DUALMODE TRANSPORTATION,

IMPACT ON THE ELECTRIC GRID

A Thesis

by

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Major Subject: Petroleum Engineering

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ABSTRACT

Dualmode Transportation, Impact on the Electric Grid. (December 2007)

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Continual increase in transport demand and uneven road capacity results in chaotic traffic congestion, brings with it high levels of air pollution, an elevated number of accidents, and an insatiable demand for oil to satisfy the motorized vehicles on roads. The dualmode transportation system is a transformational solution to address all of these problems simultaneously. This project will quantify the amount of energy needed to electrify a portion of the actual ground transportation (personal vehicle and freight) in a specific electric region grid and analyze the impact that it represents. A model that gives a close approximation of the electric energy demand that would be generated by converting existing traffic data into electricity demand was developed. This model allows for sensitivity testing of all conversion factors, data variation and variations in the different types of propulsion technology that may be used in the new system. Results show that inclusion of the new transportation system into the electric grid of Texas will not require significantly more energy than the current available resource.

DEDICATION

I dedicate my thesis:

Primary to God, the almighty, for always being there for me and blessing me with

health, strength, and peace for every goal proposed in my life

and

to my parents for their support, encouragement through the years

and for being good examples for me to emulate.

ACKNOWLEDGEMENTS

NOMENCLATURE

A	Area (Frontal) (m^2)
B_s	Breaking Severity (percent of full speed lost)
B_a	No. of break actuations
BTU	British Thermal Units
BTS	Bureau of Transportation Statistics
C_d	Co-efficient of drag
C_r	Co-efficient of rolling friction
E_a	Acceleration energy
E_{a0}	Energy to accelerate from zero
E_d	Energy to overcome drag (J)
E_{HVAC}	HVAC and equipment energy
ECAR	East Central Area Reliability Coordination Agreement
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
F_a	Force of Air resistance (N)
F_i	Force of Incline (N)
F_r	Force of rolling friction (N)
F_d	Drag force in Newton (N)

FERC	Federal Energy Regulatory Commission
FHWA	Federal Highway Administration
FRCC	Florida Reliability Coordinating Council
g	Acceleration due to Gravity(m/s^2)
GVW	Gross Vehicle Weight (Kg)
GWh	Gigawatt hour
HOV	High Occupancy Vehicle
HVAC	Heating, Ventilation and Air-Conditioning
I	Average road / guideway incline
KWh	Kilowatt-Hour
L_{trip}	Trip length (m)
MAAC	Mid-Atlantic Area Council
MAIN	Mid-America Interconnected Network
MAPP	Mid-Continent Area Power Pool
MRO	Midwest Reliability Organization
N	Number of times to accelerate from zero
NERC	National Electric Reliability Council
NPCC	Northeast Power Coordinating Council
P	Power consumed
ρ_a	Air Density ($kg\text{-}m/s^2$)
PL_{cap}	Payload Capacity for all freight vehicles
RFC	Reliability First Council

SERC	Southeastern Electric Reliability Council
SPP	Southwest Power Pool, Inc.
t	Drive time (s)
$Ton-mile_{FHWA}$	Reported Ton-Mile data for Texas/Region by FHWA
TTI	Texas Transportation Institute
v	Velocity (m/s)
VMT	Vehicle Miles Traveled
$VMT_{freight}$	Vehicle Miles Traveled by all freight Vehicles
WECC	Western Electric Coordinating Council
WSCC	Western System Coordinating Council
x	Freight Vehicle Loading Factor

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CHAPTER I

INTRODUCTION

United States road transportation today is beset with numerous challenges including traffic congestion, environmental pollution, safety and energy dependence. Texas particularly, has a challenge to grow transportation capacity at a pace adequate to meet the demand driven by population increases. The Texas population is expected to grow 64% over the next 25 years and vehicle miles traveled is expected to grow 214% over the same period[1]. At the same time road capacity is forecast to grow only 6% with inadequate funds for infrastructure construction. This mismatch between the growth in demand and capacity, results in increasing traffic congestion causing non-productive use of time and fuel while reducing economic competitiveness. Texas also needs to improve air quality. The major metropolitan areas of Texas are in non-attainment or near non-attainment status regarding air quality. A major contributor to the air quality problem is mobile emissions due to the internal combustion engine and a dependence on hydrocarbon primary fuels which are currently the most cost effective energy source for transportation. Cleaner alternatives do not have access to the transportation market.

This thesis follows the style of the *Journal of the Transportation Research Record.*

On the safety front, Texas has the second highest number of traffic fatalities among the 50 states with 3,675 deaths in 2003[2]. In 2000 there were 1450 fatalities involving high blood alcohol levels in Texas (38% of all fatalities) and the Department of Public Safety issued over a half million speeding violations. Clearly driver behavior is a major factor in both fatalities and accidents causing injuries or property damage. These combined challenges represent an opportunity for innovation. Solutions which hold the promise of reduced infrastructure cost, reduced traffic crashes due to driver error and other causes, and reduced mobile emissions with primary fuel flexibility should be of high interest. Dualmode vehicles are potentially such a solution and TxDOT is wise to investigate this opportunity on behalf of the citizens of the state of Texas.

Several concepts such as the introduction of High Occupancy Vehicle (HOV) Lanes, Car Pooling, Electric Hybrid Vehicles, Fuel Cell technology cars, to mention a few, have been implemented or proposed[3,4]. Unfortunately, these approaches only focus on the solution of one or two of the key problems. An alternative, which proposes a simultaneous solution to four of the major problems, congestion, pollution, safety and energy dependence, is dualmode vehicles and infrastructure.

A definition of dualmode used in the proceedings of a 1974 Transportation Research Board conference on dualmode systems[5], is:

> Dualmode transportation is that broad category of systems wherein
> vehicles may be operated in both of two modes: (a) manually controlled

and self propelled on ordinary streets and roadways and (b) automatically controlled and externally propelled (or both) or powered on special guideways. In general dual-mode transportation systems can include both common carrier and private vehicles and provide for the transport of both persons and freight over a common guideway facility.

The dualmode system proposed in this research refers to the capability of a single vehicle to be manually driven on conventional roadway system and also automatically controlled and propelled using a special guideway infrastructure that provides electric power to the vehicle in real time.

The new infrastructure may originally be designed and constructed to parallel existing highway infrastructures and would cater to both freight and personal vehicles as the current highway infrastructure does.

CHAPTER II

PROBLEM DESCRIPTION

The United States and Texas in particular have a transportation challenge that requires addressing the following four issues simultaneously: traffic congestion, environmental pollution, safety and energy dependence. In pursuit of a solution to these transportation challenges, various technological alternatives have been proposed. Notable among these alternatives is the concept of dualmode. Dualmode vehicles work like usual roadway vehicles using on-board energy storage when not on an electrified guideway but are equipped to be conveyed automatically using electricity provided in real time from the electric grid when on electrified guideways. This technology can impact both freight and passenger transportation and adds significant traffic capacity at a fraction of the cost for conventional capacity additions.

Electric power providers have expressed an interest in estimating how much electricity would be needed to electrically power much of ground transportation. So far, none of the varied groups of creative inventors have addressed the question of how much more energy is needed on the current electric grid to implement their proposed new technology. This project investigates the impact on the existing electric grid of electrifying highway transportation using dualmode transportation on an electric guideway infrastructure paralleling the existing Interstate highways and urban expressways. Data for the study include electric demand data from the Electric Reliability Council of Texas (ERCOT) and transportation data in vehicle miles traveled

for various personal and freight vehicle classes from the Texas Transportation Institute (TTI). Transportation energy requirements are converted to gigawatt hours (GWh) to estimate the capacity and peaking characteristics resulting from the conversion of a large portion of highway transportation energy demand to the electric grid.

