GO-ALRT

ELECTRIFICATION SYSTEM SELECTION

STUDY REPORT

ADDENDUM No. 1

OCTOBER, 1983

Ontario
Ministry of
Transportation and
Communications

COLE
SHERMAN
TRANSMARK
TRANSPORTATION SYSTEM CONSULTANTS

GO-ALRT

ELECTRIFICATION SYSTEM SELECTION

STUDY REPORT

ADDENDUM NO. 1

October 1st, 1983

SUMMARY

The GO-ALRT electrification system selection study, completed by Cole Sherman Transmark Inc. in July 1983, recommended that a 25 kV ac system be adopted. Subsequently, changes to the vehicle design to improve performance raised doubts that there was sufficient space for the ac equipment, and it was decided that the 1500 V dc option should be reconsidered. Accordingly, Cole Sherman Transmark was asked to carry out a sub-study to determine whether the new input data altered the original recommendation.

Because compatibility with a LIM-powered ICTS was no longer a requirement, the 1500 V dc option was included in this later evaluation along with the 25 kV ac and 1500 V overhead systems.

The changes to the vehicle design made the 25 kV ac option even more attractive than before. The 1500 V dc overhead option is impracticable for the higher currents required for improved performance, and while a 1500 V dc third/fourth rail system is feasible, considerable cost and safety penalties would be incurred in adopting it.

GO-ALRT PROGRAM

ELECTRIFICATION SYSTEM SELECTION

Study Report Addendum No. 1

CONTENTS

1. INTRODUCTION

The July 1983 Study Report to which this present report is an addendum was completed while review of the GO-ALRT vehicle design was still taking place. This design review process continued, primarily with the aim of increasing performance, and eventually led to an increase in the number of trucks per vehicle from 6 to 8 which raised doubts that there was sufficient space for the ac traction equipment as then planned. It was considered important, therefore, to reconsider the 1500 V dc option, and because compatibility with a LIM-powered ICTS was no longer a requirement, a fourth rail system was considered simultaneously with the overhead dc system.

Since the original study was completed, significant changes have taken place in the input data, as follows:

- 64% increase in AW0 Vehicle Mass
- Revised Ridership Forecast (GO-ALRT Scenario "C" of 83-09-23)
- Allowance for 3000 kg weight penalty against the ac vehicle
- Allowance for 20% higher hotel power for the dc vehicle
- Revised cost estimates for Vehicle Electrical Equipment (MCL - 83-09-29)

In preparing this addendum, the opportunity has also been taken to discuss aspects of the original report which have received constructive criticism from readers.

2. UPDATING OF ASSUMPTIONS AND DATA

2.1 TRAFFIC FLOWS

At a meeting held in the GO-ALRT Offices on September 27th, MTC's ridership forecasts of September 23rd were reviewed. Figures were extracted from these ridership tables to prepare the figure on page 3 of Appendix "A", indicating the expected maximum passenger flows and train frequencies of the mature system.

The tables indicate in detail the predicted link volumes between access points on the system. The figures used in our chart are the maxima between the major locations. For instance, between Hamilton and Oakville the maximum one-way daily volume occurs from Fourth Line to Oakville Station and is 20 237, giving a total daily ridership of 40.4 K. The corresponding peak hour traffic is estimated at 7 419, again one-way.

Train frequencies in the peak hour were derived by dividing the passenger flow in the loaded direction by the nominal capacity of a 5-vehicle train, i.e. 830 passengers, made up of 124 seated passengers and 42 standees per vehicle.

These latest revisions to the ridership forecasts have the effect of reducing the number of peak hour trains on the Western Section while increasing the number on the Eastern Section. At the same time, the numbers of trains on the North and South Links are again at a level which corresponds with the service used as a basis for our earlier calculation, i.e. trains at 3 minute intervals arriving at Oakville and Pickering, with some going on to the ends of the system and some short-turning at these stations.

2.2 VEHICLE DESIGN

The vehicle design parameters on which the addendum report is based are given in Appendix "A". Reviews of the basic vehicle design have continued concurrently with the preparation of this report, and consequently some of the assumptions we have made may prove to be inaccurate. For instance, at the end of the week (83-09-03) it appeared that the mass would be less than that quoted in Appendix "A". However, it would not be by a sufficient amount to invalidate cost comparisons. Similarly, the estimate of the difference in mass between the two systems varied from 2000 to 3000 kg over the week.

It was understood that a major reason for this sub-study was the difficulty of installing a suitable transformer for 25 kV. It is of interest that further work done by MCL, resulting in underfloor layouts for 25 kV ac and 1500 V dc equipment, which indicates the space occupied by the dc equipment will be approximately 9.5 m^2 compared with 7 m^2 for the ac equipment. The higher figure for the dc system is largely accounted for by the need for two large static inverters to supply auxiliary machinery.

2.3 ELECTRIFICATION SYSTEMS UNDER CONSIDERATION

2.3.1 1500 V dc Systems (Report Section 3.2.3)

The 1500 V dc Third/Fourth Rail system was eliminated from the initial evaluation because it was judged to be incompatible with ICTS. While it was decided late in the course of the study that TTC would operate the same vehicle as GO-ALRT, it was nevertheless decided that a conductor rail system would show little economic or technical advantage over a 1500 V overhead contact system.

Consideration of the conductor rail system has been included in this addendum since it may be argued that such a system has certain advantages, i.e.:

- In comparison with overhead line systems, it may be more acceptable environmentally.
- In comparison with a 1500 V dc overhead contact system, the 1500 V dc conductor rail, if properly protected, may be less prone to current collection problems when there is severe icing.

However, operational and safety implications of a conductor rail system must also be considered. The presence of the conductor rail interferes with track maintenance and snow clearance, more so with 1500 V insulation than the conventional 600 V system, since the conductor rail would be higher and thus cause problems, particularly at junctions and yards. Also, the higher voltage will require special design measures, such as a substantial protective shield, to prevent accidental contact by staff and others.

