0.0024
" " Depreciation	2.25	0.0027
Lubrication	8.80	0.0106
Brake Shoes 831 miles	.77	0.00093
Other supplies for freight	610.12	0.7350
Yardmaster telephone	13.36	0.0161
" office rent	75.00	0.0903
" " light	134	0.0016
" " heat	14.22	0.0171
Taxes om Locomotive	41.67	0.0502
Elect. Power	312.32	0.3780
Repairs to trolley Equip.	83.05	0.1000
Freight car damage	112.96	0.1360
Any other expenses	490.11	0.5900
Tax on freight	750.00	0.9030
Rent of C.N.S.&M.Loco	$285.00	0.3430
	$6663.37	$8.02

Dec 1920

Train Crew	$2,841.78	$3.425
Insp. & repairs	398.84	0.470
General Office clerks	15.00	0.0181
Elec. Loc. Int. @ 7½%	399.20	0.472
" " Depreciation	191.62	0.2305
" " Insurance	14.27	0.0172
Sand Dryer Interest @7½%	1.69	0.0024
" " Depreciation	2.25	0.0027
Lubrication	8.80	0.0106
Brake shoes	.57	0.0009
Other supplies		
Yardmaster telphone	14.52	0.0218

Jan. 1921 (cont.)

Rent, Yardmasters Office	$75.00		$0.1125
Light, " "	1.34		0.0020
Heat, " "	14.22	1	0.0213
Taxes on Loco.	41.67		0.0625
Electric Power	213.10		0.3200
Reprs to trolley equip.	40.93		0.0614
Freight car damage	34.30		0.0515
Other expenses	85.45		0.1280
Tax on Freight	750.00		1.1250
Repairs, C.N.S.&M.Loco.	40.88		0.0613
	$4911.34		$7.36

Feb. 1921

Train Crew	$1,770.36	$3.3000
Insp.& repairs	129.88	0.2420
General Office Clerks	15.00	0.0280
Cost of Sand	0,00	0.0000
Stationery	13.50	0.0252
Elec. Loco. Interest @ 7½%	399.20	0.7450
" " Depreciation	191.62	0.3570
" " Insurance	14.27	0.0266
Sand Dryer, Int. @ 7½%	1.69	0.0032
" " Depreciation	2.25	0.0042
Lubrication	8.58	0.0160
Brake Shoes, 536 mi.	0.46	0.0009
Yardmaster's telephone	15.14	0.0283
" Office, Rent	75.00	0.1400
" " , Light	1.34	0.0025
" " , Heat	14.22	0.0265
Taxes on Loco.	41.67	0.0777
Elec. Power	116.50	0.2175
Freight car damage	9.91	0.0185
Other Expences	56,85	0.1060
Tax on Freight	750.00	1.4000
	$3,627.44	$6.77

March, 1921		
Train Crew	$1395.45	$2.7300
Insp. & repairs	89.21	.1745
General office clerks	15.00	.0294
Cost of sand	47.64	.0933
Elect. Loc. Interest@7½%	399.20	.7820
" " Depreciation	191.62	.3750
" " Insurance	14.27	.0280
Sand Dryer Interest @7½%	1.69	.0034
" " Depreciation	2.25	.0044
Lubrication	6.03	.0118
Brake shoes 511 miles	.44	.0009
Yardmaster's telephone	13.90	.0272
Yardamster's office telephone	75.00	.1470
Yardmaster's office light	1.34	.0026
Yardmaster's office heat	14.22	.0278
Taxes on locomotive	41.67	.0816
Elect. Power	110.20	.2160
Maint. of Overhead Equip.	95.94	.1880
Any other expenses	55.72	.1090
Tax on freight	750.00	1.4700
	3305.79	6.4700

Totaling and averaging the various items over the five months, and grouping them under the proper headings another table can be prepared as on the following page;