CHAPTER III

SYSTEM DESCRIPTION

As a result of the urgent need to improve the transportation system, there have been several studies conducted by various groups in search of possible dualmode technologies. The system proposed in this study requires the development of both a new infrastructure and dual-mode vehicles that can access the new system as well as conventional roads. A brief description of the general idea for the system modeled in this study is presented in this chapter.

3.1 Vehicle

This study did not require any assumption on the way dualmode vehicles are powered in off-guideway mode. While on the guideway, vehicles will be powered in real time, directly from the guideway. This can be done through inductive coupling, sliding contact, maglev technology or any other suitable means. Because this power can also be used to charge an on-board battery, electric vehicles can leave the guideway with a fully charged battery. The stored battery energy can be used to power the vehicles while they are off-guideway, for a fully electric vehicle.

To optimize infrastructure construction costs, the guideway system will impose size and weight limitations on the guideway vehicles. The system is intended to accommodate personal, public transit and freight vehicles. Personal vehicle size and weight constraints should not make consumers reluctant to use the system. On the contrary, because the

system is envisioned to accommodate freight, personal vehicle size and style options much like what people drive today are envisioned with some light-weighting and aerodynamic improvements. Public transit vehicles would be personal vehicle (van or taxi) sizes operated in personal rapid transit (PRT) mode to achieve capacity.

Freight vehicles are assumed to carry light weight high value freight fitting within a 10 ft x 5 ft x 5 ft envelope with each vehicle capable of carrying two pallets weighing 2200 lbs each. High value goods are conceptually defined as those goods with a value greater than $715 per ton. Automation on the guideway would enable driverless operation for freight transport on terminal-to-terminal segments. Driverless operation of freight vehicles will avoid the current need to aggregate most freight to large loads. Freight that is too large in size or weight to fit within the guideway constraints would still need to be transported on regular highways or by rail.

3.2 Guideway

To avoid intersecting other systems, the electrified guideway should be constructed off-grade, preferably elevated. An elevated infrastructure could also be used to convey new transmission lines, as well as fiber-optic and communications cables. Power for the guideway will be supplied directly from the electric grid that may be tapped from the transmission side of the grid.

A modular design is envisioned. Guideway automation enables reducing the headway between vehicles to less than one foot even at high speed, thereby providing a capacity about 8 times that of conventional highways for a guideway velocity of 60 mph. As such, the elevated construction might be limited to 3 lanes in most applications, with the extra lane to be used when one lane is shut down for maintenance or in the rare event of a blockage of one of the guideway lanes.

To minimize vehicle power requirements and to ensure guideway automation, the model in this study assumes that the guideway on and off ramps provide acceleration and deceleration. Because the guideway operates at constant velocity, once vehicles are on the guideway, there is no need for any significant braking or acceleration. Regenerative braking while decelerating or traveling downhill will be captured with some conversion losses.

CHAPTER IV

DATA GATHERING

To investigate the effect of electrifying existing interstate/freeway transportation, as a start, the existing traffic volume and electric demand data and usage pattern is needed for a given region. A challenge for this study was to find both traffic and electric data for the same region. Electric data in North America is managed by electric regions as shown in Figure 1. Transportation data typically is supplied by state. Figure 1 shows that the Electric Reliability Council of Texas (ERCOT) covers mainly only the state of Texas. Since, in addition, the Texas Transportation Institute provides detailed information on traffic flow in Texas, Texas was used as the basis for the study. The regional mismatch due to ERCOT regions missing from Texas and outside Texas was assumed to be only a small error because these regions involve small populations.
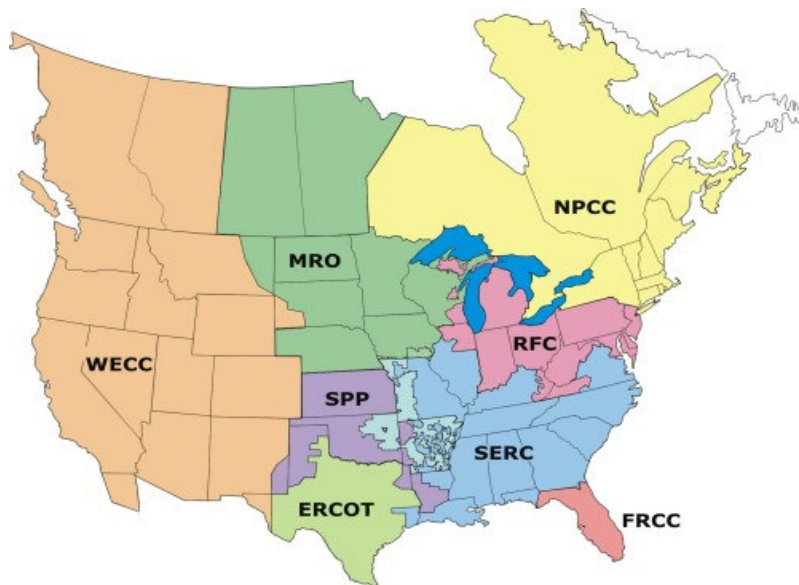

Figure 1: United States' Electric Reliability Regions (Source NERC).

4.1 Traffic Data

Traffic data for the regional case study area (Texas) were obtained from a myriad of sources including the Texas Transportation Institute (TTI)[6], the Federal Highway Administration (FHWA)[7] and the Bureau of Transportation Statistics (BTS)[8].

To research the impact of electrifying transportation on the electric grid in the study areas, this study required calculation of the additional energy demand that will be imposed on the grid by conveying on the new guideway freight and passenger vehicles currently driven on the freeways and interstate highways.

The calculation required total vehicle miles traveled (VMT) and the hourly volume pattern by each vehicle class and road type obtained from TTI data[7]. The total trucking freight tonnage for the city of Houston and the state of Texas obtained from reports compiled by the FHWA[8] were also used. Other required data such as the average passenger weight[9], average person per vehicle[10] and vehicle payload capacity[11] by class were also collected from different sources.

To illustrate the sort of data used in the study, Figure 2 depicts a graph of TTI data showing the seasonal difference in traffic volume by the day of the week. It would be noted that Monday through Thursday is lumped into a single curve because TTI traffic surveys in the region have not yielded a statistically significant difference in the volume and pattern of traffic for those days. Also notable in the graph is that on average, the peak traffic volume in Texas occurs on Fridays during the summer months.
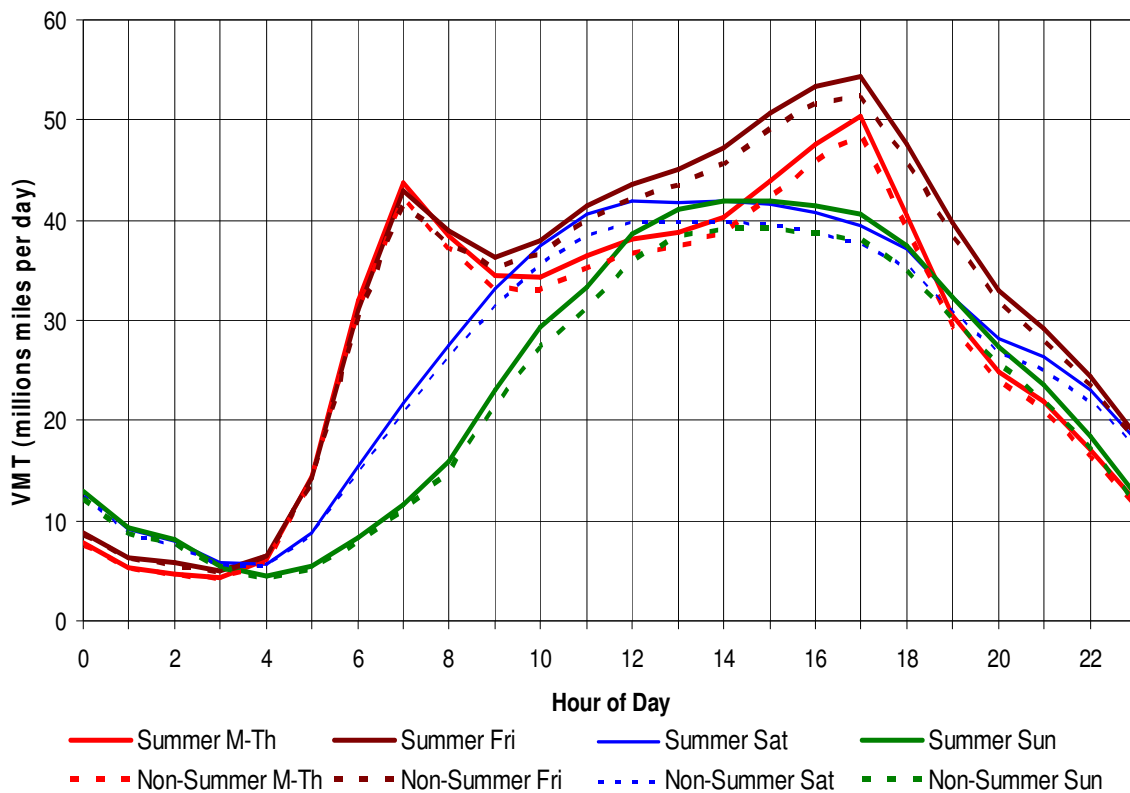
Figure 2: Vehicle Miles Traveled in Texas.