2.3.2 25 kV ac Systems (Report Section 3.2.6)

No examples were quoted of the use of 25 kV ac on transit systems so that by comparison with Report Section 3.2.4, the impression may have been created that the 25 kV ac system is largely confined to other applications. However, recent examples of the application of the 25 kV ac system to suburban, as opposed to mainline, services can be found in Helsinki, Brisbane, Istanbul, Ankara, Hong Kong (K.C.R.) and Buenos Aires.

Also relevant are examples of dc suburban electrifications where the only economic solution to coping with increased traffic has been to convert the system to ac operation, e.g. London (Anglia Suburban Lines) converted from 1500 V dc, and New York (Morriston Line) converted from 3 kV dc.

While worldwide comparisons are useful to gain a feel for current technology, local factors may be more important in determining the most economic system for a particular application.

3. SYSTEM DESIGN

3.1 INCREASE IN TRAIN LOADS (Report Section 9.2.4)

The principal effect on system design arises from the increased tractive effort required to accelerate the heavier train. Comparing peak train currents with those used in the Study Report, the revised estimates are:

Peak Train Current	Revised Estimate	Study Report
@ 25 kV ac	270 A	195 A
@ 1500 V dc	3643 A	2602 A

Looking at these figures alone, without any detailed evaluation of traffic pattern, it is obvious that the 2000 A current rating adopted for 1500 V dc overhead line equipment, could easily be exceeded even after allowing for short-term thermal overload capability. An overhead 1500 V dc system would therefore require very heavy conductors and is accordingly no longer considered practicable. A more practicable current collection system at 1500 V dc would use conductor rails. To maintain compatibility with a possible 1500 V LIM vehicle, positive and negative rails would be required to keep traction current out of the running rails.

With the latest traction design data, energy consumption is high both in terms of specific energy for the train and energy consumption per unit of route.

	Revised Estimate	Study Report
Specific Energy Consumption (per train km)	27 kWh	20.5 kWh
Annual Consumption on Western Arm (per route km)	1.6 GWh	1.1 GWh

3.2 CHANGES IN TRAFFIC PATTERN (Report Section 8.2)

The effect of increased train accelerating current is somewhat alleviated on the Western Section, which was used for detailed evaluation in the Study Report, since the latest traffic figures for the mature system show a reduction from 11 to 9 trains per hour in the loaded direction. However, this would still be derived from a 3-minute interval service on the South Link and some at least of the trains would run through at 3-minute headway. Both the maximum current in any one section and at the supply point will still be substantially higher than those values predicted in the Study Report.

The electrification system design on the Eastern and Western Arms will in any case have to cater for short term peak situations with the initial service picking up passengers from the bi-level trains. Since this initial service is envisaged as being carried in 3-vehicle trains, the loadings should be below those predicted for the mature system.

3.3 APPLICABILITY OF ANALYSIS TO MATURE SYSTEM (Report Section 9.3.1)

The revised ridership forecast indicates substantially the same traffic levels on other sections apart from part of the Northern Link, where heavier short distance flows are predicted. The comments made in the Study Report on applicability of analysis to the mature system, remain valid in that the unit costs for 1500 V dc fixed equipment derived from the Western Arm will be somewhat understated if extrapolated to the mature system.

No firm information is yet available on total fleet size, but this factor is now largely irrelevant to the choice of electrification system since the latest costs quoted by MCL for the vehicle electrical equipment show no difference between ac and dc control systems. The costs of the ac transformer/rectifier are offset by higher costs on the dc vehicle for auxiliaries and the pantograph.

4. REVISED COST COMPARISONS (Report Section 8.7)

The revised costs detailed below represent only those affected by the choice of electrification system. Now that 1500 V dc overhead equipment has been excluded on technical grounds, the comparison is between 25 kV ac overhead and 1500 V dc conductor rail systems. The latest available information from MCL gives the cost of vehicle electrical equipment as $500,000 for either ac or dc systems so these costs can be eliminated from the comparison.

	$ million	
	25 kV ac Overhead	1500 V dc 4th Rail
Contact System	4.71	11.61
Electricity Supplies	2.85	8.85
Construction Costs	1.75	2.39
Corrosion/Interference Measures	5.52	3.77
	14.83	26.62

The construction costs estimated above represent only the direct costs of the Transit Authority in facilitating and supervising contract work.

Annual costs have been excluded from this up-date since the differences are insignificant compared with capital costs. Nevertheless, ac annual costs would be lower in all aspects of maintenance and energy charges.

5. OTHER CONSIDERATIONS

5.1 GENERAL

The Study Report showed that neither of the electrification systems evaluated had a clear cost advantage. It was concluded, therefore, that selection of the preferred system would hinge on such qualitative considerations as reliability and availability of suitably rated equipment.

In setting out these arguments no mention was made of the relative performance of ac and dc overhead equipment under adverse weather conditions, or the effect on energy consumption and train performance, of the difference in vehicle mass between the two control systems. These additional points are set out below.

5.2 ADVERSE WEATHER CONDITIONS

Experience with 1500 V dc overhead equipment has shown the need, during adverse weather conditions, to employ wire sweeping trains at two-hourly intervals, to prevent ice formation on the contact wire. On those lines which have now been converted to 25 kV ac operation, the wire sweeping trains have been found to be unnecessary under similar weather conditions because of the higher contact voltage. Conductor rails are also prone to icing under adverse weather conditions. However, the provision of the substantial protective shield required for safety reasons should minimize the problem.

5.3 VEHICLE MASS PENALTY AGAINST 25 kV AC

The latest estimates of vehicle mass indicate that a saving of up to 3000 kg could be made if the 1500 V dc system was adopted. This difference is made up of the transformer mass and its frame mounting, offset by the mass of the static inverter required for auxiliary supplies on the dc system.

