

Chapter 2

Risk Adverse Society

Acronyms

AC and DC	Alternating current and direct current
APM	Automated people mover
ATC	Automatic train control
ATO	Automatic train operation
ATP	Automatic train protection
ATS	Automatic train supervision
CAPEX and OPEX	Capital expenses and operational expenses
CCTV	Closed-circuit television
CBTC	Communication-based train control
CALM	Continuous air-interface, long and medium range
DSRC	Dedicated short-range communications
DVR	Digital video recorder
DTO	Driverless train operation
EMU	Electrical multiple unit
ETMS	Electronic train management system
ETD	End of train device
EGNOS	European Geostationary Navigation Overlay Service
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
EDR	Event data recorder
GPS	Global positioning system
GSM	Global system for mobile communication
ITCS	Incremental train control system
IP	Internet protocol
IMS	IP multimedia subsystem
JPEG	Joint photographic experts group
LDW	Lane departure warning
LMA	Limit of movement authority
LTE/4G	Long-term evolution/fourth generation
MADD	Mother Against Drunk Driving
MPEG	Moving Picture Experts Group

MSAS	Multi-functional Satellite Augmentation System
NDGPS	National Differential GPS
NHTSA	National Highway Traffic Safety Administration
NTSC/PAL	National Television System Committee/Phase Alternating Line
OCC	Operational Control Centers
OCR	Optical Character Recognition
PRT	Personal rapid transit
PTC	Positive train control
PDF	Probability of failure on demand
RRF	Risk reduction factor
SIL	Safety integrity level
STO	Semi-automatic train operation
SDP	Service delivery platform
SOA	Service oriented architecture
SIP	Session Initiation Protocol
UTO	Unattended train operation
UMT	Universal Mobile Telecommunication
UPnP	Universal Plug and Play
VCC	Vehicle control center
VCU	Vehicle control unit
VII	Vehicle infrastructure integration
VOBC	Vehicle on-board controller
V2C	Vehicle-to-cloud
V2I	Vehicle-to-infrastructure
V2V	Vehicle-to-vehicle
VANET	Vehicular ad hoc network
VoIP	Voice over IP
WAAS	Wide Area Augmentation System
WAVE	Wireless Access in Vehicular Environments
WLAN	Wireless Land Area Network
WHO	World Health Organization
Wi-MAX	Worldwide Interoperability for Microwave Access

2.1 Introduction

We've used the expression "risk adverse society" to describe several elements and factors of modern society that are growing in importance and creating a durable impact on the way people see things and how they help shape laws. Although these megatrends are seen by many as favorable per se, they have consequences that can create issues for society and will have a strong impact on transportation. Two mega

trends play a key role in this new behavior: the graying of society and a society prone to litigation.

On the other hand, an important mega trend which is the increasing role of women in modern society cannot be associated as a key factor for a more risk adverse society. Indeed, two studies have tended to show that women don't seem more risk adverse than men.

A 2008 study¹ on the Kasai tribe of India showed that it is untrue that the average female avoids risky behavior more than the average male. Additionally a 2009 study² "Gender differences in risk behavior: Does nurture matter" shows that an *"average girl from single-sex schools are found in their experiment to be as likely as boys to choose the risky behavior. This suggests that observed gender differences in behavior under uncertainty found in previous studies might reflect social learning rather than inherent gender traits"*.

Maybe can we only say that women bring more caring to society? Definitely the creation of associations such as Mother Against Drunk Driving (MADD) is a good example of such attitude. Such a program, summed up hereafter has a great impact on transportation policies in the USA:

- Education about the dangers of drunk driving, advocacy and victim assistance;
- Strict policy on illegal blood alcohol content (0.8 % or lower) and using stronger sanctions for offenders;
- Helping victims of drunk driving;
- Maintaining the minimum legal drinking age at 21 years; and
- Mandating alcohol breath-testing ignition interlock devices for everyone convicted of driving while legally impaired.

2.1.1 *Graying of Society*

Steady advances in medical technology, increase in wealth, better diets as well as a wide range of other factors have caused populations around the world to reach old age in growing numbers. Life expectancy of a woman in Japan is now of more than 82 years, while the average world age expectancy is about 67 years according to the

¹Kasai tribe of India; Author studied by Gneezy, Leonard and List (2008).