4.2 Electric Load Data

To ensure a good approximation of the impact of additional electric load on the existing electric grid, the electric load data used had to overlap the same region for which the traffic study was been carried out. As such, some historical demand data from the Electric Reliability Council of Texas (ERCOT) was obtained from an internal database upon request.

The electric load data used for this research was sourced from a 2006 energy demand archive file[12]. This file contains electric demand data for the year 2006, for the five

ERCOT regions (North, North East, South, West and Houston) in hourly intervals for each day of the year.

Figure 3 is a graph of typical daily electric demand for the Electric Reliability Council of Texas (ERCOT). The graph displays the average electric demand for each day for 2 weeks, one in January and one in August. It should be noted that in the ERCOT region, summer is the season with the highest electric demand and August is usually the month with the peak demand. January on the other hand is on average the coldest winter month in Texas[13]. This graph is designed to give the reader an insight into the electric demand pattern, based on seasonal differences, for the study region.
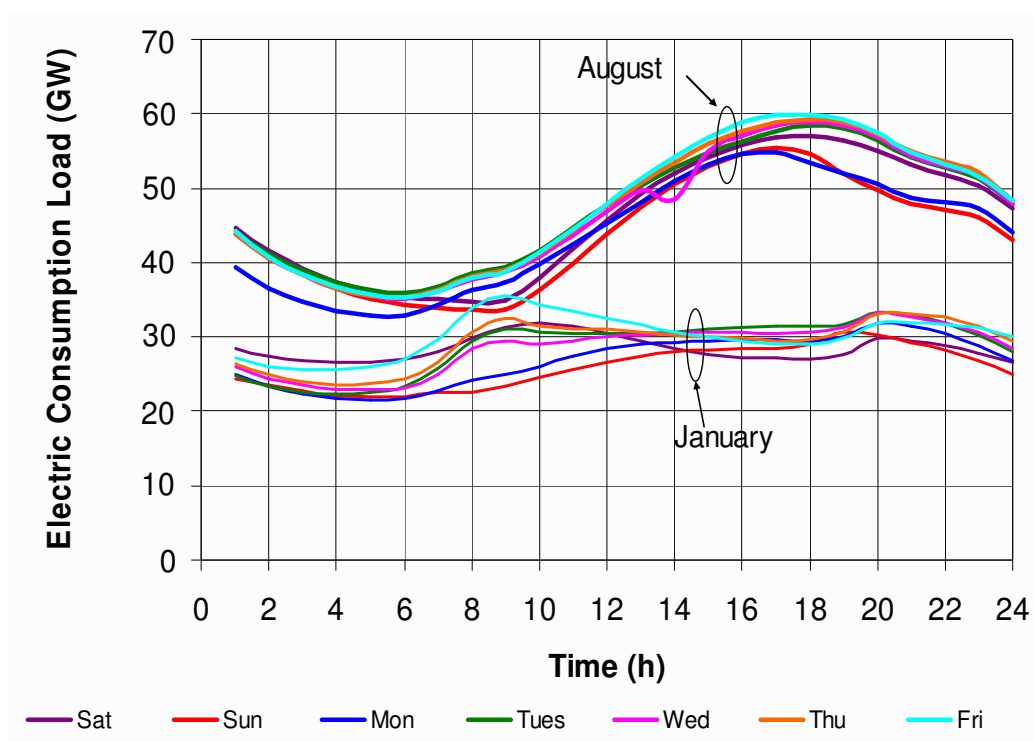

Figure 3: 2006 Electric Consumption Load in Texas (ERCOT).

CHAPTER V

ENERGY CONVERSION

In order to assess the impact on the electric grid that will result from the electrification of transportation, which according to the Energy Information Administration (EIA), currently makes up about 27% of total energy consumption in the US, the model developed for this study gives a close approximation of the electric energy demand that would be generated by converting existing traffic data into electricity demand. This model allows for sensitivity testing of all conversion factors, data variation and variations in the different types of propulsion technology that may be used in the new system. This section will explain the model to enable the reader to understand the process and easily repeat it for verification purposes.

5.1 Model Description

The traffic-to-electric conversion model developed for this research integrates the basic calculations for energy demand, in British Thermal Units (BTU), for a concept vehicle in motion and applies metric conversion to obtain the kilowatt-hour (kWh) equivalent.

The model is designed to dynamically accept values for the various factors considered which may vary due to technological availability and limitations. A concise description of the model will be explained using a capture view of the model shown in Tables 1 and 2. This should provide the reader with an understanding of the model that allows the

reader to be able to perform sensitivity testing based on factor values available to the

reader from various sources.

Table 1: Inputs into the Conversion Sheet.

Inputs	Analysis
Personal Vehicle (PV) Trip Length (miles)	11
Freight Trip Length (miles)	45.7
Vehicle Weight (Pounds)	2000
Freight Weight (Pounds)	4,400
Average Passenger Weight (Pounds)	173
Average Number of Passengers per Vehicle	1.6
Speed (mph)	100
Frontal Area of Vehicle (m^2)	2.07
Drive-Train Efficiency	0.9
Roll Resistance Co-efficient	0.0025
Drag Co-efficient	0.2
Average percent Incline (%)	0
Air Density (kg/m^3)	1.29
Power for Truck HVAC and Control Equipments (watts)	500
Power for Car HVAC and Control Equipments (watts)	1,000
Break Actuations per Trip	1
Average Breaking Severity (% of Full Speed Lost)	0.3
Number of Accelerations from Zero / Trip	1
Electric Motor Conversion Efficiency	0.9

The model calculations can be broken down into three main categories:

- Energy required to overcome drag forces

- Acceleration Energy

- Heating, Ventilation and Air-Conditioning (HVAC) & Equipment Energy

Table 2: Outputs from the Conversion Sheet.