With the AW1 Nominal Capacity adopted for system design calculations, the difference in vehicle mass is:

AW1 with ac traction	68 850 kg
AW1 with dc traction	65 850 kg

This mass penalty equates to a difference in energy required to accelerate a 5 vehicle train up to line speed, of 3.3 kWh at the rail or 4.6% of total energy.

The significance of this mass penalty against ac traction is offset by consideration of comparative system energy losses and peak billing demands as set out in Section 9.2.5 and 9.2.6 of the Study Report. Also losses in static inverters providing auxiliary power on a dc vehicle lead to an increase in demand from 300 kW to 360 kW per 5 vehicle train, which equates to an increase in energy consumption on the Oakville-Hamilton trip of 25 kWh or 3% of total traction energy consumption. This difference becomes more significant when turnaround and active storage times are taken into account.

6. CONCLUSIONS & RECOMMENDATIONS

6.1 CONCLUSION

The conclusion reached in July that 25 kV ac was the most suitable voltage for GO-ALRT is reinforced by subsequent changes to the input data.

The 1500 dc overhead line option is no longer considered desirable with the increased traction loadings and the only practicable alternative to the recommended system is a 1500 V dc 4th rail system. The main advantage of this alternative system would be on environmental grounds but capital costs would be increased by at least $75 M for the mature system.

6.2 RECOMMENDATION

6.2.1 It is recommended that the 25 kV ac overhead line system be adopted by GO-ALRT.

6.2.2 It is further recommended that an early start should be made on electrification system design work to meet program dates. An early approach should be made to Ontario Hydro particularly in respect of supply to the pre-build section.

Before system loading studies can start, it will be necessary to finalize vehicle peformance specifications, route data and train timetables.

6.2.3 It is further recommended that a study be made into the measures necessary to mitigate electro-magnetic interference with tele-communications and signal circuits, involving all those authorities concerned.

APPENDIX "A"

BASIC DATA ASSUMPTIONS

GO ALRT ELECTRIFICATION

BASIC DATA ASSUMPTIONS - Revised 83.09.30

Vehicle Configuration

The vehicle is a two-section articulated unit of 36 m length

Height from top of rail	3.6 m
Width	2.8 m
Frontal area	6.56 m^2 - body
	1.73 m^2 - undercarriage
Pantograph Width	1950 mm - UIC 608 Annex 4a
Height	4.57 m - max working height
Frontal area	.225 m^2
Wheel diameter	28 inches

Mass: *

A.C. Vehicle

Empty	AWO	57,230 kg	- no passengers
Nominal Capacity	AW1	68,850 kg	- 166 passengers
Rated Performance Load	AW2	72,000 kg	- 211 passengers

D.C. Vehicle

Empty	AW0	54,230 kg	- no passengers

Performance

Max Speed	120 km/h
Acceleration	0.84 m/s^2 maximum at AW1
Deceleration	1.0 m/s^2 - from 120 down to 5km/h with dynamic braking
Traction Motor	8 motors per vehicle - all axles motored

Train Size

Up to 5 vehicles

* Masses quoted are based on an estimate by MCL made on 83-09-26.

.... (continued)

Train Resistance

$$R = 2 \times 10^{-2} M + 1.85 \times 10^{-3} NV + 5.9 \times 10^{-7} (L-20) AV^2 + 2.68 \times 10^{-5} AV^2$$

Where M = train mass - tonnes
N = number of axles on train
A = frontal cross sectional area - m^2
V = speed - km/h
L = Length of train - m
R = Train resistance in kN

Starting resistance 20 N/tonne assumed

Train mass at nominal loading	- ac vehicle - 5 x 68.85 = 344.25 tonnes
	- dc vehicle - 5 x 65.85 = 329.25 tonnes

Rotational inertia allowance - 18% of vehicle mass.

Auxiliaries

Hotel power	- summer and winter.
A.C. vehicle	- 60 kW per vehicle
D.C. vehicle	- 72 kW per vehicle

