Technology Roadmap for 21st Century Vehicle Transportation Systems

Prepared for

The Center for Energy, Environment and Transportation Innovation

By

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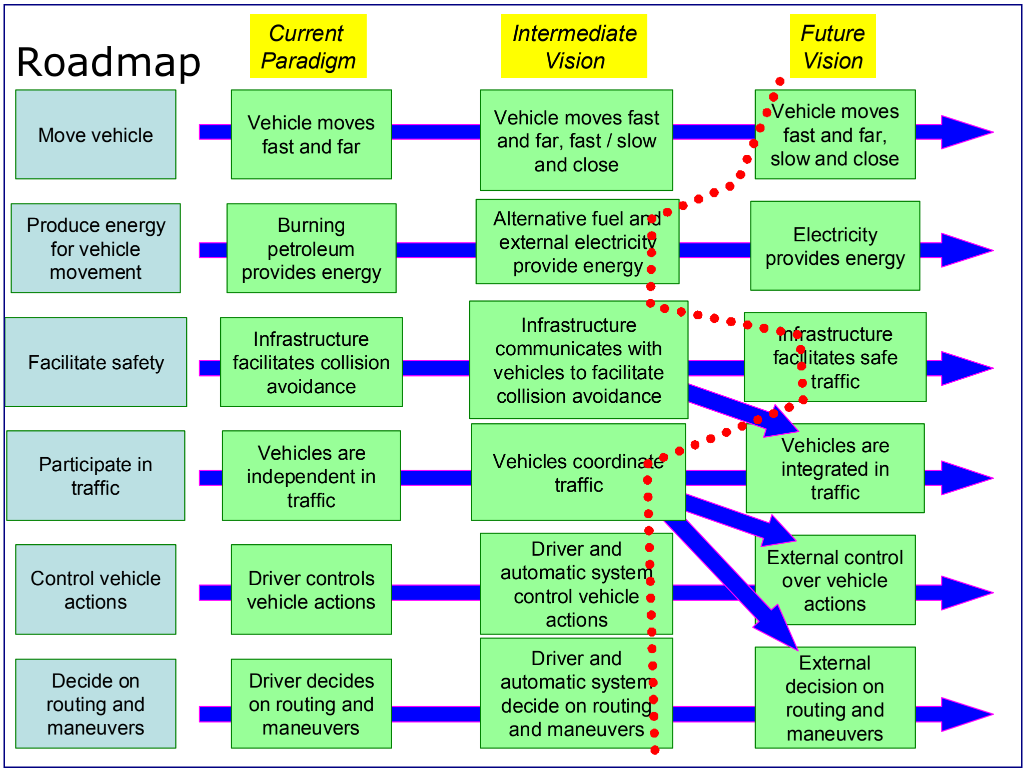
Executive Summary

The goal of this project was to develop a roadmap for the technical evolution of vehicle transportation systems in the 21st Century with an emphasis on dual-mode vehicles and electrified guideways. The project was completed by personnel from Texas A&M University, Bruce McHenry and personnel from Pretium Consulting Services. The roadmap is shown below. The dotted red line represents a future paradigm which is a likely state of future development approaching the Ideal Future Vision.



The roadmap is a likely scenario of future developments leading to dual mode vehicles which can travel on local roads with conventional or hybrid power and are also powered by electricity delivered to the vehicles through high technology guideways when traveling for longer distances at high speeds. The methodology used was a proprietary technique developed by Pretium Consulting Services and is based on a unique application of TRIZ technology.

TRIZ is the Russian acronym for Theory of Inventive Problem Solving. This theory was first developed in 1946 by Genrich Altshuller. At the time, Altshuller was a patent agent in the Soviet Navy and he saw a lot of patents, both foreign and domestic, come across his desk. He began to question whether invention was the result of creative genius alone or was there a structure or method by which inventions were made? Altshuller studied about 200,000 patents looking for structure in the inventions. Of the 200,000 patents he examined, he identified about 40,000 that embodied innovations. A further study of these 40,000 odd patents revealed 40 patterns of invention. These patterns are themes which recur many times. Altshuller developed a number of innovation algorithms based on his discovery. Pretium Consulting has refined the original TRIZ methodologies developed by Altshuller into a Systematic Value Advancement Process and a Technology Roadmapping Process. Systematic Value Advancement generates innovative problem solutions that resolve technical contradictions inherent in almost all technical problems.

Technology Roadmapping is based on the primary TRIZ postulate which is that technological systems evolve not randomly, but according to predictable patterns which can be revealed from the patent literature.

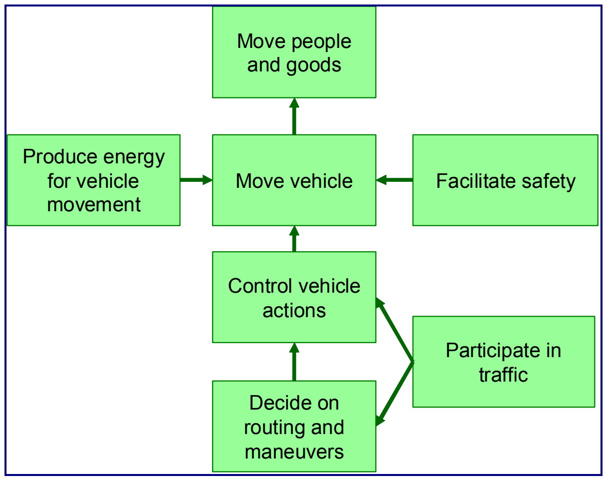
The major steps in the Roadmapping process are

- Assessment of Current Paradigms
- Functional Modeling of the Current Paradigm
- Functional Analysis of the Current Paradigm
- Resolution of Contradictions in the Current Paradigm
    - Movement toward the New Paradigm
- Development of a Future Vision
- Developing one or more Roadmaps to the future vision
    - Development of intermediate paradigms

The report concludes with an example of how the Technology Roadmap can be used to functionally decompose the models developed. Functional decomposition develops more and more detail about what functions are required to get to the future paradigm or a selected intermediate paradigm. The functional decomposition is accomplished be repeated application of the Systematic Value Advancement Process. The final result is a a list of project required to provide the functional requirements of the new paradigm.

Current Paradigm

Technology Roadmapping begins with a definition of the system to be studied. We also define the sub-systems under the main system of interest and the super-system(s) under which the main system operates. In this case the system is *Motor Vehicle Transportation*. The super-system is *Transportation Systems.* Sub-systems include *Vehicle Systems, Road Systems, Energy Systems, Vehicle Control System, Safety Systems* and *Navigation Systems.* The underlying process relating these systems is functionally described below.

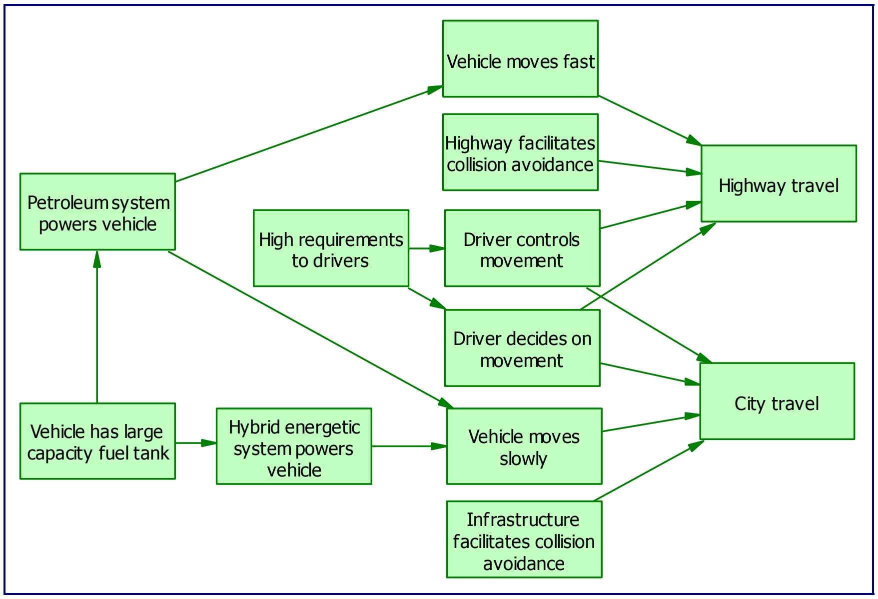


Transportation: Underlying Processes

In the drawing above, each box represents a function. Boxes in green represent useful functions. Harmful functions, if any, are shown in red. If a useful function produces a harmful function or a harmful function produces a useful function, a contradiction exists. Whenever a contradiction exists, the interior of the box is shown in yellow while the border of the box is green for useful functions or red for harmful functions. Contradictions are important because they represent opportunities for innovation. A typical engineering solution when faced with a contradiction is to compromise. We may be willing to give up some of a useful function to reduce some of a harmful function. An innovative solution, by contrast, resolves the contradiction. Innovative approaches find ways to retain of enhance the useful function while eliminating or reducing the harmful function. The function of *Move Goods and People* is produced by *Move Vehicle*. *Move Vehicle* in turn is produced by *Produce Energy, Facilitate Safety* and *Control Vehicle Actions*. *Control Vehicle Actions* is produce by *Decide on Routing and Maneuvers* and *Participate in Traffic*. *Decide on Routing and Maneuvers* is produced by *Participate in Traffic*.

