DC Traction Power Loadflow Report

D2 - Subway

Dallas, Texas
January 28, 2020

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1 INTRODUCTION

HNTB Corporation was contracted to perform a Traction Power Load Flow study for the DART D2 Subway Project for the purposes of system planning and electrical capacity requirements.

The D2 Subway project is a future second light rail line through downtown Dallas that extends from Victory Park to Deep Ellum. The proposed system is nearly two miles long consisting of four new passenger stations and one relocated station. The associated power system consists of three new traction power substations.

The load flow study is intended to confirm the initial assumptions for new substations along the system and validate the substation ratings. Simulations were conducted at design headways based on the DART D2 between the existing Lucas substation and Fair Park substation for the Green Line, between Lucas substation and Sanders substation for the Orange Line.

This report summarizes the results of the traction power simulation (load flow) study performed and is intended to provide confirmation for the rectifier capacity, substation spacing, operating voltage at the train under normal, and outage conditions, as well as the state fair special event schedule.

2 SYSTEM DESCRIPTION / PHILOSOPHY

The objective of this traction power load flow study is to verify that the proposed infrastructure is adequate to meet the load demands of the 15-minute peak service along the DART D2 Subway alignment, based on the proposed D2 Operating Plans Memorandum (dated October 7, 2019). The vehicle to be used in the study is the new Kinkisharyo SLRV with Toyo Denki propulsion equipment operating at 845VDC.

Based on the configuration of the existing system, which typically utilizes 2.5MW traction power substations spaced approximately 1 mile apart, the approach was to maintain similar spacing and capacity. The expectation was that the simulation results would demonstrate that the three new traction power substations would meet all the operational requirements based on the proposed D2 Subway operating plans. The proposed power system for the new D2 line was essentially a standalone system with the new substations only powering the extension. Under emergencies they could be connected to the existing mainline at each end of the D2 alignment, however this was not as part of the scope of this study.

The operating conditions were to be met under peak 15-minute headways for both the Green and Orange Lines. This requirement was to be maintained for normal conditions (all substations in service) and for contingency circumstances (one substation out of service, and state fair special event service). As this is a new alignment connected to the existing system, six existing traction power substations (Lucas, Arena, Baylor, Fair Park, Portal, Sanders) are included in the model.

Due to the D2 configuration and operations routing trains that previously operated on the mainline which combined Green, Orange, Red, and Blue trains in the main downtown area, using the D2 alignment for the Orange and Green trains alleviates the loading on existing traction power facilities. As a result, these other facilities outside the D2 alignment and the reduction of load on them was not evaluated as this does not impact the D2 alignment substations, their spacing and their ratings.

3 BACKGROUND

DART operates a light rail service over 85 route miles of track. The light rail service consists of four lines as follows:

- Red Line 28 miles (Westmoreland to Parker Road)
- Blue Line 32 miles (Downtown Rowlett to UNT Dallas)
- Green Line 28 miles (North Carrollton/Frankford to Buckner)
- Orange Line 34 miles (DFW Airport to LBJ/Central)

This load flow study models parts of the existing Green and Orange Lines starting at Victory station to Baylor University Medical Center for Green Line, and Cityplace / Uptown for Orange Line. The proposed stations Museum Way, Metro Center, Commerce, and CBD East for the D2 Subway alignment are included in the model.

The D2 alignment is required to alleviate overloading and increase service levels through downtown Dallas to enhance ridership.

4 TASK DESCRIPTION

The loadflow study encompasses the DART D2 Subway traction power system and its interface with the existing DART traction power system.

The study is comprised of three scenarios:

1. Normal Operating Conditions – 15-minute peak headways Green/Orange Lines with all traction power substations in service.

2. Outage Conditions - 15-minute peak headways Green/Orange Lines with one traction power substation out of service at any one time. Train simultaneous starts were also modelled under these conditions with worst case simultaneous train acceleration at the nearest platform to the substation out of service.

3. State Fair Special Event Service – 10-minute peak Green Line headways, 15-minute peak Orange Line headways with all traction power substations in service. This was also modelled with outage conditions.

The existing system parameters and data were determined by as-built information. The physical parameters for the proposed system for the DART D2 Subway alignment were extracted from the proposed track alignment, profile and speed charts. The vehicle information was provided by DART for the Toyo Denki tractive effort curves for the existing and new vehicles.

Electrical parameters for the study are presented in Section 5 below and is based on standard DART power system configurations and equipment.

HNTB has utilized Train Operations Model (TOM) software to perform the DC traction power loadflow study. Train Operations Model (TOM), developed at Carnegie-Mellon University, was used to simulate the LRT system train operations and the power network. The TOM program contains all the necessary computer tools to simulate the operation of the DART system. It contains a train performance simulator and an electric network simulator, and these are used in sequence to model the train operations and performance and then insert these into the electrical traction power network. The simulation, mimicking the everyday light rail operations, makes calculations at every point in the electrical network on a second-by-second basis. The results are selectable and typically provided for train voltage and substation loading although this can be expanded for rail potentials, wire temperatures and energy usage reporting. This program is widely used in the industry and has been verified for accuracy by the supplier. Version 3.8.6 was used.

Each scenario entails building the physical and electrical models and running TOM simulations for the train and system operations described above. The resulting output is obtained, reviewed, analyzed, and checked to ensure the correct results are provided. The output data and assessment is presented in this report.

5 SCOPE OF STUDY

5.1 System Configuration

5.1.1 Track Alignment

The track alignment (stationing and curves) and profile (gradients) are based on the proposed DART D2 Urban Design Package, included in Appendix A. As-built information was utilized to build the model for the existing parts of the alignment.

5.1.2 Traction Power System

The existing system outside of the D2 alignment is a simple catenary system with a messenger supplied at 845VDC via the traction power substations. For the D2 Subway alignment, aluminum conductor rail (OCR) was used for the underground segments in this study, as is often used for tunnel installations on various light rail systems; catenary was used for the areas outside of the tunnel segments. If catenary is proposed for the tunnel segments in lieu of OCR, the minimum voltage is not expected to be infringed. Catenary can be modelled in the tunnel segments in due course if requested. The merits of OCR versus a catenary system are beyond the scope of this load flow report.

The main elements of the positive network are:

- the AC incoming utility services
- the traction power substations which convert the AC to DC power for traction (rectifier and rectifier-transformer)
- the positive traction power feeder cables
- the overhead catenary system

The negative network comprises the

- running rails
- negative return cables

The electrical network parameters are shown on the next page in Table 1.

Description	Value
Contact Wire Size	350 kcmil HD Cu trolley wire (20% worn) + 500 kcmil messenger wire, 75 deg C
Conductor Rail	Aluminum Conductor Rail, 75 deg C
Positive Feeder Cable Size	(3) 750 kcmil Cu per power section Nominal length assumed to be 500ft
Negative Return Cable Size	(6) 750 kcmil Cu (per track) Nominal length assumed to be 500ft
Rail Type	115lb (both rails used for negative return)
Conductor Temperature	75 deg C
Rail Temperature	40 deg C, no wear
TPSS Power Rating	2500 kW (Heavy Traction Power Duty per IEEE 1653.2) ANSI Circuit #31 configuration, 12 pulse Thyristor Controlled Rectifier *** To provide worst case results the rectifiers have been modelled in TOM as uncontrolled diode rectifiers ***
TPSS Regulation	4.5 %
Full Load (Nominal) Voltage	845 VDC

Table 1. Electrical Network Parameters

The loadflow simulation utilizes a common milepost for each train along its route. The mileposts used are based on the starting milepost (MP -1.688) being at existing Lucas Substation and continuing to Fair Park Substation for the Green Line (MP 3.068), and Sanders Substation for the Orange Line (MP 3.558). For the milepost locations, as translated for the system refer to the system CAD drawings in Appendix B.

The station and substation locations are shown on the next page in Table 2. The station and substation locations are also represented in the CAD drawings of the electrical model. Refer to Appendix B for the CAD drawings of the electrical model. Refer to Appendix C for a track schematic of the DART D2 Subway alignment.

Station / Traction Power Substation (TPSS)	Approx. STA	Track Reference	Model MP
Lucas TPSS	213+05	NW1	-1.688
Market Center	195+60	NW1	-1.356
Arena TPSS	150+00	NW1	-0.494
Victory	127+46	NW1	-0.067
New 1 TPSS (Proposed)	14+75	CBD2	0.090
Museum Way	30+20	CBD2	0.382
Metro Center	51+95	CBD2	0.067
New 2 TPSS (Proposed)	61+30	CBD2	0.972
Commerce	71+90	CBD2	1.172
CBD East	95+65	CBD2	1.622
New 3 TPSS (Proposed)	107+70	CBD2	1.850
Baylor TPSS – Green Line	139+97	SE1	2.270
Baylor University Medical Center – Green Line	144+22	SE1	2.351
Fair Park TPSS – Green Line	182+05	SE1	3.068
Live Oak – Orange Line	114+90	SE1	2.031
Portal TPSS – Orange Line	182+85	NC1	2.421
Cityplace / Uptown – Orange Line	237+88	NC1	3.463
Sanders TPSS – Orange Line	242+90	NC1	3.558

Table 2. Station and Substation Locations

5.2 Vehicle Data

The simulation uses the new Kinkisharyo SLRV vehicle with Toyo Denki propulsion equipment. The vehicle operates at 845 VDC nominal voltage. A summary of vehicle parameters is shown below in Table 3. All vehicle data is included in Appendix D. Each train comprises three cars.

Description	Value
Simulation Model Weight	(AW2) 172,648 lbs
Approx. Peak Line Current	2000 A
Auxiliary Power	83kW (continuous)
Regeneration	Off
Maximum Speed	65 mph
Minimum Voltage	525 VDC
Vehicle Design Voltage	750 VDC
Nominal Operating Voltage	845 VDC

Table 3. Kinkisharyo SLRV Vehicle Parameters

On the electrical side of the vehicle, the cars are assumed to operate at full power at 845VDC with a peak line current of approximately 2000A per car. The line current will vary with the voltage delivered to the pantograph of the vehicle. Auxiliary power per car is 83kW. As is consistent with traction power studies, this auxiliary load is assumed to be on at all times.

The Kinkisharyo SLRV vehicles with Toyo Denki propulsion equipment are designed to operate with a full load line voltage range of 845VDC with occasional swings due to unusual load demands to as low as 525VDC and as high as 900VDC. Therefore, per the design criteria, the voltage used in the analysis for the voltage at the train below which "dropout" of the propulsion system will occur is 525 Volts.

For the purposes of the study, the trains have not been modeled to regenerate current.

5.3 Load Flow Simulations

In order to provide an evaluation of the relevant service levels and in accordance with the proposed DART D2 Subway operating plans, the following scenarios were selected to be modeled. A 30 second station dwell time was used in TOM to determine electrical loading on the system. Three cars trains were operated on both lines.

5.3.1 Scenarios

1. Normal Operating Conditions – 15-minute peak headways Green/Orange Lines with all traction power substations in service.

2. Outage Conditions - 15-minute peak headways Green/Orange Lines with one traction power substation out of service at a time. A simulation is run for each new substation out of service.

    a. Normal operating schedule

    b. Schedule configured for simultaneous train starts at the nearest platform to the substation out of service. To simulate simultaneous starts, two additional Green Line trains are added at a specific time (varies for each substation outage) for each substation outage to create a worst case scenario near the substation that is out of service. See Table 4 on the next page for a summary of simultaneous start locations.

Outage Condition	Platform where Simultaneous Start Occurs	Distance from New 1 TPSS	Distance from New 2 TPSS	Distance from New 3 TPSS
New 1 TPSS Out [STA. 14+75, CBD2]	Victory [STA.127+46, NW1]	N/A	5,480 ft	10,120 ft
New 2 TPSS Out [STA. 61+30, CBD2]	Commerce [STA.71+90, CBD2]	5,710 ft	N/A	4,640 ft
New 3 TPSS Out [STA. 107+70, CBD2]	CBD East [STA. 95+65, CBD2]	8,090 ft	3,430 ft	N/A

Table 4. Simultaneous Start Locations

3. State Fair Special Event Service – 10-minute peak Green Line headways, 15-minute peak Orange Line headways with all traction power substations in service. This was also modelled with outage conditions (one traction power substation out of service at a time).

5.3.2 Other Parameters Applicable to the Simulation

- Propulsion systems are modeled using a constant-current model (propulsion current does not vary significantly with variations in line voltage but varies based on mechanical energy required to move and accelerate trains).
- No stored trains were included along the D2 alignment.

5.3.3 Substations and Outages

The normal operations scenario is modeled with all equipment in service and operating to schedule. All traction power equipment is assumed to be operational and providing power to the system as originally intended.

The outage operations scenario is modeled with one substation out of service and operating to schedule. All traction power equipment at in-service substations is assumed to be operational and providing power to the system as originally intended. As part of the outage scenarios, worst case conditions are modelled by performing simultaneous starts at the platform nearest to the substation that is out of service.

The main power equipment installed on the D2 Subway traction power substations are as follows. Each substation is configured to have a 13.2kV in-feed and produce 845V dc at 100% load. Each rectifier-transformer set comprises of a thyristor-controlled rectifier configured in an ANSI #31 configuration. An output regulation of 4.5% for the rectifier-transformers has been used at all locations. For the purposes of this simulation, the rectifiers were modelled as standard uncontrolled diode rectifiers instead of thyristor-controlled rectifiers to provide worse case (voltage drop) results. The new traction power substations are summarized below in Table 5.

DART D2 Subway – New Traction Power Substations		
Model Name	**TPSS Name**	**Substation Capacity**
TPSS New 1	Name TBD	1 – 2.5 MW
TPSS New 2	Name TBD	1 – 2.5 MW
TPSS New 3	Name TBD	1 – 2.5 MW

Table 5. DART D2 Subway - New Traction Power Substations

5.3.4 DC Feeder Cables

For the purposes of the simulation study, a standard feeder cable length of 500ft has been used. This will vary depending on the actual TPSS sites used. Each feeder circuit to each section (north and south of the substation per track) is via (3) 750 kcmil. As a conservative approach, the resistance used for each cable is for a 75 deg C continuous operating temperature.

The OCS is comprised of 500 kcmil hard drawn copper messenger wire and 350 kcmil hard drawn copper trolley wire (20% worn), per track. This is conservative as it is very unlikely that a system will reach 20% worn throughout the system but allows for spot areas of increased wear while maintaining system requirements. The resistance used for each cable is for a 75 deg C continuous operating temperature. Aluminum conductor rail is used in areas within the tunnel. Within the TOM model all conductors have been included as a conductor, or set of conductors, in parallel with the OCS and the calculations have been performed to treat each configuration as one equivalent conductor between the nodes within the model. The cable and OCS layout can be seen in the electrical model CAD drawings in Appendix B.

5.3.5 Negative Return Cabling

The negative return system uses the following assumptions.

- The running rails are 115lb steel rails.
- The traction power negative return circuit has been modeled to comprise 2-115lb running rail per track and is configured as one equivalent conductor. Negative return connections are made at the substation sites.

The negative return connections can be seen in the system electrical models in Appendix B.

6 INITIAL DISCUSSIONS & OBSERVATIONS

6.1 DC Cable Current Capacity

While not part of this scope of work, HNTB has previously performed a cable capacity analysis to determine realistic capacities and ratings for the DC cables installed in similar condition to that on the DART D2 Subway Project.

The results of previous the cable capacity calculations for the 750 kcmil cables used yielded cable capacity ratings of 420 amps per cable or 1,260 A for the three 750 kcmil cables/conduit configuration for a 90 degrees C steady state condition. There are three 750 kcmil cables per power section, for a total of six 750 kcmil cables per track.

It should be noted that ductbank configurations and fill will vary throughout the power system therefore, the conservative approach adopted as described in the use of parameters above, is appropriate.

7 SIMULATION RESULTS

7.1 Simulation Software

The TOM software employs a highly efficient electrical network simulator capable of solving very large traction power electrical network models. These network, positive and negative, are represented in the model by an assembly of "branches" and "nodes", which are used to model individual or combined pieces of equipment. A branch is any conductor (wire, cable, bus bar, third rail, running rail, etc.) that can be modeled as a linear resistance, and a node is simply one end point of a branch. Parallel conductors can be explicitly modeled as separate branches, if desired, or combined into equivalent conductors. Rectifiers are modeled as branches with a variable resistance which increases with high forward load current in a manner specified by the user. The alternating current (AC) side of the rectifiers are modeled as Thevenin equivalents of the connected AC power sources (the electric utility). Any conceivable configuration of electrical equipment can be efficiently simulated to the desired degree of detail, due to advanced solution and memory management techniques incorporated into the software.

The Traction Power Load Flow program performs a time-based simulation of a traction power system. This involves the selection by the user of a time period over which the simulation will occur, plus the scheduling of the desired vehicle or train dispatches during this period. During the simulation time period, the TOM program moves scheduled trains, based on the Train Performance Simulator (TPS) module output, along their respective routes according to the train movement simulation information contained in the appropriate power profiles. Via the Electric Network Simulator (ENS) module, at regular user-selected time intervals (typically, every second), new network nodes are created for each vehicle or train at their proper location on the power system and a network solution ("snapshot") is performed. Depending on whether a voltage-dependent train model is selected by the user or if the train is regenerating current into the system, further network solutions may be performed to arrive at a solution based on an adjusted vehicle or train load. Results from each "snapshot" are written to various output data files for review and further processing using either commercial spreadsheet programs or within TOM's own graphical features. Information derived from each snapshot is also stored and managed internally to produce a comprehensive summary report file at the end of the simulation.

7.2 Summary

7.2.1 General / Criteria

As described above each scenario has been simulated under scheduled service conditions. Each has been analyzed and the results described on the following page.

For each scenario, Voltage at the train is presented in graphical form. Rectifier/Transformer capacity and cable loading are present in tables.

For the voltage plots, the critical voltage of 525V dc is used to determine if the proposed operating scenario will result in the vehicles stalling and losing power. Long cable lengths, long section lengths, long distances between substations and feed points all increase the electrical resistance of the circuits resulting in voltage drop. These drops increase as the traction power load increases. 845VDC is also shown on the voltage as the nominal voltage for normal operations.

For the Rectifier-Transformer capacity the 100% load capability is used. E.g. a 2.5MW rectifier supplying power at 845V will be able to provide 2959A continuously. In addition, the traction power transformers and rectifiers are heavy traction power duty rated which allows this equipment to supply 150% of full loads for 2 hours and 300% load for 5 minutes intervals.

The feeder cable loads have not been reported as part of this study but based on the RMS currents at each substation node, no cable overloading is expected. One value in particular is focused on i.e. rms loading during the simulation time period. The rms (root mean square) load is used and compared against the 100% current carrying capacity of the cables at the maximum allowed temperature (90 deg C). Cables do have emergency ratings for 130 degrees C and 250 degrees C but these are very seldom encountered or calculated, but these are short duration values and will lead to loss of equipment service life.

The rail potential has not been analyzed as part of this study.

7.2.2 Summary of Results

The results can be found in Appendices E, F, G, and H. Appendices E, F, and G present voltage profiles for the model system between existing Lucas substation and Fair Park substation for the Green Line, and between existing Lucas substation and Sanders substation for the Orange Line. Appendix H presents rectifier capacity and loading.

7.2.3 Train Voltages

The important criteria are shown in the summary results tables and voltage plots provided in the Appendices of this report. A summary of the lowest voltage per scenario is provided in Table 6 below. Trains are operated a full performance for all scenarios. A heavy gradient and speed change at the edge D2 limits cause a similar minimum voltage under all scenarios, so a minimum voltage within the trunk section is also provided. State Fair Special Event minimum voltages are provided for outage conditions but is assumed that all substations would be in service during these conditions.

SUMMARY OF MINIMUM VOLTAGES

Scenarios and Substation Status:	**Min. Train Voltage [Milepost]**	**Trunk Min Voltage [Milepost]**
Normal Operations:		
All Substations in Service	678 [-1.234]	780 [0.52]
Outage Operations:		
New 1 TPSS Out of Service	676 [-1.234]	700 [-0.17]
New 2 TPSS Out of Service	678 [-1.234]	685 [0.75]
New 3 TPSS Out of Service	678 [-1.234]	775 [0.55]
Simultaneous Start Operations:		
New 1 TPSS Out of Service	676 [-1.234]	700 [-0.17]
New 2 TPSS Out of Service	678 [-1.234]	678 [0.75]
New 3 TPSS Out of Service	678 [-1.234]	775 [0.55]
State Fair Special Event Operations:		
All Substations in Service	636 [-0.908]	700 [0.52]
New 1 TPSS Out of Service	393.8 [-0.166] (see below)	600 [0.4]
New 2 TPSS Out of Service	335.8 [0.737] (see below)	520 [0.6]
New 3 TPSS Out of Service	636.6 [-0.908]	690 [0.55]

Table 6. Summary of Minimum Voltages

As can be seen in Table 6, the 525V criteria is not infringed for any normal, outage or simultaneous start operating scenarios.

The 525V criteria is infringed during the state fair special event operations when New 2 TPSS or New 3 TPSS are out of service. If one of these outage conditions are present at the time of the state fair, then alternate operational requirements will be required. Further assessment can be considered such as electrically tie-ing into the mainline or operating as controlled rectifiers to establish if minimum operating voltages can be met.

7.2.4 Rectifier Loading

The Table 7 below and Table 8 on the following page summarize the rectifier loading currents observed for each scenario. In all cases the rectifier loading is within the equipment capacity.

Under normal operation the maximum rms load any rectifier does not exceed 31.5%.

Under the substation outages, the maximum loading is 39.95% at existing Arena TPSS.