GO-ALRT PROGRAM

ELECTRIFICATION

2021 DESIGN YEAR RIDERSHIP FORECAST

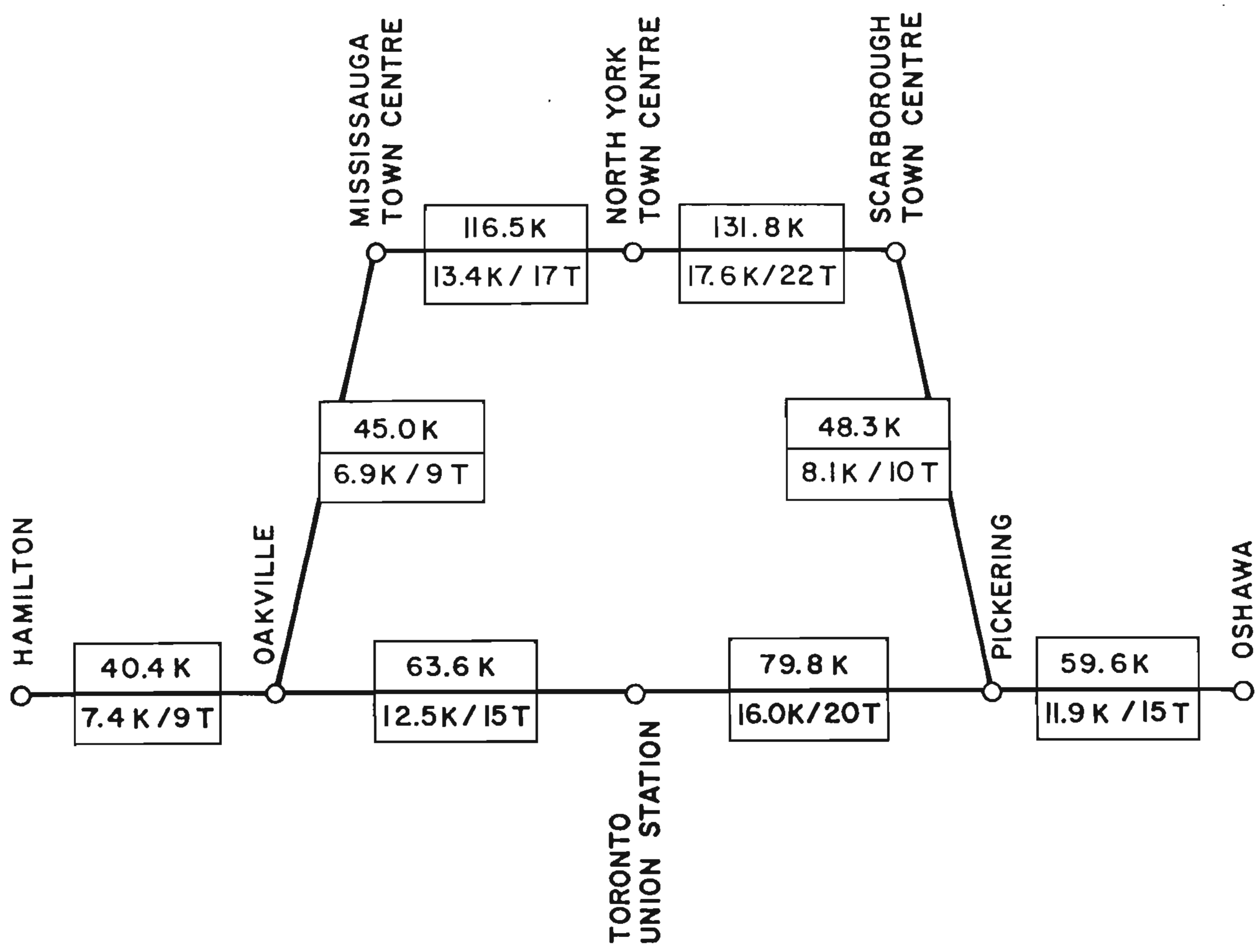
GO-ALRT SCENARIO "C" OF 83-9-19

KEY	
	Passengers per day
	Passengers/Trains (per peak hour)

Assumptions:

a) Average load of 5 vehicle train is 830 passengers during peak hour.

b) Schedule speed, including average intermediate station dwell time of 20 secs, to be 70 km/h.