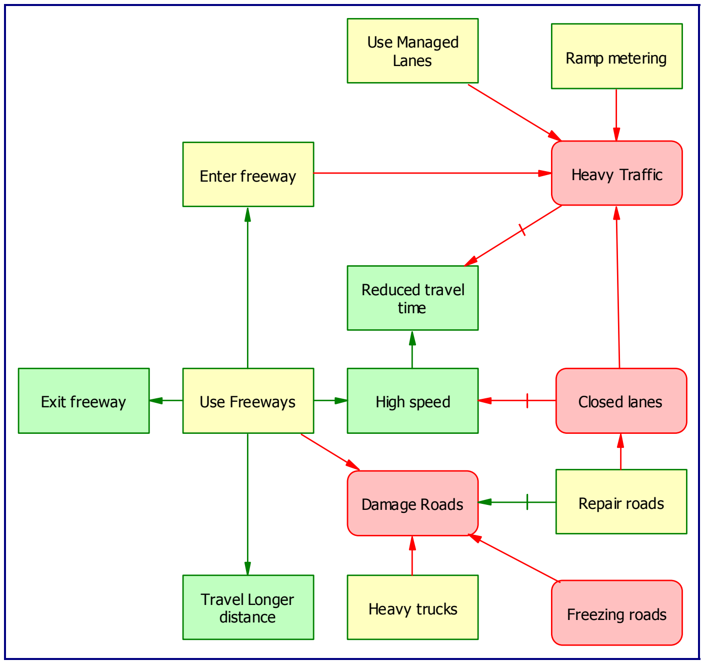
Functional Models of the Current Paradigm

Underlying functional models were developed to further understand the system. These models are shown below and describe the current paradigm.



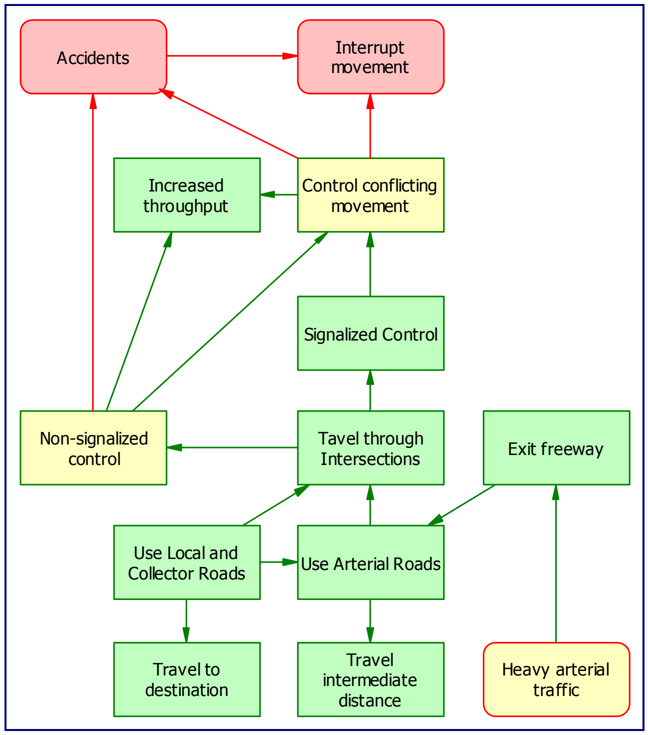
Current Paradigm: Functional Model of Vehicle and Energy Systems

This model looks at two modes of travel: *Highway Travel* and *City Travel.* In *Highway* Travel the *Vehicles Move Fast* while in *City* Travel the *Vehicles Move Slowly.* Highway *Travel* and *City Travel* are both subject to *Driver Controls Movement* and *Driver Decides on Movement*. This places *High Requirements on* Drivers to assure that travel is both efficient and safe. In the case of *City Travel*, accident avoidance is effected by *Infrastructure Facilitates Collision Avoidance.* In this case infrastructure includes traffic signals and traffic signs such as stop signs, yield signs and one-way signs. In the case of *Highway Travel*, accident avoidance is effected by the design of the highway itself. Exit and entrance ramps with ample merge lanes, smooth/banked curves and limited access are all design features of highways aimed at reducing collisions. Whether the vehicles are moving fast or slowly, *Petroleum System Powers Vehicle* is the predominant source of energy today. This requires that the *Vehicle Has a Large Capacity Fuel Tank*. Also, in the case of low speed city travel, *Hybrid Energetic System Powers Vehicle* has recently emerged as a more effective way to propel vehicles at low speed. Both petroleum power and hybrid power are present in society today.



Current Paradigm: Functional Model of Highway Systems

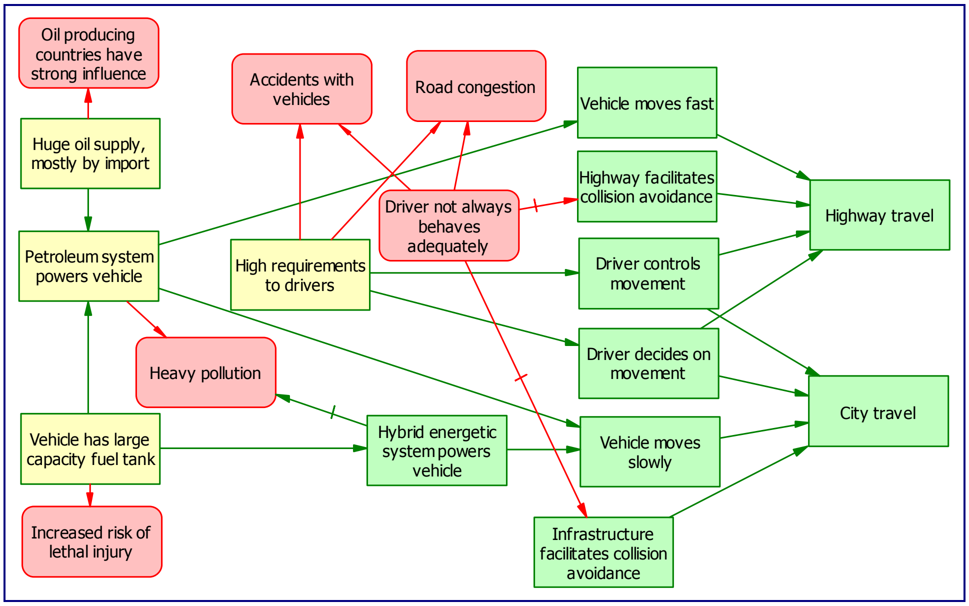
This model looks at the high speed roads system, highways or freeways. *Use Freeways* produce four useful functions, *Enter Freeway, Exit Freeway, Travel Longer Distances* and *High Speed. Use Freeways* also produces the harmful function *Damage Roads*. Note that the useful function *Use Freeways* in the above diagram embodies a contradiction because it produces the harmful function *Damage Roads*. The harmful function *Heavy Traffic* is produces by *Ramp Metering, Using Managed Lanes* and *Enter Freeway. Heavy Traffic* counteracts *Reduced Travel Time*, as indicated by the cross hatch in the arrow between the two functions. *High Speed* is counteracted by *Closed Lanes* which also contributes to *Hevy Traffic*. *Closed Lanes* results from *Repair Roads* which also counteracts *Damage Roads*. Finally, *Freezing Roads* and *Heavy Trucks* also produce *Damage Roads*. In the above model the functions *Use Freeway, Enter Freeway, Heavy Trucks* and *Repair Roads* embody contradictions.



Current Paradigm: Functional Model of Local Road Systems

This model looks at travel on local roads which includes both residential streets and arterial roads. In this model we *Use Local and Collector Roads* to *Travel to Destinations*. *Use Local and Collector Roads* also leads us to *Use Arterial Roads* and to *Travel Through Intersections*. We also *Use Arterial Roads* when we *Exit Freeway*. *Exit Freeway* can produce *Heavy Arterial Traffic.* When we *Travel Through Intersections* we encounter *Signalized Control* and *Non-signalized Control* which produces *Control Conflicting Movement*. *Increased Throughput* is produced by both *Non-signalized Control* and *Control Conflicting Movement.* Both *Non-signalized Controls* and *Control Conflicting Movement* can result in *Accidents* which can *Interrupt Movement*.