Outputs	Values
Gross Vehicle Weight (lbs)	6,400
Gross Vehicle Weight (Kg)	2,900
Trip Length (km)	73.5
Speed (km/h)	161
Speed(m/s)	45
Approximate Drive Time	0.46
ForceOfRolling Friction	71.2
ForceOfAirResistance	535
ForceOfIncline	0
Total Drag Force	606
Energy to overcome drag	44,500,000
Acceleration Energy from Zero	2,900,000
Acceleration Energy from Zero per Trip	2,900,000
Acceleration Energy to Regain Speed	870,000
Total Acceleration Energy	3,770,000
HVAC & Equipment Energy (joules)	822,000
Total Trip Energy (joules)	49,100,000
Total Trip Energy (mmbtu)	0.0465
System Efficiency	0.81
Primary Fuel Energy Requirement (joules)	60,600,000
Primary Fuel Energy Requirement (mmbtu)	0.0574
Energy Requirement (kWh)	16.8

5.1.1 Energy to Overcome Drag Forces

The drag forces acting on the vehicle is comprised of the forces of rolling friction, air

resistance and incline.

$$F_d = F_a + F_i + F_r \tag{1}$$

$$F_a = 0.5 * C_d * \rho_a * A * v^2 \tag{2}$$

$$F_i = I * GVW * g \tag{3}$$

$$F_r = C_r * GVW * g \tag{4}$$

Where,

C_d -   Co-efficient of aerodynamic drag

C_r -   Co-efficient of rolling resistance

ρ_a -   Air density (kg/m^3)

A -   Area (Frontal) (m^2)

F_a -   Aerodynamic drag (N)

F_d -   Total drag force (N)

F_i -   Force to overcome elevation (N)

F_r -   Rolling resistance (N)

v -   Velocity (m/s)

g -   Acceleration due to Gravity (m/s^2)

GVW -   Gross Vehicle Weight (kg)

I -   Average road or guideway incline (%)

The energy to overcome drag is the product of the total drag force and the trip length:

$$E_d = F_d * L_{trip} \tag{5}$$

Where,

E_d -   Energy to overcome drag (J)

L_{trip} -   Trip length (m)

5.1.2 Acceleration Energy

The acceleration energy of the guideway vehicles comprises of the initial energy to accelerate to full speed and the acceleration energy to regain full speed after break actuations in a trip. This value of the acceleration energy required is clearly affected by the number of break actuations per trip. For the guideway vehicles, we have assumed a single break actuation per trip based on the consideration that guideway vehicles will be able to enter and exit the guideway seamlessly without considerably interrupting the constant cruising velocity of vehicle that are already or remain on the guideway. Total acceleration energy is the sum of energy to accelerate from zero and the energy to regain speed.

$$E_a = N * E_{a0} + B_s * E_{a0} * B_a \tag{6}$$

$$E_{a0} = 0.5 * GVW * v^2 \tag{7}$$

Where,

B_s -   Breaking Severity (percent of full speed lost)

B_a -   Number of break actuations

E_a -   Acceleration energy (J)

E_{a0} -   Energy to accelerate from zero (J)

N -   Number of times to accelerate from zero

For an ideal case considered for a guideway infrastructure, the breaking severity may be 1% or less, which greatly reduces the amount of energy to regain cruising speed in the case of a break actuation and as such does not present a significant increase in the energy demand.

5.1.3 Heating, Ventilation and Air-Conditioning (HVAC) & Equipment Energy

The HVAC and Equipment energy is a measure of the total energy that will be consumed by the various electronics, control, lighting, entertainment, comfort and climate control systems of the vehicle. A combined wattage rating is used to represent the power required for all this system.

$$E_{HVAC} = P * t \tag{8}$$

Where,

$$t = (L_{trip} / v) * 3600 \tag{9}$$

And

E_{HVAC} - HVAC and equipment energy (J)

P - Power consumed (J/s)

t - Drive time (s)

The total energy, E_t, required by the vehicle per trip on the guideway, is a simple addition of the component energy listed above.

$$E_t = E_a + E_{HVAC} + E_d \tag{10}$$

It should be noted that for this study, a payload capacity of 2 tons or 4,400 pounds has been set for a guideway freight vehicle. This payload capacity is equivalent to the approximate weight of two loaded freight pallets. The low payload capacity allows for a low gross vehicle weight (GVW) and the 2 pallet limit ensures that the guideway freight vehicle is easily loaded and sent across the guideway without having to delay shipments while pallets pool up. This limit on the payload capacity also makes it possible to determine the number of guideway freight vehicles that will be needed to convey the equivalent freight tonnage as reported by the FHWA for the region in a year.

The set payload capacity also lends itself to the determination of the average Trip-Length that each guideway vehicle will go to equal the FHWA estimated vehicle miles traveled (VMT) by freight in the city of Houston and the state of Texas. The average trip-length is a key sensitivity factor that was found to have considerable effect on the energy demand, this will be discussed further in the results.

CHAPTER VI

DATA INTEGRATION AND RESULTS

The two previous chapters on data gathering and energy conversion, described the data available for this study and presented the conversion model. This chapter will present the data processing used to convert the available data into the form required by the model. Furthermore, it will present some results that give an estimate for the total energy demand on the electric grid at a time when the guideway system is implemented.

6.1 Data Processing

As a result of constraints due to the granularity, specificity and accuracy of the available traffic data, some assumptions, which will be discussed, were made during the processing of the traffic data. The approach used in the processing is presented below.

6.1.1 Vehicle Miles Traveled (VMT)

Data from TTI has VMT information for the state of Texas averaged by season (summer, non-summer), day of the week (Weekday, Friday, Saturday, Sunday), Road Class (Freeway/Interstate, Collector, Arterial), Vehicle Class (using EPA classification shown in Table 3) and ratio by hour of day. The data is presented by county which is specified in terms of urban and rural areas.

Table 3: EPA Classification of Vehicle by Class.

EPA	Description	GVWR [lbs]	Payload Cap. [lbs]
LDV	Light-Duty Vehicles	0 - 6,000	1,500
LDT	Light-Duty Trucks	0 - 6,000	1,500
HDV2B	Class 2b Heavy-Duty Vehicles	8,501 - 10,000	3,100
HDV3	Class 3 Heavy-Duty Vehicles	10,001 - 14,000	6,200
HDV4	Class 4 Heavy-Duty Vehicles	14,001 - 16,000	8,600
HDV5	Class 5 Heavy-Duty Vehicles	16,001 - 19,500	13,100
HDV6	Class 6 Heavy-Duty Vehicles	19,501 - 26,000	14,600
HDV7	Class 7 Heavy-Duty Vehicles	26,001 - 33,000	16,100
HDV8A	Class 8a Heavy-Duty Vehicles	33,001 - 60,000	43,600
HDV8B	Class 8b Heavy-Duty Vehicles	> 60,000	45,500

To arrive at the VMT by vehicle class for all interstate/freeways, the VMT by vehicle class for all urban and rural counties were averaged and multiplied by the percentage of VMT for urban (38.773%) and rural (19.275%) environments. This gave the average daily VMT by day of the week for each vehicle class. Then the hourly ratio was used to decompose the daily VMT into hourly data. At the end this process provided the VMT by vehicle class and hour of day for each day of the week.

6.1.2 Tonnage

FHWA 'Truck Tonnage by state[8], provides data for the freight tonnage leaving, entering, within and through the state of Texas and BTS 'Commodity Flow Survey[9] provides data for the trucking ton-miles for the state of Texas. Unfortunately, the available tonnage and ton-mile data cannot be easily refined to obtain freight data on only interstate/freeways in Texas. For this reason, an approximate technique was developed

that allows the entry of the ton-mile data for each road type into my model. This technique combines the U.S. Environmental Protection Agency (EPA) vehicle classification, payload capacity by vehicle class and the established VMT from TTI data to compute the estimated ton-mile data for Texas. Built into this approach is the ability to apply different loading factors to run sensitivities on the ton-mile data. For the purpose of this research, the loading factor (x) for the base case was calculated by multiplying the total VMT for freight vehicles in the state of Texas by the max payload capacity calculated for freight vehicles and comparing the result to the ton-mile data from BTS 'Commodity Flow Survey[9]. This process is illustrated in equation 11.

$$x = \frac{PL_{cap} * VMT_{freight}}{Ton-Mile_{FHWA}} \quad (11)$$

Where,

PL_{cap} -Payload Capacity for all freight vehicles (ton)

x -Freight Vehicle Loading Factor

$VMT_{freight}$ -Vehicle Miles Traveled by all freight Vehicles (miles)

$Ton-mile_{FHWA}$ -Reported Ton-Mile data for Texas/Region by FHWA

By this mechanism, the loading factor determined for this study is 60%.