²Gender differences in risk behavior: Does nurture matter. Author Alison L. Booth and Patrick j. Nolen (University of Essex/Australia) 2009 study.

World Factbook of the CIA³. Global population aged 65 and over is set to double by 2050.

In wealthy nations, older people now constitute 15 % of the population but will account for 26 % by 2050. Poor nations historically have had very low percentages of older people, but this percentage is expected to increase from about 6 % now to 15 % in 2050.

At the same time, citizens of all continents, except Africa, are deciding to have fewer children. Several countries are now experiencing a fertility index of less than 2.1, level at which deaths are replaced by births. This growth in old age population cannot compensate for the decline in growth in many rich countries, and thus population in countries such as Japan and Germany is shrinking.

While we all know senior citizens that can be more risk prone than many teens, the reality is that they are on average more cautious, conservative and risk adverse. A study published in 2013⁴, by the Yale School of Medicine showed that with increased age comes decreased risk-taking in decision-making.

To add to this scientific analysis, we will use the thoughts of Isaac Asimov, probably the most renowned science fiction novelist. In his first library success in the 1950s, “The Caves of Steel”⁵ an earth police officer Elijah Baley, was sent to resolve a murder mystery on Aurora, a planet colonized by explorers whose life expectancy was between 300 and 350 years. Hans Fastolfe, an Auroran politician who was a colleague of the murdered victim expressed his wary of the drawbacks of such a long life to Baley:

“If you were to die now, you would lose perhaps forty years of your life, probably less. If I were to die, I would lose a hundred fifty years, probably more”.

Horried by all of this, Baley thought Aurorans were unable to collaborate with one another and too risk-averse, because of their longevity.

We believe that the graying of society will give a formidable push on e-mobility technologies and especially self-driving cars. We know that older generations still have a love affair with their cars, especially men. For those who live in the downtown area, grocery shops, hair dressers, banks, doctors, and all the other services that we take for granted when we are young can still be easily available for

³World Factbook of the CIA (Public domain). <https://www.cia.gov/library/publications/the-world-factbook/index.html>.

⁴Study published in 2013 by the Yale School of Medicine (If at Levy, assistant professor in comparative medicine and neurobiology at Yale, and colleagues).

⁵The novel “The Caves of Steel”; Author Isaac Asimov, (1954).

people with eyesight or reflex problems. However, for senior citizens living in suburbs or on the countryside, not being able to drive is a synonym of having to rely on family or friends to get by.

Transport is freedom and not being able to commute means very often having to move into old age residences or at least settling into a more urbanized environment. Having driverless cars would allow senior citizens to delay or even avoid the day when they need to go through such a traumatizing experience. Furthermore, and as we will see, unmanned technology is much safer than driven technology. The baby boomers will plebiscite safer and more reliable transportation means.

2.1.2 *Society of Litigation*

Already in 1981, A.E. Dick Howard an American specialist in constitutional law suggested in the Wilson quarterly report⁶:

we may be well on our way to becoming a “litigation society”. The courts have often served as a useful “safety valve” – they led the way in ending de jure racial segregation. But of late, they have tried to resolve an increasing number of social questions that are less susceptible to judicial remedy. The real difficulty, Howard says, may be the breakdown of old sense of community and compromise that led Americans to settle political disputes out of court – in legislatures and party conventions.

2.1.3 *Impact of These Trends on Transportation*

The graying of society and the increasing importance of litigation throughout the world have three immediate impacts on transportation:

Safety In Public transport, this has been an important investment driver, creating new technologies, which have reduced drastically the number of fatalities and injuries. Society doesn’t accept fate in this regulated environment. Although accident statistics have improved throughout the years in private transport, there are still too many killed and injured people. With the emergence of e-mobility technologies, road fatality numbers will need to drop or there will be massive class actions against car manufacturers or road infrastructure operators.