Cost Item	Total 5 mo.	Av./ mo.	Cost/Loc. Mile
Fixed Chgs.			
Interest	$1996.00	$399.20	$ .5780
Depreciation	958.10	191.62	.2725
Insurance	71.35	14.27	.0203
Taxes	208.35	41.67	.0594
Sand Dryer Int.	8.45	1.69	.0024
" " Depr.	11.25	2.25	.0032
Operating Expenses.			
Labor	$11500.66	$2300.13	$3.2750
Insp. Repairs	1419.54	283.91	.4036
Labor Gen.Off.	75.00	15.00	.0213
Sand	145.04	29.01	.0414
Stationery	13.50	2.70	.0038
Lubrication	40.90	8.18	.0116
Brake shoe chgs.	3.14	.63	.0009
Supplies	617.75	123.55	.1760
Telephone	70.45	14.09	.0200
Light	6.70	1.34	.0019
Heat	71.10	14.22	.0202
Fuel & Power	1074.36	214.87	.3060
Other expenses	797.23	159.45	.2270
Tax on freight	3750.00	750.00	1.0680
Maintainance and Damages			
Trolley Equipment	123.98	24.80	.0353
Freight Cars	157.17	31.43	.0447
Overhead	95.94	19.19	.0273
Grand Total	$23850.63	$4770.13	$6.7266

This gives the total cost of the electrical operation as $6.7366 per locomotive mile, an average over the five months. This is the figure to be used in comparing the cost of electric locomotive service with that of steam. While there is some chance of error due to the fact that records were taken over only five months, still these five months should give a fair approximation of the yearly average. At any rate, the error is negligible when some of the assumptions necessary in determining the steam costs are taken into consideration.

COST OF STEAM OPERATION.

The steam locomotives used in the switching service on the Evanston Line of the C. M. & St. P. R. R. were of the Northwestern I-5 class. This is a 0-6-0 type of switching engine having a tractive effort of 28,158 lb., a weight on drivers of 127,000 lb., and a grate area of 25.8 sq. ft. Complete dimensions and specifications are shown on the accompanying blueprint and table.

This type of engine was used on the switching service for the reason that it was the only type of C.M.& St.P. switcher that was light enough to operate on the elavated structure. It so happens that if its weight and tractive effort are calculated theoretically, they agree substantially with the actual results.

As was explained before, the cost data on steam operation is largely of an arbitrary nature, and represents average costs on the Chicago Terminal Division of the C. M. & St. P. R. R. rather

than the specific cost of operation on the Evanston Line.

To reduce these costs to the locomotive mile unit, three different methods were used.

For fixed charges, the total yearly charge was divided by the yearly mileage which would prevail if the electric locomotives continued to operate at their present average net speed.

For operating costs, exclusive of labor and those items which were common to both steam and electric operation, figures were first obtained on a locomotive hour basis. This was possible because all the C. M. & St. P. costs are figured on an average switching speed of six miles an hour. This cost per locomotive hour was then divided by an arbitrary speed of one and one quarter miles an hour, which represents the approximate speed on the Evanston Line.

For labor costs, the wages per hour were divided by the speed of one and one quarter miles an hour

TABLE OF ITEMS ENTERING INTO THE COST OF STEAM OPERATION..

Itemized Factors	Cost per loc. hr.	Cost per loc. mi.
Fixed Charges		
Interest		.2380
Depreciation		.1427
Insurance		.0013
Taxes		.0391
Coal	1.8500	1.4800
Repairs (running)	.5148	.4110
Repairs (classified)	.2844	.2275
Enginehouse expense	.8676	.6940
Water	.1014	.0811
Lubricants	.0252	.0202
Other supplies	.0489	.0391
Labor		4.4300
General office clerks etc.		.0214
Telephone - Yardmaster		.0194
Rent - Yardmaster's office		.1068
Light - " "		.0019
Heat - " "		.0202

(Continued on next page.)

TABLE OF ITEMS ENTERING INTO THE COST OF STEAM OPERATION.

(Continued)

Itemized Factors.	Cost per loc. mi.
Freight car damage	.0480
Tax on freight	1.0680
Any other expenses	.2270
Total cost of steam operation	9.3177

The detailed figures and methods used in obtaining the above results are shown in the following discussion:

YEARLY MILEAGE.

The yearly mileage used in computing the fixed charges per locomotive mile for steam operation was assumed to be the same as for the electric service. This is true for all practical purposes because the distance transversed by two locomotives of practically the same size and power, in performing a definite service is nec-

essarily the same.

From figures furnished by the transportation department of the Chicago Elevated R.R., the total mileage made by the two electric locomotives from Nov. 1, 1920, to Mar.31, 1921, was 3,513. As this represents the mileage for five months for two locomotives, the yearly mileage per locomotive would be:

$$3513 \times \frac{12}{5} \times \frac{1}{2} = 4210.$$

NET SPEED

The total mileage and the total hours of service of the two electric locomotives were obtained for the months of November and December, 1920.