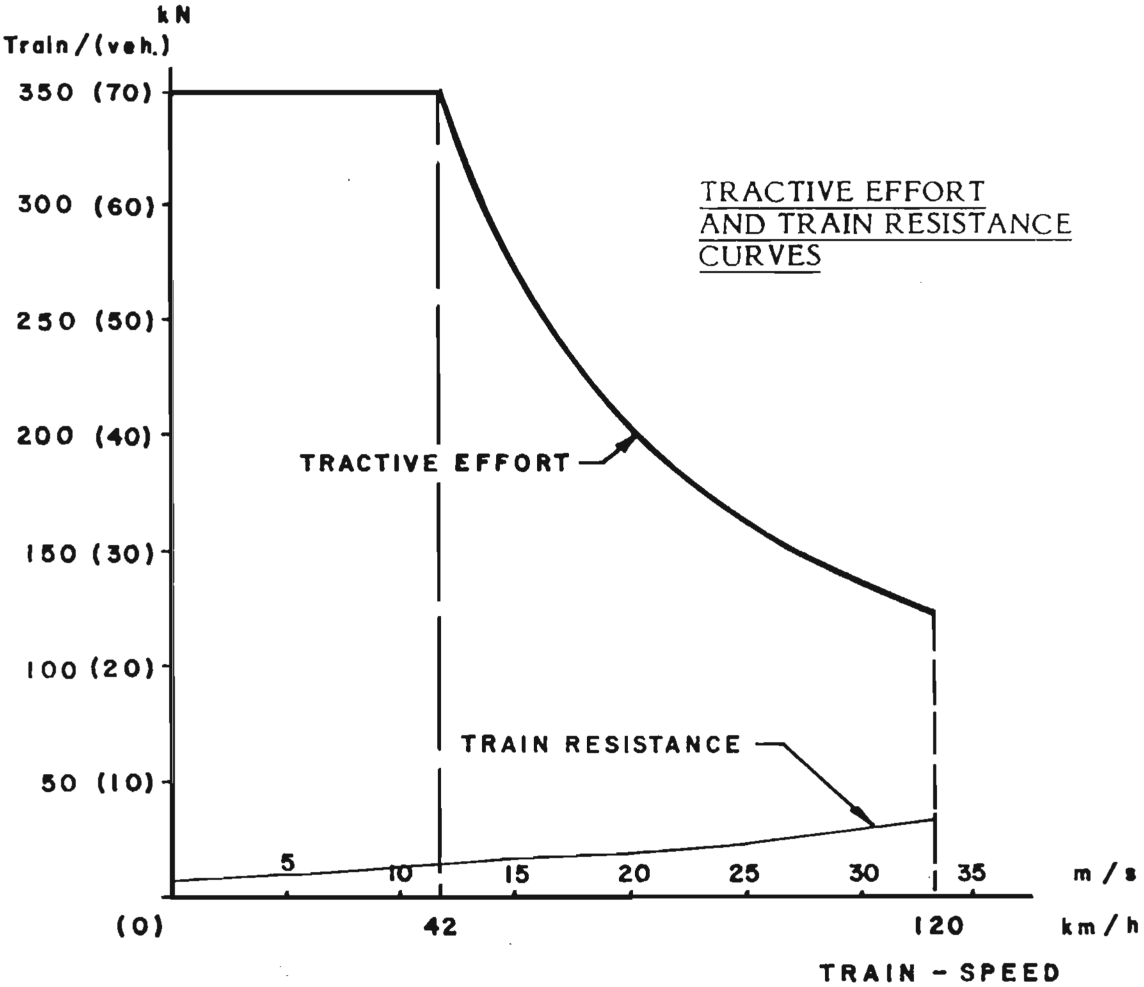


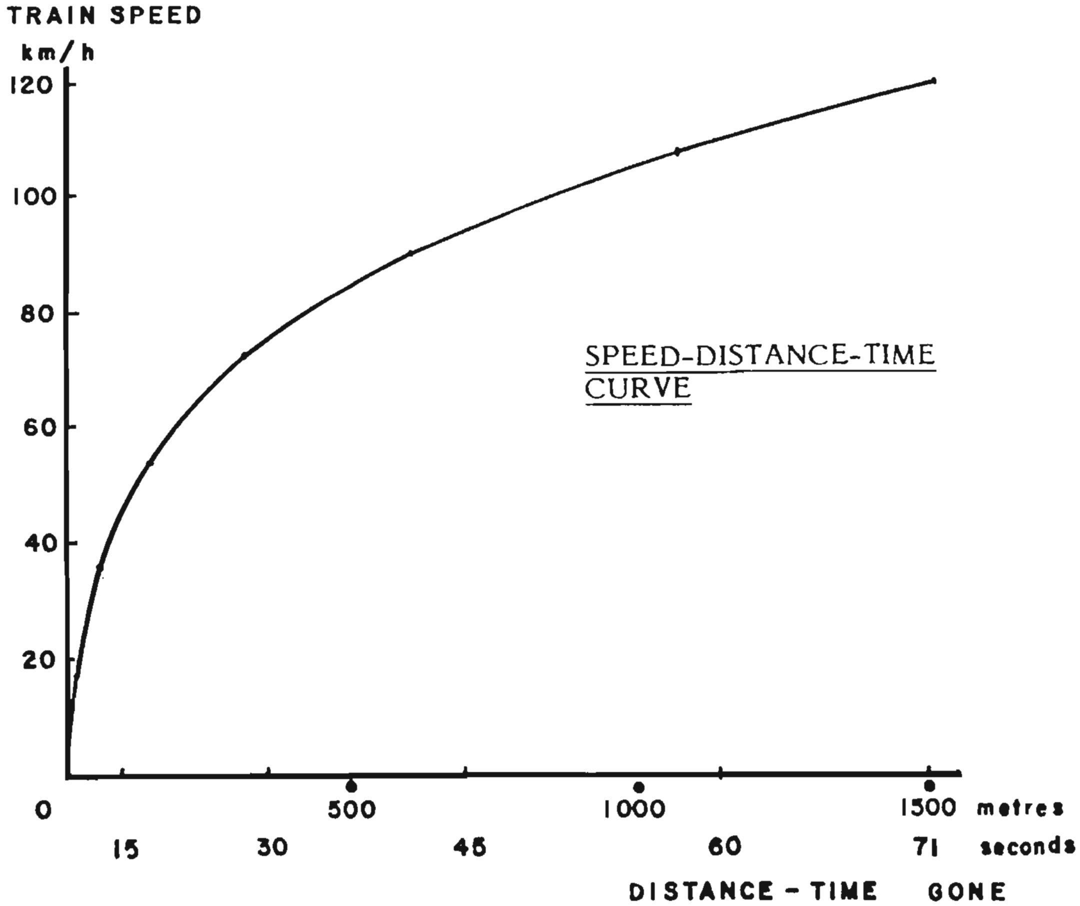
APPENDIX "B"

TRAIN PERFORMANCE DATA

GO-ALRT TRAIN PERFORMANCE

5 VEHICLE TRAIN - 8 AXLE VEHICLES (83-09-29 DATA)
NOMINAL LOAD





A.C. TRACTION MOTOR CASE

ACCELERATION DATA: 28/09/83

*** 4 trucks per 36 m. married pair
*** level tangent track, no headwind

(train mass = 344.25 tonnes ; 5 veh. per train - 166 passengers per vehicle)
(rotational inertia = 18%) ***