Security Senior citizens who are very often the most vulnerable people in public transport need to feel comfortable and secured while traveling. Under terrorism threats and other security issues, more and more specific security technologies are

⁶A.E. Dick Howard; Wilson quarterly report (1981).

being developed for public transport, especially CCTV. Here, also society doesn't accept inaction, and public transport authorities will therefore cover all stations and onboard vehicles with IP cameras, which is able through intelligent software to detect abnormal behavior or situations.

System homologation A litigation society always needs someone to blame. Homologating bodies' role is perceived as being the system's ultimate guarantor, creating extra hurdles on system approvals, with huge impact on delivery schedule and cost of all new systems.

We will present in the next sections, the worldwide issues that transportation is facing in regards to safety, homologation and security, and how they are impacted by the e-mobility revolution.

2.1.4 Safety Facts and Figures

Safety is the condition of being protected against physical consequences as a result of failure, damage, error, accidents, harm, or any other non-desirable event. It integrates the control of recognized hazardous situations to achieve an acceptable risk level. It also takes into account protection measures against exposure to an event that could cause health or economical losses. It considers protection of people and assets.

Worldwide accident statistics According to the World Health Organization (WHO)⁷, each year nearly 1.3 million people die as a result of a road traffic collision. Worst, more than half of these fatalities aren't even on board the car. The vast majority of these victims die in poor or middle-income countries (less than 8 % die in rich ones). Twenty to fifty million more people sustain non-fatal injuries from a collision, and these injuries are an important cause of disability worldwide. To bring that to a country level, 32,885 Americans died in 2010 of car accidents, while over 2 million people were injured!

Due to a quick increase in car use in developing countries, the WHO is estimating that the death number will skyrocket, more than doubling by 2030. On top of the terrible consequences for the families and the injured themselves, economic losses due to car crashes are catastrophic. Based on an estimated negative impact on the economy between 1 and 3 % of the respective GNP of the world countries, these crashes can generate a total yearly cost for society of over \$500 billion (Tables 2.1 and 2.2).

⁷Global Plan for the Decade of Action for Road Safety 2011–2020, produced by the World Health Organization (WHO).

Table 2.1 Description of fatalities according to Private and Commercial Transportation type

Transport mode	Private transportation		
	Crashes solely involving Private users	Crashes with commercial highway carriers	Crashes with trains and rail transit
Cars and light trucks	26.678	3.766	245
Pedestrian and bicycles	4.930	545	592
Motorcycles	3.989	156	2
Other	1.252	–	–2
Total	36.849	4.467	837
Large trucks	Commercial transportation		
	Passengers	Employees	Bystanders
Buses	30	9	
Rail Road	7	27	4
Rail Transit	22	3	–
Other			15
Total	182	883	19

Source Comparing the Fatality Risks in United States Transportation Across Modes and Over Time; Author: Ian Savage; White paper published in Research in Transportation Economics: The Economics of Transportation Safety, volume 43(1), 2013

Table 2.2 US fatalities per billion passenger miles and km (2000–2009)

Passenger fatalities per	Billion passenger	
	Miles	km
Riding a motorcycle	212.57	342.03
Driver or passenger in a car or light truck	7.28	11.71
Passenger on commuter rail and Amtrak	0.43	0.69
Passenger on urban mass transit rail	0.24	0.39
Passenger on a bus	0.11	0.18

Source Comparing the Fatality Risks in United States Transportation Across Modes and Over Time; Author: Ian Savage; White paper published in Research in Transportation Economics: The Economics of Transportation Safety, volume 43 (1), 2013

The white paper⁸ from Mr. Ian Savage describes the fatalities from the various transportation modes during the period of 2000–2009. The most important finding is that 94 % of the US total deaths happened on the

⁸Comparing the Fatality Risks in United States Transportation Across Modes and Over Time; Author: Ian Savage; White paper published in Research in Transportation Economics: The Economics of Transportation Safety, volume 43(1), 2013.