Functional Analysis of Current Paradigm

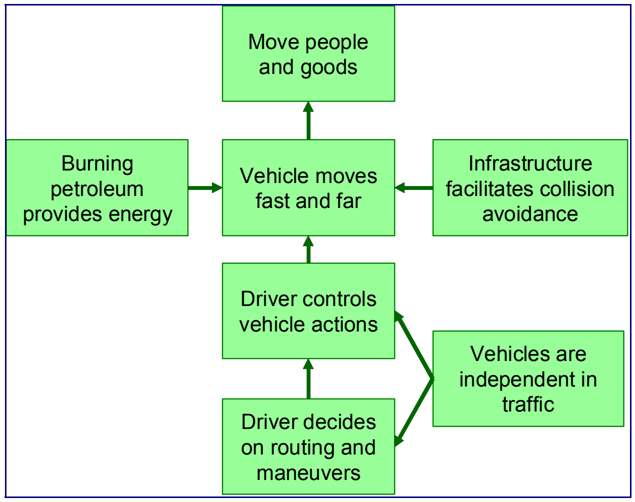


Problems Inherent to the Current Paradigms

A number of problems are inherent to the current transportation paradigms. First of all, the use of gasoline, including current hybrid designs, produces *Heavy Pollution*. Transportation accounts for 66% of all carbon monoxide, 38% of all nitrogen oxides, 26% of all volatile organic compounds and 30% of all carbon dioxide emitted to the atmosphere. The use of gasoline also results in *Increased Risk of Lethal Injury* because gasoline is both flammable and toxic and *Oil Producing Countries Have Strong Influence*. Current oil consumption is about 40 quadrillion BTUs per year. Of this, about 27 quadrillion BTUs goes into transportation. This is roughly equal to the amount of oil that is imported. Therefore, foreign producers can exert tremendous economic and political influence. A key problem is that *Drivers Do Not Always Behave Adequately*. Driver errors result in *Accidents with Vehicles* and *Road Congestion*. Congestion on the roads results in $63 billion per year in wasted fuel & lost productivity in US[1], $375 billion required to restore or renew ground transport infrastructure to acceptable levels[2] and only 33% of required roads can be afforded[3]. Accidents result in 41,000+ US highway deaths annually, 3.2 million people injured in 2002 vehicle crashes, 4.2 million crashes causing property damage only and over $230 billion cost per year to treat injuries and repair damage due to traffic accidents[4].

Based on the preceding analysis of the current paradigms in transportation systems, the following normalized model results. In this model the *Vehicle Moves Fast and Far*, as a result of *Burning Petroleum Provides Energy*, *Driver Controls Vehicle Actions* and *Infrastructure facilitates Collission Avoidance*. In addition, the system opoerates under the conditions of *Driver Decides on Routing and Maneuvers* and *Vehicles are Independent in Traffic*.

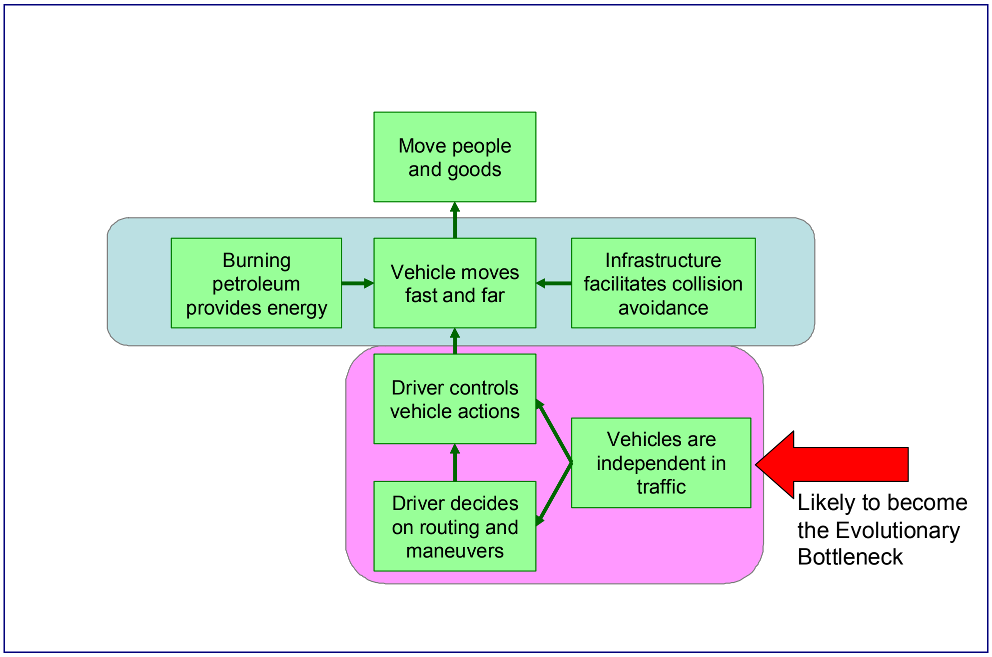
[1] Texas Transportation Institute 2004 Urban Mobility Report
[2] ASCE 2003 Report Card for America's Infrastructure
[3] TTI
[4] US DOT, National Highway Traffic Safety Administration, Traffic Safety Facts 2001



Current Paradigm Normalized

An analysis of the normalized paradigm leads to the following conclusions. First, the functions *Burning Petroleum Provides Energy, Vehicle Moves Fast and Far,* and *Infrastructure Facilitates Collision Avoidance* have received significant development over the past 100 years. Beginning with the development of mass produced vehicles by Henry Ford in 1903, the development of roads to support vehicles and mass production of gasoline to fuel vehicles has dominated transportation development. In general, drivers have had to adapt to the requirements of the vehicles and the roads. In the future, it is likely that *Driver Controls Vehicle Actions*, *Driver Decides on Routing and Maneuvers* and *Vehicles are Independent in Traffic* are likely to become the evolutionary bottlenecks because there has been little development in this functional area. Today, we are beginning to see some early developments. Cruise control and adaptive cruise control are systems which will modify *Driver Controls Vehicle Actions*. GPS navigation systems offer routing advice and impact *Driver Decides on Routing and Maneuvers.*

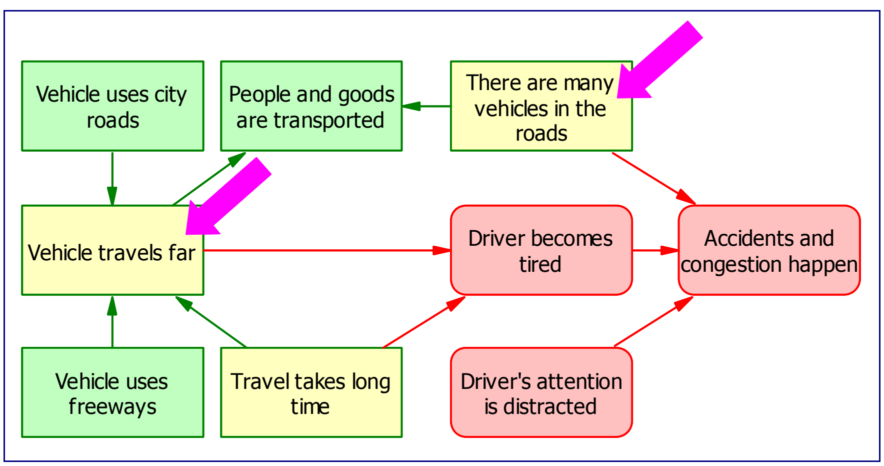
In the current paradigm the driver decides on the destination and route, exercises control over vehicle movement and processes feedback from vehicle movement, roads and surrounding traffic. These paradigms are based on the assumption that the human brain is capable of processing these inputs and that the driver is capable of making appropriate and rational judgments in a timely manner. This assumption is wrong when the driver is tired, using a cell phone, or is distracted in some other way. Some drivers are incapable because of alcohol or drug use while driving. The consequences of these erroneous assumptions are manifested in 1.6 fatalities per 100 million vehicle miles per year. The problems of driver inadequacy are not likely to be resolved in the boundaries of current transportation paradigm. Therefore, a new functional model which will become the new paradigm must be considered.



Analysis of Normalized Paradigm

Resolving Contradictions: Moving to the New Paradigm

The model below highlights several contradictions that must be resolved in order to move to a new transportation paradigm. First, *Vehicle Travels Far* produces *People and Goods are Transported* and it also produces *Driver Becomes Tired. Vehicle Takes a Long Time* also contributes to *Driver Becomes Tired.* The second significant contradiction results because *There are Many Vehicles on the Road* produces both *People and Goods are Transported* and *Accidents and Congestion Happen.*



Contradictions in Moving to a New Paradigm

Therefore, the two contradictions to be resolved are

- Resolve the contradiction: (*Vehicle Travels Far*) should produce (*People And Goods Are Transported)* and should not produce (*Driver Becomes Tired*).

- Resolve the contradiction: (*There Are Many Vehicles In The Roads*) should produce (*People And Goods Are Transported*) and should not produce (*Accidents And Congestion Happen*).

The TRIZ principle that can be used to resolve the first contradiction is Separation. There are four variants of Separation that can be applied: Separation in Space; Separation in Time; Separation in Structure and Separation on Condition. An example of Separation on Condition follows. Many people would like to get the benefit of the nutrients and other healthful ingredients of wine without the harmful effects of the alcohol. We can heat the wine to evaporate the alcohol, but heating destroys some of the nutrients and other healthful ingredients. The more we apply heat, the worse the contradiction becomes. Therefore, our problem is to

- Resolve the contradiction: (*Heat is applied*) should produce (*Evaporation of the alcohol*) and should not produce (*destroy nutrients*).