In the case of personal vehicles, the average person weight in the study area (173 lbs)[10] is multiplied by the average number of persons per vehicle (1.6)[11] in the region to obtain the approximate passenger weight for personal vehicles on the guideway.

6.1.3 Trip-length

To determine the average trip-length for each guideway freight vehicle, the total VMT by all freight class vehicles is divided by the total number of guideway freight vehicles. The number of vehicles used in this calculation is obtained by dividing the total freight tonnage by the guideway vehicle payload capacity. Personal vehicle trip-length on the other hand is gotten from a national estimate. This number can be varied to account for differing passenger trip-length for various regions depending on the sprawl of the region, especially the urban areas within the region.

For personal vehicles, in this study the urban average trip-length was assumed to be 11 mi, and the rural average trip-length was assumed to be 100 mi. For freight the urban average trip-length calculated for Houston as 45.7 mi, (shown in Table 1) was used as a proxy for all urban areas, and the rural average trip-length was assumed to be 100 mi as for personal vehicles.

6.2 Results

The data (payload, and trip-length) obtained from the data processing section above is fed into the conversion model to generate the electric demand per guideway truck/car which is then multiplied by the number of guideway trucks/cars for each hour of the day.

6.2.1 Sensitivity Study

Figures 4 and 5 show electric demand computed by the model for freight and personal vehicles at potential urban and rural guideway speeds. This study assumes that two system velocities will be developed, one for urban transportation and another at higher velocity for intercity transportation.

Figure 4 shows the electric demand by time of day calculated by the model for the movement of freight on the guideway. This is a graph for a base case scenario given the current volume of freight through the state of Texas. Figure 5a shows the electric demand at a 60% loading factor in urban areas for speeds of 50, 75, and 100 mph, while Figure 4b depicts a similar picture for rural areas at speeds of 100, 150, and 200. These figures show that the energy required is highly dependent on the vehicle velocity. Figure 4c shows 3 scenarios, each assuming one velocity for the urban guideway and double the urban velocity for the rural guideway and combining the two in proportion to actual urban and rural transportation data. Summer traffic data were used for this calculation.

In a similar way, Figure 5 shows a graph of electric demand for personal vehicles for the same speeds, also using summer traffic data. Comparison of Figures 4 and 5 reveals that the potential electric demand is greater from freight than from personal vehicles, even though weekly average VMT by personal vehicle were much greater (more than 170 million) than by truck freight (more than 22 million during summer months. Although the urban energy demand is estimated to be greater for personal vehicles, the rural energy demand is much greater for freight vehicles, accounting for the overall greater demand in this sector. In particular, the aerodynamic drag force in Eqn. 2 shows that the assumed higher velocities for rural transport combined with the drag co-efficient, C_d which is 0.2 for personal vehicle while 0.4 for truck freight, and the frontal area of vehicle, A, which is 2.04 m^2 for personal vehicle and 5.57 m^2 for truck freight accounts for the overall greater estimate for freight energy demand.
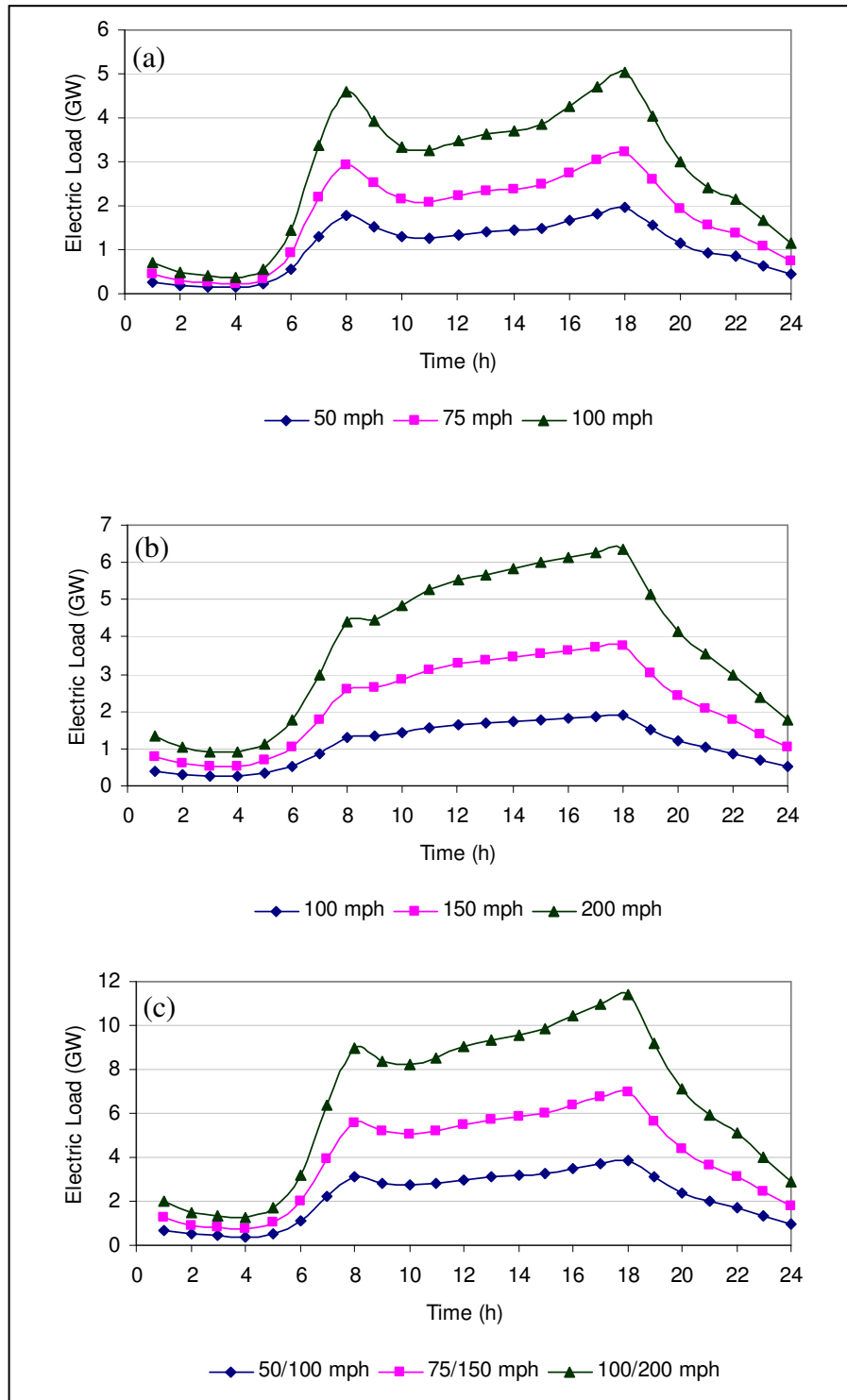
Figure 4: Summer Electric Load for Freight in Texas (a) Urban (b) Rural (c) Urban + Rural.
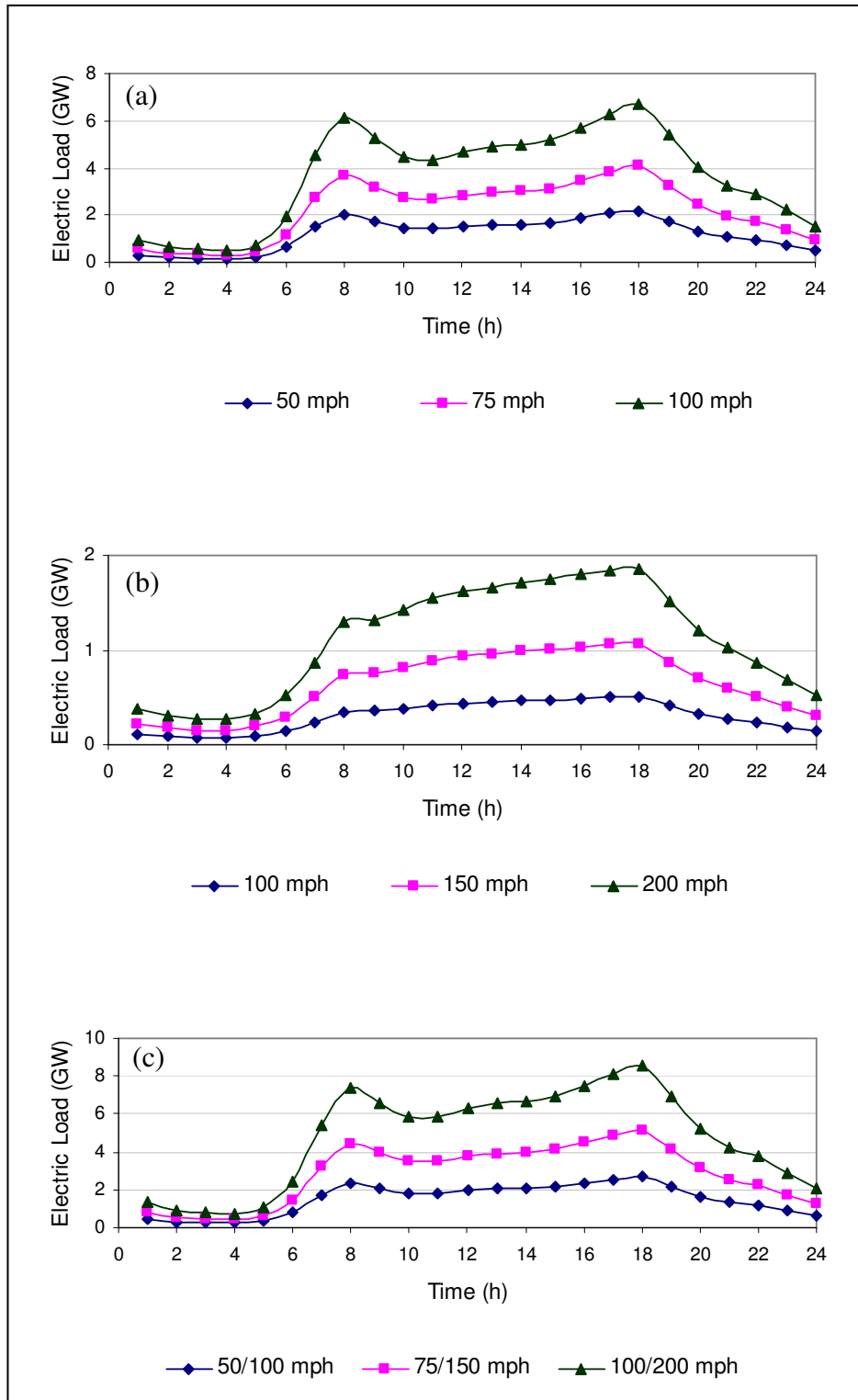
Figure 5: Summer Electric Load for Personal Vehicles in Texas (a) Urban (b) Rural (c) Urban + Rural.