Table 2.3 Fatality comparison between the USA and the UK, IRTAD 2012^a

Measure (2009)	Country	Highways	Rural roads	Urban street	Total
Fatalities	USA	4.122	17.264	12.497	33.883
	UK	132	1.423	782	2.337
Distance driven (billion km)	USA	1.154	1.191	2.414	4.759
	UK	101	224	191	516
Distance driven (km) per thousand licensed drivers	USA	5.5	5.7	11.5	22.7
	UK	2.8	6.3	5.4	14.4
Distance driven (km) per thousand licensed drivers	USA	3.8	3.9	7.9	15.5
	UK	1.6	3.6	3.1	8.3

^aIRTAD: Database including accident and traffic data and other safety indicators for 29 countries (2012); <http://internationaltransportforum.org/irtadpublic/about.html>

American road network. Of these road fatalities, 74 % were car and light truck passenger related. 55 % of the fatalities were involved in crashes with no other vehicle, but occurred when a vehicle rolled-over without a prior collision, stroked a fixed object at the side of the road, an animal or debris in the roadway, or caught fire. Almost 10 % of all fatalities were motobikers, an unreasonably high number considering the low biker percentage. About 15 % of total road fatalities were not occupants of motorized vehicles, but mainly pedestrians.

Car accidents Even though there are several campaigns against drunk driving and for buckling up, about a third of highway fatalities involved in the US at least one car or motorcycle driver impaired by alcohol and almost half the fatalities concerned occupants not wearing a seat belt or using a child safety seat at the time of death. The type of road also has a significant effect on the fatality risk. The following chart, extracted from the IRTAD 2012 study⁹, shows fatality values for the USA and the UK (Table 2.3).

Based on this data, roads in rural areas have a fatality risk that is 2.7 times greater than that in urban areas. In general, the lower average speeds, greater provision of lighting, greater deployment of traffic control devices and fewer curves in urban areas more than compensate for factors such as the greater number of intersections and the presence of pedestrians. The safest functional class of roads is the Interstate Highway System. This type of highway has a fatality rate per vehicle km that is about half the US average for all roads.

⁹IRTAD: Database including accident and traffic data and other safety indicators for 29 countries (2012). <http://internationaltransportforum.org/irtadpublic/about.html>.

Table 2.4 Fatality comparison between the US and a few European countries; IRTAD 2012^a

Measure	Year	US	Sweden	UK	Netherlands	S.UK.N Total
Fatalities	2006	42,708	445	3298	730	4473
	2007	41,259	471	3058	709	4239
	2008	37,423	397	2645	677	3719
	2009	33,883	358	2337	644	3339
	2010	32,885	266	1905	537	2708
	Average	37,632	387	2649	659	3696
Population (in thousands)	2006–10	303,965	9.188	61,408	16,436	87,032
Vehicles (in thousands)	2006–10	256,944	5.351	34,850	9045	49,246
Vehicle distance driven (million km)	2009	4,758,450	81,444	516,007	126,966	724,417
Vehicle distance driven/person (million km)	2009	15,511	8799	8345	7701	8272
Fatality rate per million people	2009	123.8	42.2	43.1	40.1	42.5
Fatality rate per million motorized vehicles	2009	146.6	72.4	76	72.9	75
Fatality rate per billion km driven	2009	7.1	44.4	4.5	5.1	4.6

^aIRTAD: Database including accident and traffic data and other safety indicators for 29 countries (2012); <http://internationaltransportforum.org/irtadpublic/about.html>

Safety improvement to infrastructure such as elimination of intersections and integration of space or concrete blocks between opposite lanes reduce the frequency of crashes, albeit crashes when they do occur tend to be more severe due to higher speeds. In general, the riskiest types of roads are those in rural areas that do not have a middle division between oncoming traffic.

Table 2.4, extracted from the same study, gives the number of fatalities, population, motor vehicles (excluding mopeds), and vehicle distance driven by country. It shows that the fatality rate is substantially lower for each studied European countries than for the USA.

Compared with road transport, other modes have considerably lower annual fatality counts, even though the totals are still substantial.

Railway and mass transit accidents Public transport figures are much better though not perfect. Fatal train collisions and derailments command most media attention because they are usually spectacular, even though they are infrequent and account for only a small minority of railway fatalities.