We can change the conditions under which we heat the wine. By lowering the pressure, a liquid will boil at a lower temperature and evaporation rate will increase. By heating the wwine under lower pressure we can achieve the same evaporation rate as before but at a much lower temperature.

The same principle of Separation on Condition can be applied in our first contradiction above. We can take separate actions based on the conditions of speed and time.

- When the vehicle is driven at high speed for a long time, it will be driven automatically.
- When the vehicle is driven at low speed for a short time, it will be driven manually.

This implies that we must have two kind of roads for these two conditions: High speed roads with automatic control of the vehicle and low speed roads where vehicles are manually controlled.

The TRIZ principle that can be used to resolve the second contradiction is Integration. When systems or functions are integrated, new properties will often result and these new properties may be useful in resolving the contradiction. In addition, an additional object or substance may be added to the system, even temporarily, to obtain new and useful properties. An example of Integration follows. Thin panes of window glass are very economical. Window glass is often shipped in wooden crates that separate the panes of glass. Vibration and sudden movement during transport will often break the glass. It is not uncommon that as much as 50% of glass being shipped is broken because individual panes of glass are very fragile. Therfore, out problem is to:

- Resolve the contradiction: (*Thin panes of glass*) should produce (*Economic windows*) and should not produce (*breakage during shipment*).

We can temporarily integrate the multiple panes of glass during shipment. We can put a thin coating of oil on the panes of glass and then put them in contact with each other. The viscosity of the oil makes it easy to slide the panes next to each other and the surface tension holds them together. The thin panes of glass, now integrated, have properties similar to a thick pane og glass which is much stronger and more difficult to break.

The same principle of Integration can be applied to resolve our second contradiction above. Today, vehicles move independently and do not communicate. By exchanging information, we can virtually integrate the movement of the vehicles. If a vehicle knows the precise location of all other vehicles in the vicinity, the movement can be coordinated, collisions can be avoided and speed can be increased.

Therefore, our future vision of vehicle transportation systems is

- Introduce new road infrastructure with:
    - Long-distance, high speed roads for automatic driving
    - Short-distance, low speed roads for manual driving

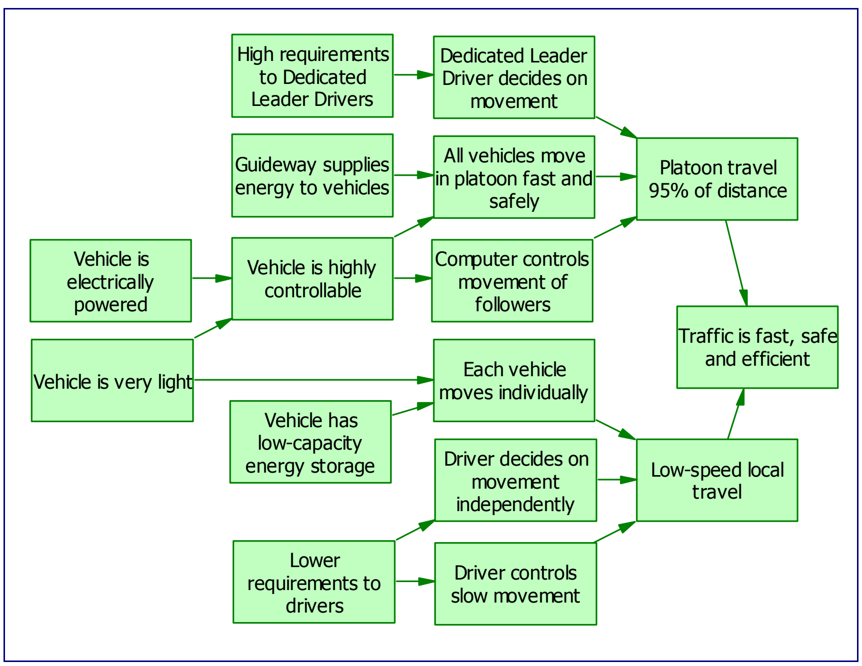
- Automate vehicle movement with:
    - Integrated movement of vehicles in groups on high speed roads
    - Each vehicle in the group is automatically controlled by an external computer
    - Group routing and maneuvering decisions are made by a centralized system

Future Vision

To create a future vision we go through the following steps.

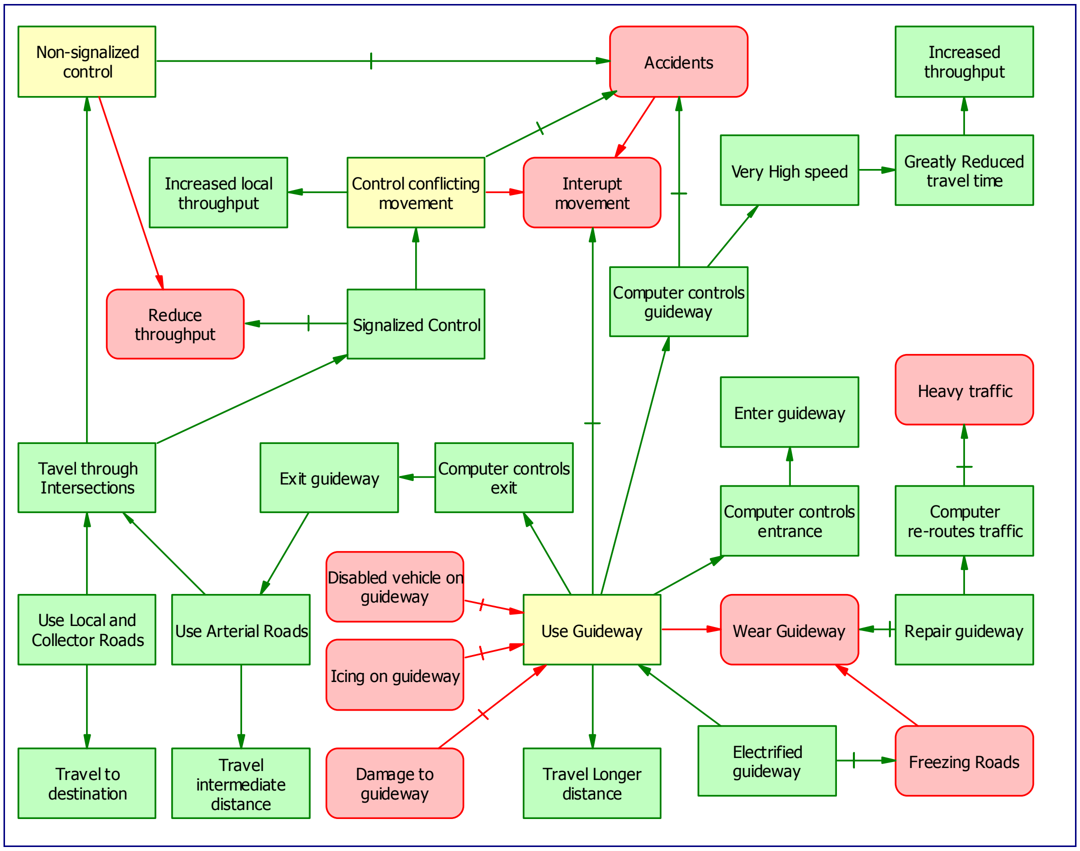
1. Functional modeling of the current system with the major contradictions resolved
2. Building a "Normalized" functional model of New Vision
3. Formulating the challenges of shifting the Vision
4. Development of an Intermediate Vision
5. Creation of the Future Vision

The model below incorporates the resolution of contradictions developed in the previous step. In provides for *Low-speed Travel on Local Roads* and *Platoon Travel* on high speed roads. *Platoon Travel* requires a *Dedicated Leader Driver* and *Computer Control of Movement*. With *Low-speed Local Travel*, *Each Vehicle Moves Individually* and the *Driver Decides on Movement Independently.* The concept of a dedicated leader driver places *High Requirements on Dedicated Leader Drivers.* This is a concept that has both technical and cultural issues. In the Ideal Vision, there would be no human driver, but rather all vehicle control at high speed would be performed automatically by a highly redundant, reliable network of computers. Platooning is another important concept. In platoons vehicle movement can be closely coordinated by computer and directed by the *Dedicated Leader Driver*. Platoons also have excellent aerodynamics resulting in significant energy savings. In the high speed mode, the *Guideway Supplies Energy to Vehicles.* This mode of energy supply offers the advantage that resources native to the United States, coal and nuclear, can be utilized, thus minimizing the dependence on foreign oil. Current efforts to develop alternate fuel vehicles such as hydrogen or alcohol, are completely compatible with this vision because these are requirements for vehicles traveling on low-speed local roads.