Under the substation outages with simultaneous starts, the maximum loading is 45.43% at existing Arena TPSS.

Under the State Fair Special Event conditions with all TPSS in service, the maximum loading is 40.29% at existing Arena TPSS.

Computer Loadflow Simulation Study for DART D2 Subway Project										
Substation Rectifier Loading Results										
All Substations in Service										
Normal Scenario										
			Simulated Load Current		Rectifier Load Ratings			Rectifier Loading Analysis		
		Substation	(Col. 1)	(Col. 2)			1 Min.	Rms Loading Results (1)		Peak Loading (2)
		Rectifier	RMS	Peak	Continuous	2-Hr NEMA	NEMA	% of Contin.	% of 2-Hr	% of 1 Min.
Substation		Capacity	(Continuous)	(Instantaneous)	Ratings	Ratings	Ratings	Rectifier	Rectifier	Rectifier
Name	MP	(kW)	Amps	Amps	(Amps)	(Amps)	(Amps)	Rating	Rating	Rating
E1 - LUCAS	-1.688	2500	803	3,552	2,959	4,438	8,876	27.1	18.1	40.0
E2 - ARENA	-0.494	2500	912	2,364	2,959	4,438	8,876	30.8	20.5	26.6
N1 - NEW 1	0.090	2500	767	2,574	2,959	4,438	8,876	25.9	17.3	29.0
N2 - NEW 2	0.972	2500	933	3,180	2,959	4,438	8,876	31.5	21.0	35.8
N3 - NEW 3	1.850	2500	654	2,112	2,959	4,438	8,876	22.1	14.7	23.8
E3 - PORTAL	2.421	2500	622	2,784	2,959	4,438	8,876	21.0	14.0	31.4
E4 - SANDERS	3.558	2500	719	4,200	2,959	4,438	8,876	24.3	16.2	47.3
E5 - BAYLOR	2.270	2500	462	2,436	2,959	4,438	8,876	15.6	10.4	27.5
E6 - FAIR PARK	3.068	2500	145	821	2,959	4,438	8,876	4.9	3.3	9.3

Table 7. Rectifier Loading for Normal Conditions

Computer Loadflow Simulation Study for DART D2 Subway Project
Substation Rectifier Loading Results
Substations Out Of Service As Indicated - State Fair Schedule Included
SS indicates emergency simultaneous start case

Substation Name	MP	Substation Rectifier Capacity: Total Rectifier Capacity (kW)	100% Continuous Rating (Amps)	2-Hr NEMA RI-9 Rating (Amps)	Rectifier RMS Load Current with Indicated Substation Out Of Service: System Normal	OUT1 N1 - NEW 1	OUT2 N2 - NEW 2	OUT3 N3 - NEW 3	OUT4 / SS N1 - NEW 1	OUT5 / SS N2 - NEW 2	OUT6 / SS N3 - NEW 3	State Fair Schedule
E1 - LUCAS	-1.688	2500	2,959	4,438	803	837	811	806	997	895	2,081	939
		% of Continuous Rectifier Capacity Used			27.14%	28.30%	27.41%	27.23%	33.69%	30.25%	70.33%	31.75%
E2 - ARENA	-0.494	2500	2,959	4,438	912	1,182	973	929	1,344	1,080	1,518	1,192
		% of Continuous Rectifier Capacity Used			30.82%	39.95%	32.89%	31.39%	45.43%	36.50%	51.30%	40.29%
N1 - NEW 1	0.090	2500	2,959	4,438	767		1,033	831		1,196	914	971
		% of Continuous Rectifier Capacity Used			25.93%		34.91%	28.07%		40.42%	30.88%	32.83%
N2 - NEW 2	0.972	2500	2,959	4,438	933	1,180		1,124	1,326		1,205	1,171
		% of Continuous Rectifier Capacity Used			31.54%	39.88%		38.00%	44.83%		40.73%	39.57%
N3 - NEW 3	1.850	2500	2,959	4,438	654	758	985		853	1,217		810
		% of Continuous Rectifier Capacity Used			22.10%	25.62%	33.30%		28.84%	41.15%		27.38%
E3 - PORTAL	2.421	2500	2,959	4,438	622	647	697	725	664	769	722	651
		% of Continuous Rectifier Capacity Used			21.02%	21.88%	23.56%	24.50%	22.45%	25.98%	24.41%	22.01%
E4 - SANDERS	3.558	2500	2,959	4,438	719	722	727	729	723	737	634	723
		% of Continuous Rectifier Capacity Used			24.31%	24.42%	24.56%	24.65%	24.44%	24.90%	21.41%	24.44%
E5 - BAYLOR	2.270	2500	2,959	4,438	462	490	554	600	542	656	632	582
		% of Continuous Rectifier Capacity Used			15.62%	16.57%	18.74%	20.27%	18.31%	22.18%	21.34%	19.66%
E6 - FAIR PARK	3.068	2500	2,959	4,438	145	153	170	183	167	199	192	182
		% of Continuous Rectifier Capacity Used			4.89%	5.15%	5.75%	6.18%	5.64%	6.73%	6.49%	6.17%

Table 8. Rectifier Loading for Special Conditions

8 CONCLUSION

As applies to all simulations, it is very difficult to exactly match the actual system operations for a multitude of reasons. However, the simulations are intended to be pessimistic in their approach and the results obtained may or may not in practice occur during day-to-day operations. As a result, the DC traction power simulation has been performed under multiple scenarios. These scenarios and results for the expected future operations are used to confirm if the traction power system as per the model simulated is suitable to maintain reliable operations.

As is seen in the results, the voltages do not fall below the minimum level of 525VDC under expected operating conditions.

The rectifier loading is not exceeded for any new DART D2 Subway traction power substations.

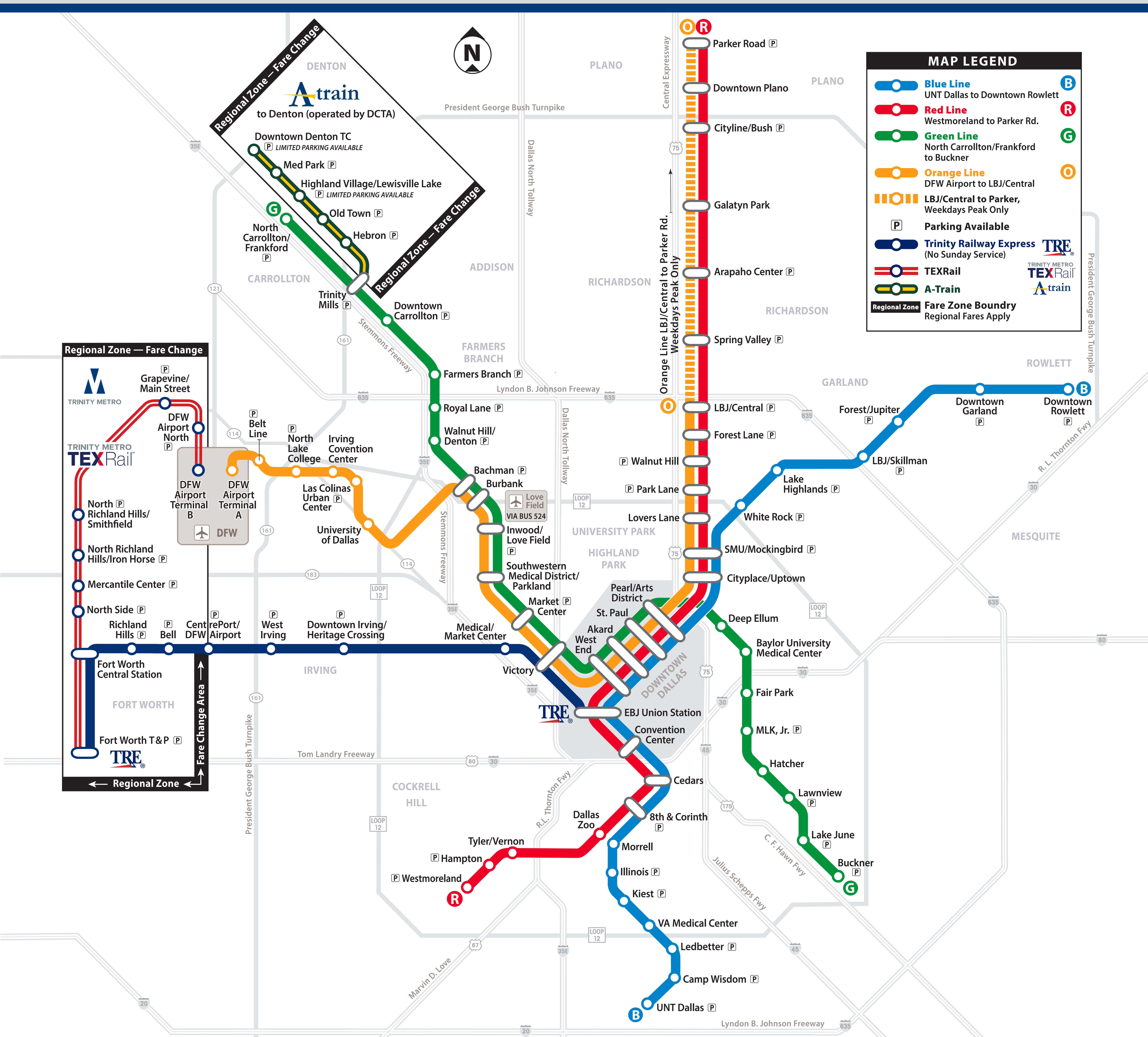
The system as modeled with three new 2.5MW traction power substations is adequate to meet the demands of the DART D2 Subway Project for the conditions, electrical system, and scenarios simulated.

Appendix A – DART System Information

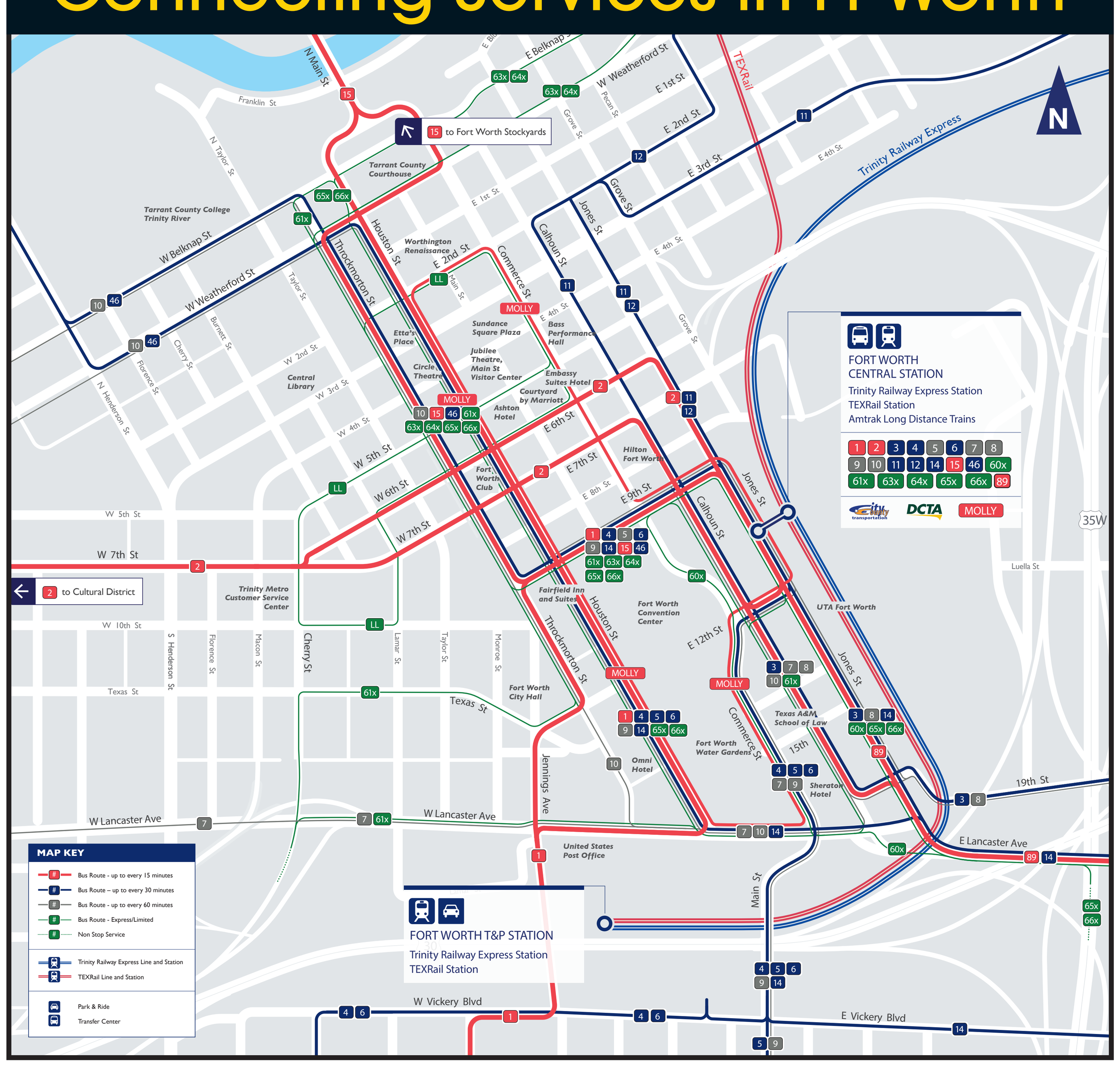
Rail System Map

DART/TRE/TEXRail/DCTA

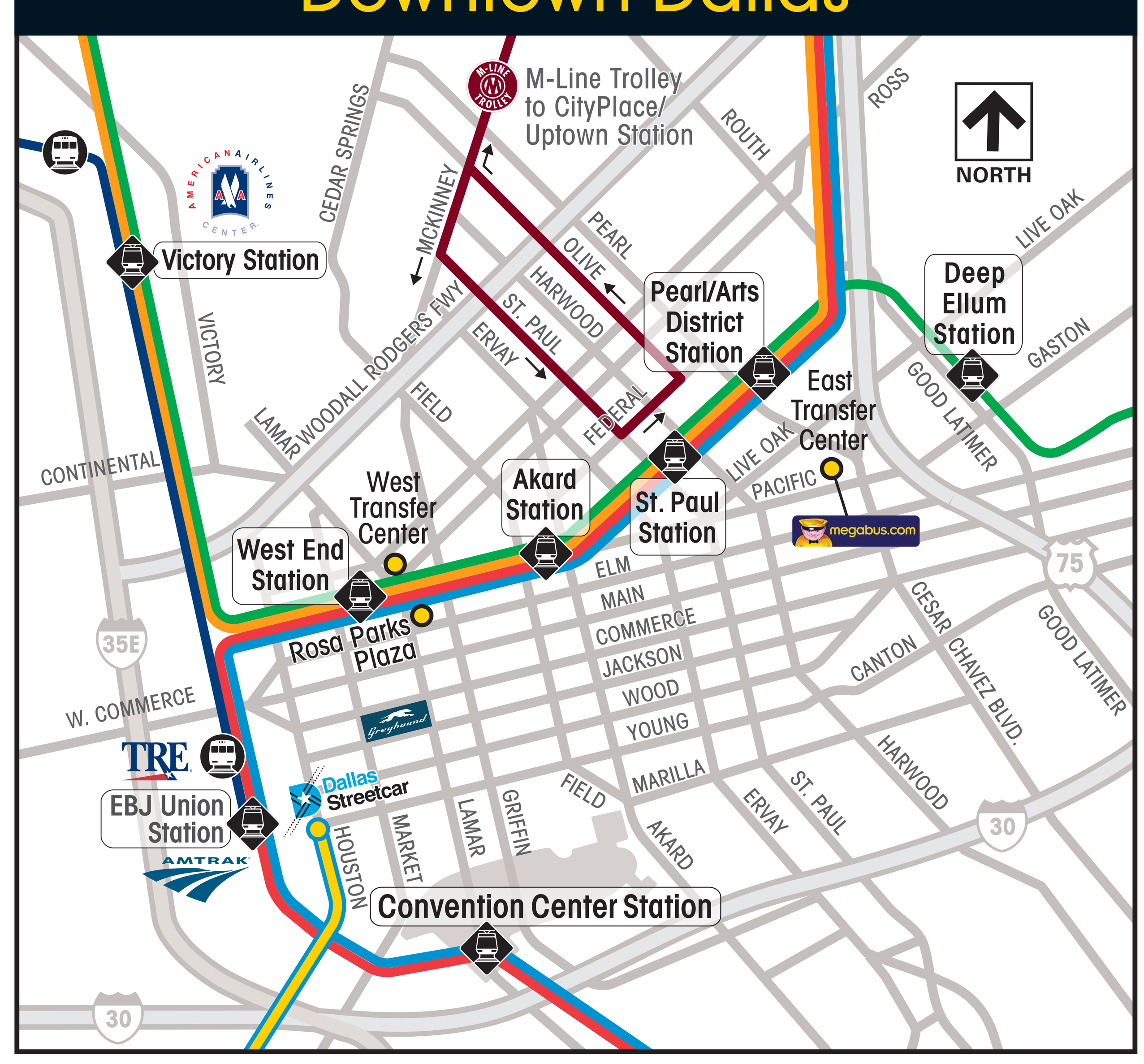
Effective: August 12, 2019



Connecting Services in Ft Worth



Downtown Dallas



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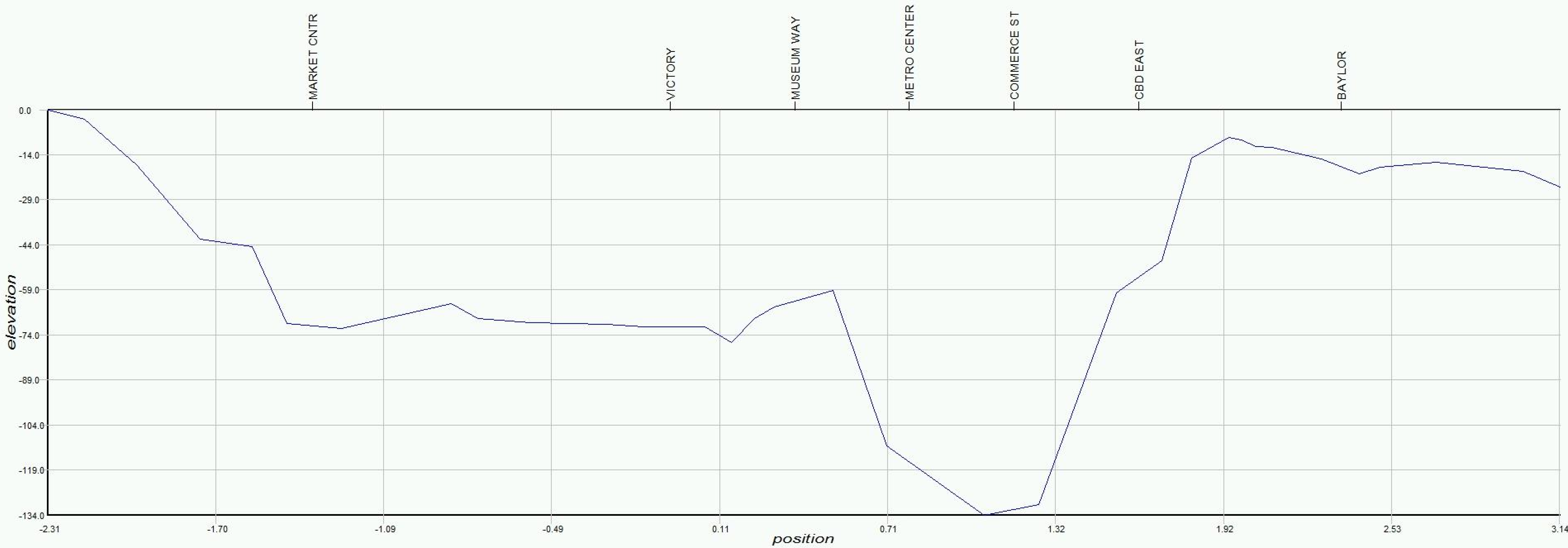
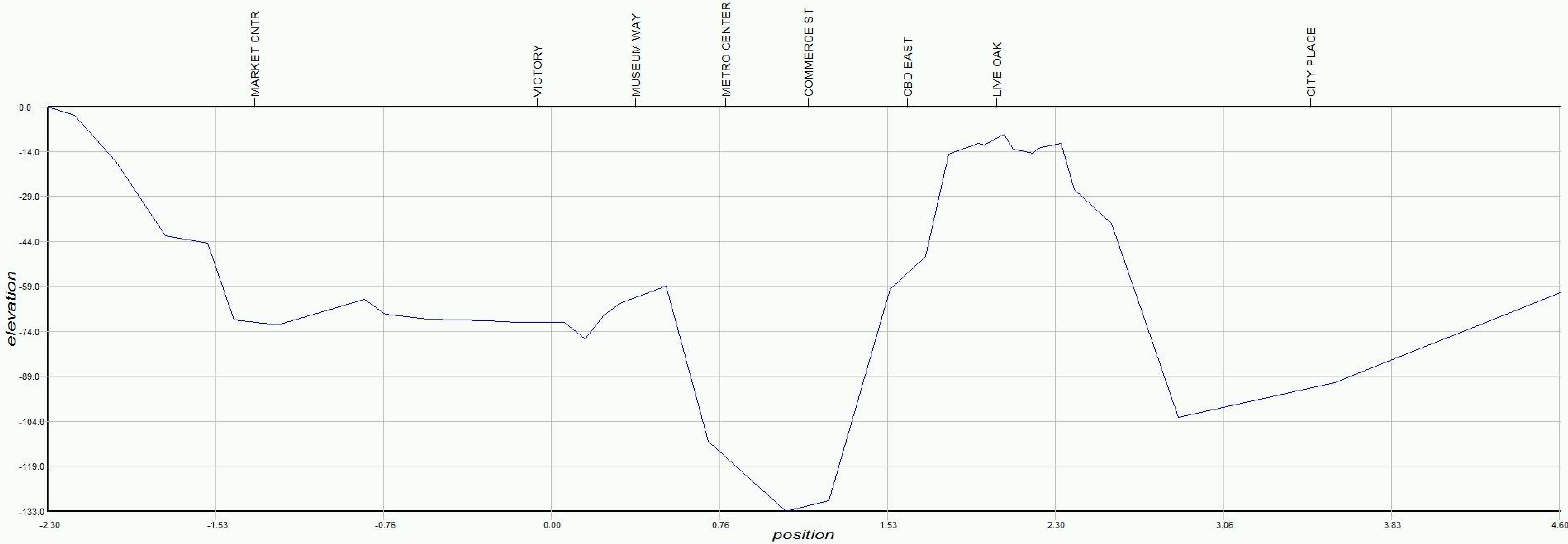
Elv File: C:\tom\tomdat\drt\EL-GNN.drt
Stn File: C:\tom\tomdat\drt\ST-GNN.drt