Table 2.5 Main cause of accidents on Indian Railways, per type of users; Indian Railway yearbook^a

Year	Collisions	Derailments	Level crossing accidents	Fire	Other	Total
2001	20	344	83	15	2	464
2002	30	279	88	9	8	414
2003	16	216	96	14	7	349
2004	9	197	95	14	5	320
2005	13	136	70	10	3	232
2006	9	130	75	15	4	233
2007	8	96	79	4	8	195
2008	8	100	77	5	4	194
2009	13	85	69	3	7	177
2010	9	80	70	2	4	165

^aIndian Railway Yearbooks; (2012 study)

In the USA, railroads (which includes in that country a very large network of freight lines) and mass transit claimed an average of 63 lives a year to which we would need to add 65 fatalities involving pedestrian trespassers (2013 Study with data considering more than 10 years of statistics) (see Footnote 8).

The yearly average in this study shows that there were on the American rail transit 22 passenger deaths and 3 employees' death.

To give the reader a rough order of magnitude of casualties in developing countries, we decided to select India. The following charts show the improving evolution of accidents in this country with a huge train network but still with deficient safety systems. Tables 2.5 and 2.6 were extracted from the Indian Railway Yearbooks¹⁰. It shows that the main cause of accidents is derailments followed by level crossing accidents and collisions.

The table 2.6 from the same yearbooks gives an idea of what are the main causes of the accidents on the Indian network. As expected it clearly indicates that at the origin of an accident, 75 % of the time, a human being was involved, be it is a staff member, a passenger or another person, such as a trespasser or a car or lorry driver.

Tables 2.7 and 2.8 from the same yearbooks show the favorable trend in the number of accidents and the number of casualties and injuries per type of people. If we look at the 2010 figures, we can see that the reduction achieved was significant with only 0.17 accidents per million train × km.

¹⁰Indian Railway Yearbooks; (2012 study).

Table 2.6 Main causes of accidents on Indian Railways; Indian Railway Yearbook^a

Cause	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Failure of railway staff	284	248	184	161	119	120	85	86	76	63
Failure of other person	109	103	118	107	78	86	84	81	75	75
Rolling stock problem	16	11	6	6	5	1	4	4		3
Track problem	17	13	11	7	7	6	6	3		3
Electrical problem			1	1	2					
Signaling				2		1		1		14
Sabotage	19	14	10	18	4	5	8	7	13	1
Combination of factors	4		2		1		1		4	4
Incidental	11	20	15	15	14	11	6	8	5	2
Other	4	5	2	3	2	3	1	4	4	
Total	464	414	349	320	232	233	195	194	177	165

^aIndian Railway Yearbooks; (2012 study)**Table 2.7** Train accident evolution on Indian Railway (2001–2010): Indian Railway Yearbook^a

Year	Accidents per million train km s in %
2001	0.65
2002	0.55
2003	0.44
2004	0.41
2005	0.29
2006	0.28
2007	0.22
2008	0.21
2009	0.19
2010	0.17

^aIndian Railway Yearbooks; (2012 study)

Bus accidents The following table 2.9 from the US department of transport shows that buses have a great safety track record. It also shows that the trend in fatalities is favorable but might have hit a threshold at about 275 fatalities per year.

Public versus Private transport track record The clear conclusion from all these numbers is that public transport is much safer than private transport. In fact, any American has a 15 times higher probability of dying in his car than on board a train or a bus. The odds of dying in a motorcycle accident are just staggering and it is surprising that in a country prone to litigation, no class action has yet been done against motorcycle manufacturers.

Table 2.8 Number of accidents on Indian Railways, per type of users; Indian Railway Yearbook^a

Year	Passengers		Railway employees		Others	
	Killed	Injured	Killed	Injured	Killed	Injured
2001	55	281	8	27	153	175
2002	114	595	14	38	168	175
2003	157	658	29	45	232	279
2004	84	279	3	28	155	159
2005	35	86	5	8	181	209
2006	168	483	9	31	138	113
2007	38	227	6	24	164	151
2008	9	245	10	26	172	135
2009	52	257	12	22	145	165
2010	67	253	4	9	167	135

^aIndian Railway Yearbooks; (2012 study)

With such a poor track record, what could the automotive industry learn from the railway or bus industries? Well, as we will see they can go driverless. By doing this, the number of accidents and fatalities will drop drastically, probably to a level comparable to the other transportation means.