6.2.2 Seasonal Scenario Comparison of the Electricity Requirement

Figure 6 compares summer versus non-summer scenarios showing the total demand that would be imposed on the ERCOT electric grid assuming that all freight and personal vehicles currently using interstate highways and urban freeways would instead travel on the guideway. Combining potential electricity demand for the guideways with current electric demand on the same graphic illustrates that this fraction of transportation demand is much smaller than the summer electric demand, but both transportation and electric energy demands peak at about the same times. When added to the current electric demand, the total demand for electricity exceeds the available capacity of 70,500 MW. In the non-summer scenario, as shown in Figure 3, the electric demand is much lower, while transportation energy demand is slightly higher in this time frame. Nonetheless, in this case the combined demand is much less than the available capacity.

The summer month is August, non-summer month is February, and for a worst case scenario, the assumed speed is 100 mph urban and 200 mph rural, and the freight payload factor is 100%. It should be noted that the available resource for ERCOT is the maximum guaranteed power that ERCOT can supply. This is less than installed capacity.

At current U.S. cost of gasoline at $3 per gallon and national average cost of electricity at 8.5 cents per kilowatts, a Dualmode vehicle runs on an equivalent of 75 cents per gallon, which is more than 300% in fuel efficiency.
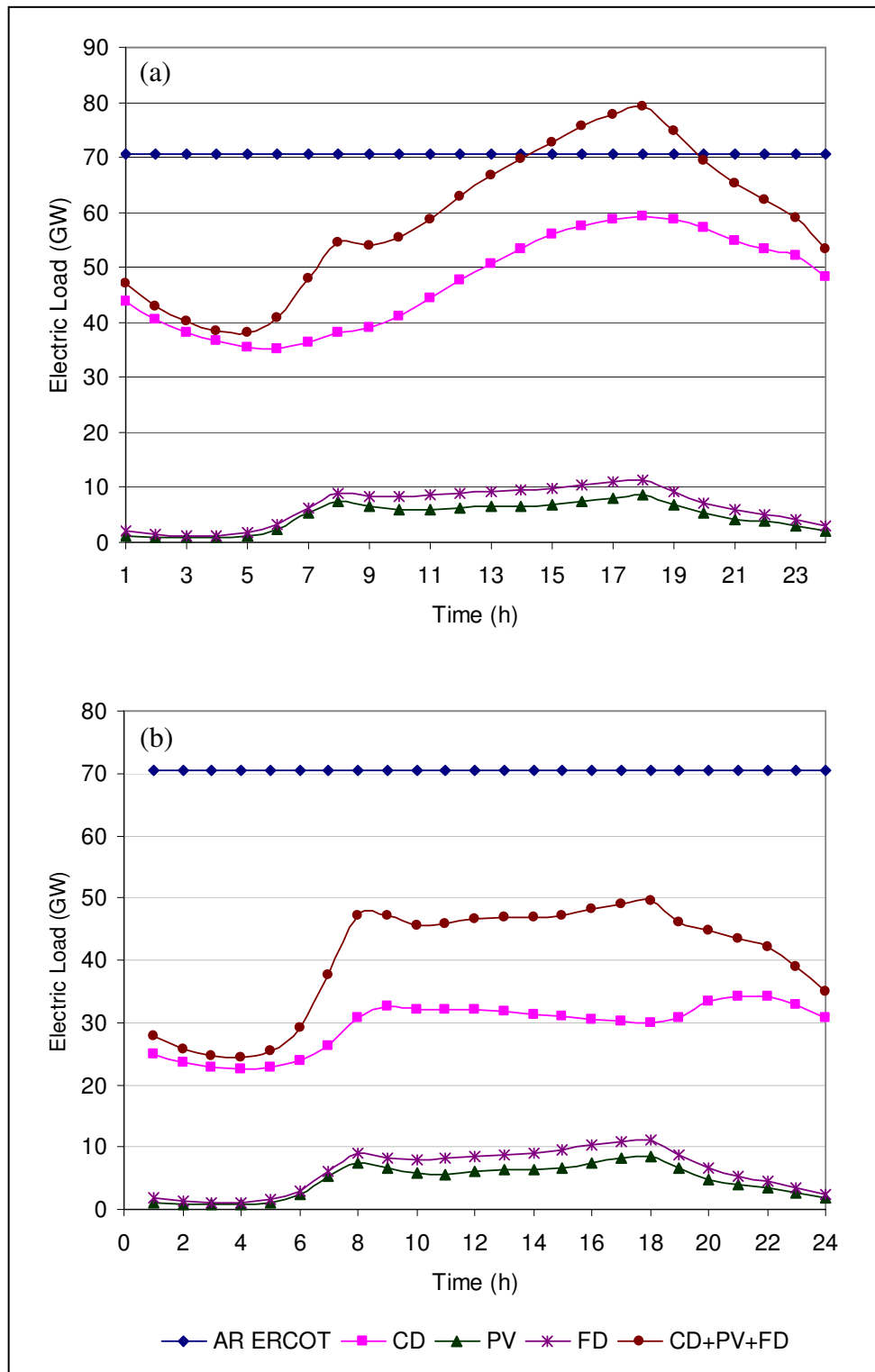
Figure 6: Total Electric Demand: (a) Summer, (b) Non-Summer.