ELEVATION Greenline Northbound



ELEVATION Orangeline Northbound (clockwise)



Memo

Date:	Monday, October 07, 2019
Project:	GPC6 Task Order 39: D2 Subway Project Development Services
To:	Kay Shelton, DART Ernie Martinez, DART Tom Shelton, HDR
From:	Susan Rosales, Connetics Transportation Group
Subject:	D2 Operating Plans – DISCUSSION DRAFT

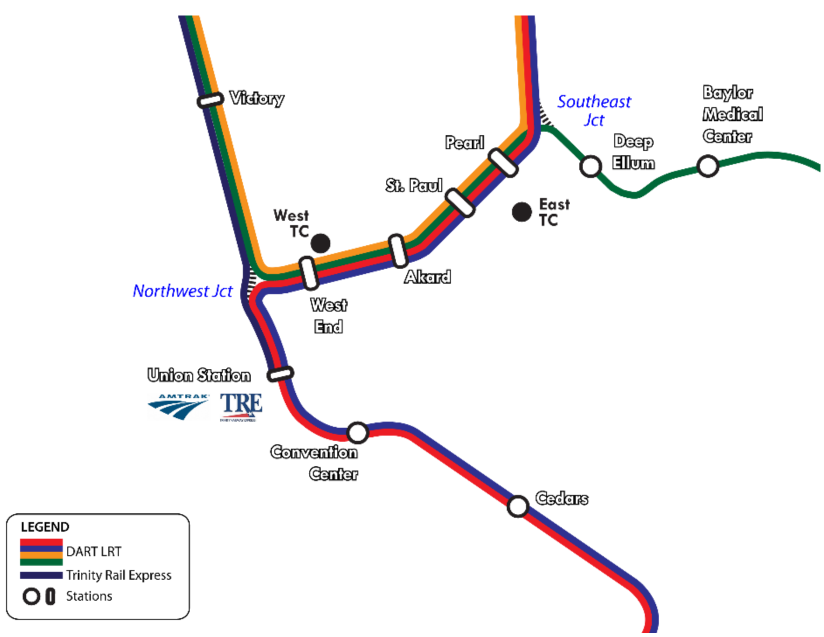
The purpose of this Technical Memorandum is to describe DART's LRT operating plan incorporating the D2 alignment for the following scenarios:

1. Routine Operations
2. Special Event State Fair Service
3. Incident Management

Routine Operations

Currently, DART operates four light rail transit (LRT) lines. Each line generally offers 15 minute peak period service frequencies and 20 minute midday and evening service frequencies on weekdays. On weekends, service frequencies are 20 minutes, tapering to 30 minutes in the evenings. All four LRT lines currently converge on the transit mall in downtown Dallas, as shown in **Figure 1.**

Figure 1. *Existing DART Light Rail Transit Configuration in Downtown Dallas*



The D2 alignment will be used by DART's Orange Line and Green Line, whereas DART's Red Line and Blue Line will remain on the transit mall in downtown Dallas, as shown in **Figure 2**. This frees up capacity on the transit mall, allowing additional Red Line service to be added during the peak hour to address core capacity. Endpoints for each of the four lines will remain the same as existing service, as summarized in **Table 1** and **Figure 3**. The D2 project incorporates full wye movements at the Deep Ellum Junction as well as the Southeast Junction, allowing operational flexibility for interaction between the lines.

Figure 2. *DART Light Rail Transit Configuration with D2 Alignment*

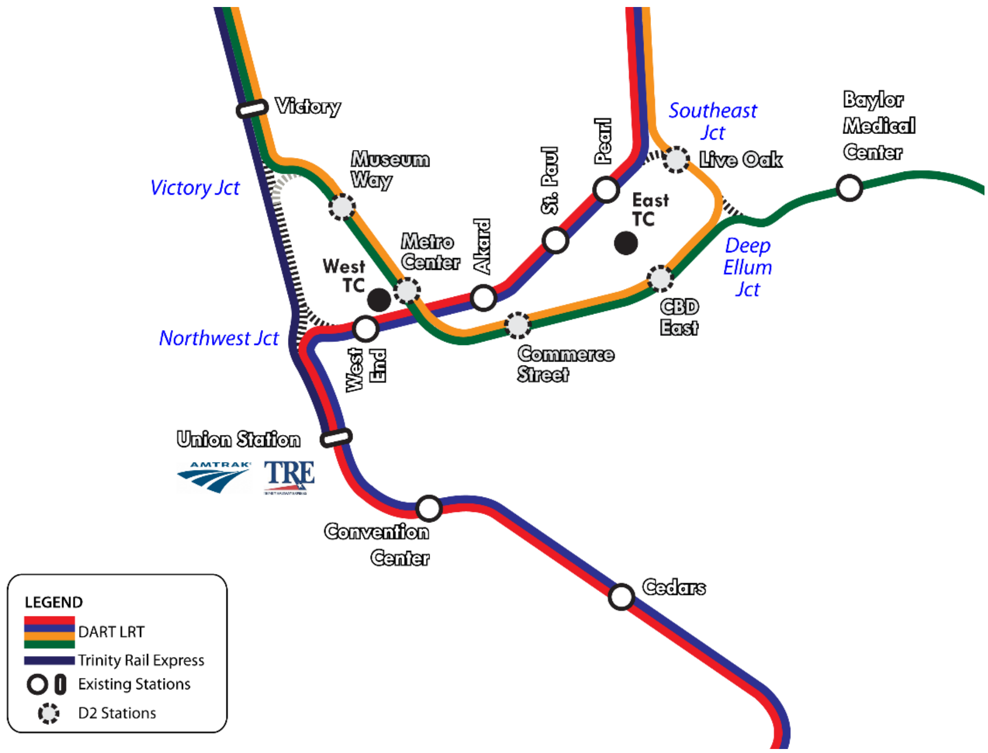


Table 1. *DART Light Rail Transit Lines*

LRT Line	Downtown Alignment	From	To
Red Line	Transit Mall	Parker Road	Westmoreland
Blue Line	Transit Mall	Downtown Rowlett	UNT Dallas
Green Line	D2	North Carrollton/Frankford	Buckner
Orange Line	D2	DFW Airport Terminal A	Parker Road (weekday peak) or LBJ Central (all other times)

Figure 3. *DART Light Rail Transit System with D2*

Each line's span of service and service frequencies are presented in **Table 2**, and the resulting operating plan is schematically illustrated in **Figure 4**.

Table 2. *DART Light Rail Transit Span and Service Frequency by Line*

LRT Line	Weekday		Weekend	
	Span	Service Frequencies	Span	Service Frequencies
Red Line	4am – 2am	15 minute peak*; 20 minute midday and evening	3:15am – 2am	20 minute base; 30 minute early morning and evening
Blue Line	3:30am – 2am	15 minute peak; 20 minute midday and evening	3:30am – 2am	20 minute base; 30 minute early morning and evening
Green Line	3:15am – 1:45am	15 minute peak; 20 minute midday and evening	3:45am – 1:45am	20 minute base; 30 minute early morning and evening
Orange Line	2:45am – 2am	15 minute peak; 20 minute midday and evening	2:45am – 2am	20 minute base; 30 minute early morning and evening

*Plus one added insert train from Parker Road to Cedars Station during heaviest peak hour

Station-to-station travel times were estimated for the D2 alignment, accounting for speed limitations introduced by curves and station placement. This geometric data is used in tandem with vehicle acceleration and deceleration rates to provide vehicle travel times between stations along the D2 segment. Because these stations serve central Dallas, a dwell time of 30 seconds per station was assumed.

Table 3 and **Table 4** provide resulting travel times. For the Green Line, the D2 alignment is about 0.13 miles shorter and saves about 2.8 minutes compared to the transit mall. For the Orange Line, the D2 alignment adds about 0.4 miles and adds about 1.2 minutes compared to the transit mall.

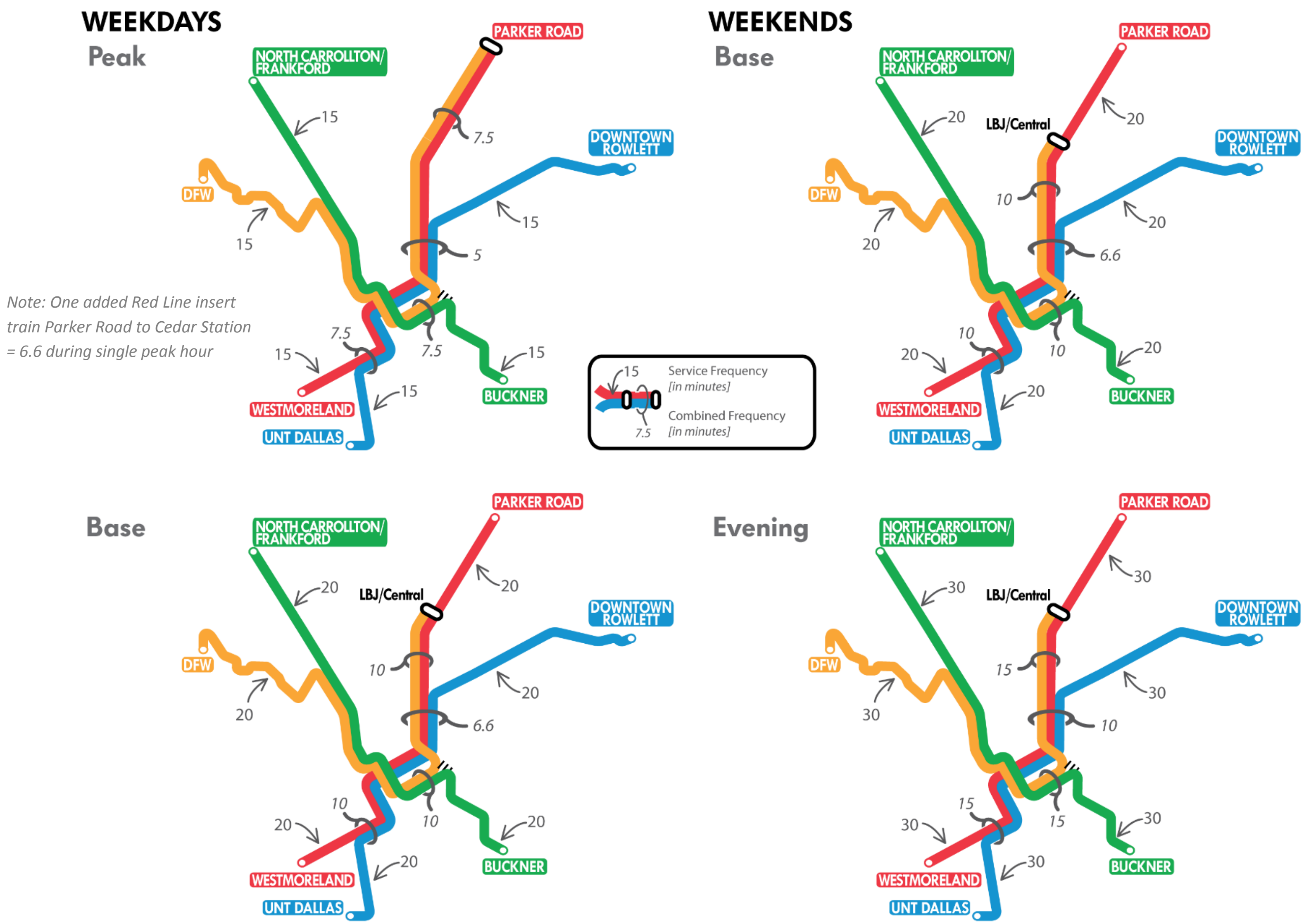
Table 3. *D2 Green Line Travel Times between Victory Station and Baylor UMC Station*

Begin Station	End Station	Distance	Travel Time	Dwell Time	Total Time	Avg. Speed
VICTORY STATION	MUSEUM WAY STATION	0.45	0:02:05	0:00:30	0:02:35	12.8
MUSEUM WAY STATION	METRO CENTER STATION	0.42	0:01:07	0:00:30	0:01:37	22.4
METRO CENTER STATION	COMMERCE ST STATION	0.44	0:01:30	0:00:30	0:02:00	17.6
COMMERCE ST STATION	CBD EAST STATION	0.38	0:01:17	0:00:30	0:01:47	17.8
CBD EAST STATION	BAYLOR UMC STATION	0.74	0:02:42	0:00:30	0:03:12	16.4
TOTALS		**2.42**	**0:08:41**	**0:02:30**	**0:11:11**	**16.7**

Table 4. *D2 Orange Line Travel Times between Victory Station and Cityplace/Uptown Station*

Begin Station	End Station	Distance	Travel Time	Dwell Time	Total Time	Avg. Speed
VICTORY STATION	MUSEUM WAY STATION	0.45	0:02:05	0:00:30	0:02:35	12.8
MUSEUM WAY STATION	METRO CENTER STATION	0.42	0:01:07	0:00:30	0:01:37	22.4
METRO CENTER STATION	COMMERCE ST STATION	0.44	0:01:30	0:00:30	0:02:00	17.6
COMMERCE ST STATION	CBD EAST STATION	0.38	0:01:17	0:00:30	0:01:47	17.8
CBD EAST STATION	LIVE OAK STATION	0.39	0:02:02	0:00:30	0:02:32	11.5
LIVE OAK STATION	CITYPLACE/UPTOWN STATION	1.33	0:03:09	0:00:30	0:03:39	25.3
TOTALS		**3.40**	**0:11:10**	**0:03:00**	**0:14:10**	**18.3**

Figure 4. *DART Light Rail Transit Operations for Routine Service*



Special Event Service

State Fair

DART provides special event service during the annual State Fair held each fall. The fairgrounds are served by two Green Line stations -- Fair Park Station, located on Parry Avenue at the main entrance to the fairgrounds, and MLK, Jr. Station, located south of R.B. Cullum Blvd. and convenient to the MLK fairground entrance (Gate 6) and the Cotton Bowl Stadium.

The current service concept for State Fair service makes the following modifications to routine service:

- Extra Green Line trains are added approximately every 20 minutes between Victory and Lawnview stations from 9:30 a.m. to 3:30 p.m. weekdays and 9:30 a.m. to 7:30 p.m. on weekends, effectively providing 10 minute Green Line service between Victory and Lawnview.
- Blue Line weekend evening service is enhanced from 30 minutes to 15 minutes.
- Orange Line trains are extended to Parker Road Station (except game day for Red River Showdown).

If basically maintaining the same service plan as currently employed for special event service, passengers riding DART light rail lines transfer at the following locations, given the realignment of Green and Orange Line service to D2:

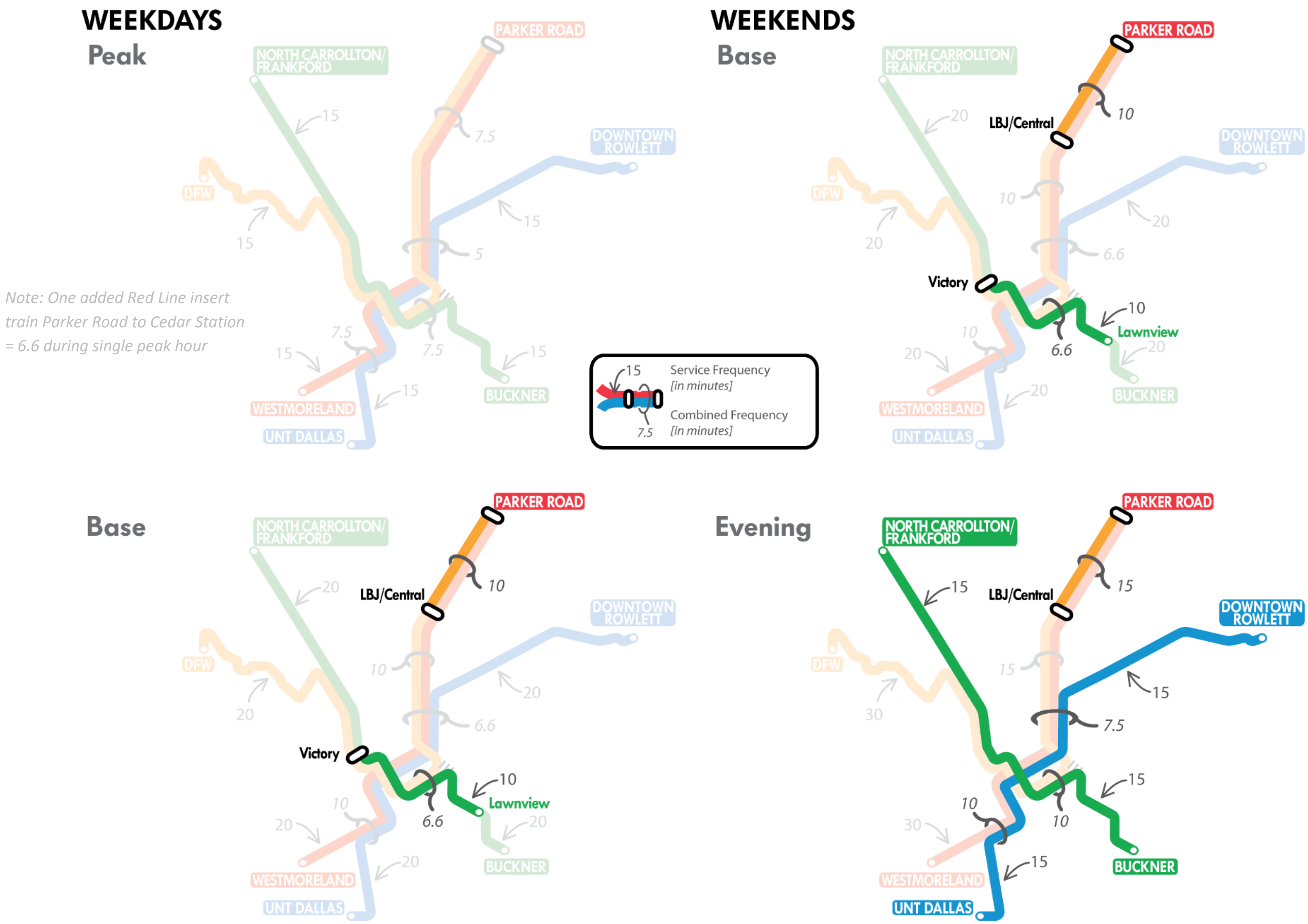
- Red and Blue Line passengers transfer to the Green Line at West End/Metro Center.
- Westbound Orange Line passengers transfer to the Green Line at CBD East Station.
- Eastbound Orange Line passengers transfer to the Green Line at Bachman Station.
- TRE passengers transfer to the Green Line at Victory Station.

The State Fair service plan, as based on current service but with the realignment of Green and Orange Line service to D2, highlights changes compared to routine service in **Figure 5**.

Since the D2 alignment provides additional capacity in downtown Dallas and the project incorporates all movements at the Southeast and Deep Ellum junctions, State Fair service can consider other patterns providing direct service to the fairgrounds:

- Parker Road to fairgrounds
- Downtown Rowlett to fairgrounds
- DFW to fairgrounds (beyond the three weekend PM trips in current State Fair schedule)
- Westmoreland to fairgrounds
- UNT Dallas to fairgrounds

Figure 5. *DART Light Rail Transit Operations for State Fair Service (based on existing practices)*



The extent to which these additional patterns can be accommodated is limited by the headway limitations of the Green Line segment from the Deep Ellum junction to the fairgrounds. It is worth noting that Red and Blue Line southbound transfers to the Green Line would cause undesirable backtracking to transfer at West End/Metro Center, so these corridors may warrant particular consideration of direct service. The remaining movements (Red and Blue Line northbound transfers to the Green Line as well as either direction of Orange Line) do not necessitate major out-of-direction travel.