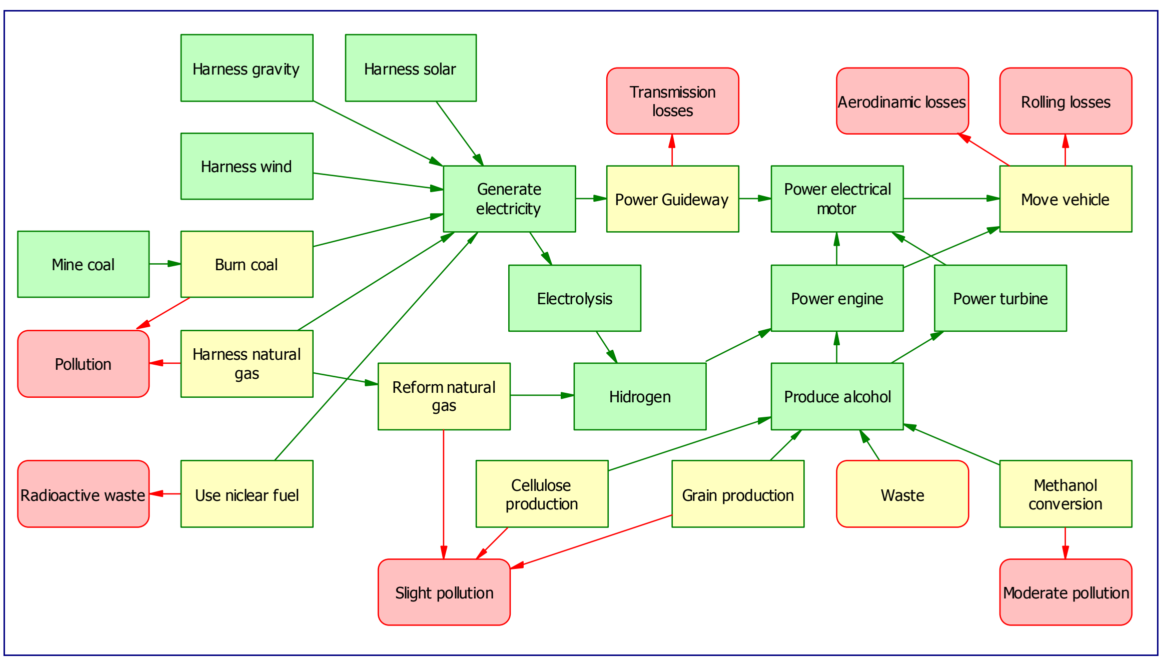
High Level Functional Model of Future Transportation System

Two additional functional models were constructed. The model below details the useful and harmful functions associate with guideways, arterial roads and local roads.



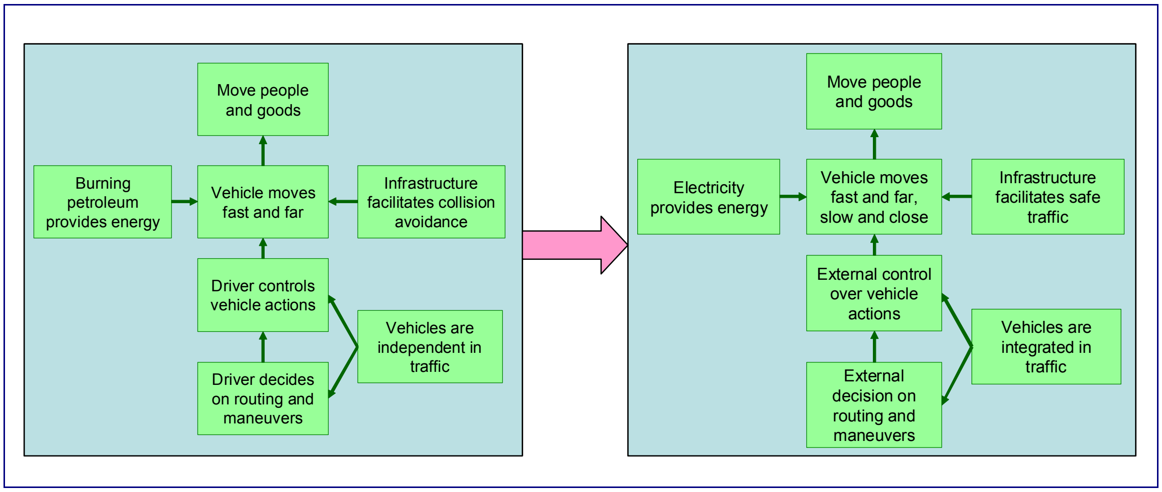
Functional Model of Road Systems

The model below details the useful and harmful functions associated with energy systems.

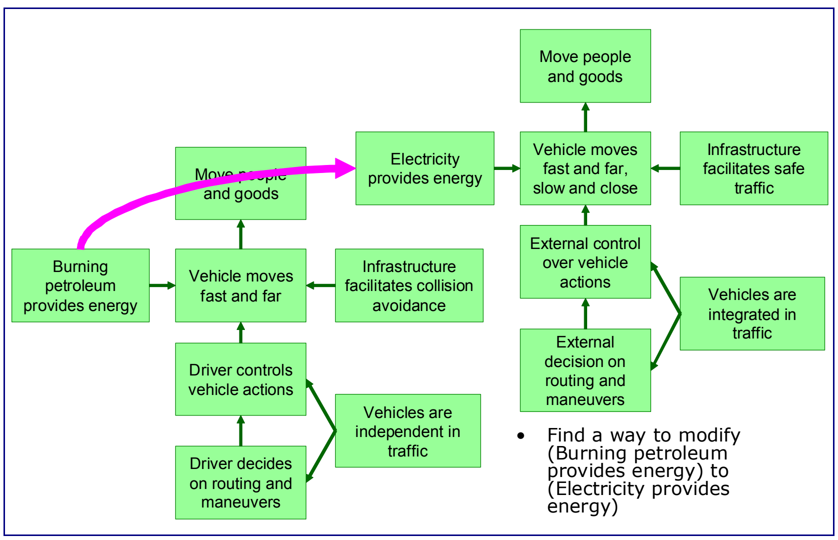


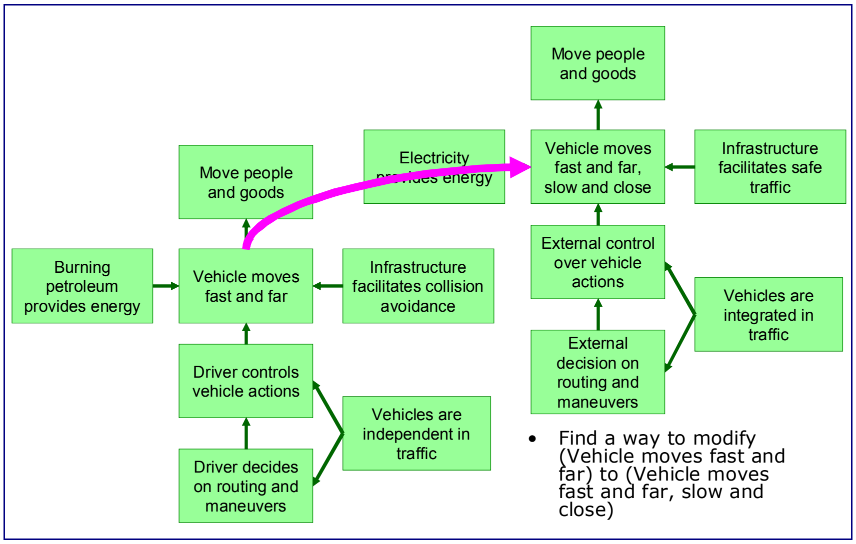
Functional Model of Energy Systems

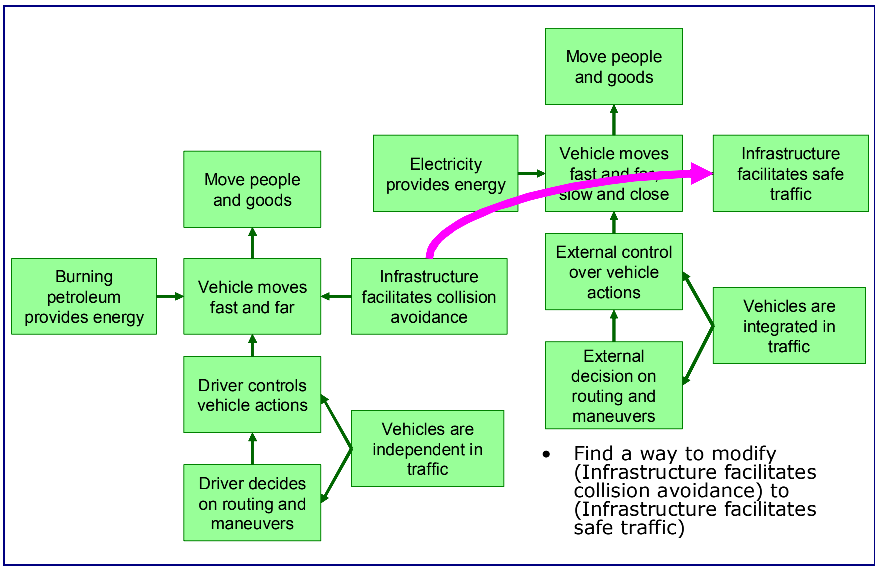
The diagram below shows the "Normalized" functional model depicting the transition from the current system to the New Vision.