Month	Mileage	Hours	Net Speed
Nov.	968.48	728	1.325
Dec.	831.00	639	1.305

It is known that the net speed attained in steam operation is smaller than that in electric service, but no definite figures were obtainable

for the former. Therefore an arbitrary speed of one and one quarter miles an hour was assumed, which is slightly less than the net speed of electric operation. This is probably higher than the true net speed of the steam service, but it will serve for purposes of comparison.

FIXED CHARGES

A value of $20,000 was given to the class I-5 steam locomotives as a present day reproduction price. This was obtained by applying a factor of 2.5 to the "before-the-war" value ($8000).

INTEREST.

The rate paid by large railroads such as the C. M. & St. P. for money ranges from 4-1/2 % to 5-1/2 %. An average value of 5 % was assumed for this purpose. The yearly interest charge is divided by the yearly mileage to obtain the cost per locomotive mile.

$$\frac{20,000 \times .05}{4210} = .238 \text{ / loc. mi.}$$

DEPRECIATION

The depreciation rate charged against steam locomotives of the I-5 class is 3 %. This represents a 33 year life, altho at the end of that time the locomotive may be made of totally different materials due to classified repairs.

$$\frac{20,000 \times .03}{4210} = \$.1427 \text{ / loc. mi.}$$

INSURANCE

Very little data was obtainable on insurance rates for steam locomotives. From an analysis of the cost of work train service prepared by the Illinois Central R. R., a rate of .00028 on the value of the locomotive was found.

$$\frac{20,000 \times .00028}{4210} = \$.00133 \text{ / loc. mi.}$$

TAXES

The allocation of taxation charges to individual locomotives is a very difficult task, and is never carried out on a road of the size of the C. M. & St. P. It is known, tho, that the rate is the same for steam and electric locomotives in the same service. Therefore that proportion-

al part of the charge on the electric unit, determined by the ratio of the present day values, was used for the steam engine taxation charge.

$$\frac{20,000}{32,000} \times .0625 = \$.0391 \text{ / loc.mi.}$$

COAL

An attempt was first made to obtain the weight of coal used by the identical locomotives in the Evanston service over a period of time for which the mileage was known. Because of the complexity of the records, the value of such a figure would not be worth the time expended.

Instead, the average weight of coal burned per locomotive mile on the Chicago Terminal Division of the C. M. & St. P. R. R. was obtained from the office of the Terminal Superintendent over three months of average operation. The service on this division is entirely switching, and equal parts of it are handled by locomotives of classification I and C. Therefore, if the average coal consumption is multiplied by the ratio of the I-5 grate area to the average grate area of the division, a fair value for I-5 operation

may be found.

Average coal consumption on Chicago Ter. Div. for Oct., Nov., and Dec. 1920 = 173#/loc. mi.

Average grate area on Chicago Ter. Div. = 36.6 sq. ft.

Grate area of I-5 locomotive = 25.8 sq. ft.

Therefore Class I-5 consumption =

$$173 \times \frac{25.8}{36.6} = 122, \text{ say } \underline{125} \text{ lb. / loc. mi.}$$

The cost of coal delivered to the locomotive on the Chicago Terminal Division is $4.94 / ton. Taking into account the auditing department speed of 6 mi. / hr., and the actual speed of 1.26 mi. per hr., the cost of coal per locomotive mile may be determined as follows:

$$\frac{125}{2000} \times \frac{6}{1.25} \times 4.94 = \$1.4800 \text{ / loc. mi.}$$

REPAIRS (RUNNING)

The cost of running repairs was determined for three locomotives operating in the Evanston service. The cost per locomotive mile on a basis of a speed of 6 mi. / hr. was first determined, and from this, the cost in the industry service

was found by use of the speed ratio.

Locomotive	Cost	Mileage	Cost / loc. mi.
1507	1367.00	14,861	.0920
1522	1531.62	19,965	.0767
1526	297.52	2,433	.1204
	3196.14	37,259	.0858

$$.0858 \times \frac{6.00}{1.25} = .4100 \text{ / loc. mi.}$$

REPAIRS (CLASSIFIED)

The cost of classified repairs was obtained in the same manner as was the cost of running repairs.