Table 5. *Potential State Fair Operating Plans with D2*

LRT Line	D2 Based on Current Plan		D2 Example of Alternate Plan	
	Weekday	Weekend	Weekday	Weekend
Red Line	15 min peak; 20 min base	20 min base; 30 min eve	15 min peak; 20 min base (full); 20 min base Parker Rd to Lawnview	20 min base; 30 min eve (full); 20 min base Parker Rd to Lawnview
Blue Line	15 min peak; 20 min base	20 min base; 15 min eve	15 min peak; 20 min base	20 min base; 30 min eve
Green Line	15 min peak; 20 min base (full); 20 min base Victory to Lawnview	20 min base; 15 min eve (full); 20 min base Victory to Lawnview	15 min peak; 20 min base (full); 20 min base Victory to Lawnview	20 min base; 30 min eve (full); 20 min base Victory to Lawnview
Orange Line	15 min peak; 20 min base; extend all trips to Parker Rd	20 min base; 30 min eve; extend all trips to Parker Rd	15 min peak; 20 min base	20 min base; 30 min eve

The example shown in **Table 5** focuses adding Red Line direct fairground service from Parker Road to Lawnview via the Southeast and Deep Ellum junctions. Blue Line southbound trains would be able to take advantage of this direct service by transferring at SMU/Mockingbird, rather than having to transfer at West End/Metro Center and backtrack through downtown Dallas on the Green Line. The transfer between the Blue and Red Line fairground service at SMU/Mockingbird (or Cityplace/Uptown) could be a timed transfer. The Green Line supplemental service between Victory and Lawnview is maintained to respond to increased transfers from northbound Red and Blue, transfers from TRE at Victory station, and transfers from the Orange Line from either direction.

The example's resulting 12 trains an hour (5 minute average headway) between SMU/Mockingbird and the Southeast Junction can clearly be accommodated, as this matches the current trunk headway in this segment for weekday peak period service.

The example would lead to 9 trains an hour (6.6 minute average headways) between the Deep Ellum Junction and Lawnview. As noted earlier, the Green Line's minimum frequency between trains would need to be confirmed in order to determine how much direct service to the fairgrounds can be accommodated.

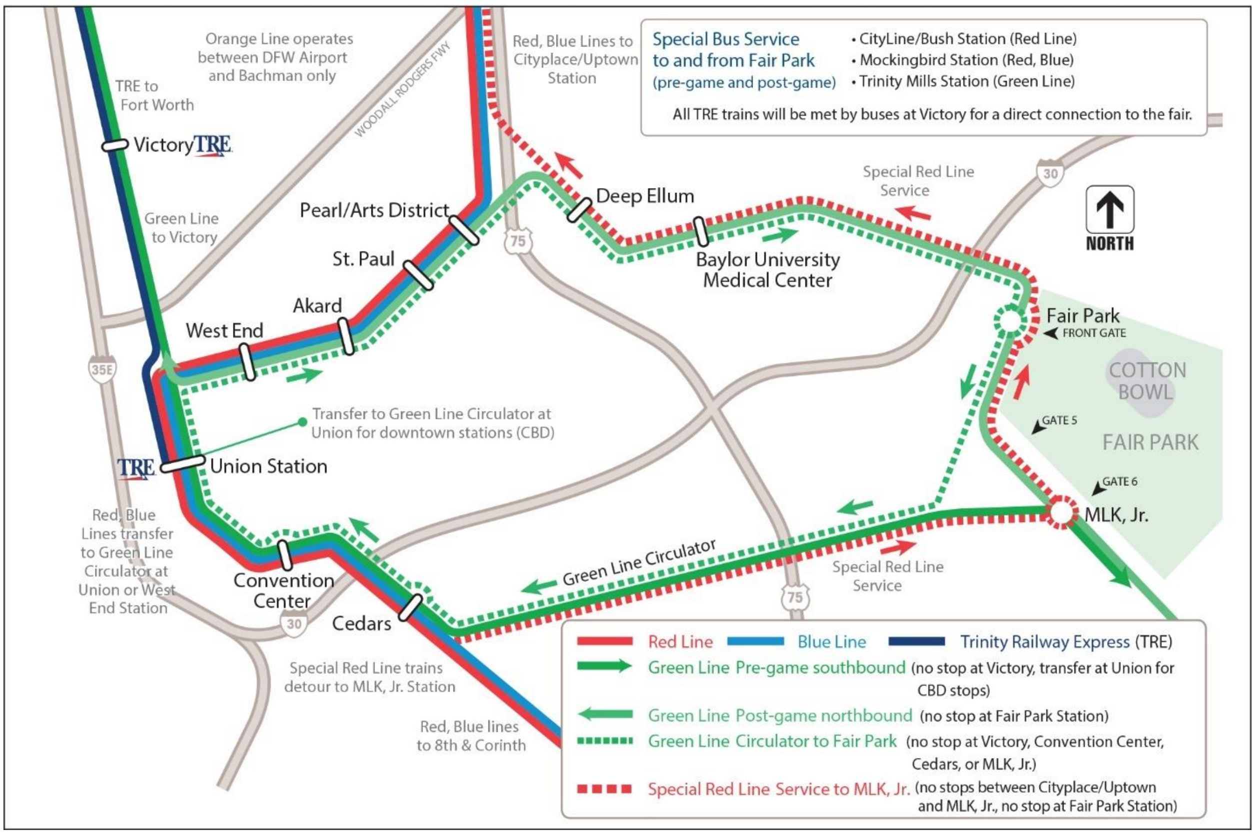
While other patterns can be incorporated, the intent is to make the direct service to the fairgrounds regular and frequent enough for riders to depend on the service.

[Note: schematic to be developed]

Red River Showdown

Existing Service. The Red River Showdown annual football game is held on a single day during the State Fair. DART's current service provides a sophisticated system of additional train service, including the integration of the Green Line Circulator loop, special Red Line service, and additional shuttle buses. Due to capacity constraints on the transit mall, DART employs its yard lead connections to cut across downtown Dallas to the south. This connection is used as a bypass for rerouting Green Line southbound trips as well as special Red Line service to the stadium before the game. The Green Line circulator maintains access to downtown stations that are bypassed by these rerouted trips. **Figure 6** provides a schematic of service focusing on central Dallas and the fairgrounds.

Figure 6. *DART Light Rail Transit Current Operations for Red River Showdown*



- **Green Line.** Southbound Green Line trains operate every 10 minutes from North Carrollton/Frankford Station for MLK, Jr. Station as early as four hours before the game. Prior to kick-off, these trains use an alternate routing proceeding from Market Center Station to Union Station, then directly to MLK, Jr. Station, thereby skipping Victory, West End, Akard, St. Paul, Pearl/Arts District, Deep Ellum, Baylor and Fair Park stations. The skipped downtown stations are accessed by transferring to the Green Line circulator at Union Station.

Northbound Green Line trains leave every 10 minutes from Buckner Station for MLK, Jr. Station as early as three hours before kickoff. These trains skip Fair Park Station, but continue to serve all other stations.

The special Green Line circulator starts four hours before the game and operates every 10 minutes, serving stations noted in **Figure 6**. The Green Line circulator does not stop at Convention Center or Cedars stations and operates continually until approximately four hours after the game.

- **Red Line.** Red Line trains following the typical route between Parker Road and Westmoreland Station operate on a regular Saturday schedule with 20 minute service transitioning to 30 minutes in the evenings. Southbound Red Line passengers transfer to the Green Line Circulator at Pearl/Arts District Station while northbound Red Line passengers transfer at Akard Station.

  For direct service to the stadium, specially marked southbound Red Line trains operate every 10 minutes from Parker Road Station to MLK, Jr. Station starting as early as four hours before kickoff. The specially marked southbound Red Line trains do not stop after Cityplace/Uptown Station and head directly to MLK, Jr. Station using the yard lead routing as described for the Green Line. After the game, these specially marked northbound Red Line trains depart from MLK, Jr. Station for the trip back to Parker Road Station, skipping the Fair Park Station.

- **Blue Line.** Southbound Blue Line trains operate every 15 minutes from Downtown Rowlett Station starting four hours before kickoff, with transfers to the Green Line Circulator at Pearl/Arts District Station. Northbound Blue Line passengers follow a regular Saturday schedule and can transfer to the Green Line Circulator at Akard Station.

- **Orange Line.** Eastbound Orange Line passengers from DFW Airport and Irving's five stations transfer to the Green Line at Bachman Station at 20 minute headways. Orange Line trains only operate between DFW Airport and Bachman stations from approximately four hours before the game to four hours after the game, when service along the full route to Parker Road is resumed at 30 minute headways.

Potential Reconfigured Game Day Service with D2. A second alignment through downtown opens up greater opportunities to provide game day service using existing revenue track. This replaces the need to use the yard lead track and potentially eliminates the Green Line Circulator. The following concept is an example of how Game Day service may operate, incorporating D2.

- **Green Line.** Green Line trains operate every 15 minutes between North Carrollton/Frankford Station and Lawndale or Buckner from three to four hours before kickoff, serving all usual Green Line stations. (Northbound and Southbound may choose to serve either Fair Park or MLK, Jr. Stations if there are limitations to stopping at both.)

- **Orange Line.** On game day, all Orange Line trains are reconfigured to operate every 15 minutes between DFW and Lawndale. This in effect leads to 7.5-minute trunk service on the Green Line route from Bachman to Lawndale.

- **Red Line.** Red Line trains following the typical route between Parker Road and Westmoreland Station operate on a regular Saturday schedule with 20 minute service transitioning to 30 minutes in the evenings. Red Line passengers heading from either direction can transfer to the Green or Orange Line at West End/Metro Center to continue to the fairgrounds.

  Direct Red Line service to the stadium is added, with southbound trains operating every 15 minutes from Parker Road Station via Southeast Junction and Deep Ellum Junction to Fair Park Station or MLK, Jr. Station starting as early as four hours before kickoff.

- **Blue Line.** Blue Line trains operate every 15 minutes between Downtown Rowlett Station and UNT Dallas from three to four hours before kickoff. Southbound Blue Line riders can transfer at SMU/Mockingbird to catch Red Line service heading directly to the stadium. Northbound Blue Line riders can transfer to the Green or Orange Line at West End/Metro Center.

This example leads to the following combined service levels:

- Bachman to Deep Ellum Junction: Green and Orange = 8 trains/hour (7.5 minute average headway)
- Deep Ellum Junction to Fairgrounds: Green, Orange and Red special = 12 trains/hour (5 minute average headway)
- SMU/Mockingbird to Southeast Junction: Red regular, Red special, Blue = 11 trains/hour (5.4 minute average headway)
- Southeast Junction to 8th/Corinth: Red regular, Blue = 7 trains/hour (8.6 minute average headway)

A summary of the current plan versus the example D2 plan is provided in **Table 6**. *[Note: schematic to be developed]* As can be seen, the example leads to somewhat less frequent service on the Green Line north of Bachman and less frequent Red Line stadium service. This is offset by more frequent service between Bachman and the fairgrounds, improved frequency and direct service from DFW rather than truncating the Orange Line, and improved travel times to the stadium by eliminating the alternate routing using the yard lead.

Table 6. *Potential Red River Showdown Operating Plans with D2*

LRT Line	Current Game Day Plan	Potential D2 Game Day Plan
Red Line	20 minute regular; 10 minute stadium with skipped CBD stations	20 minute regular; 15 minute stadium (bypasses downtown routing)
Blue Line	15 minute regular	15 minute regular
Green Line	10 minute with skipped CBD stations southbound; separate 10 minute CBD circulator	15 minute regular (no need for separate circulator)
Orange Line	20 minute DFW to Bachman	15 minute DFW to Lawnview (together with Green Line, provides 7.5-minute trunk service Bachman-Lawnview)

The key segment that determines the amount of service to the fairgrounds is from Deep Ellum Junction to the fairgrounds. Proposed headways among various lines can be rebalanced based on the maximum allowable level of service. It is understood that there will be delays associated with waiting for train slots at Southeast Junction and Deep Ellum Junction. Regardless, bypassing the downtown routing is still likely to save time even with the delays at the junctions.

Incident Management

Whether due to DART service interruptions/disabled vehicles in downtown Dallas or emergency actions interfering with DART right-of-way (e.g., fire hoses blocking Bryan-Pacific transit mall), the D2 alignment provides an alternate path through downtown Dallas and allows DART to reroute LRT service from one downtown corridor to the other.

If there is a service interruption/disabled vehicle in the D2 segment, then Green and Yellow Lines would revert back to the transit mall per existing operations.

If there is a service interruption/disabled vehicle in the Bryan-Pacific transit mall segment, then southbound Red and Blue Lines can bypass the Southeast Junction and enter D2 at the Deep Ellum Junction, proceed to Victory Station, then use the pocket track to switch southward continuing past Northwest Junction onto Union Station and continuing southward. Northbound Red and Blue Lines would proceed northward from Union Station to Victory Station, then use the pocket track to switch southward and onto the D2 alignment, turning northward at Deep Ellum Junction back toward the Southeast Junction where they pick up their usual alignment. **Figure 7** reflects the rerouting of both the Red and Blue Lines onto D2.

Figure 8 is a modified plan that focuses on rerouting just the Red Line onto D2 while truncating the Blue Line on either end of downtown. This concept puts less stress on D2 operations. This alternate plan may lead to less impacts during a peak period when demands on D2 would be greatest.

__Figure 7.__ DART Incident Management Plan Rerouting Off Transit Mall – Both Red and Blue Lines

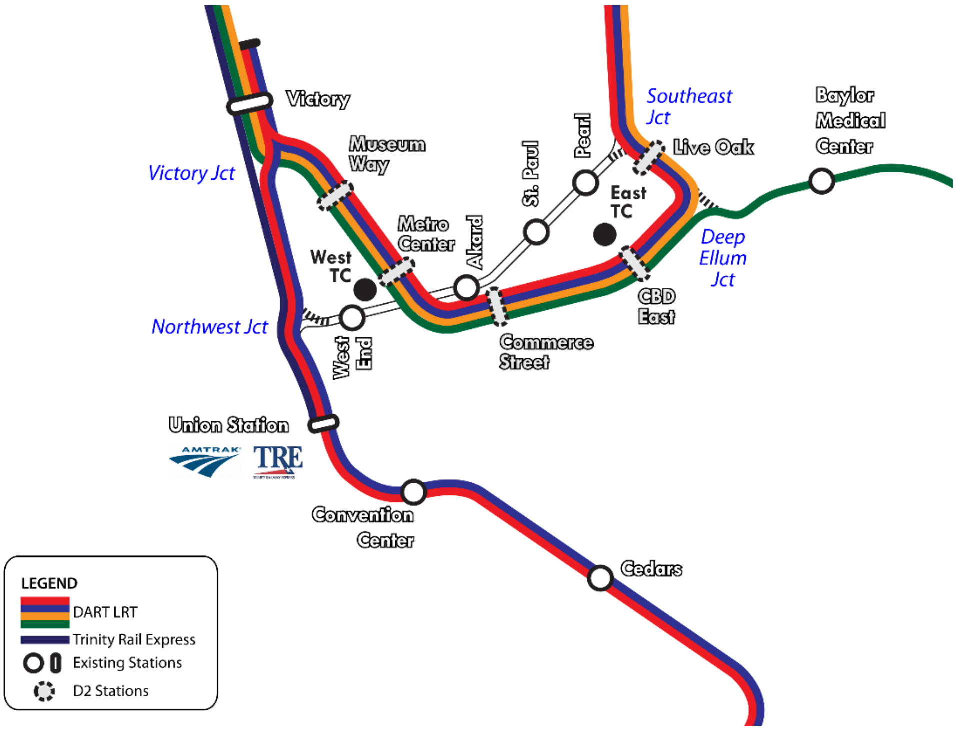
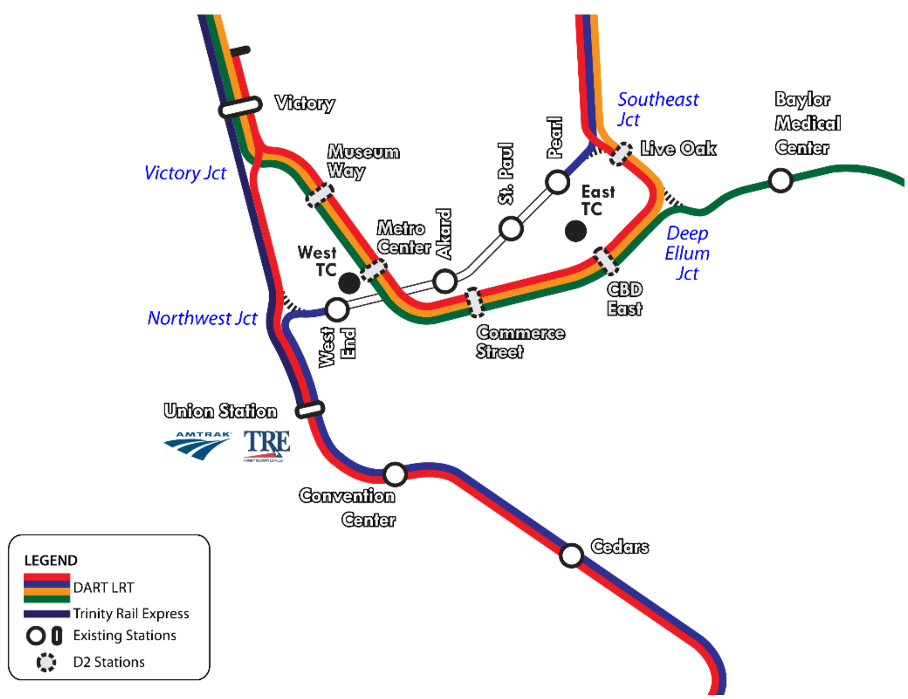
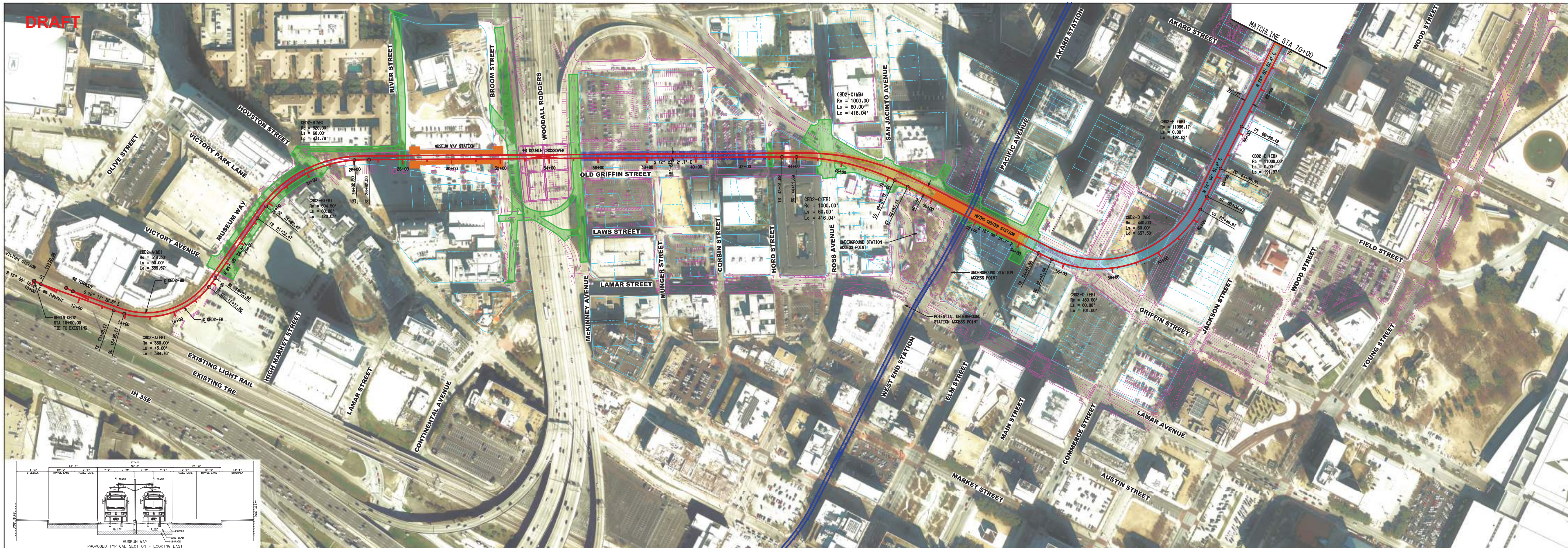


__Figure 8.__ DART Incident Management Plan Rerouting Off Transit Mall – Red Line Only





SCALE (IN FEET)
0 50 100 200

PLAN VIEW LEGEND

- EXISTING DART LIGHT RAIL
- PROPOSED D2 LIGHT RAIL ALIGNMENT
- APPROXIMATE PORTAL LIMITS
- APPROXIMATE CUT AND COVER LIMITS
- APPROXIMATE TUNNEL LIMITS
- STATION PLATFORM
- PROPERTY LINES
- STREET RECONSTRUCTION LIMITS
- TOPOGRAPHIC SURVEY DATA
- POTENTIAL PEDESTRIAN ACCESS TO SUBWAY STATION

PROFILE VIEW LEGEND

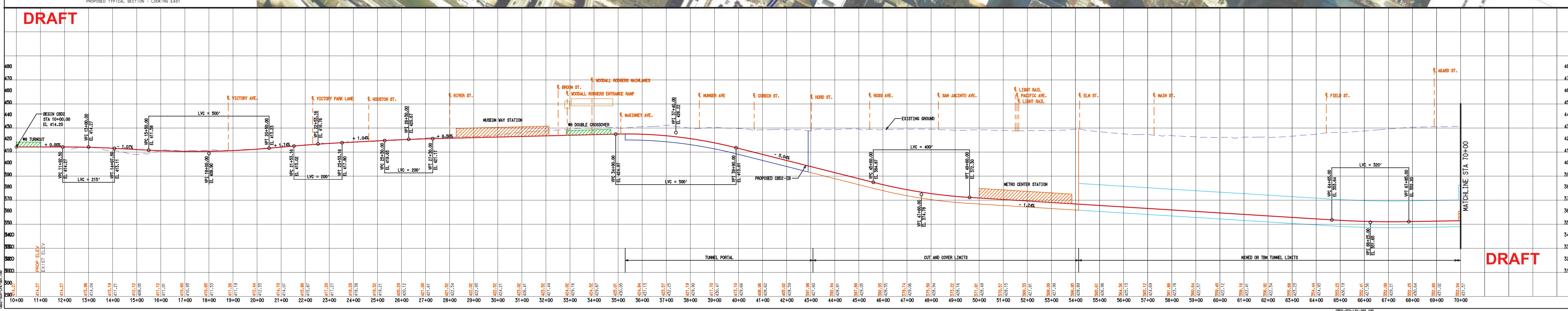
- PROPOSED D2 LIGHT RAIL ALIGNMENT
- EXISTING GROUND
- APPROXIMATE PORTAL LIMITS
- APPROXIMATE CUT AND COVER LIMITS
- APPROXIMATE TUNNEL LIMITS
- STATION PLATFORM LIMITS
- SPECIAL TRACK LIMITS