Transitions can be identified between corresponding functions in the current system and the New Vision. The sequence of diagrams below show the required transitions and identifies the improvements (modifications) required for the transition to the New Vision.




Move people and goods
Electricity
energy
Vehicle moves fast and far, slow and close
Infrastructure facilitates safe traffic
Move people and goods
Burning petroleum provides energy
Vehicle moves fast and far
Infrastructure facilitates collision avoidance
External control over vehicle actions
Vehicles are integrated in traffic
External decision on routing and maneuvers
Driver controls vehicle actions
Vehicles are independent in traffic
Driver decides on routing and maneuvers
• Find a way to modify (Vehicle moves fast and far) to (Vehicle moves fast and far, slow and close)


Move people and goods
Move people and goods
Electricity provides energy
Vehicle moves
slow and close
Infrastructure facilitates safe traffic
Burning petroleum provides energy
Vehicle moves fast and far
Infrastructure facilitates collision avoidance
External control over vehicle actions
Vehicles are integrated in traffic
External decision on routing and maneuvers
Driver controls vehicle actions
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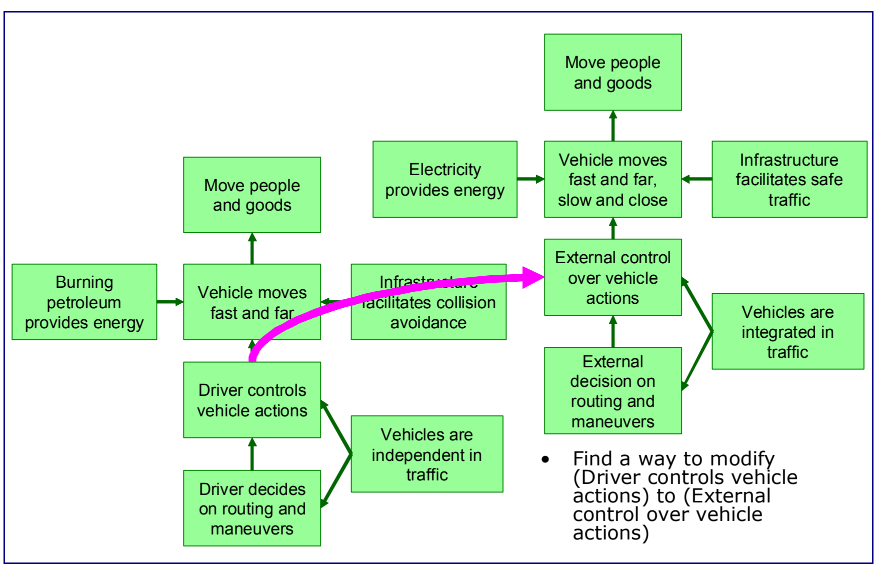
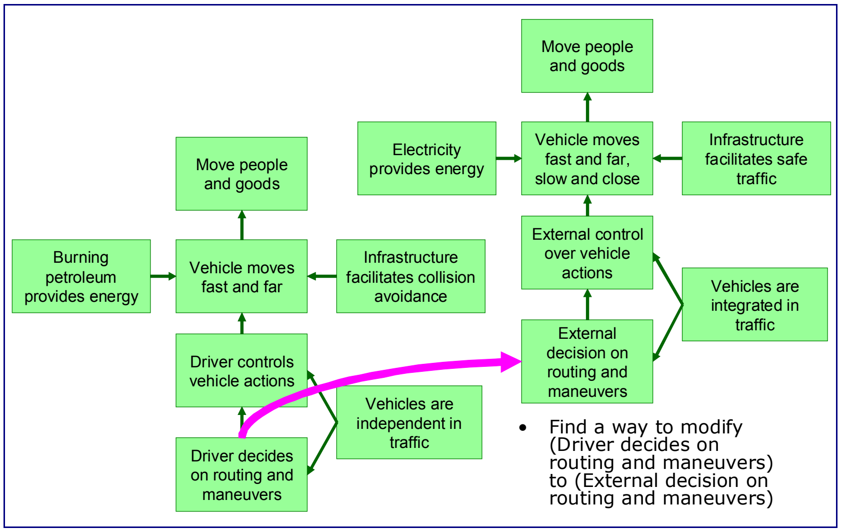
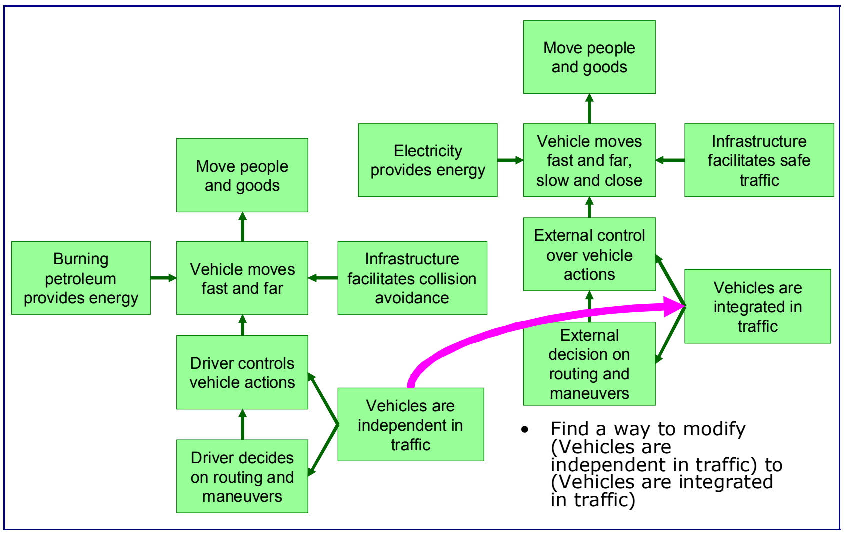
Driver decides on routing and maneuvers
• Find a way to modify (Infrastructure facilitates collision avoidance) to (Infrastructure facilitates safe traffic)


Move people and goods
Move people and goods
Electricity provides energy
Vehicle moves fast and far, slow and close
Infrastructure facilitates safe traffic
Burning petroleum provides energy
Vehicle moves fast and far
facilitates collision avoidance
External control over vehicle actions
Vehicles are integrated in traffic
External decision on routing and maneuvers
Driver controls vehicle actions
Vehicles are independent in traffic
Driver decides on routing and maneuvers
• Find a way to modify (Driver controls vehicle actions) to (External control over vehicle actions)





It is rare that a system transitions from the current system directly to the New Vision. Instead, it is common for one or more intermediate systems to emerge. In our work, we formulated one possible Intermediate Vision. This Intermediate Vision can then be used later to generate a number of possible new paradigms which will emerge. The Intermediate Vision includes the following elements:

- From the current system - infrastructure and available vehicle design determine strong requirements imposed on drivers
- To the Intermediate Vision - low requirements imposed on drivers determine infrastructure and vehicle design

The sequence of diagrams below indicate the likely Intermediate Vision.

- From "Burning petroleum provides energy"
- Through "Alternative fuel and external electricity provide energy"
- To "Electricity provide energy"

- From "Vehicle moves fast and far"
- Through "Vehicle moves fast and far, fast / slow and close"
- To "Vehicle moves fast and far, slow and close"

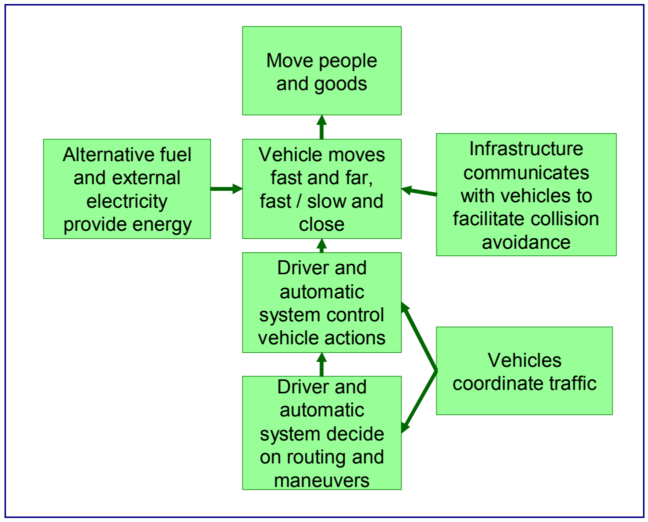
- From "Infrastructure facilitates collision avoidance"
- Through "Infrastructure communicates with vehicles to facilitate collision avoidance"
- To "Infrastructure facilitates safe traffic"

- From "Driver controls vehicle actions"
- Through "Driver and automatic system control vehicle actions"
- To "External control over vehicle actions"

- From "Driver decides on routing and maneuvers"
- Through "Driver and automatic system decide on routing and maneuvers"
- To "External decision on routing and maneuvers"