Locomotive	Cost.	Mileage.
1504	1044.62	690
1505	-------	18,732
1507	1484.54	14,861
1522	583.19	19,965
1528	-------	11,452
	3112.35	65,700

$$\frac{3112.35}{65,700} \times \frac{6.00}{1.25} = \$.2275 \text{ / loc. mi.}$$

ENGINEHOUSE EXPENSE

The average cost of enginehouse expense per locomotive mile on the Chicago Terminal Division was obtained from the Terminal Superintendant for the months of Oct., Nov., and Dec. 1920. This figure was multiplied by 6/7, the ratio of the weight on drivers of the class I-5 engines to the average weight on drivers of the entire division. It was again multiplied by the speed ratio to obtain the cost per locomotive mile for the industry service.

$$.1686 \times \frac{6}{7} \times \frac{6.00}{1.25} = \$.6940 \text{ / loc. mi.}$$

WATER

This figure and the two following were obtained in the same manner as the above.

$$.0198 \times \frac{6}{7} \times \frac{6.00}{1.25} = \$.0811 \text{ / loc. mi.}$$

LUBRICANTS

$$.0049 \times \frac{6}{7} \times \frac{6.00}{1.25} = \$.0202 \text{ / loc. mi.}$$

OTHER SUPPLIES

This includes the cost of repairs to tools, furniture, and other movable articles required by steam locomotives.

$$.0095 \times \frac{6}{7} \times \frac{6.00}{1.25} = \$.0391 \text{ / loc. mi.}$$

LABOR

This item includes the wages of the train crew, the switchman at Buena, and one half of the wages paid the yardmaster at Division St. It represents the same complement of men as are taken into account in the cost of electric operation. The total hourly wages paid are divided by the speed of 1.25 mi. per hr. to obtain the cost per locomotive mile.

REMAINING ITEMS

The remaining costs are those which are common to both steam and electric operation. They are taken directly from the electric operation cost data and transferred.

SUMMARY

All of the cost data obtained on the two s systems of freight service for the St. Paul industry tracks are summed up in the comparative table given below.

COST ITEMS	COST PER LOCO.*MI. ELECTRIC	STEAM
Fixed Charges		
Interest on Locomotive	$0.5780	$0.2380
Depreciation "	0.2725	0.1427
Insurance "	0.0203	0.0013
Taxes "	0,0594	0.0391
Interest on Sand Dryer	0.0024	-
Dépreciation " "	0.0032	*
TOTAL	$0.9355	$0.4211
Operating Expenses		
Train Crews	$3.2750	$3.5790
General Office Clerks	0.0213	0.0213
Electric Power	0.3060	-
Coal	-	1.4400
Water	-	0.0788

COST ITEMS	COST PER LOCO.-MI.	
	ELECTRIC	STEAM
Lubricants	$0.0116	$0.1960
Inspection & Repairs	0.4045	1.2950
Supplies for Locomotive	0.0452	0.3800
Yardmaster's Office Rent	0.1068	0.1068
" " Light	0.0019	0.0019
" " Heat	0.0202	0.0202
" " Telephone	0.0200	0.0200
Supplies for Freight Service	0.1760	0.1760
Other Expenses	0.2270	0.2270
Tax on Freight	1.0680	1.0680
TOTAL	$5.6835	$8.6138
Maintenance & Damages		
Repairs to Trolley Equip.	$0.0353	-
Maint. of Ovsrhead Equip.	0.0273	-
Repairs to Freight Buildings	-	-
Damage to Freight Cars	0.0447	0.0447
TOTAL	$0.1073	$0.0447
GRAND TOTAL	$6.7266	$9.0796

These figures show that the total operating costs of steam locomotives are greater than those of electric locomotives for this switching service, due to the much greater operating expenses. The fixed charges against electric operation are however, more than twice those against the steam. This is due principally to the much greater original cost of the electrical equipment, and in some measure to the fact that the steam road can obtain money at a lower rate of interest, and that the depreciation is less on a steam locomotive because the factor of obsolesence is not considereded.

Maintenance and damage to equipment other than the locomotive is of course greater for the electric engine, because of the extra electrical equipment so affected.