NOTES:

1. PORTAL AND CUT AND COVER LIMITS ARE SUBJECT TO CHANGE.
2. UNDERGROUND STATION ACCESS LOCATIONS ARE SUBJECT TO CHANGE.

DRAFT

NOT AN APPROVED DRAWING
PRELIMINARY ENGINEERING 20% DESIGN



IN-PROGRESS

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ON 03/06/2020
HDR ID # F-754

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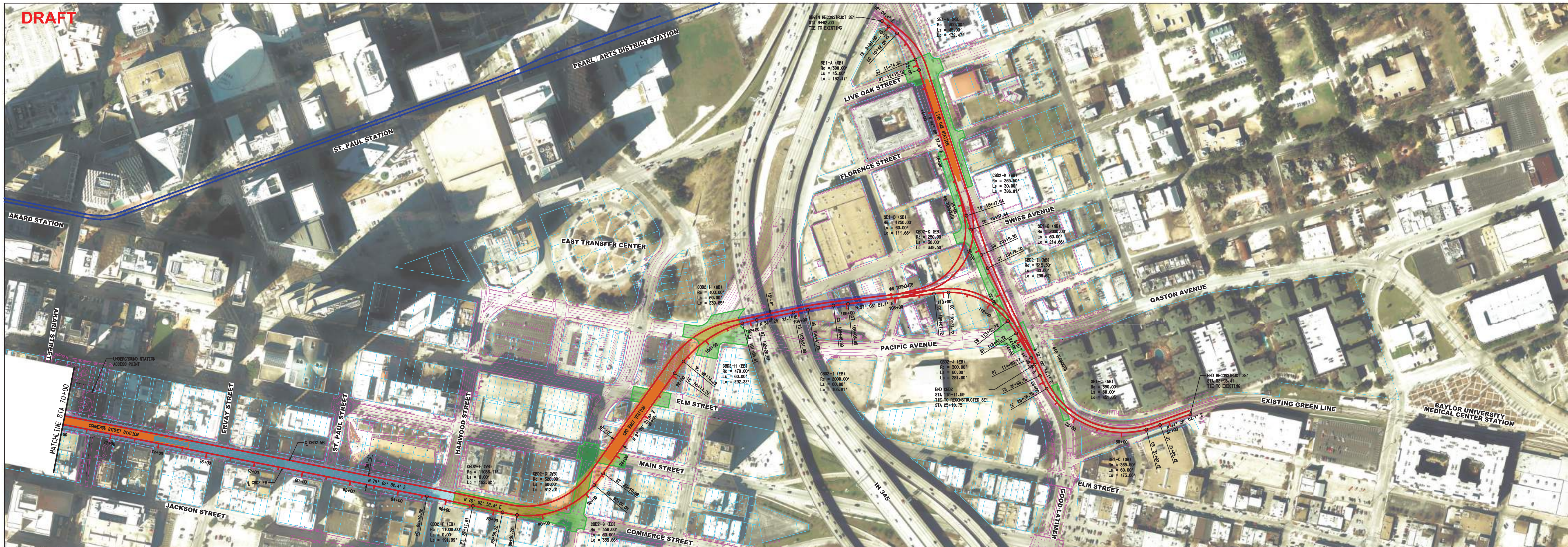
LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

STA 10+00 TO STA 70+00
COMMERCE / VICTORY / SWISS

SHEET 1 OF 2



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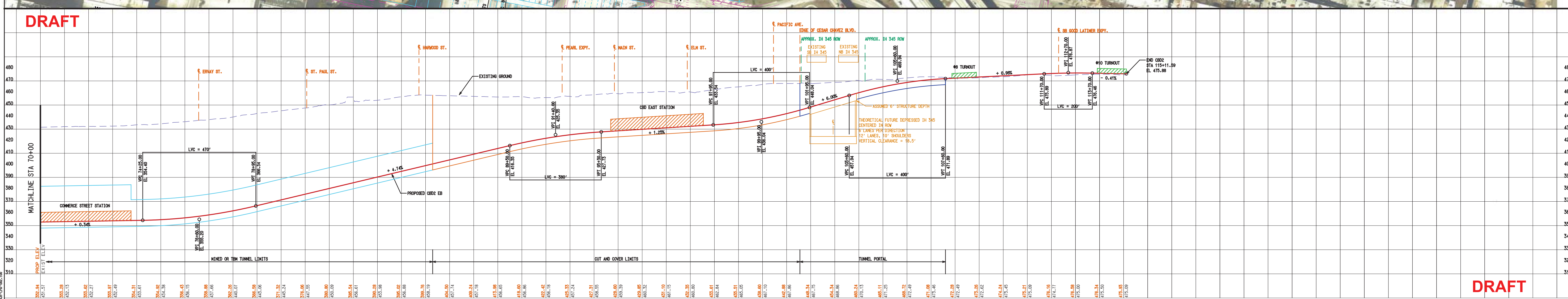
PRELIMINARY ENGINEERING 20% DESIGN



SCALE (IN FEET) 0 50 100 200

PLAN VIEW LEGEND
- EXISTING DART LIGHT RAIL
- PROPOSED D2 LIGHT RAIL ALIGNMENT
- APPROXIMATE PORTAL LIMITS
- APPROXIMATE CUT AND COVER LIMITS
- APPROXIMATE TUNNEL LIMITS
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PROFILE VIEW LEGEND
- PROPOSED D2 LIGHT RAIL ALIGNMENT
- EXISTING GROUND
- APPROXIMATE PORTAL LIMITS
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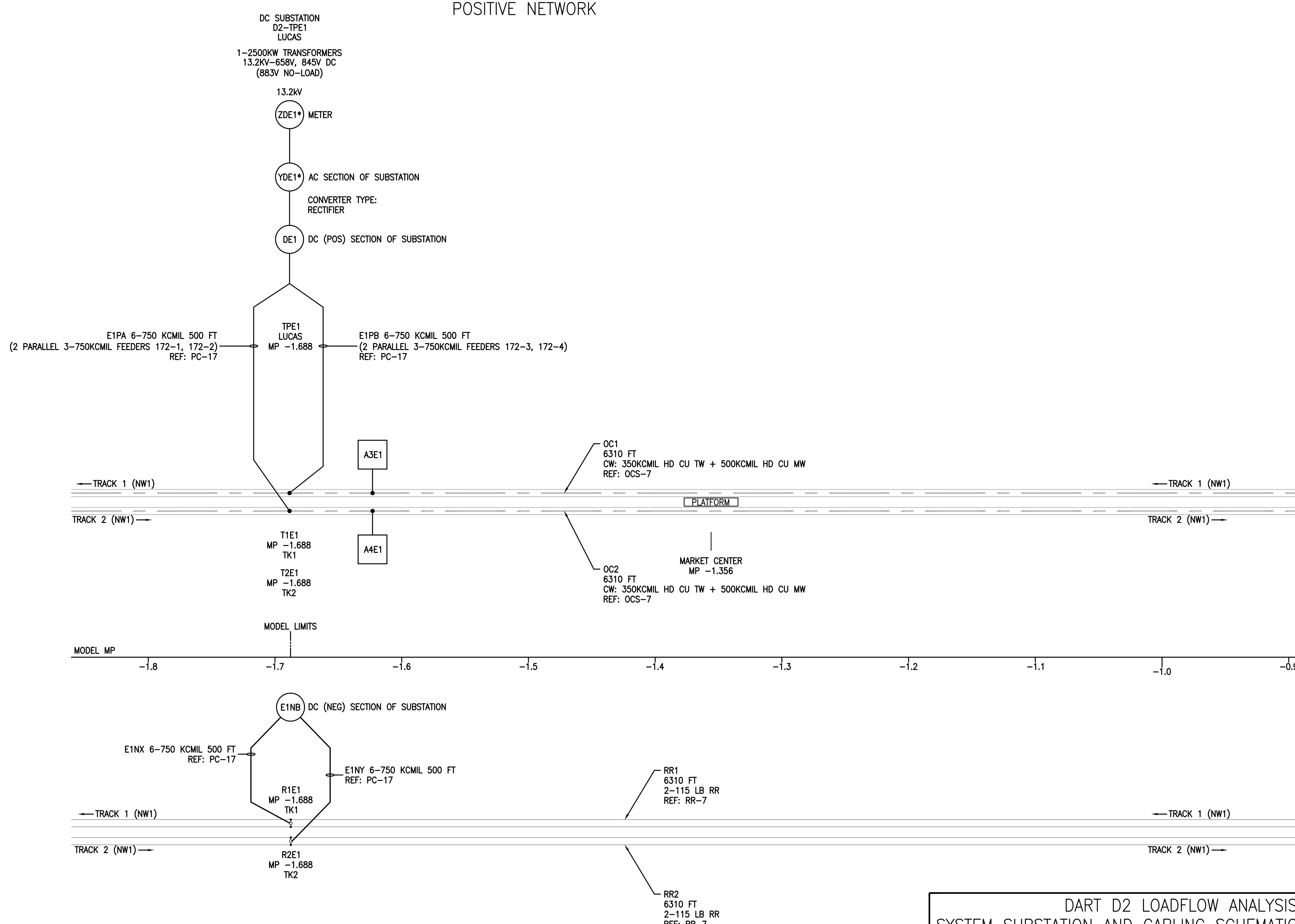
LIGHT RAIL TRANSIT SYSTEM
LINE SECTION CBD-2

STA 70+00 TO STA 115+11.59
COMMERCE / VICTORY / SWISS

SHEET 2 OF 2

Appendix B – TOM CAD Electrical Model

POSITIVE NETWORK



NEGATIVE NETWORK

NOTES:

1. CONDUCTOR TEMP USED IS 75 DEG F.
2. RAIL TEMP USED IS 40 DEG F.
3. OCS TW WEAR USED IS 20%.
4. AMMETER LOCATION SHOWN SCHEMATICALLY. ACTUAL LOCATION IN MODEL IS AT SUBSTATION TRACK NODES.
5. * INDICATED NODE GENERATED BY TOM.

DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 1 OF 8
SHEET TP001
REV. A

NOTES:

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DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 2 OF 8
SHEET TP002
REV. A

DATE: Jan 22, 2020 – 4:04pm FILENAME: rail lineplan TOM – DART D2 TPSS.dwg

NOTES:

1. CONDUCTOR TEMP USED IS 75 DEG F.
2. RAIL TEMP USED IS 40 DEG F.
3. OCS TW WEAR USED IS 20%.
4. AMMETER LOCATION SHOWN SCHEMATICALLY. ACTUAL LOCATION IN MODEL IS AT SUBSTATION TRACK NODES.
5. * INDICATED NODE GENERATED BY TOM.

DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 3 OF 8
SHEET TP003
REV. A

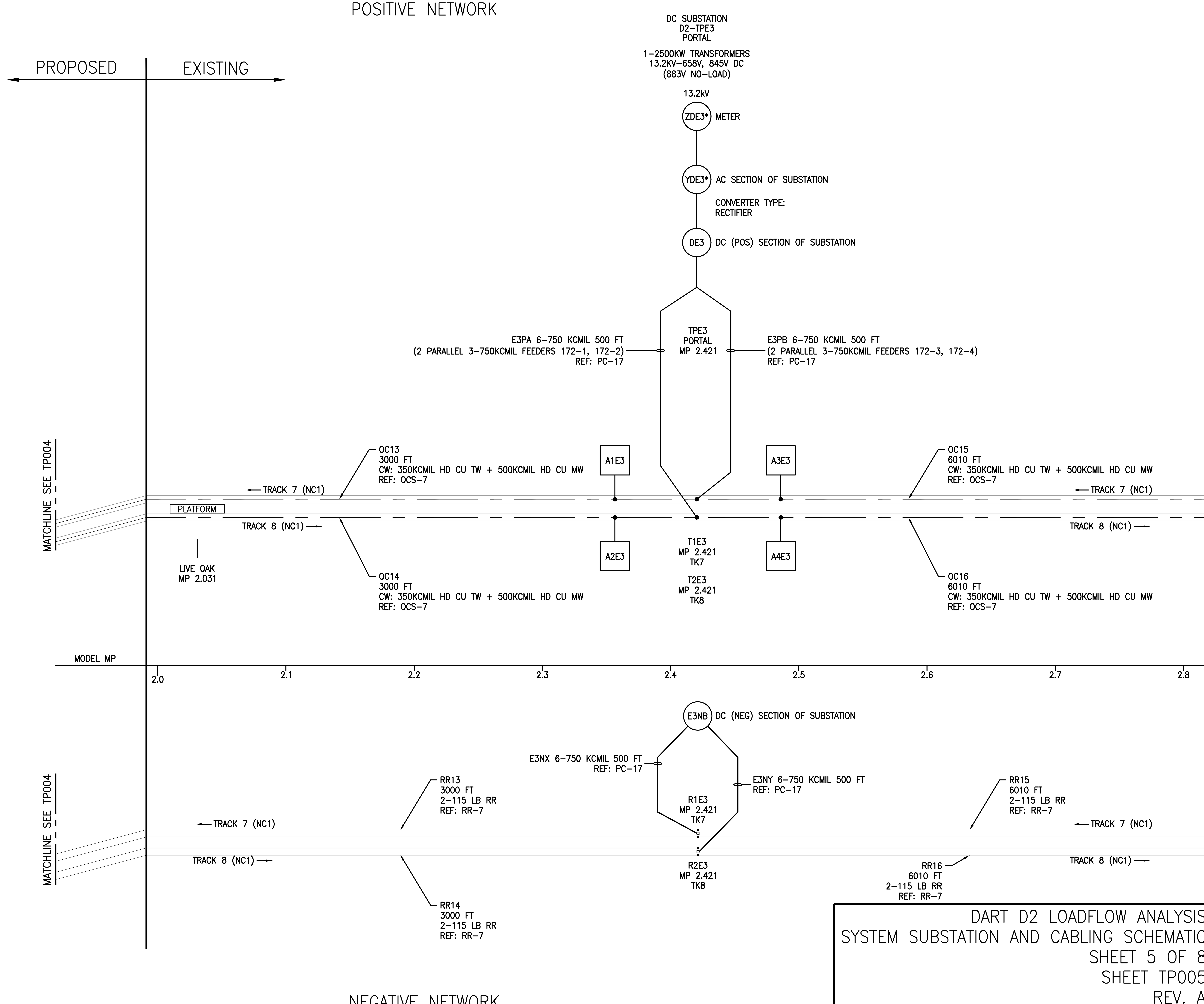
DATE: Jan 22, 2020 - 4:04pm FILENAME: rail lineplan TOM - DART D2 TPSS.dwg

NOTES:

1. CONDUCTOR TEMP USED IS 75 DEG F.
2. RAIL TEMP USED IS 40 DEG F.
3. OCS TW WEAR USED IS 20%.
4. AMMETER LOCATION SHOWN SCHEMATICALLY. ACTUAL LOCATION IN MODEL IS AT SUBSTATION TRACK NODES.
5. * INDICATED NODE GENERATED BY TOM.

DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 4 OF 8
SHEET TP004
REV. A

DATE: Jan 22, 2020 - 4:04pm FILENAME: rail lineplan TOM - DART D2 TPSS.dwg



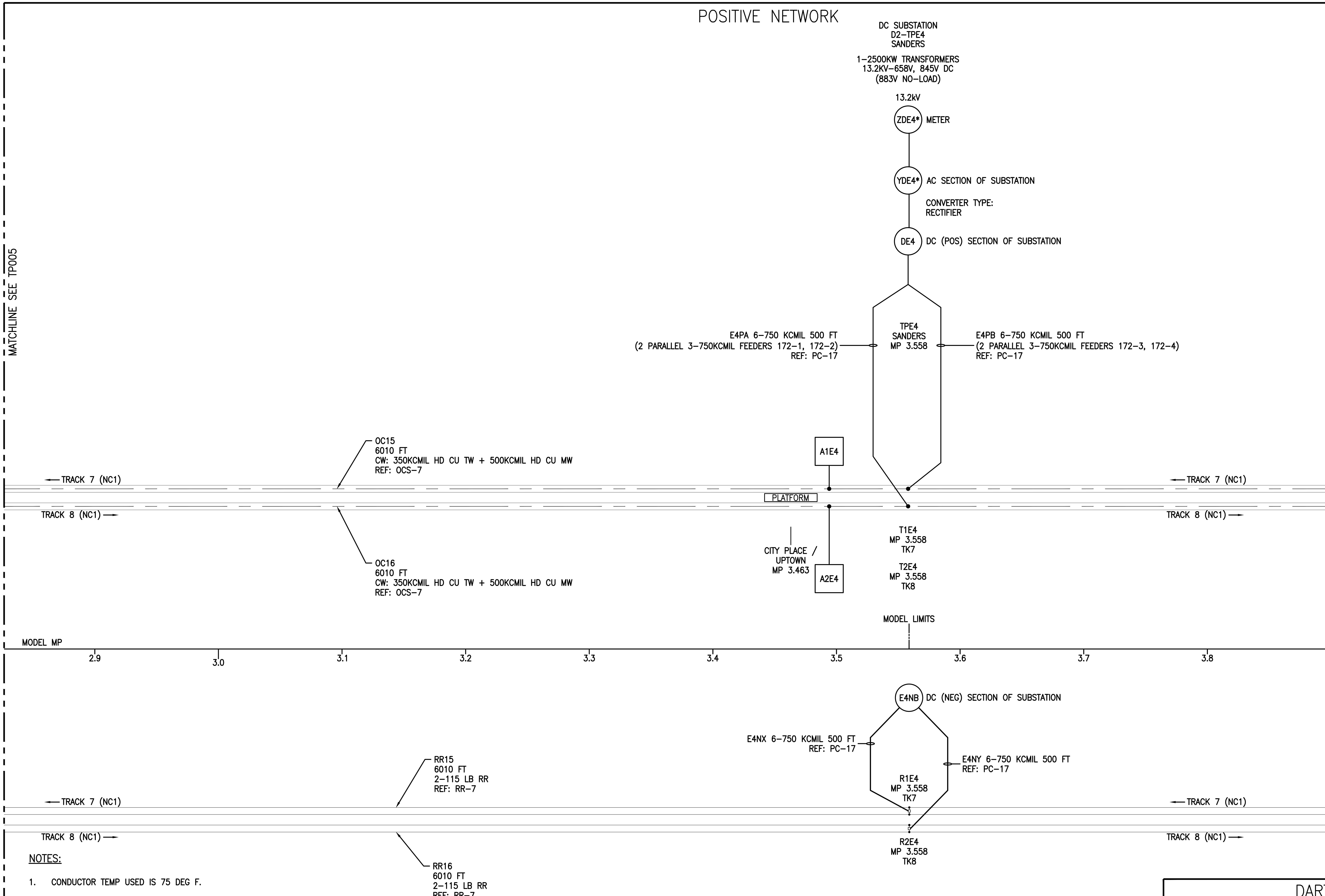
NOTES:

1. CONDUCTOR TEMP USED IS 75 DEG F.
2. RAIL TEMP USED IS 40 DEG F.
3. OCS TW WEAR USED IS 20%.
4. AMMETER LOCATION SHOWN SCHEMATICALLY. ACTUAL LOCATION IN MODEL IS AT SUBSTATION TRACK NODES.
5. * INDICATED NODE GENERATED BY TOM.

DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 5 OF 8
SHEET TP005
REV. A

DATE: Jan 22, 2020 - 4:04pm FILENAME: rail lineplan TOM - DART D2 TPSS.dwg

POSITIVE NETWORK



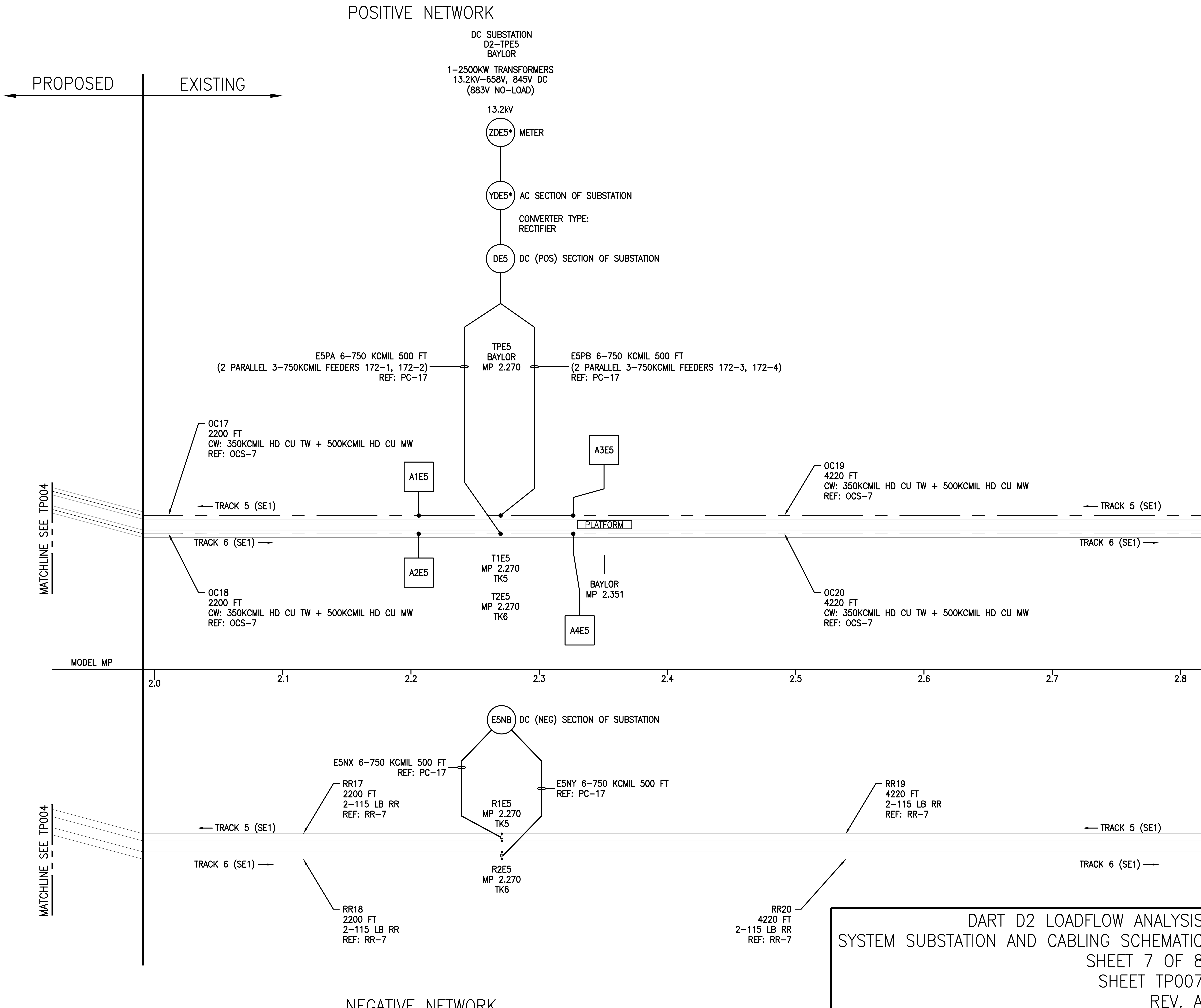
NOTES:

1. CONDUCTOR TEMP USED IS 75 DEG F.
2. RAIL TEMP USED IS 40 DEG F.
3. OCS TW WEAR USED IS 20%.
4. AMMETER LOCATION SHOWN SCHEMATICALLY. ACTUAL LOCATION IN MODEL IS AT SUBSTATION TRACK NODES.
5. * INDICATED NODE GENERATED BY TOM.

NEGATIVE NETWORK

DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 6 OF 8
SHEET TP006
REV. A

DATE: Jan 22, 2020 - 4:04pm FILENAME: rail lineplan TOM - DART D2 TPSS.dwg

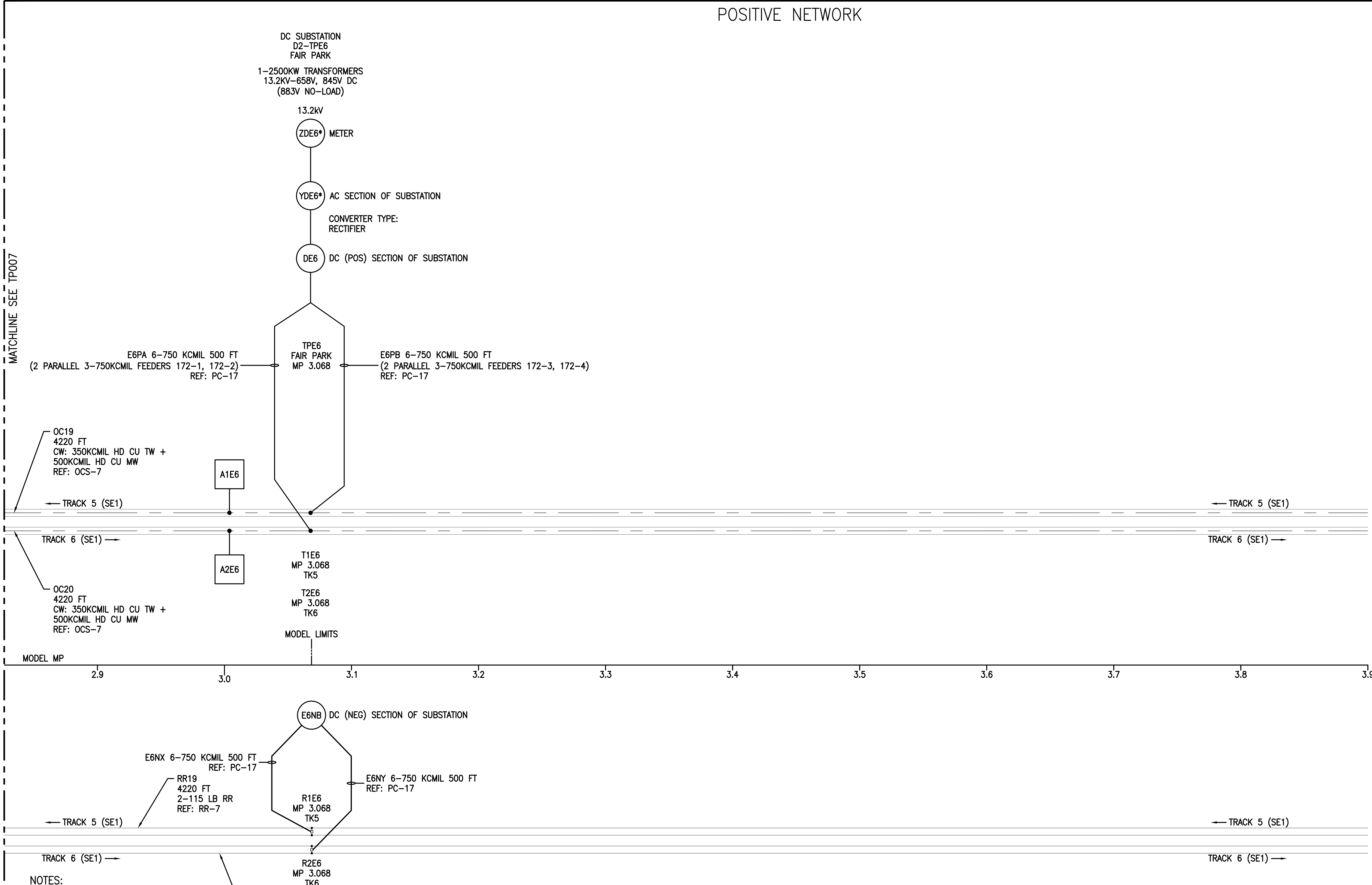


NOTES:

1. CONDUCTOR TEMP USED IS 75 DEG F.
2. RAIL TEMP USED IS 40 DEG F.
3. OCS TW WEAR USED IS 20%.
4. AMMETER LOCATION SHOWN SCHEMATICALLY. ACTUAL LOCATION IN MODEL IS AT SUBSTATION TRACK NODES.
5. * INDICATED NODE GENERATED BY TOM.

DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 7 OF 8
SHEET TP007
REV. A

DATE: Jan 22, 2020 - 4:04pm FILENAME: rail lineplan TOM - DART D2 TPSS.dwg



NOTES:

1. CONDUCTOR TEMP USED IS 75 DEG F.
2. RAIL TEMP USED IS 40 DEG F.
3. OCS TW WEAR USED IS 20%.
4. AMMETER LOCATION SHOWN SCHEMATICALLY. ACTUAL LOCATION IN MODEL IS AT SUBSTATION TRACK NODES.
5. * INDICATED NODE GENERATED BY TOM.

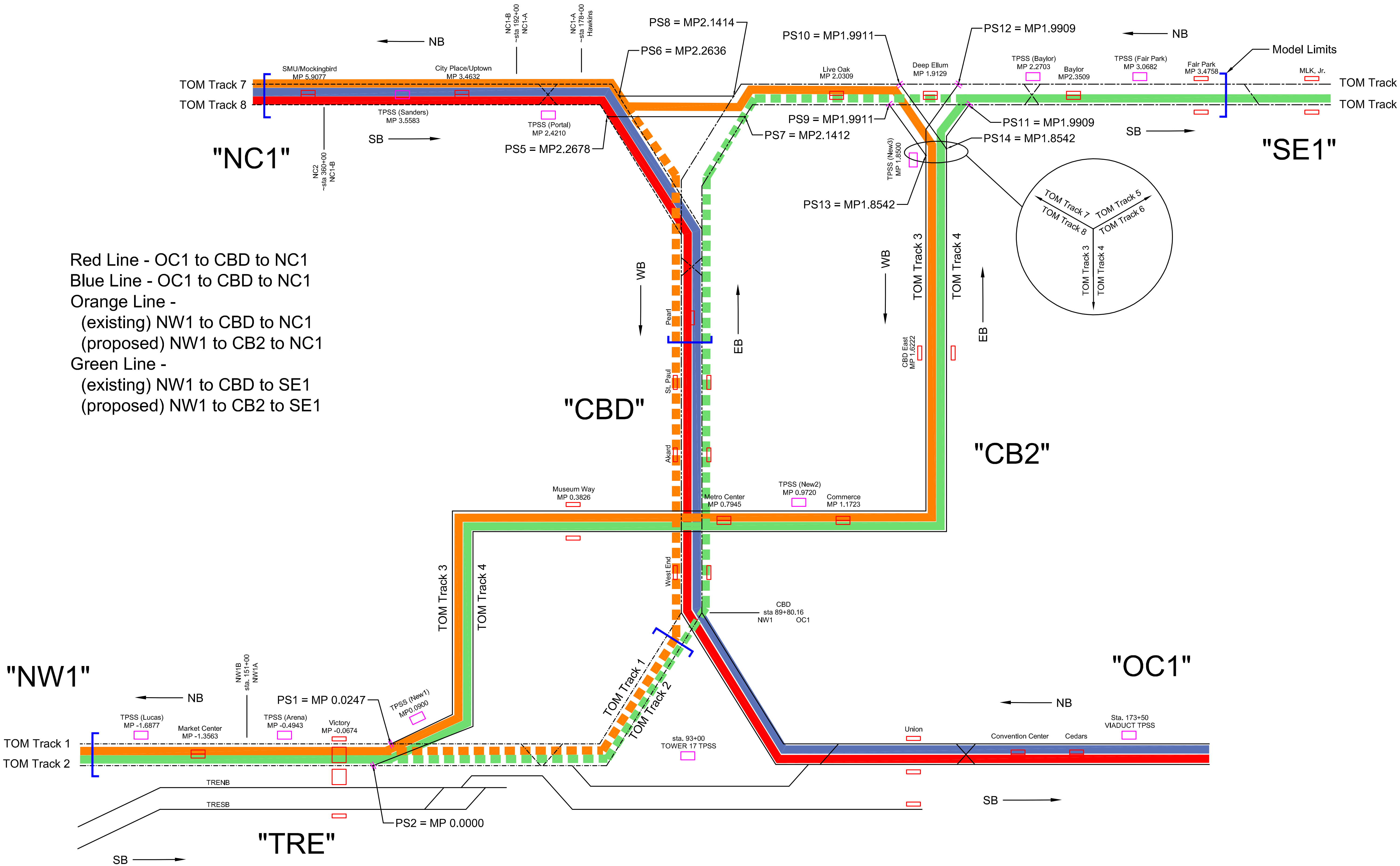
NEGATIVE NETWORK

DART D2 LOADFLOW ANALYSIS
SYSTEM SUBSTATION AND CABLING SCHEMATIC
SHEET 8 OF 8
SHEET TP008
REV. A

DATE: Jan 22, 2020 - 4:04pm FILENAME: rail lineplan TOM - DART D2 TPSS.dwg

Appendix C – DART D2 Track Schematic

DART D2 SCHEMATIC



Appendix D – Kinkisharyo SLRV / Toyo Denki Vehicle Data

Acceleration curve for DART Kinkisharyo SLRV / Toyo Denki Car

Vehicle and System Assumptions:	1 car vehicle				
Car weight - AW0	70.00	US tons	140000 lbs	1 Car	
Loaded Car - AW2	86.32	US tons	172648 lbs	1 Car	
Rotary inertia	7.0	US tons	14000 10% of AW0	1 Car	
Train length	1	cars			
Frontal area	90	sq. feet	12960 sq. in.	Guessed	
Initial Accel	1.252	m/s^2	4.5072 kph/s	2.8007	mph/s
1 car data 6 of 4 powered axles	1.252	m/s^2	4.5072 kph/s	2.8007	mph/s
Power train effic.	84.70%				
Design Voltage	750	Volts			
Max Regen Voltage	937.5	Volts			
Min Operating voltage	525	Volts			
Limiting traction current	2000	Amps		1 Car	

Train Type:	n/a				
Train Info:	Toyo Denki				
	4 - DC motors per car				
Regen status:	off				
# motoring points					
# of regen points					
Car length	37.643	m	123.50	ft	
# of cars per train	3				
Aux power (kW) per car	83	kW			
Braking rate	1.57	m/s^2	5.634 kph/s	3.5009	mph/s
Maximum Speed	112	kmh	69.60	mph	
Number of Axles per car	8				
Davis Eqn Data	A	90.15549976 Frontal Area			
	B	0.0441 Wheel Flange Co-eff			
	C	0.0024 Leading Car drag Co-eff			
Wheel diameter	610	mm			

Propulsion Design Parameters

- Hold the constant tractive effort up to 32 kph   37.01 kph = 23.00 mph

Modeling Assumptions:

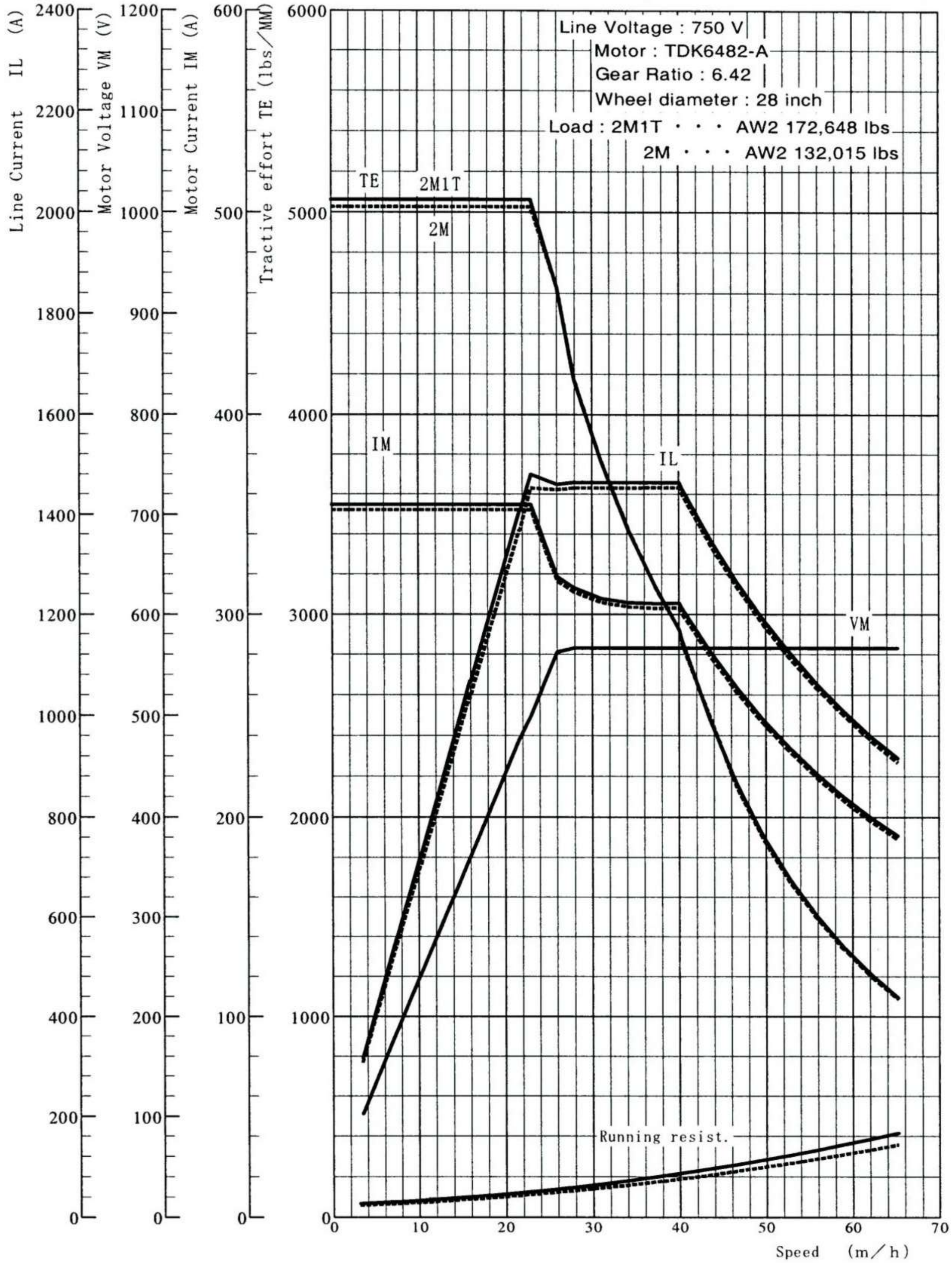
- For initial tractive effort use 15% of max at 0 mph and 65% of max ot 0.5 mph
- Assume that the system has constant losses below the first corner point
- Time calculations are rough, and are used for reasonableness checks
- no foldback voltage used in simulations

MOTORING for 1 car set

750 Volts and above

Speed km/h	Speed (mph)	3MP data Gross Tractive Effort kN	Gross Tractive Effort (lbs)	Train Resistance kN	Train Resistance (lbs)	Net Tractive Effort (lbs)	Acceleration (MPHPS)	Power (kW)	Propulsion Current *at 750V* (amps)	Elapsed Time (seconds)
0.00	0.00		3000	1.50	337	2663	0.18	132	176	0.0
0.80	0.50		13000	1.50	337	12663	0.85	145	193	1.0
1.61	1.00		20000	1.75	393	19607	1.32	172	229	1.4
16.09	10.00		20000	1.75	393	19607	1.32	530	706	8.3
32.19	20.00		20000	2.00	450	19550	1.31	939	1253	15.9
37.01	23.00		20000	2.75	618	19382	1.30	1080	1441	18.2
48.28	30.00		15000	3.00	674	14326	0.96	1057	1409	24.4
64.37	40.00		11280	3.50	787	10493	0.70	1060	1413	36.3
80.46	50.00		7200	3.50	787	6413	0.43	846	1127	54.0
96.56	60.00		4960	4.00	899	4061	0.27	699	932	77.3
104.60	65.00		4320	4.50	1012	3308	0.22	660	879	97.5

CHARACTERISTIC CURVE (POWERING/New car)

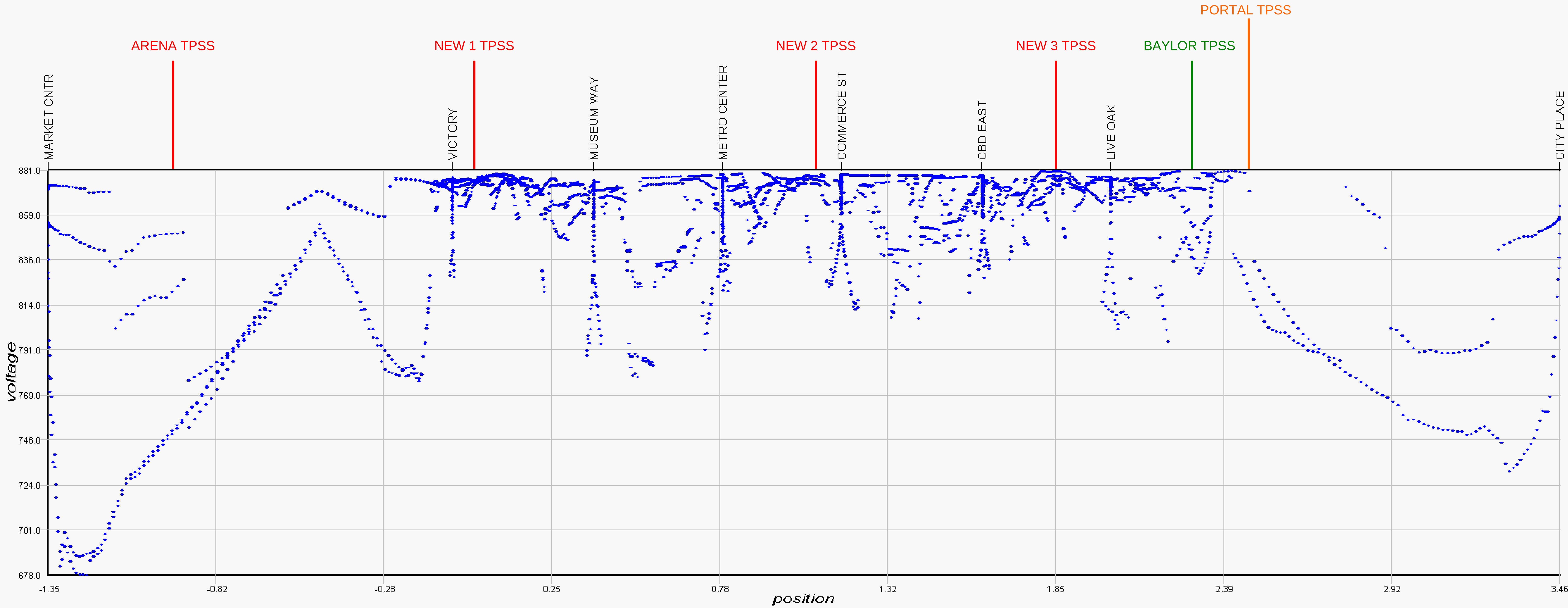


Appendix E – Normal Operations Scenario Simulation Results

Outp File: C:\tom\tomdat\drt\AO-Norm.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt