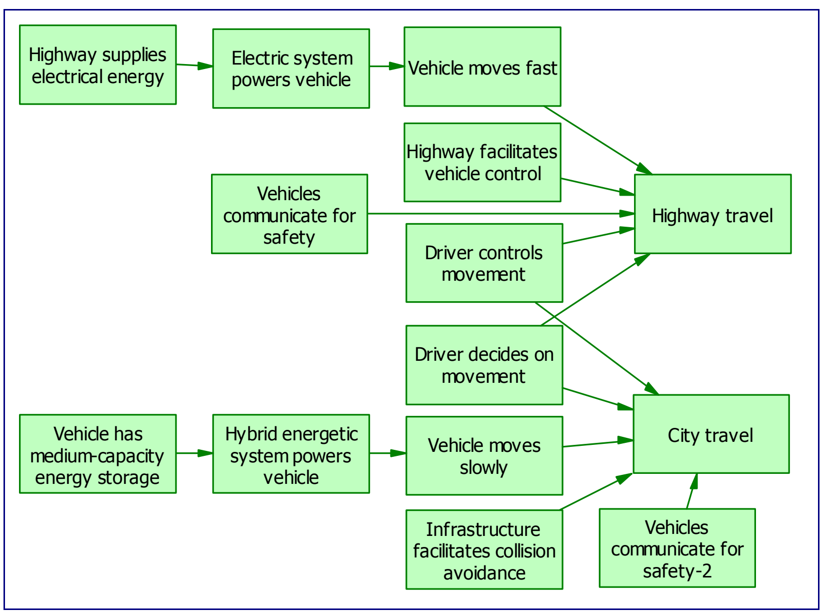
- From "Vehicles are independent in traffic"
- Through "Vehicles coordinate traffic"
- To "Vehicles are integrated in traffic"

The result of these Intermediate Visions results in the following Normalized Intermediate Paradigm.



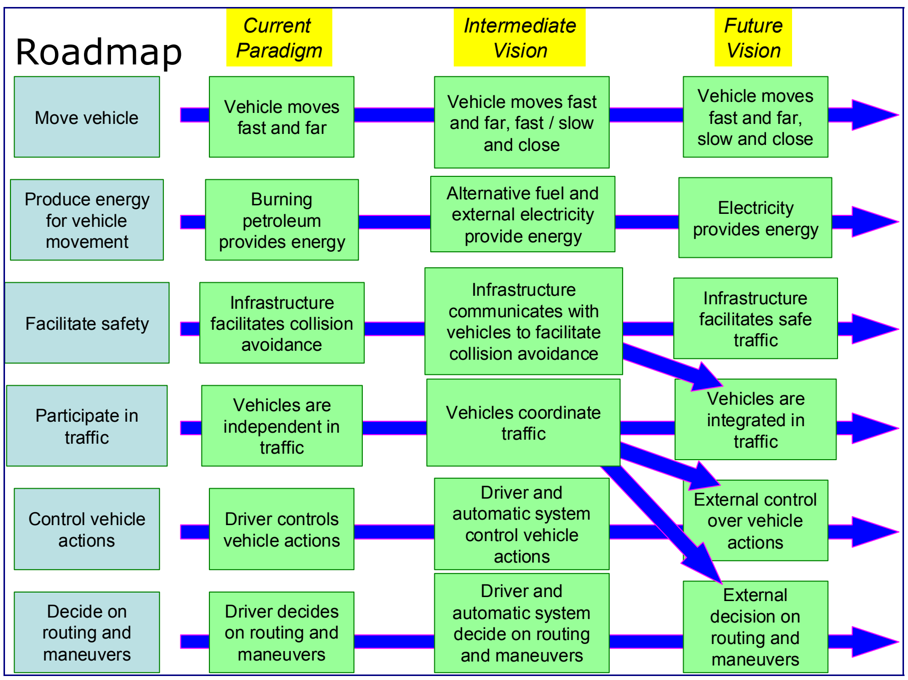
Normalized Intermediate Paradigm

From the Normalized Intermediate Paradigm we can produce a functional model of the Intermediate Vision.



Roadmap to the Future Vision

The following roadmap relates the functions in four basic vehicle transportation models developed thus far. As we move from left to right along the arrows, we see the evolution of functions within a family. In the far left column are the functions that make up the current vehicle transportation system. The next column to the right shows the functions that make up the normalized current vehicle transportation paradigm. The next column to the right shows functions in one intermediate vision. This is a high level analysis and further study could generate more than one intermediate step in the evolution of functions in a family. Also, different families may involve different numbers of intermediate visions. At the far right is the future vision. This is the state in which all major contradictions have been resolved and harmful functions are eliminated or greatly reduced. The arrows traveling from left to right show one possible sequence of developments. Note that functional development in one family may be required for development in other families to occur. Thus, *Infrastructure Communicates With Vehicles to Facilitate Collision Avoidance* is a prerequisite for *Vehicles are Integrated in Traffic,* while *Vehicles Coordinate Traffic* is a prerequisite for *External Control Over Vehicle Actions* and *External Decisions on Routing and Maneuvers.*

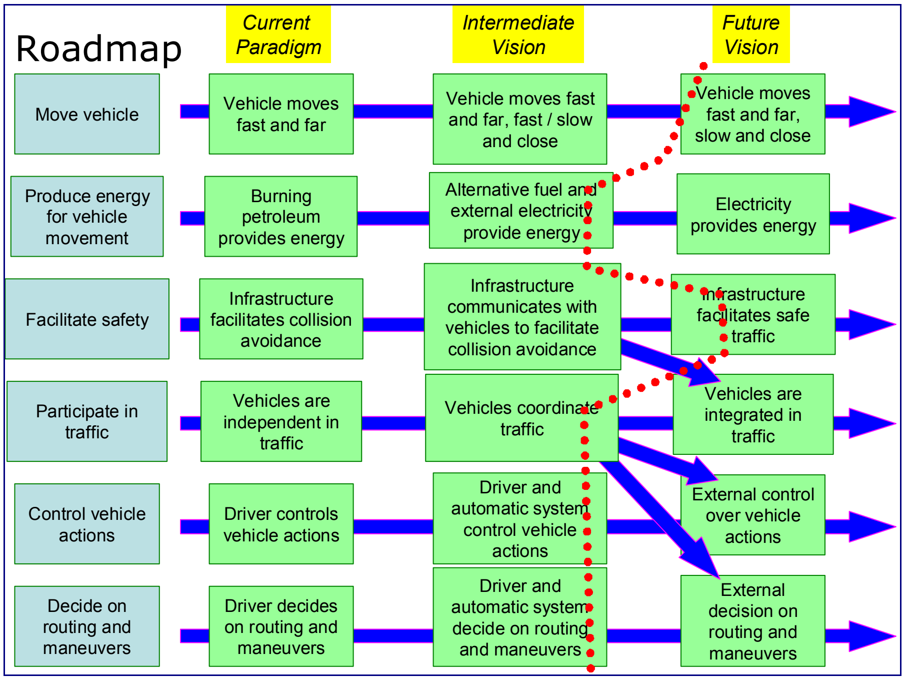


Technology Roadmap

A paradigm is a snapshot that shows the functions in existence at a given point in time that defined how a system is functioning at that time. One possible future paradigm is indicated below by the dotted red line. In this paradigm the vehicle transportation system consists of the following functions.

- *Vehicle Moves fast and Far, Slow and Close*
- *Alternate Fuel and External Electricity Provide Energy*
- *Infrastructure facilitates Safe Traffic*

- *Vehicles Coordinate Traffic*
- *Driver and Automatic System Control vehicle Actions*
- *Driver and Automatic System Decide on Vehicle Routing and Maneuvers*



Example of Roadmap Use

The scope of this project was limited and, therefore, the roadmap has not been used to detail future evolutionary developments. Following is one example of how this roadmap can be used to enhance the development of 21st century vehicle transportation systems. The roadmap can be used to drill down to more and more detailed functional descriptions. More importantly, the roadmap can be used to simplify the problems to be resolved by breaking high level problems down into a series of lower level problems. We can consider four levels of problem as follows.

Problem Level	Description
1	Single dimension engineering problems with known solutions
2	Multi-dimension engineering problems requiring new designs
3	Multi-dimension engineering problems requiring innovative solutions for complete solution
4	Paradigm shifts

As an example, consider moving from one functional model to another as indicated by the purple boxes below. This is a transition from *Driver Controls Vehicle Actions* to *Driver And Automatic System Control Vehicle Actions.*