6.3 Power Leveling

Recalling that vehicles on the guideway are going to be fully automated and hence for freight driverless, there will be a significant incentive for the freight industry to use the guideway system. At proposed guideway speeds it will be possible to ferry freight over a 600 mile distance in as little as 3 to 4 hours. Without the need for drivers, it will be possible to transport goods during the off demand peak hours of the night which in turn creates a sustainable demand for off peak electricity that could be charged at a lower rate as an incentive for those who take advantage of the time window. This results in a win-win situation for both the freight and electric industry. Figure 7a compares the possible result of this approach for the summer season, while figure 7b shows the non-summer equivalent.

Figure 7a indicates still a need for additional generation capacity and illustrates that dualmode transportation could represent a great incentive for the electric industry providing both a sustained need and potentially a hardened infrastructure for additional transmission lines.

So far the modeling has not addressed the additional electric demand represented by electric dualmode cars using battery power when not on the guideway. Incentives could encourage consumers to charge electric car batteries at off peak times. However, it is easily seen that if all electric vehicles were to be charged during the current off peak hours, the timing of peak demand could shift dramatically.
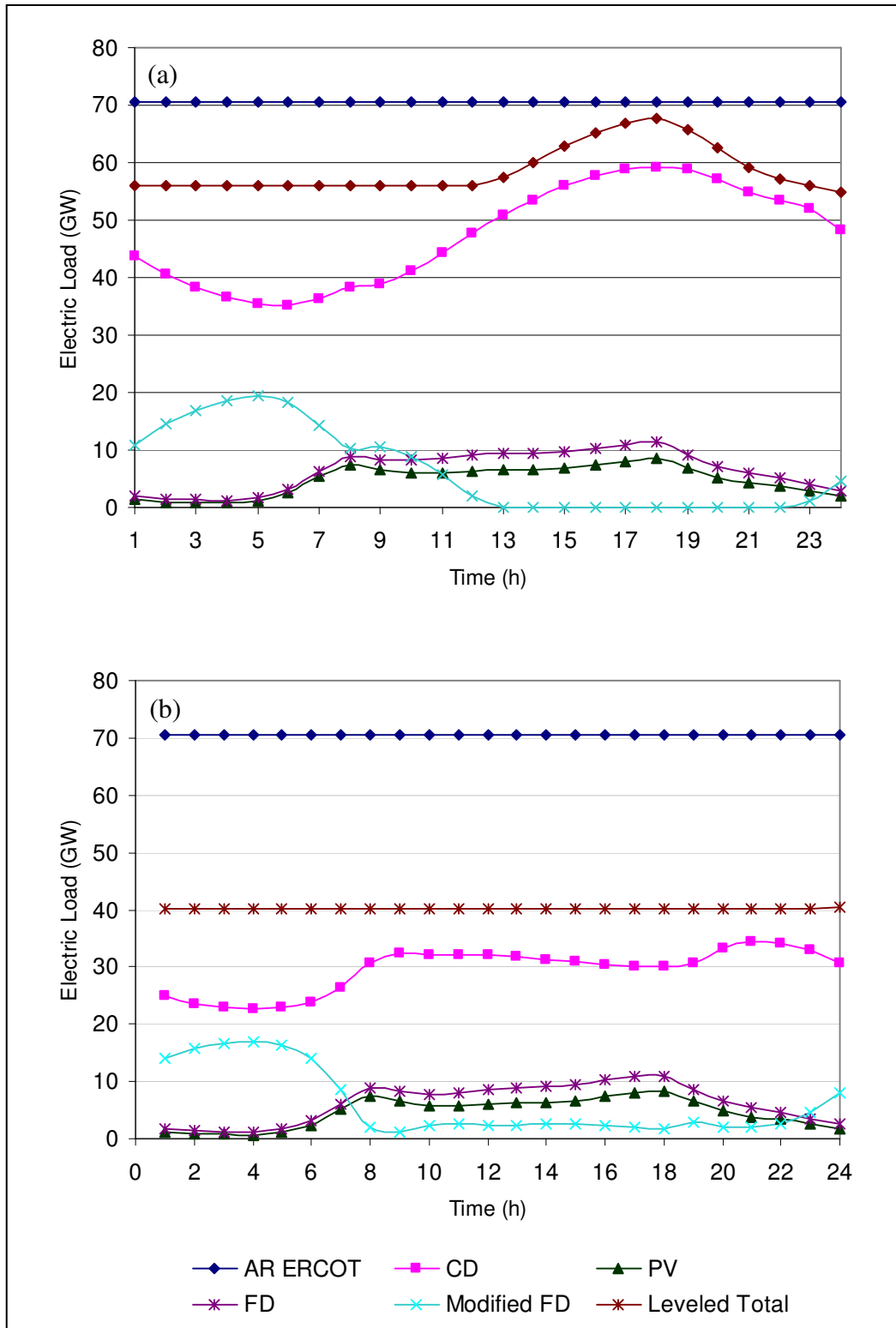
Figure 7: Total Electric Demand with Load Leveling by Shifting Freight: (a) Summer, (b) Non-Summer.

6.4 Data Gap

As discussed in Chapter IV, finding data for this study was a challenge. ERCOT manages essentially only the state of Texas (Figure 1) which was the base case of this project, but in the northern states the situation is different with one regional reliability council managing several states. The Midwest Reliability Organization (MRO) region, for instance, spans eleven states, including two Canadian provinces covering roughly one million square miles. The MRO region includes more than forty organizations supplying approximately 280,000,000 megawatt-hours to more than twenty million people. Those organizations are distributed among the eleven states delivering the electricity requested, but this electric consumption is not filed by state, or at least is not available on line.

Regarding traffic data, TTI has wonderful detailed statistics for Texas, such as, by season, summer (from June to August), non-summer (from September to May), VMT by area type (rural/urban) and classification group (Interstate/Freeway arterials and collector/local arterials), VMT ratios distributed along 24 hours by each EPA class of vehicle (Table 3) during weekdays (Monday to Thursday), Fridays, Saturdays and Sundays separately. A similar study in another region would require data with similar detail to that found for Texas. Unfortunately, exhaustive searches and even personal contacts were never successful in finding these data for other states.

As a result it has not been possible to replicate the model used for Texas in any other region.

6.4.1 Northern State Analysis

The Texas study shows that the total electric demand by time of day calculated by the model for the movement of traffic on the guideway (again assuming that all freight and personal vehicles currently using interstate highways and urban freeways would instead travel on the guideway) is slightly higher in the summer than the winter season. It would be useful to show that this kind of analysis can be applied to other regions or even on a national scale. Further, climate variations might suggest that load balancing implications could be quite different depending on the region. For example, Figure 8 shows an indication of climate variability between a southern state, Texas, and a northern state, Wisconsin.
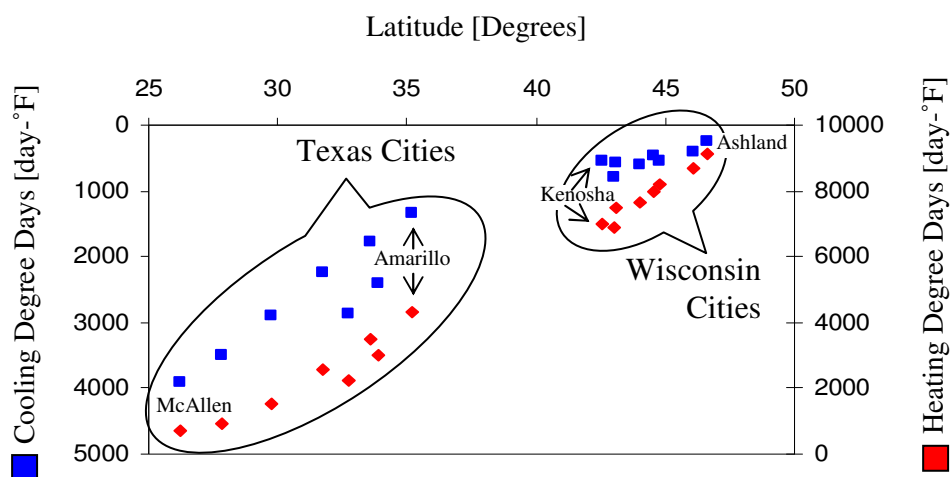

Figure 8. Degree Days[14] in Texas and Wisconsin State.