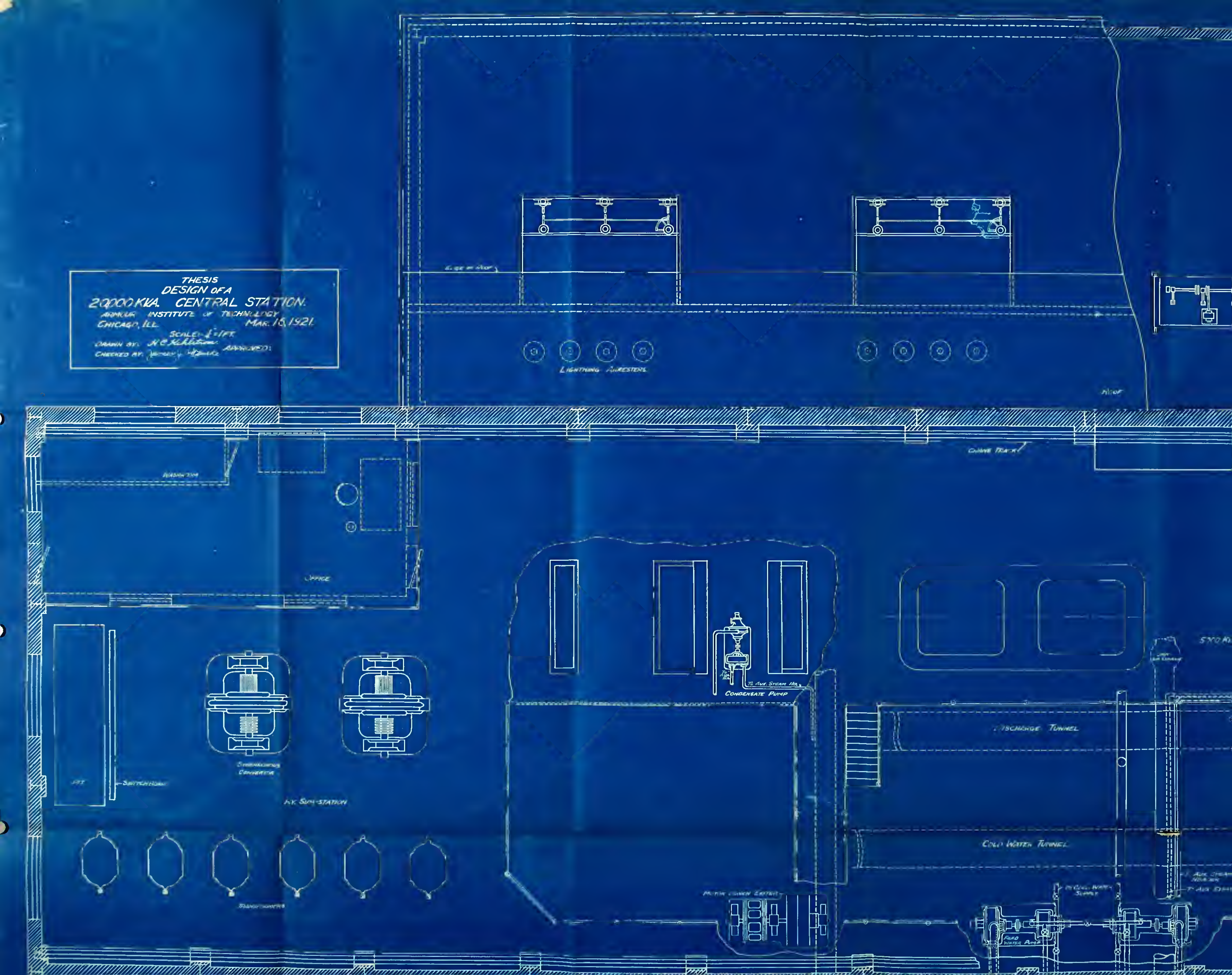
The operating costs show the great advantages of the electric locomotive. The largest saving is, as may be expected, in the fuel cost, the electric locomotive requiring only $0.306

per locomotive mile for electric power as against $1.5188 for coal and water on the steam locomotive. The next greatest saving is in the item for inspection,reapirs and renewals. Where this amounts to only $0.3929 per locomotive mile for the electric locomotive,the steam engine requires $1.2950. Other items show a proportianate saving.