vel.	T.E.	R	net T.E. avail.	accel.	avg. accel over int.	interval time	cum. time	interval distance	cum. distance	avg. OUTPUT power	work done	cum. work
m/s	kN	kN	kN	m/s2	m/s2	sec	sec	m	m	kW	kWh	kWh
0	350	6.89	343.11	.84465								
1	350	7.17	342.83	.84396	.84431	1.1844	1.1844	.59220	.59220	175	.05758	.05758
2	350	7.48	342.52	.84320	.84358	1.1854	2.3698	1.7781	2.3703	525	.17287	.23045
3	350	7.82	342.18	.84236	.84278	1.1865	3.5564	2.9664	5.3367	875.00	.28840	.51885
4	350	8.19	341.81	.84145	.84191	1.1878	4.7442	4.1572	9.4939	1225	.40418	.92302
5	350	8.59	341.41	.84047	.84096	1.1891	5.9333	5.3510	14.845	1575	.52024	1.4433
6	350	9.03	340.97	.83938	.83992	1.1906	7.1239	6.5482	21.393	1925	.63663	2.0799
7	350	9.49	340.51	.83825	.83882	1.1922	8.3160	7.7490	29.142	2275	.75338	2.8333
8	350	9.98	340.02	.83704	.83765	1.1938	9.5098	8.9536	38.096	2625	.87049	3.7038
9	350	10.5	339.5	.83576	.83640	1.1956	10.705	10.163	48.258	2975.0	.98803	4.6918
10	350	11.06	338.94	.83439	.83508	1.1975	11.903	11.376	59.635	3325	1.1060	5.7978
11	350	11.64	338.36	.83296	.83367	1.1995	13.102	12.595	72.229	3675	1.2245	7.0223
12	340.28	12.25	328.03	.80752	.82024	1.2192	14.322	14.020	86.250	3969.1	1.3442	8.3665
13	314.10	12.9	301.20	.74149	.77450	1.2911	15.613	16.139	102.39	4089.9	1.4668	9.8333
14	291.67	13.57	278.10	.68460	.71305	1.4024	17.015	18.933	121.32	4088.9	1.5929	11.426
15	272.22	14.27	257.95	.63501	.65981	1.5156	18.531	21.976	143.30	4088.2	1.7211	13.147
16	255.21	15.01	240.20	.59131	.61316	1.6309	20.162	25.279	168.58	4087.6	1.8518	14.999
17	240.20	15.77	224.43	.55248	.57189	1.7486	21.910	28.851	197.43	4087.1	1.9852	16.984
18	226.85	16.57	210.28	.51766	.53507	1.8689	23.779	32.706	230.13	4086.7	2.1216	19.106
19	214.91	17.39	197.52	.48625	.50196	1.9922	25.771	36.856	266.99	4086.3	2.2613	21.367
20	204.17	18.25	185.92	.45768	.47197	2.1188	27.890	41.317	308.31	4086.0	2.4048	23.772
21	194.44	19.13	175.31	.43158	.44463	2.2491	30.139	46.106	354.41	4085.8	2.5525	26.325
22	185.61	20.05	165.56	.40756	.41957	2.3834	32.523	51.243	405.66	4085.5	2.7049	29.029
23	177.54	20.99	156.55	.38532	.39647	2.5223	35.045	56.751	462.41	4085.4	2.8623	31.892
24	170.14	21.97	148.17	.36475	.37507	2.6662	37.711	62.656	525.06	4085.2	3.0255	34.917
25	163.33	22.97	140.36	.34554	.35515	2.8157	40.527	68.985	594.05	4085.0	3.1951	38.112
26	157.05	24.01	133.04	.32751	.33653	2.9715	43.498	75.774	669.82	4084.9	3.3718	41.484
27	151.23	25.07	126.16	.31059	.31905	3.1343	46.633	83.059	752.88	4084.8	3.5564	45.041
28	145.83	26.17	119.66	.29458	.30258	3.3049	49.938	90.884	843.76	4084.7	3.7498	48.790
29	140.80	27.29	113.51	.27944	.28701	3.4842	53.422	99.299	943.06	4084.6	3.9532	52.744
30	136.11	28.45	107.66	.26503	.27224	3.6732	57.095	108.36	1051.4	4084.5	4.1676	56.911
31	131.72	29.64	102.08	.25130	.25817	3.8735	60.968	118.14	1169.6	4084.4	4.3947	61.306
32	127.60	30.85	96.754	.23818	.24474	4.0860	65.054	128.71	1298.3	4084.4	4.6357	65.942
33	123.74	32.1	91.637	.22559	.23189	4.3125	69.367	140.15	1438.4	4084.3	4.8926	70.834
3.333	122.50	32.52	89.981	.22151	.22355	1.4896	70.856	49.405	1487.8	4083.4	1.6896	72.524

COASTING PHASE

29/09/83

*** 4 trucks per 36 m. married pair
*** level tangent track, no headwind

(train mass = 344.25 tonnes ; 5 veh. per train - 166 passengers per vehicle)
(rotational inertia = 18%) ***

vel. m/s	T.E. kN	R kN	net T.E. avail. kN	accel. m/s2	avg. accel over int. m/s2	interval time sec	cum. time sec	interval distance m	cum. distance m
33.333	0	32.52	-32.52	-.0801					
33	0	32.1	-32.1	-.0790	-.0795	4.1866	4.1866	138.86	138.86
32	0	30.85	-30.85	-.0759	-.0775	12.906	17.093	419.44	558.30
31	0	29.64	-29.64	-.0730	-.0745	13.431	30.523	423.07	981.37
30	0	28.45	-28.45	-.0700	-.0715	13.986	44.509	426.56	1407.9
29	0	27.29	-27.29	-.0672	-.0686	14.575	59.084	429.97	1837.9
28	0	26.17	-26.17	-.0644	-.0658	15.197	74.281	433.11	2271.0
27	0	25.07	-25.07	-.0617	-.0631	15.855	90.137	436.02	2707.0
26	0	24.01	-24.01	-.0591	-.0604	16.553	106.69	438.66	3145.7
25	0	22.97	-22.97	-.0565	-.0578	17.293	123.98	440.97	3586.7
24	0	21.97	-21.97	-.0541	-.0553	18.078	142.06	442.91	4029.6
23	0	20.99	-20.99	-.0517	-.0529	18.911	160.97	444.42	4474.0
22	0	20.05	-20.05	-.0494	-.0505	19.796	180.77	445.41	4919.4
21	0	19.13	-19.13	-.0471	-.0482	20.736	201.50	445.82	5365.2
20	0	18.25	-18.25	-.0449	-.0460	21.734	223.24	445.55	5810.8
19	0	17.39	-17.39	-.0428	-.0439	22.795	246.03	444.51	6255.3
18	0	16.57	-16.57	-.0408	-.0418	23.923	269.96	442.58	6697.9
17	0	15.77	-15.77	-.0388	-.0398	25.122	295.08	439.63	7137.5
16	0	15.01	-15.01	-.0370	-.0379	26.395	321.47	435.51	7573.0
15	0	14.27	-14.27	-.0351	-.0360	27.747	349.22	430.08	8003.1
14	0	13.57	-13.57	-.0334	-.0343	29.182	378.40	423.14	8426.2
13	0	12.9	-12.9	-.0318	-.0326	30.692	409.10	414.35	8840.6
12	0	12.25	-12.25	-.0302	-.0310	32.303	441.40	403.79	9244.4
11	0	11.64	-11.64	-.0287	-.0294	34.007	475.41	391.08	9635.5
10	0	11.06	-11.06	-.0272	-.0279	35.790	511.20	375.79	10011.
9	0	10.5	-10.5	-.0258	-.0265	37.682	548.88	357.98	10369.
8	0	9.98	-9.98	-.0246	-.0252	39.669	588.55	337.19	10706.
7	0	9.49	-9.49	-.0234	-.0240	41.727	630.27	312.95	11019.
6	0	9.03	-9.03	-.0222	-.0228	43.868	674.14	285.14	11305.
5	0	8.59	-8.59	-.0211	-.0217	46.108	720.25	253.60	11558.
4	0	8.19	-8.19	-.0202	-.0207	48.417	768.67	217.87	11776.
3	0	7.82	-7.82	-.0193	-.0197	50.745	819.41	177.61	11954.
2	0	7.48	-7.48	-.0184	-.0188	53.100	872.51	132.75	12086.
1	0	7.17	-7.17	-.0177	-.0180	55.456	927.97	83.184	12170.
0	0	6.89	-6.89	-.0170	-.0173	57.783	985.75	28.892	12198.