TRAIN VOLTAGE   Normal Operating Conditions - All TPSS in Service

Max Voltage = 881.9 - Min Voltage = 678.9

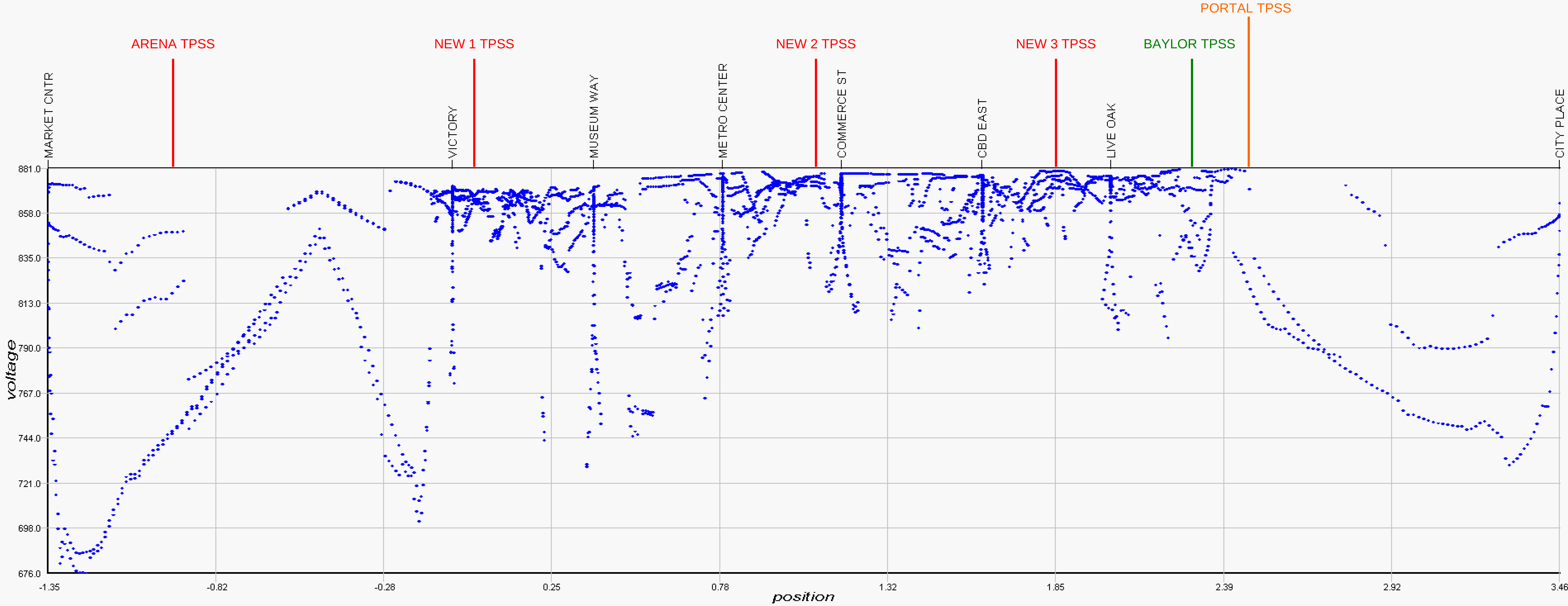


Appendix F – Outage Operations Scenario Simulation Results

Outp File: C:\tom\tomdat\drt\AO-N1O.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt

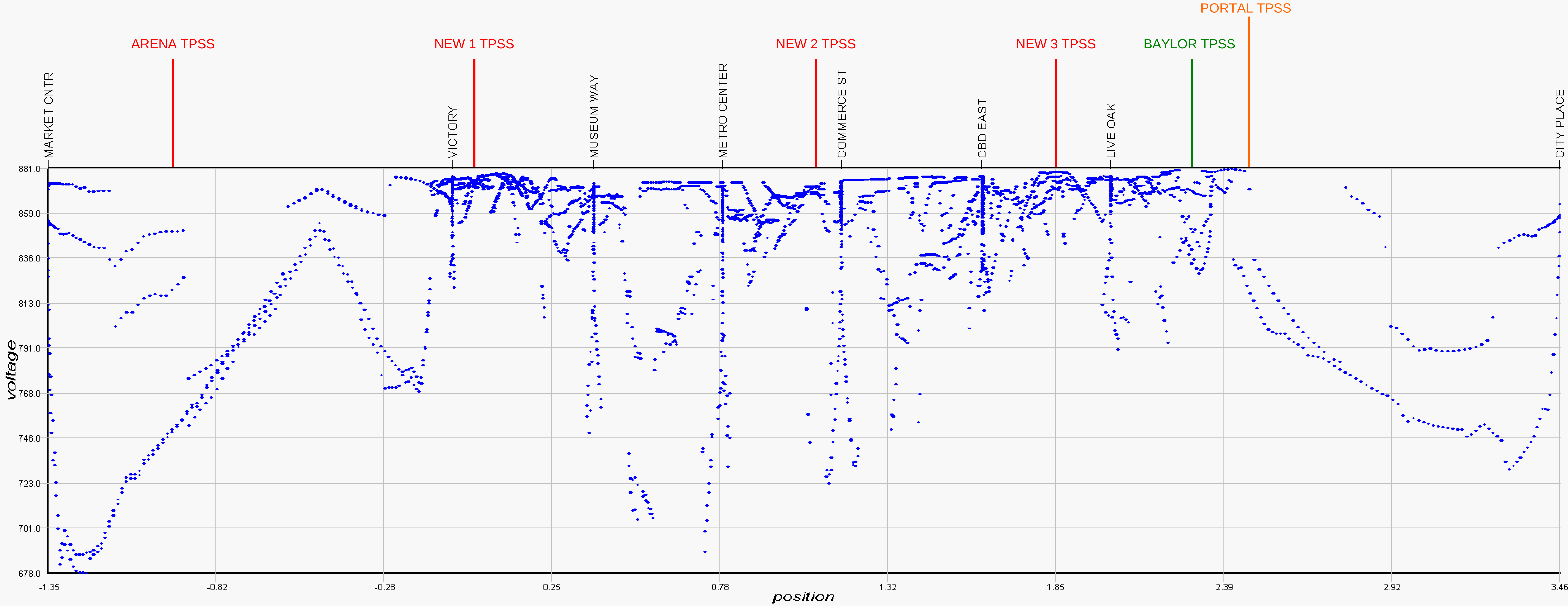
TRAIN VOLTAGE N1 TPSS Out of Service - Normal Schedule

Max Voltage = 881.7 - Min Voltage = 676.0



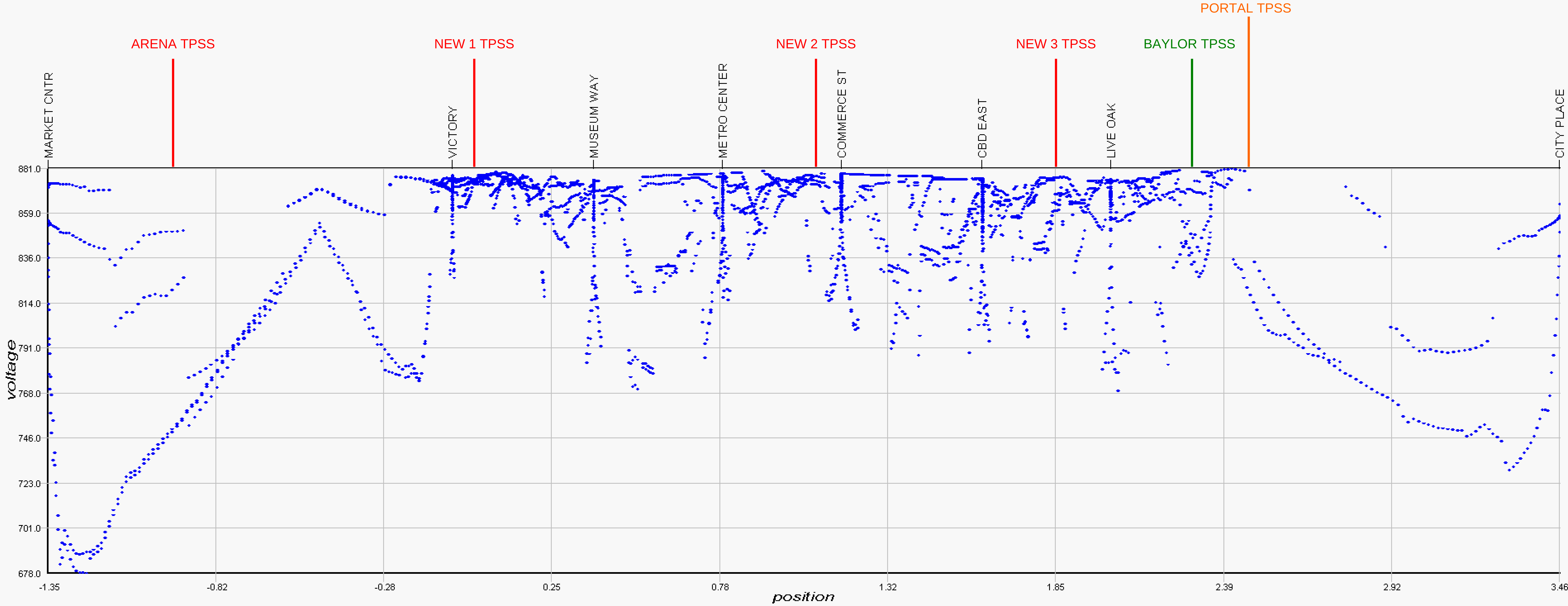
Outp File: C:\tom\tomdat\drt\AO-N2O.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt

TRAIN VOLTAGE N2 TPSS Out of Service - Normal Schedule
Max Voltage = 881.6 - Min Voltage = 678.5



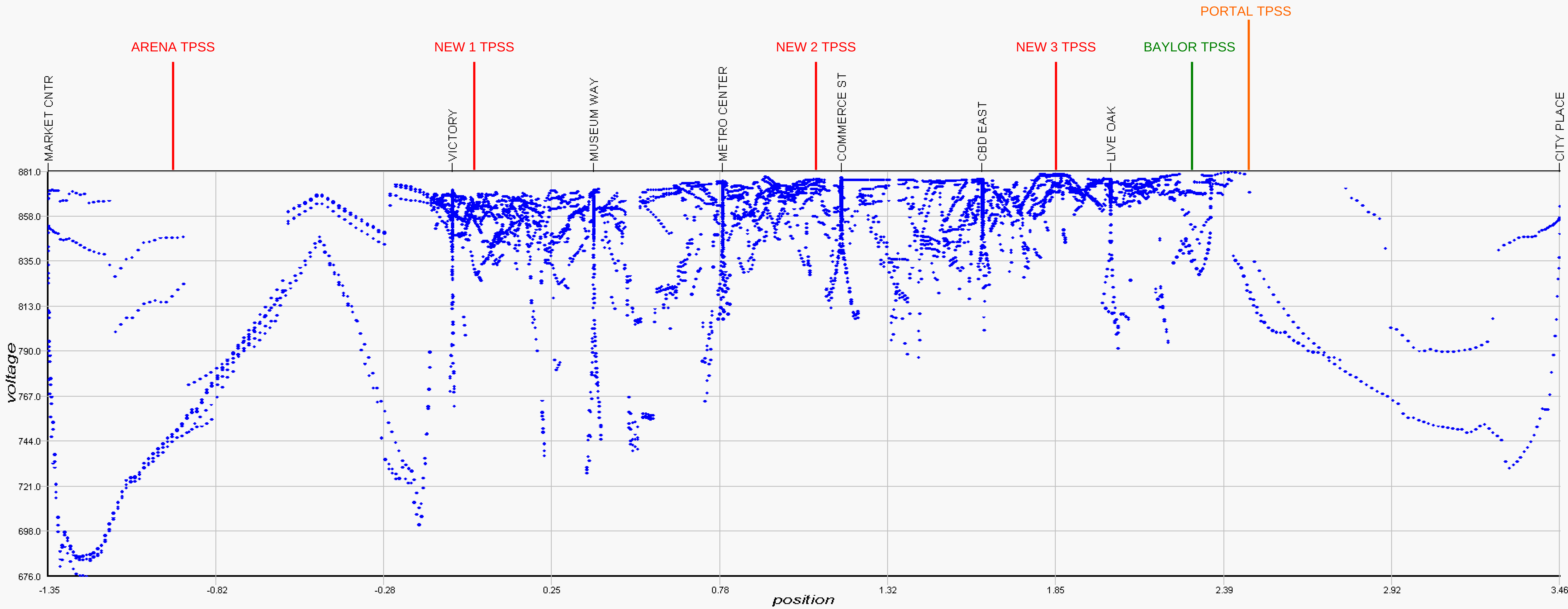
Outp File: C:\tom\tomdat\drt\AO-N3O.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt

TRAIN VOLTAGE   N3 TPSS Out of Service - Normal Schedule
Max Voltage = 881.7 - Min Voltage = 678.7



Outp File: C:\tom\tomdat\drt\AO-N1SS.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt

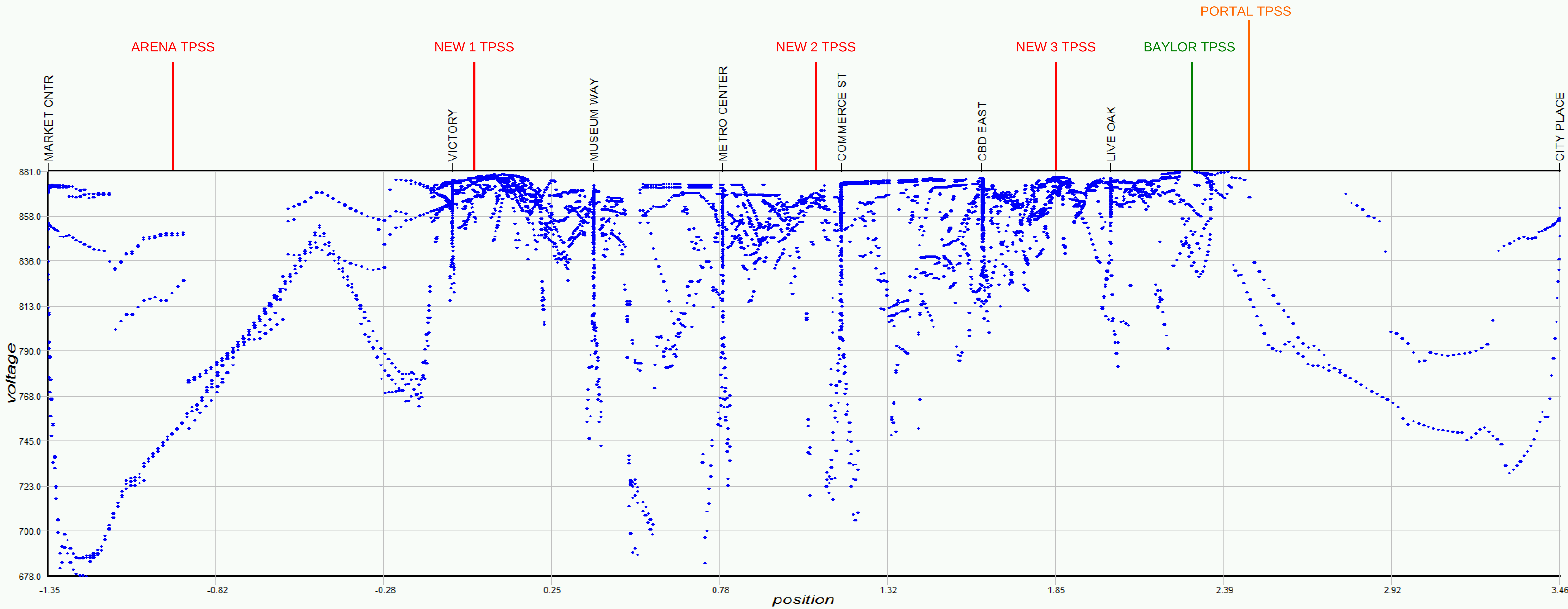
TRAIN VOLTAGE Simultaneous Start at near N1 TPSS - Victory
Max Voltage = 881.7 - Min Voltage = 676.0

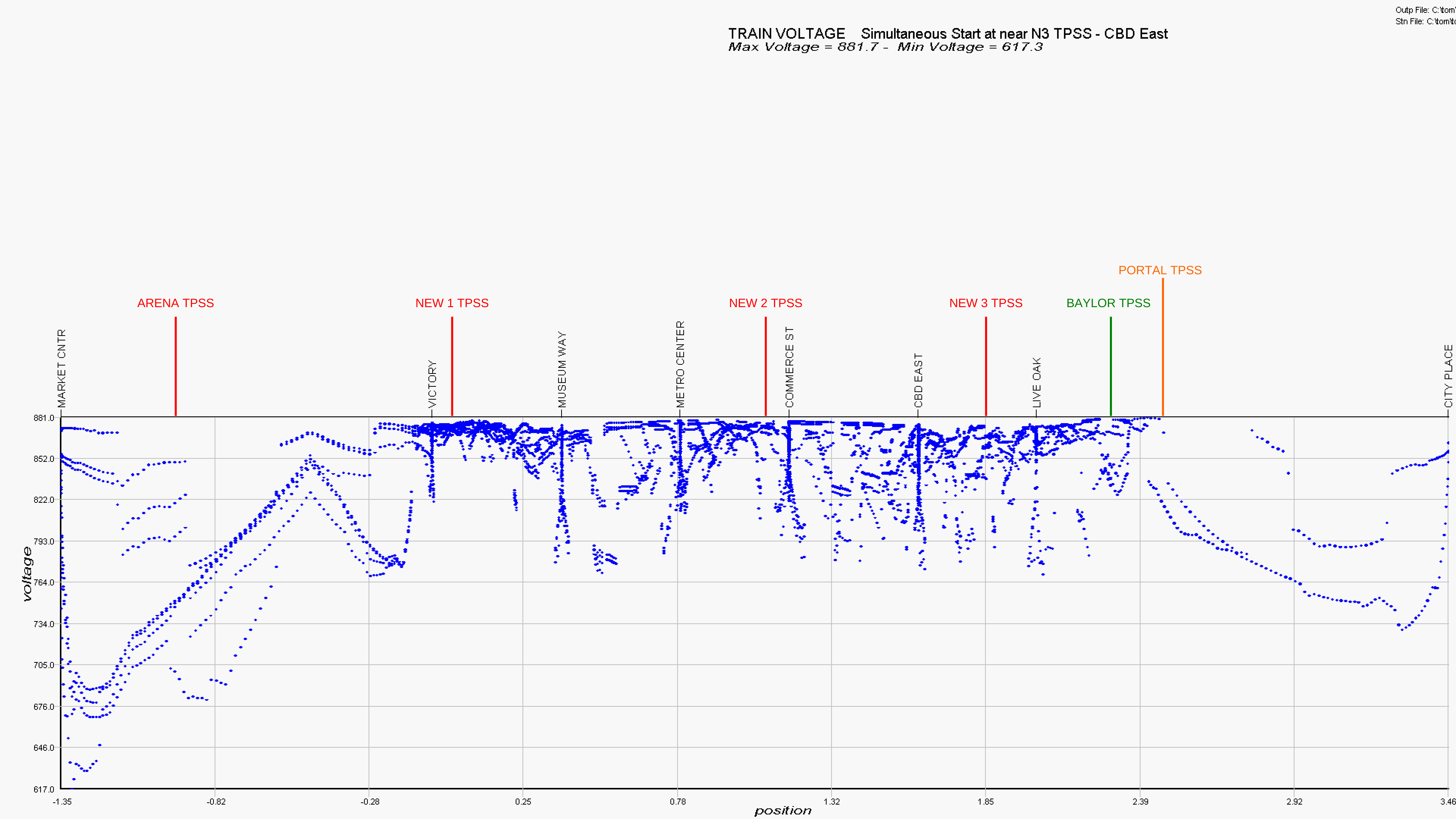


Outp File: C:\tom\tomdat\drt\AO-N2SS.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt