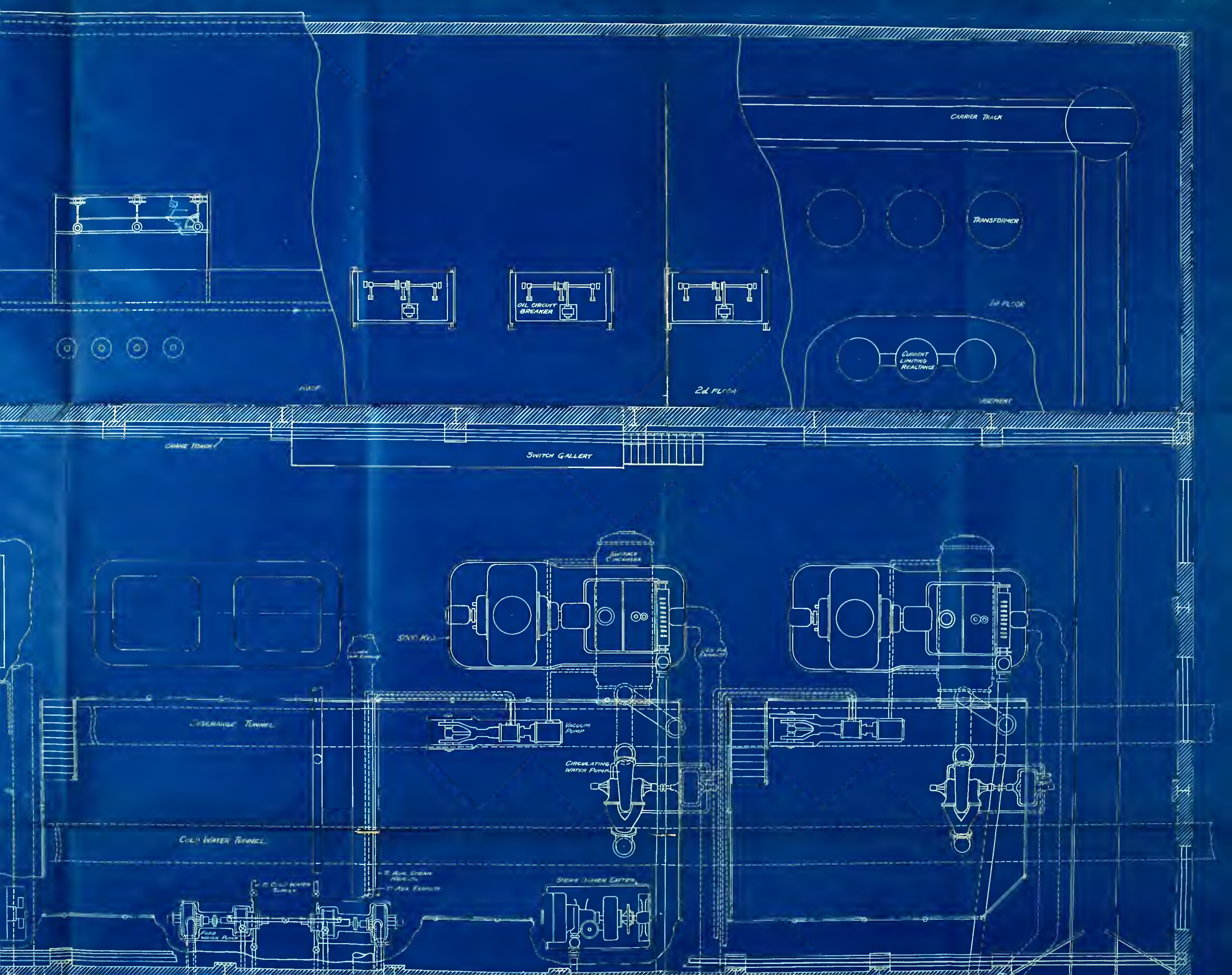
It will be noticed that many items are taken at the same figures for both steam and electric operation.For the most part, these are arbitrary assumptions based upon the condition of approximately equal service rendered. Such items as Yardmaster's Office expenses, Supplies for freight, tax on freight,general office clerks etc., are taken as for equal amounts of freight service, and corresponding numbers of locomotive miles per year. While not strictly, accurate, this is sufficiently so for these items.

Considered as a whole, the electric locomotive is much the more economical for the switching service on the St. Paul Industry Tracks. The total saving, as shown by these figures is practically 25% of the cost of steam operation.