DECELERATION :

vel. m/s	decel. m/s2	avg.decel over int. m/s2	interval time sec	cum. time sec	interval distance m	cum. distance m
33.333	1					
33	1	1	.333	.333	11.044	11.044
32	1	1	1	1.333	32.5	43.544
31	1	1	1	2.333	31.5	75.044
30	1	1	1	3.333	30.5	105.54
29	1	1	1	4.333	29.5	135.04
28	1	1	1	5.333	28.5	163.54
27	1	1	1	6.333	27.5	191.04
26	1	1	1	7.333	26.5	217.54
25	1	1	1	8.333	25.5	243.04
24	1	1	1	9.333	24.5	267.54
23	1	1	1	10.33	23.5	291.04
22	1	1	1	11.33	22.5	313.54
21	1	1	1	12.33	21.5	335.04
20	1	1	1	13.33	20.5	355.54
19	1	1	1	14.33	19.5	375.04
18	1	1	1	15.33	18.5	393.54
17	1	1	1	16.33	17.5	411.04
16	1	1	1	17.33	16.5	427.54
15	1	1	1	18.33	15.5	443.04
14	1	1	1	19.33	14.5	457.54
13	1	1	1	20.33	13.5	471.04
12	1	1	1	21.33	12.5	483.54
11	1	1	1	22.33	11.5	495.04
10	1	1	1	23.33	10.5	505.54
9	1	1	1	24.33	9.5	515.04
8	1	1	1	25.33	8.5	523.54
7	1	1	1	26.33	7.5	531.04
6	1	1	1	27.33	6.5	537.54
5	1	1	1	28.33	5.5	543.04
4	1	1	1	29.33	4.5	547.54
3	1	1	1	30.33	3.5	551.04
2	1	1	1	31.33	2.5	553.54
1	1	1	1	32.33	1.5	555.04
0	1	1	1	33.33	.5	555.54

D.C. TRACTION MOTOR CASE (lighter vehicle)

Appendix "B"
Page 5

ACCELERATION DATA: 29/09/83

*** 4 trucks per 36 m. married pair
*** level tangent track, no headwind

(train mass = 329.25 tonnes ; 5 veh. per train - 166 passengers per vehicle)
(rotational inertia = 18%) ***

l. /s	T.E. kN	R kN	net T.E. avail. kN	accel. m/s2	avg. accel over int. m/s2	interval time sec	cum. time sec	interval distance m	cum. distance m	avg.OUTPUT power kW	work done kWh	cum. work kWh
0	350	6.59	343.41	.88390								
1	350	6.87	343.13	.88318	.88354	1.1318	1.1318	.56590	.56590	175	.05502	.05502
2	350	7.18	342.82	.88239	.88278	1.1328	2.2646	1.6992	2.2651	525	.16520	.22022
3	350	7.52	342.48	.88151	.88195	1.1339	3.3984	2.8346	5.0997	875.00	.27559	.49580
4	350	7.89	342.11	.88056	.88103	1.1350	4.5335	3.9726	9.0723	1225	.38623	.88203
5	350	8.29	341.71	.87953	.88004	1.1363	5.6698	5.1134	14.186	1575	.49713	1.3792
6	350	8.73	341.27	.87840	.87896	1.1377	6.8075	6.2574	20.443	1925	.60836	1.9875
7	350	9.19	340.81	.87721	.87780	1.1392	7.9467	7.4048	27.848	2275	.71992	2.7074
8	350	9.68	340.32	.87595	.87658	1.1408	9.0875	8.5560	36.404	2625	.83183	3.5393
9	350	10.2	339.8	.87461	.87528	1.1425	10.230	9.7112	46.115	2975	.94414	4.4834
10	350	10.76	339.24	.87317	.87389	1.1443	11.374	10.871	56.986	3325.0	1.0569	5.5403
11	350	11.34	338.66	.87168	.87242	1.1462	12.521	12.035	69.021	3675.0	1.1701	6.7104
12	340.28	11.95	328.33	.84508	.85838	1.1650	13.685	13.397	82.419	3969.1	1.2844	7.9948
13	314.10	12.6	301.50	.77604	.81056	1.2337	14.919	15.421	97.840	4089.9	1.4016	9.3964
14	291.67	13.27	278.40	.71657	.74630	1.3399	16.259	18.089	115.93	4088.9	1.5219	10.918
15	272.22	13.97	258.25	.66472	.69064	1.4479	17.707	20.995	136.92	4088.2	1.6443	12.563
16	255.21	14.71	240.50	.61902	.64187	1.5580	19.265	24.148	161.07	4087.6	1.7690	14.332
17	240.20	15.47	224.73	.57842	.59872	1.6702	20.935	27.559	188.63	4087.1	1.8962	16.228
18	226.85	16.27	210.58	.54202	.56022	1.7850	22.720	31.238	219.87	4086.7	2.0263	18.254
19	214.91	17.09	197.82	.50918	.52560	1.9026	24.623	35.198	255.07	4086.3	2.1596	20.414
20	204.17	17.95	186.22	.47930	.49424	2.0233	26.646	39.455	294.52	4086.0	2.2965	22.710
21	194.44	18.83	175.61	.45201	.46566	2.1475	28.794	44.024	338.55	4085.8	2.4373	25.147
22	185.61	19.75	165.86	.42690	.43946	2.2755	31.069	48.924	387.47	4085.5	2.5824	27.730
23	177.54	20.69	156.85	.40371	.41530	2.4079	33.477	54.177	441.65	4085.4	2.7325	30.462
24	170.14	21.67	148.47	.38214	.39293	2.5450	36.022	59.808	501.45	4085.2	2.8880	33.350
25	163.33	22.67	140.66	.36205	.37210	2.6875	38.710	65.843	567.30	4085.0	3.0495	36.400
26	157.05	23.71	133.34	.34321	.35263	2.8358	41.545	72.314	639.61	4084.9	3.2178	39.618
27	151.23	24.77	126.46	.32551	.33436	2.9908	44.536	79.256	718.87	4084.8	3.3936	43.011
28	145.83	25.87	119.96	.30877	.31714	3.1532	47.689	86.712	805.58	4084.7	3.5777	46.589
29	140.80	26.99	113.81	.29295	.30086	3.3238	51.013	94.728	900.31	4084.6	3.7712	50.360
30	136.11	28.15	107.96	.27788	.28541	3.5037	54.517	103.36	1003.7	4084.5	3.9752	54.335
31	131.72	29.34	102.38	.26352	.27070	3.6941	58.211	112.67	1116.3	4084.4	4.1912	58.527
32	127.60	30.55	97.054	.24981	.25666	3.8962	62.107	122.73	1239.1	4084.4	4.4204	62.947
33	123.74	31.8	91.937	.23664	.24322	4.1115	66.219	133.62	1372.7	4084.3	4.6646	67.612
.333	122.50	32.22	90.281	.23238	.23451	1.4200	67.639	47.097	1419.8	4083.4	1.6107	69.222