The electric consumption in Wisconsin was estimated during 2 typical days and compared with Texas. According to NERC in the 1993-2004 timeframe about 2/3 of Wisconsin was in the Mid-America Interconnected Network (MAIN) region (Figure 9). The 2004 MAIN historical demand for Wisconsin which is filed by the electric utilities with Federal Energy Regulatory Commission (FERC), under form 714[15] was estimated. Adding 1/3 to the MAIN values resulted in a close approximation of the total hourly demand. Figure 8 shows that overall Texas climate is very hot in the summer, thereby requiring air conditioning, while Wisconsin hardly needs air conditioning. However, in winter, Texas needs far less energy for heating. For Texas this resulted in much higher electricity demand in summer.

Would the reverse be true in a northern stated like Wisconsin? The answer is not. Figure 10 & 11 show the electric demand pattern for both Wisconsin and Texas on the same days, January, 8 2004 (winter highest demand day) and August, 4 2004 (summer highest demand day). At first look, the graphs reveal that Texas demand is roughly 6 times higher than Wisconsin, but this issue is understandable, according to U.S. Census Bureau[16] the estimated population for Texas for 2006 was 23,507,783 people while for Wisconsin was 5,556,506. A second interesting fact on the graphs is that both of them had similar curve shape showing higher electric demand in summer than the winter season and similar peak load behavior, with Wisconsin peaking earlier because it is much more east with in the Central Time Zone. The explanation to the question above is that Wisconsin uses a source of energy other than electricity for heating houses or/and

buildings. As stated by EIA[17], "Wisconsin's residential and industrial sectors lead the US in natural gas consumption. Natural gas dominates the home heating market, as roughly two-thirds of Wisconsin households use natural gas as their primary fuel for home heating."

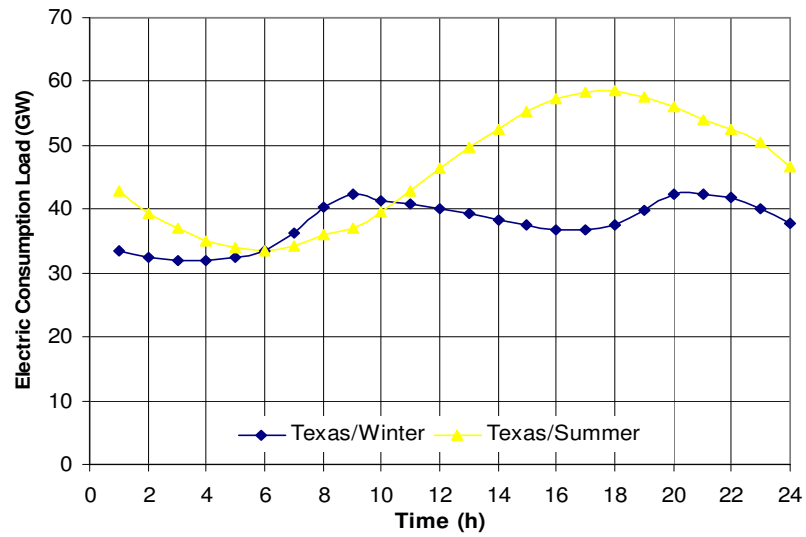Figure 9: The 10 Regional Reliability Councils in 1993-2004 Timeframe.

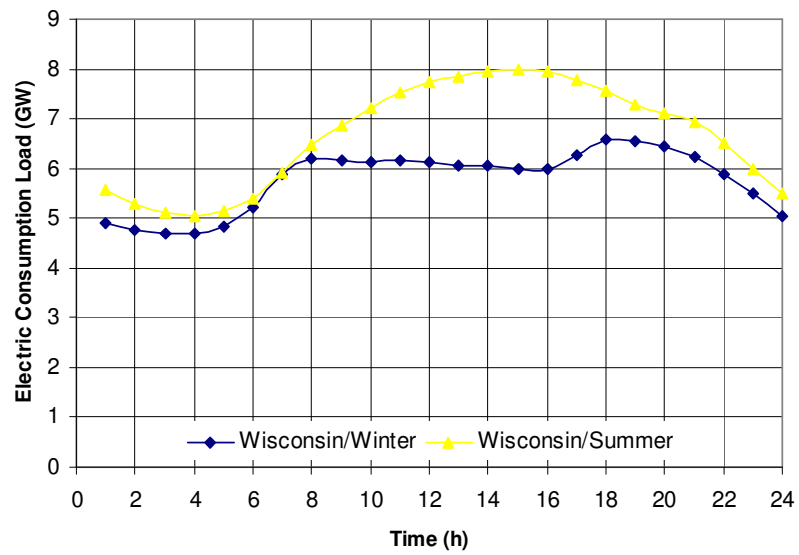Figure 10: 2004 Electric Consumption Load in Texas.

Figure 11: 2004 Electric Consumption Load in Wisconsin.

CHAPTER VII

EXPECTED IMPACT ON ELECTRIC GRID

In the results section above, it would seem that with the inclusion of the new guideway system for the state of Texas into the ERCOT electric grid, the grid will be capable of providing the required energy for the guideway system. That is, if the growth rate of traffic demand does not exceed the growth rate of available electric resources, no major action need be taken by the electric industry to reap the benefits of the new infrastructure considering only guideway traffic representing the current interstate and freeway VMT. Unfortunately, the ERCOT Reserve margin[18] proposed by the House committee on regulated industries is 12.5% of estimated peak demand. This implies that for the estimated peak demand of 67,500 MW, ERCOT would require an available capacity of 76,000 MW. Extending the demand to address the off-guideway energy is significant and would require electric capacity growth.

In addition to the need to increase available capacity to meet the new demand, additional redundancy would need to be built into the electric grid to ensure that the new infrastructure power is always-on. The new guideway infrastructure has also been proposed as a structural support for future transmission and communication lines, which can alleviate or augment existing transmission infrastructures.

CHAPTER VIII

CONCLUSIONS AND FURTHER STUDY

This study provides a model for estimating the dualmode transportation electric demand. The model shows a dramatic sensitivity to speed on the guideway. The model was applied in the ERCOT region supplying electricity mainly only to Texas. Assuming all freight and personal vehicles currently using Interstate highways and urban expressways use electric guideways instead indicates that there is sufficient ERCOT power generation capacity in non-summer months, but that some additional power generation capacity would be needed to satisfy the demand during summer months. The possibility of driverless freight transport would enable power leveling by providing incentives to shift freight during off peak demand.

An attempt to study a northern region revealed that the combination of transportation and electricity data for a common region are quite difficult to find. However, an estimation of hourly electricity demand in Wisconsin showed patterns quite similar to those observed in ERCOT data, this despite very different climates in Texas and Wisconsin. The reason is that, although Texas needs much less heating in winter, neither state relies heavily on electric heating. Therefore, both states show greatest demand for electricity during the summer. In general, EIA data show that throughout the US electric heating is rare. Therefore, the results for ERCOT may be indicative of other regions. Further study would require data that currently seems to be unavailable.

This study only assessed the impact of electrifying all highway transportation. Further study is needed to investigate the impact of battery charging if dualmode vehicles were all electric. This would pose a much greater demand on electricity generation, and load balancing considerations may be quite different than what was applied for this study.

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