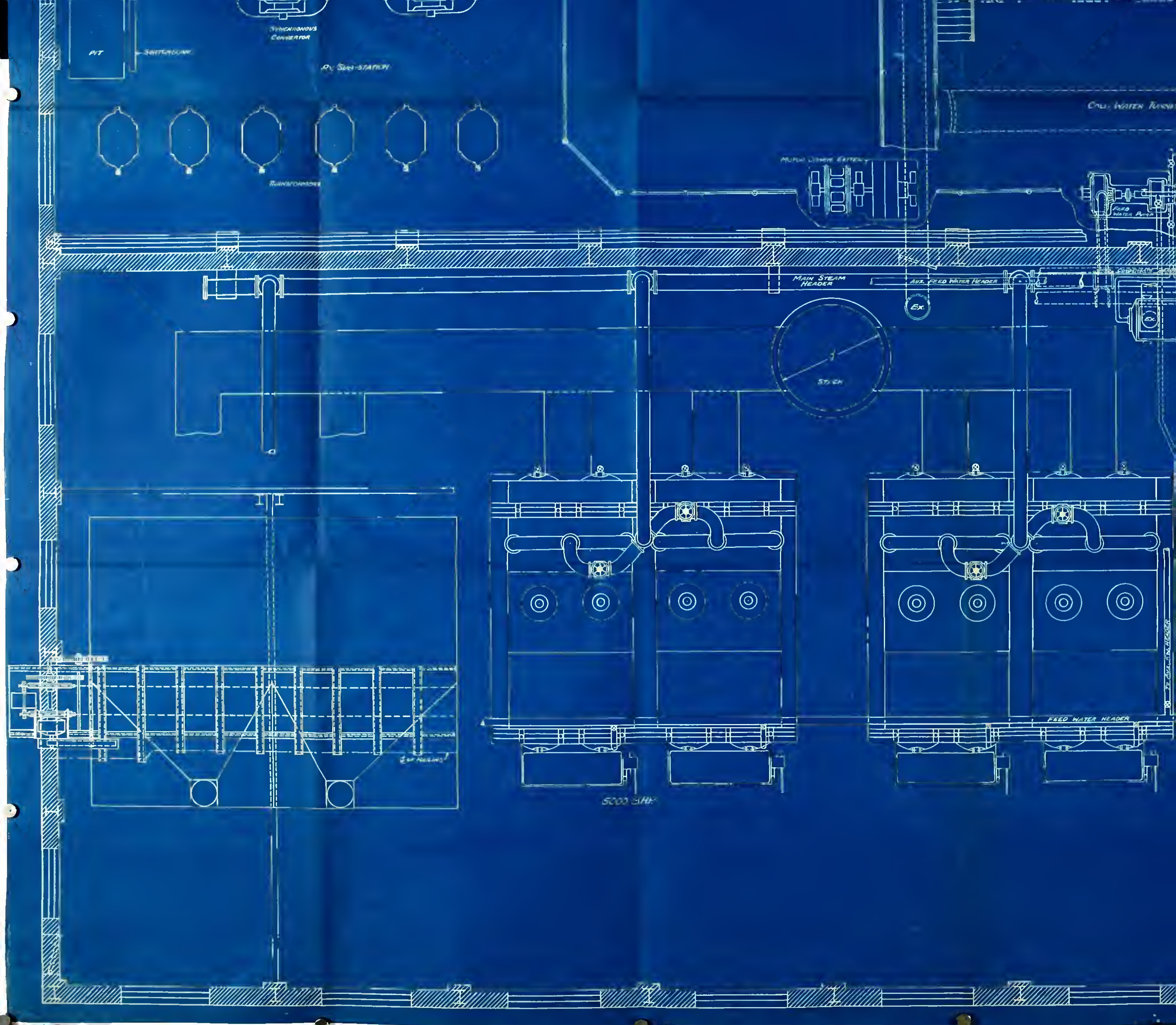
Since all of the outstanding considerations are in favor of electric operation; i.e., the greater convenience of one management and one dispatcher for the passenger and freight service; the greater speed of operation with less interference with passenger schedules and more work done per unit time; and the quietness of operation, with the elimination of the smoke and dirt nuisance, the change to electrical operation is fully justified.