APPENDIX "C"

ENERGY CONSUMPTION CALCULATIONS

ENERGY CONSUMPTION

Sample Calculations for Western Section

CASE 1 - 830 Passengers/Train

Acceleration Phase:

(0 to 120 km/h) t = 70.9 sec.
d = 1488 m

work done = 72.5 kWh (output)

Braking Phase:

(120 to 0 km/h) t = 33 sec.
d = 555 m

work done = Ø

- Allowing for an efficiency (transmission line, transformer, power conditioning, traction motors and gearing) of 80%:

Energy consumption (input) during acceleration $= \frac{72.5}{0.8} = 90.6$ kWh

Western Route	Sta. Spacing (km)	t (sec.)	Energy Consumption (kWh) During Accel.	Hotel Power (@ 300 kW/train)	Total (kWh)
Oakville	-	-	-	-	-
Oakville West	4	170+20	90.6	15.8	106.4
Bronte Road	3½	152+20	90.6	14.3	104.9
Appleby	4	170+20	90.6	15.8	106.4
Guelph	5	205+20	90.6	18.8	109.4
Waterdown	5½	225+20	90.6	20.4	111.0
Hwy. 6	3	135+20	90.6	12.9	103.5
Hamilton West	3	135+20	90.6	12.9	103.5
Hamilton	3½	152+20	90.6	14.3	104.9
			West Arm total (kWh)		850.0

Therefore, average energy demand/km $= \frac{850.0}{31.5} = 27.0$ kWh/km.train

CASE 2 - 500 Passengers/Train

Acceleration Phase:

t = 65.9 sec.
d = 1383 m

work done = 67.4 kWh

Braking Phase:

t = 33 sec.
d = 555 m

- Allowing for efficiency of 80%; input energy = 84.3 kWh

..... (continued)

Western Route	Sta. Spacing (km)	t (sec.)	Energy Consumption (kWh) During Accel.	Hotel Power (@ 300 kW/train)	Total (kWh)
Oakville			-	-	-
Oakville West			84.3	15.8	100.1
Bronte Road			84.3	14.3	98.6
Appleby			84.3	15.8	100.1
Guelph			84.3	18.8	103.1
Waterdown	as before		84.3	20.4	104.7
Hwy. 6			84.3	12.9	97.2
Hamilton West			84.3	12.9	97.2
Hamilton			84.3	14.3	98.6
			West Arm Total (kWh)		799.6

Therefore, average energy demand/km = $\frac{799.6}{31.5}$ = 25.4 kWh/km.train

RESULTS

a) Off-Peak Calculations

- (Up to 500 passengers/train)
  140 trips/day x 31.5 km/trip x 25.4 kWh/km = 112.0 MWh/day

b) Peak Hour Calculations

- Loaded (830 passengers/train)
  9 trips/hour x 31.5 km/trip x 27.0 kWh/km = 7.7 MWh/hr.

- Unloaded (up to 500 passengers/train)
  9 trips/hour x 31.5 km/trip x 25.4 kWh/km = 7.2 MWh/hr

Total peak hour = 14.9 MWh/hr

c) Daily Energy Consumption

= 112.0 MWh/day + (14.9 MWh/hr x 2 peak-hour/day)

= 141.8 MWh/day

d) Weekly Energy Consumption

- Weekday: 141.8 MWh/day
- Weekend: 112.0 x $\frac{19}{17}$ = 125.2 MWh/day

Total Weekly Consumption = 5 (141.8) + 2 (125.2)
= 959.4 MWh

d) Annual Consumption

= 52 x 959.4
= 49,889 MWh