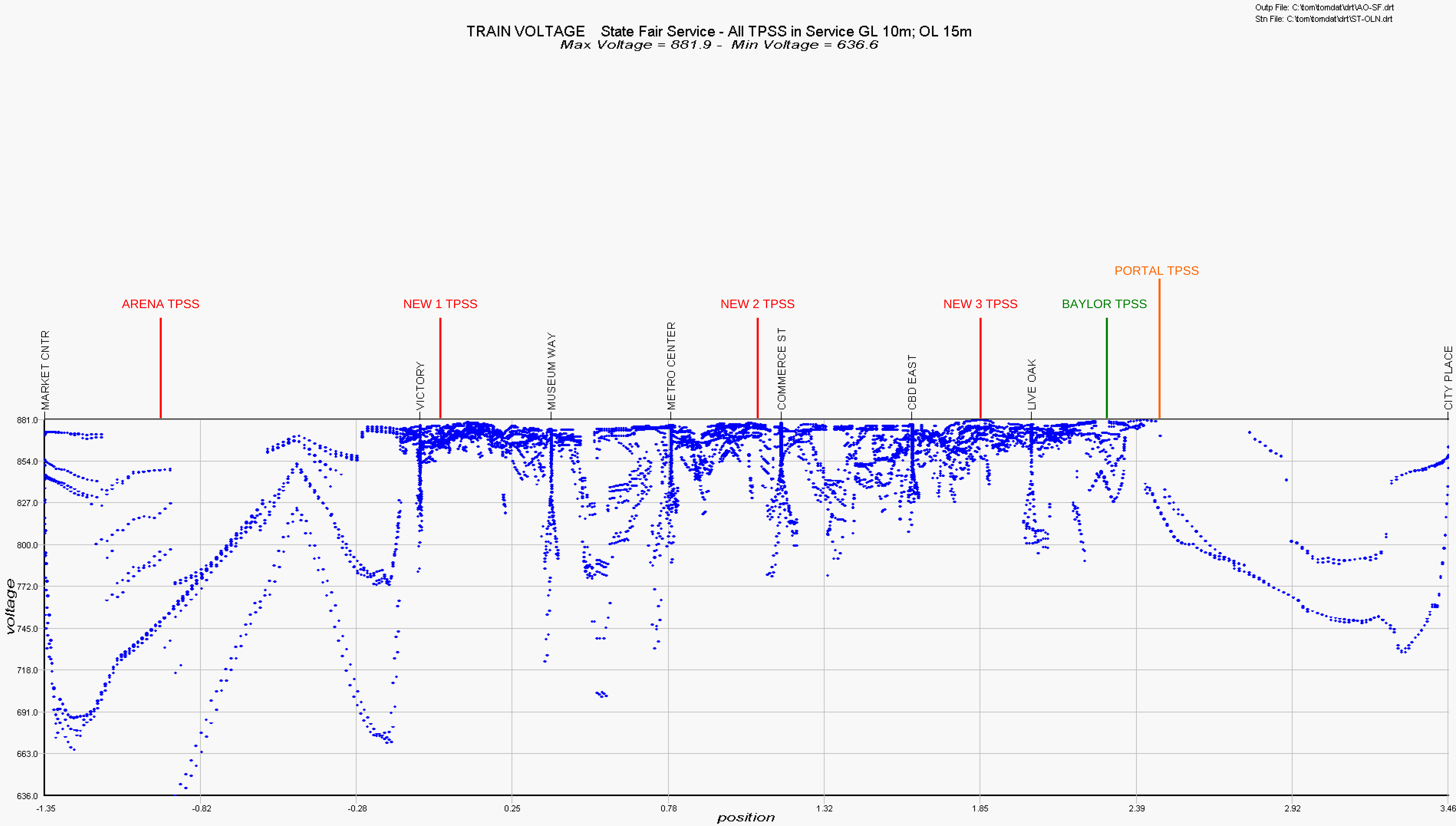
TRAIN VOLTAGE Simultaneous Start at near N2 TPSS - Commerce

Max Voltage = 881.1 - Min Voltage = 678.2




Outp File: C:\tom\
Stn File: C:\tom\to
TRAIN VOLTAGE Simultaneous Start at near N3 TPSS - CBD East
Max Voltage = 881.7 - Min Voltage = 617.3
PORTAL TPSS
ARENA TPSS
NEW 1 TPSS
NEW 2 TPSS
NEW 3 TPSS
BAYLOR TPSS
MARKET CNTR
VICTORY
MUSEUM WAY
METRO CENTER
COMMERCE ST
CBD EAST
LIVE OAK
CITY PLACE
voltage
881.0
852.0
822.0
793.0
764.0
734.0
705.0
676.0
646.0
617.0
-1.35
-0.82
-0.28
0.25
0.78
1.32
1.85
2.39
2.92
3.46
position

Appendix G – State Fair Special Event Operations Scenario Simulation Results

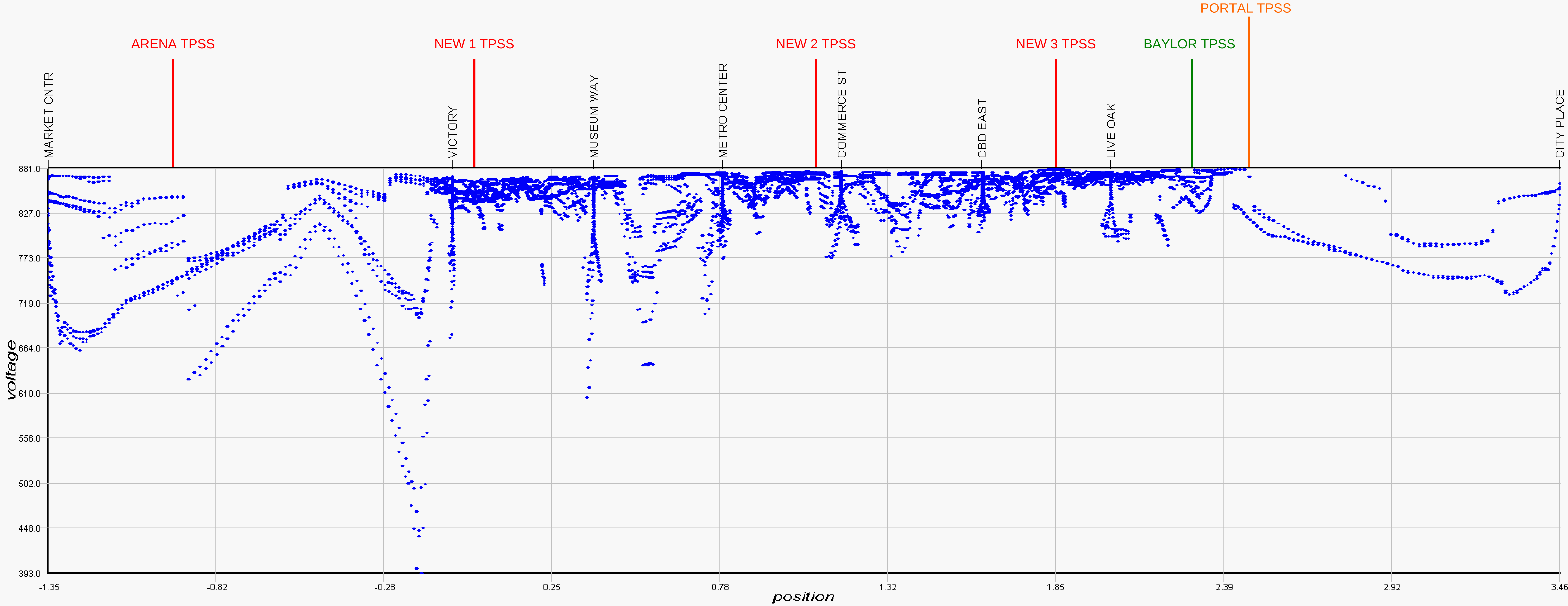


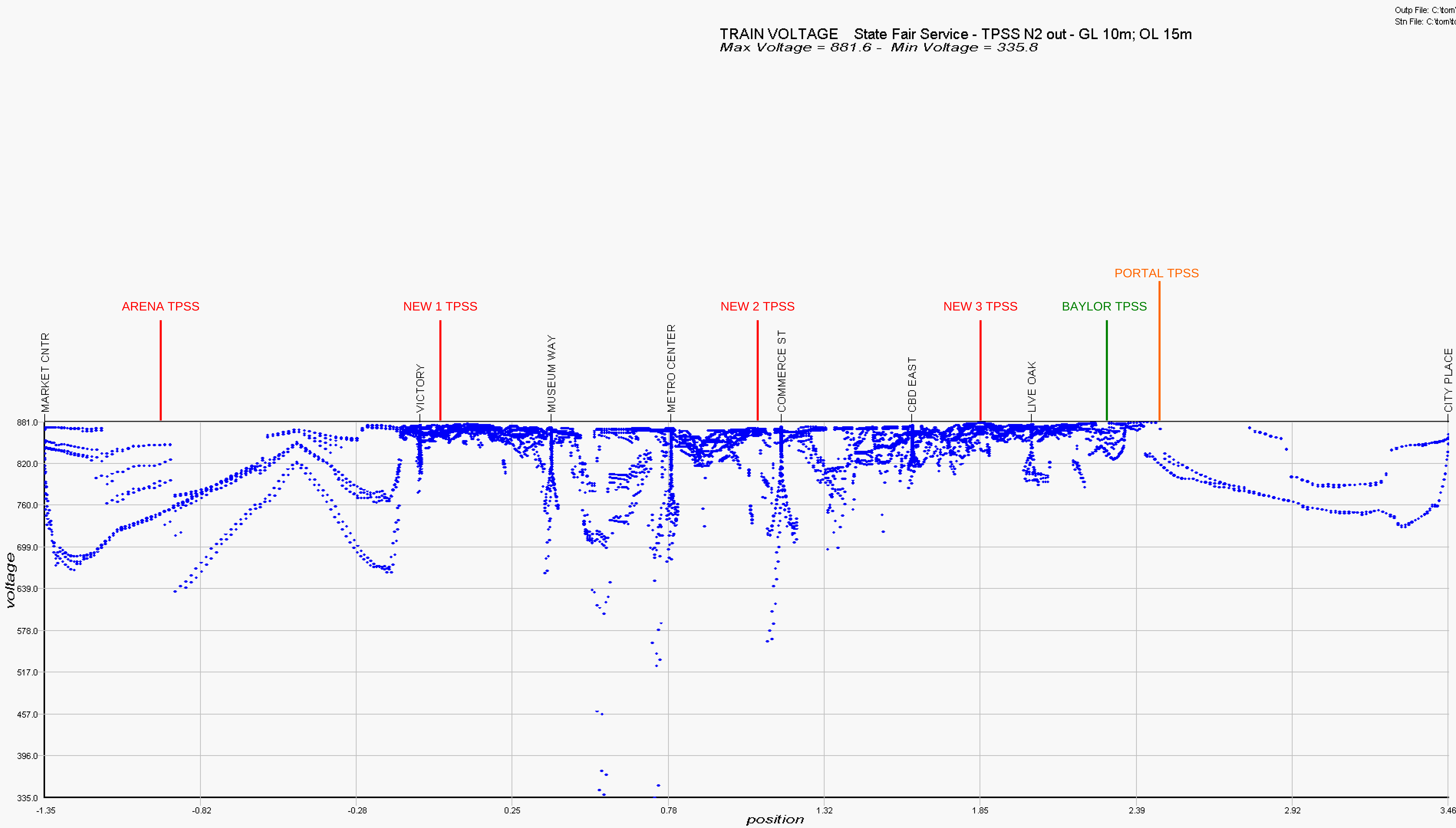
Outp File: C:\tom\tomdat\drt\AO-SF.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt
TRAIN VOLTAGE State Fair Service - All TPSS in Service GL 10m; OL 15m
Max Voltage = 881.9 - Min Voltage = 636.6
ARENA TPSS
NEW 1 TPSS
NEW 2 TPSS
NEW 3 TPSS
BAYLOR TPSS
PORTAL TPSS
MARKET CNTR
VICTORY
MUSEUM WAY
METRO CENTER
COMMERCE ST
CBD EAST
LIVE OAK
CITY PLACE
voltage
881.0
854.0
827.0
800.0
772.0
745.0
718.0
691.0
663.0
636.0
-1.35
-0.82
-0.28
0.25
0.78
1.32
1.85
2.39
2.92
3.46
position

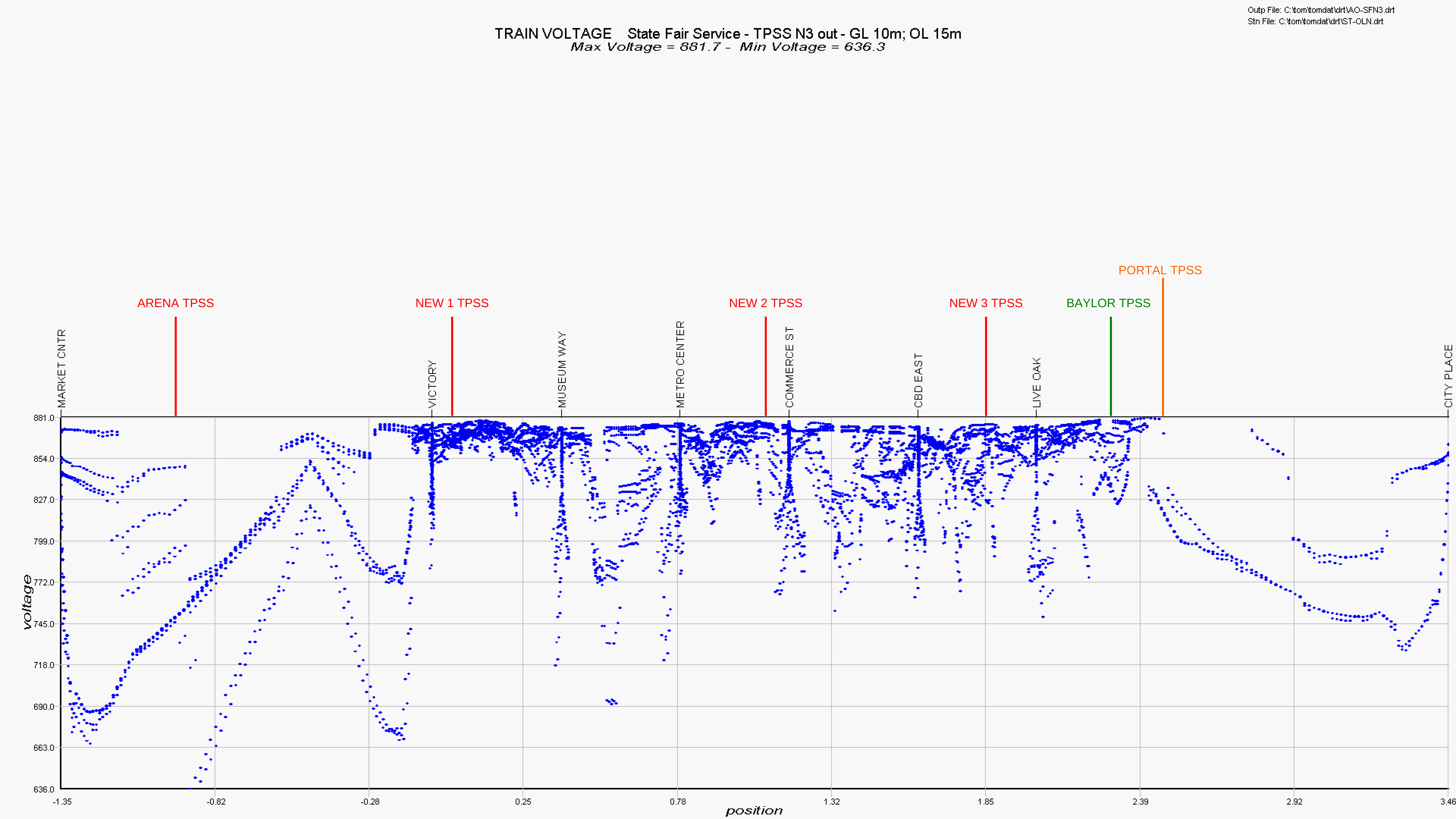
Outp File: C:\tom\tomdat\drt\AO-SFN1.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt

TRAIN VOLTAGE State Fair Service - TPSS N1 out - GL 10m; OL 15m

Max Voltage = 881.7 - Min Voltage = 393.8




Outp File: C:\tom\
Stn File: C:\tom\t
TRAIN VOLTAGE State Fair Service - TPSS N2 out - GL 10m; OL 15m
Max Voltage = 881.6 - Min Voltage = 335.8
ARENA TPSS
NEW 1 TPSS
NEW 2 TPSS
NEW 3 TPSS
BAYLOR TPSS
PORTAL TPSS
MARKET CNTR
VICTORY
MUSEUM WAY
METRO CENTER
COMMERCE ST
CBD EAST
LIVE OAK
CITY PLACE
voltage
881.0
820.0
760.0
699.0
639.0
578.0
517.0
457.0
396.0
335.0
-1.35
-0.82
-0.28
0.25
0.78
1.32
1.85
2.39
2.92
3.46
position


Outp File: C:\tom\tomdat\drt\AO-SFN3.drt
Stn File: C:\tom\tomdat\drt\ST-OLN.drt
TRAIN VOLTAGE State Fair Service - TPSS N3 out - GL 10m; OL 15m
Max Voltage = 881.7 - Min Voltage = 636.3
ARENA TPSS
NEW 1 TPSS
NEW 2 TPSS
NEW 3 TPSS
BAYLOR TPSS
PORTAL TPSS
MARKET CNTR
VICTORY
MUSEUM WAY
METRO CENTER
COMMERCE ST
CBD EAST
LIVE OAK
CITY PLACE
voltage
881.0
854.0
827.0
799.0
772.0
745.0
718.0
690.0
663.0
636.0
-1.35
-0.82
-0.28
0.25
0.78
1.32
1.85
2.39
2.92
3.46
position

Appendix H – Rectifier Loading

Computer Loadflow Simulation Study for DART D2 Subway Project										
Substation Rectifier Loading Results										
All Substations in Service										
Normal Scenario										
			Simulated Load Current		Rectifier Load Ratings			Rectifier Loading Analysis		
		Substation	(Col. 1)	(Col. 2)			1 Min.	Rms Loading Results (1)		Peak Loading (2)
		Rectifier	RMS	Peak	Continuous	2-Hr NEMA	NEMA	% of Contin.	% of 2-Hr	% of 1 Min.
Substation Name	MP	Capacity (kW)	(Continuous) Amps	(Instantaneous) Amps	Ratings (Amps)	Ratings (Amps)	Ratings (Amps)	Rectifier Rating	Rectifier Rating	Rectifier Rating
E1 - LUCAS	-1.688	2500	803	3,552	2,959	4,438	8,876	27.1	18.1	40.0
E2 - ARENA	-0.494	2500	912	2,364	2,959	4,438	8,876	30.8	20.5	26.6
N1 - NEW 1	0.090	2500	767	2,574	2,959	4,438	8,876	25.9	17.3	29.0
N2 - NEW 2	0.972	2500	933	3,180	2,959	4,438	8,876	31.5	21.0	35.8
N3 - NEW 3	1.850	2500	654	2,112	2,959	4,438	8,876	22.1	14.7	23.8
E3 - PORTAL	2.421	2500	622	2,784	2,959	4,438	8,876	21.0	14.0	31.4
E4 - SANDERS	3.558	2500	719	4,200	2,959	4,438	8,876	24.3	16.2	47.3
E5 - BAYLOR	2.270	2500	462	2,436	2,959	4,438	8,876	15.6	10.4	27.5
E6 - FAIR PARK	3.068	2500	145	821	2,959	4,438	8,876	4.9	3.3	9.3

Computer Loadflow Simulation Study for DART D2 Subway Project
Substation Rectifier Loading Results
Substations Out Of Service As Indicated - State Fair Schedule Included
SS indicates emergency simultaneous start case

Substation		Substation Rectifier Capacity			Rectifier RMS Load Current with Indicated Substation Out Of Service							
Name	MP	Total Rectifier Capacity (kW)	100% Continuous Rating (Amps)	2-Hr NEMA RI-9 Rating (Amps)	System Normal	OUT1 N1 - NEW 1	OUT2 N2 - NEW 2	OUT3 N3 - NEW 3	OUT4 / SS N1 - NEW 1	OUT5 / SS N2 - NEW 2	OUT6 / SS N3 - NEW 3	State Fair Schedule
E1 - LUCAS	-1.688	2500	2,959	4,438	803	837	811	806	997	895	2,081	939
		% of Continuous Rectifier Capacity Used			27.14%	28.30%	27.41%	27.23%	33.69%	30.25%	70.33%	31.75%
E2 - ARENA	-0.494	2500	2,959	4,438	912	1,182	973	929	1,344	1,080	1,518	1,192
		% of Continuous Rectifier Capacity Used			30.82%	39.95%	32.89%	31.39%	45.43%	36.50%	51.30%	40.29%
N1 - NEW 1	0.090	2500	2,959	4,438	767		1,033	831		1,196	914	971
		% of Continuous Rectifier Capacity Used			25.93%		34.91%	28.07%		40.42%	30.88%	32.83%
N2 - NEW 2	0.972	2500	2,959	4,438	933	1,180		1,124	1,326		1,205	1,171
		% of Continuous Rectifier Capacity Used			31.54%	39.88%		38.00%	44.83%		40.73%	39.57%
N3 - NEW 3	1.850	2500	2,959	4,438	654	758	985		853	1,217		810
		% of Continuous Rectifier Capacity Used			22.10%	25.62%	33.30%		28.84%	41.15%		27.38%
E3 - PORTAL	2.421	2500	2,959	4,438	622	647	697	725	664	769	722	651
		% of Continuous Rectifier Capacity Used			21.02%	21.88%	23.56%	24.50%	22.45%	25.98%	24.41%	22.01%
E4 - SANDERS	3.558	2500	2,959	4,438	719	722	727	729	723	737	634	723
		% of Continuous Rectifier Capacity Used			24.31%	24.42%	24.56%	24.65%	24.44%	24.90%	21.41%	24.44%
E5 - BAYLOR	2.270	2500	2,959	4,438	462	490	554	600	542	656	632	582
		% of Continuous Rectifier Capacity Used			15.62%	16.57%	18.74%	20.27%	18.31%	22.18%	21.34%	19.66%
E6 - FAIR PARK	3.068	2500	2,959	4,438	145	153	170	183	167	199	192	182
		% of Continuous Rectifier Capacity Used			4.89%	5.15%	5.75%	6.18%	5.64%	6.73%	6.49%	6.17%