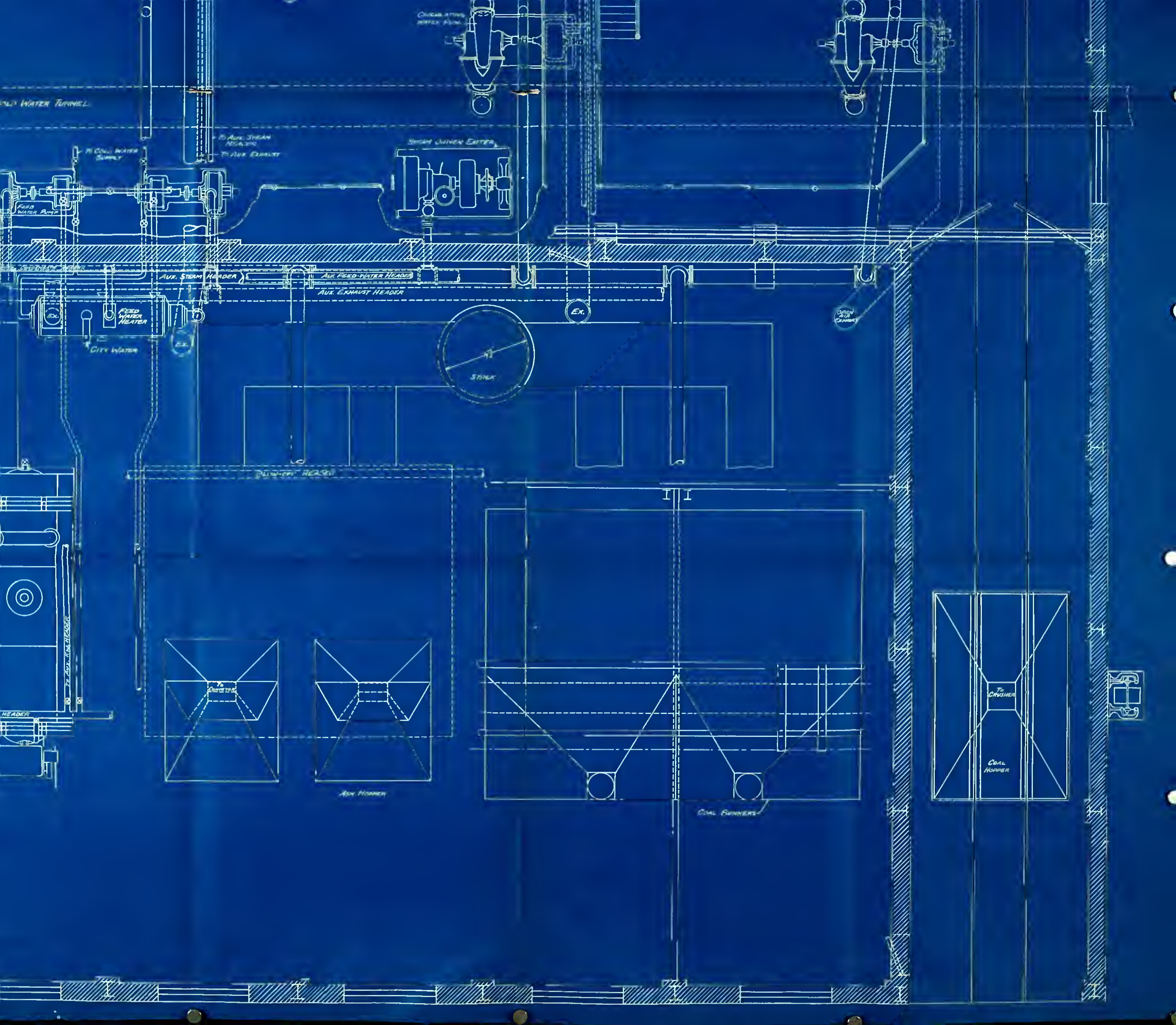
THESIS
DESIGN OF A
20000 KVA. CENTRAL STATION.
ARMOUR INSTITUTE OF TECHNOLOGY
CHICAGO, ILL. MAR. 16, 1921.
SCALE: ⅛" = 1 FT.
DRAWN BY:
CHECKED BY:
APPROVED:
LIGHTNING ARRESTERS
ROOF
CRANE TRACK
OFFICE
CONDENSATE PUMP
DISCHARGE TUNNEL
COLD WATER TUNNEL



CARRIER TRACK
TRANSFORMER
OIL CIRCUIT BREAKER
1st FLOOR
CURRENT LIMITING REACTANCE
ROOF
2d FLOOR
CRANE TRACK
SWITCH GALLERY
5000 KW.
DISCHARGE TUNNEL
VACUUM PUMP
CIRCULATING WATER PUMP
COLD WATER TUNNEL
FEED WATER PUMP



Synchronous
Convertor
Pit
Main Steam
Header
Aux. Feed Water Header
Ex.
Stack
Feed
Water Pump
Feed Water Header
5000 S.H.P.


Circulating Water Pump
Water Tunnel
To Aux. Steam Header
To Aux. Exhaust
To Cold Water Supply
Steam Driven Exciter
Feed Water Pump
Aux. Steam Header
Aux. Feed-Water Header
Aux. Exhaust Header
Feed Water Heater
City Water
Ex.
Open Air Exhaust
Stack
Ash Hopper
Coal Bunkers
To Crusher
Coal Hopper