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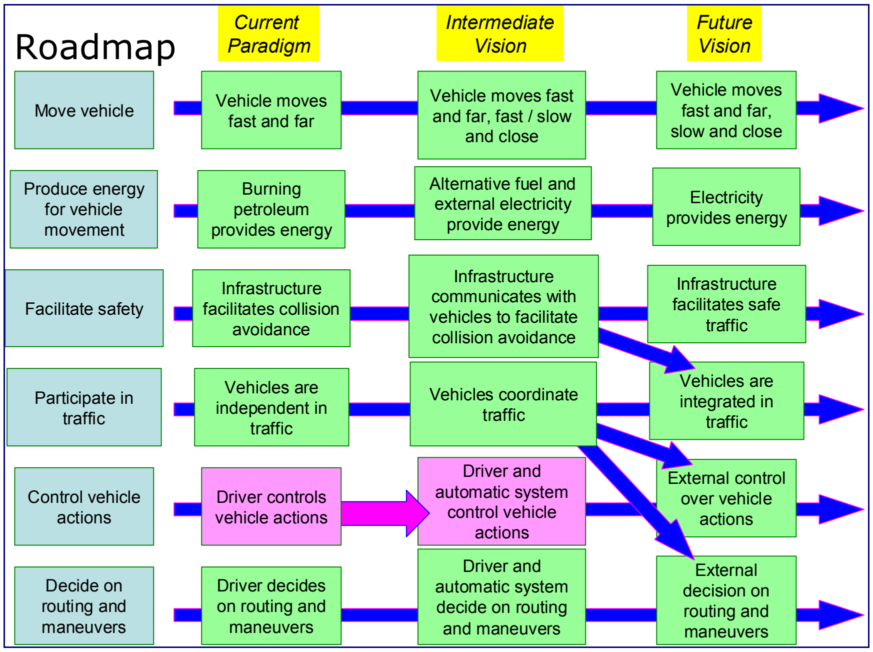
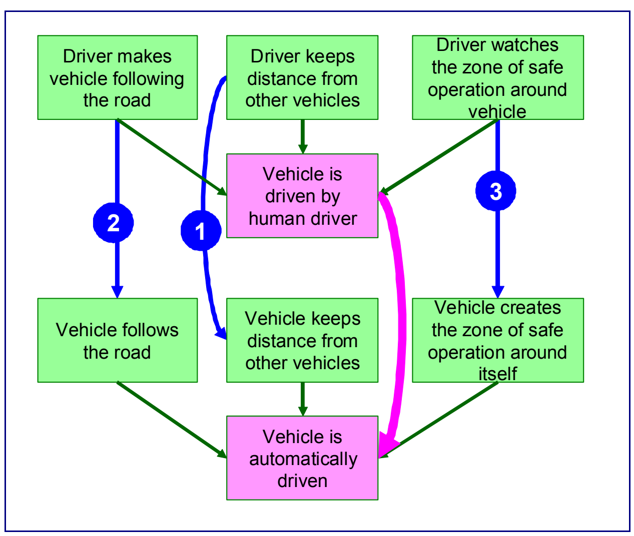


The shift from *Driver Controls Vehicle Actions* to *Driver And Automatic System Control Vehicle Actions* is a level 4 problem, a paradigm shift. Functional modeling and technology roadmapping techniques can be used to deconstruct the paradigm shift into a structured sequence of lower level problems. For example, we can first derive the functions that produce *Vehicle is Driven by Human Driver* into *Driver Makes Vehicle Follow the Road, Driver Keeps Distance from Other Vehicles and Driver Watches the Zone of Safe Operation Around Vehicle* as shown in the figure below.

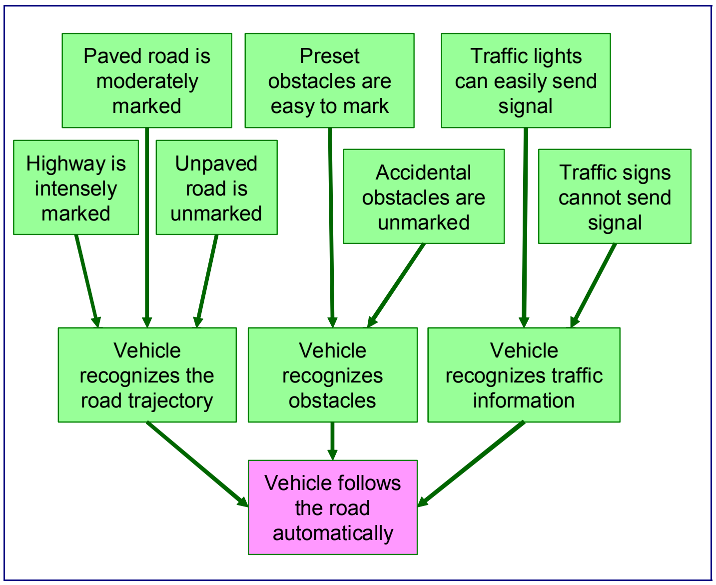


Deconstruction of Functions to Level 3 Problems

Similarly, *Vehicle is Automatically Driven* is produced by *Vehicle Follows the Road, Vehicle Keeps Distance from Other Vehicles* and *Vehicle Creates the Zone of Safe Operation Around Itself.* What was a major level 4 problem, as shown by the purple arrow above, is now deconstructed into three level 3 problems. A set of possible evolutionary milestones can be developed as follows.

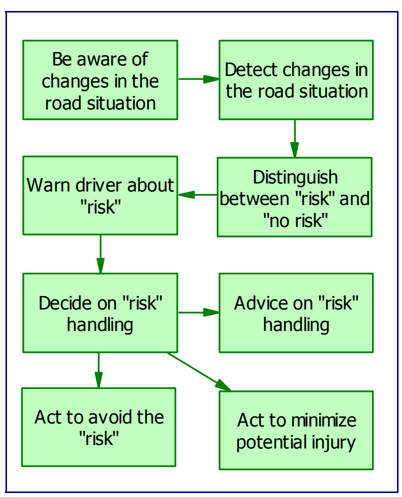
- Current Paradigm
- Vehicle keeps distance
- Vehicle follows the road
- Vehicle creates zone of safe operation
- Vehicle drives automatically

The deconstruction process can be repeated as shown below for the function *Vehicle Follows the Road Automatically*. The level of problems posed at this stage is generally level 2 – 3.



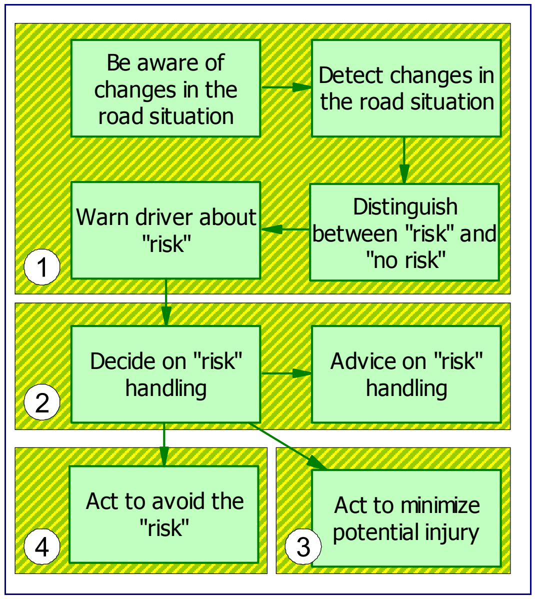
Deconstruction of Functions to Level 2-3 Problems

One additional level of deconstruction results in the following functional analysis for recognition of obstacles in the road.



Deconstruction of Functions to Level 1-2 Problems

Further grouping results in the following sequence.



Grouping into Project Sequences

This sequence can be viewed as a series of projects to produce the following results.

1. Warn driver about “risk”
2. Advise on “risk” handling
3. Act to minimize potential injury
4. Act to avoid the “risk”

The technology to solve these problems already exists and projects can be defined that meet the requirements of the function required. These problems are generally at level 1 or 2. For example, preset obstacles in the road such as guard rails or signs can be identified via GPS. Temporary obstacles, such as road construction barriers, can also be identified in this manner. Accidental or unmarked obstacles will need to be recognized by ultrasound, laser, radar or similar technology.

Conclusions

The technology roadmap began with an assessment of the current paradigm for Vehicle Transportation Systems. The current paradigm was judged to contain seven high level functions: *Move Goods and People, Move Vehicle, Produce Energy, Facilitate Safety, Control Vehicle Actions, Decide on Routing and Maneuvers* and *Participate in Traffic*. From this initial assessment functional models of the current paradigm were constructed and these models were analyzed. It was concluded that the functions surrounding vehicle systems and road systems have received the most development in the past and that the evolutionary roadblock to future development will lie in systems to automatically drive and route vehicles. Two major contradictions were identified for resolution.

- *Vehicle Travels Far* should produce *People and Goods are Transported* and should not produce *Driver Becomes Tired*.

- *There are Many Vehicles in the Roads* should produce *People and Goods are Transported* and should not produce *Accidents and Congestion Happen*.

The principles of Separation and Integration were utilized to resolve these two contradictions. The principle of Separation on Condition suggested high speed roads for automatically controlled vehicles and low speed roads for manually controlled vehicles. The principle of Integration suggested a communication system linking each vehicle with other vehicles and the road. The future vision consisted of dual mode vehicles which travel at low speeds on local roads using highly fuel efficient engines such as alcohol, hydrogen or hybrids and travel in platoons on high speed roads drawing electrical power from the roadway. An intermediate vision was developed which hybridizes many of the current systems with functions in the future vision. A roadmap was produced from the intermediate and future visions and became the basis for a future paradigm. It was finally demonstrated how the roadmap can be used to deconstruct functions in the roadmap and drill down to a set of projects representing level 1 and level 2 engineering projects.

The roadmap is a living system that can be used as the basis for many future activities including strategy development, fund raising, open source innovation and intellectual property development to name a few. Further refinement will result in a systematic approach to identifying the key technologies and projects required to make the future vision a reality.