2.1.5 Security

Security definition It is the condition resulting from the protection against deliberate action of another human being to harm someone else or damage intentionally property. It integrates the control of hazardous situations involving malevolent acts to achieve an acceptable risk level. This takes into account the protection measures against exposure to someone who causes health or economical losses, including protection of people and assets.

Nature of criminality The nature of crimes to be committed within public transport is quite diverse. It includes various threat categories to which several scenarios can be associated:

- **Crime:** pick-pocket, violence, prostitution, drug trafficking;
- **Terrorism:** conventional bombs, dirty bombs (biological, chemical, nuclear), stabbing, poisoning;
- **Fire:** Arson, person on fire;
- **Sabotage:** infrastructure, switching equipment, cable theft;
- **Vandalism:** graffiti, destruction; and
- **Disorder:** Hooligans, aggressive behavior, racial harassment.

Fear of crime Fear of crime is an important issue for the rail and bus industry. Passenger growth, and the general health of the industry, could be undermined if

Table 2.9 Analysis of bus crashes; US Department of Transport 2010^a

Year	Number of buses registered	Fatal crashes involving buses	Buses involved in fatal crashes	Occupant fatalities	Total fatalities in bus crashes	Million vehicle miles traveled	Rates per 100 million vehicle miles traveled by buses		
							Number of buses registered	Fatal crashes involving buses	Fatalities in bus crashes
2000	746,125	323	325	22	357.00	7590	4.26	4.28	4.70
2001	749,548	289	292	34	331.00	7070	4.09	4.13	4.84
2002	760,717	274	274	45	331.00	6845	4.00	4.00	4.84
2003	776,550	288	291	41	337.00	6782	4.25	4.29	4.97
2004	795,274	276	279	42	315.00	6801	4.06	4.10	4.63
2005	807,053	278	280	58	340.00	6980	3.98	4.01	4.87
2006	821,959	303	305	27	337.00	6783	4.47	4.50	4.97
2007	834,436	280	281	36	325.00	14,516	1.93	1.94	2.24
2008	843,308	251	251	67	311.00	14,823	1.69	1.69	2.10
2009	841,993	221	221	26	254.00	14,387	1.54	1.54	1.77
2010	846,051	245	249	44	276.00	13,789	1.78	1.81	2.00

^aUS Department of Transport's 2010 analysis of bus crashes; FMCSA Analysis Division/Large Truck and Bus Crash Facts 2010

stations were to become places which people would rather avoid. Security measures such as implementing CCTV systems clearly reduce malevolent acts.

On the contrary, in private transport, the type of crime is rather limited to carjacking and auto theft. With self-driving technology, we will see that cyber terrorism will become possible in the future.

2.1.6 Homologation

Homologation definition It is the granting by an authorized organization to operate or sell a given product or system, according to safety and other technical requirements.

Homologation bodies play mainly two important roles:

- Making sure that a product or system meets the specific technical requirements or the general technical requirements, as indicated in a standard; and
- Giving the authorization to operate under safety conditions.

The first role can be considered a traditional role of homologating bodies, whereas the second is quite new and becoming increasingly important.

Railway standards The railway market is highly regulated. The vast majority of products and equipment applied in such environments must meet many stringent standards. To give the reader an idea of these norms, we've indicated some of the most important railway standards:

- EN 15 227: Requirements of crash safety;
- EN 15 085: Welding of railway vehicles;
- EN 45 545/DIN 5510 EBA: Guideline for fire protection requirements;
- EN 50 155: Electrical equipment, requirements on hardware;
- EN 61 508: Functional safety, electrical systems;
- EN 50 121: Electromagnetic compatibility (EMC);
- EN 50 126: RAMS LCC Management; and
- EN 50 128/EN 50 129: Software/safety proof.

Authorization to operate In a risk adverse society, governments and administrative bodies want to be sure that a metro or train will operate safely under any condition. More importantly, they want to be sure that if any accidents happen, there will be someone to blame. Till a few years ago, these homologating bodies were there mainly to review the information supplied by the engineering or manufacturing companies. However, they are now being seen as the guarantor of the system safety. Not only have these companies been prosecuted in case of accidents, but also their employees have been personally liable to criminal inquiries.

This simple change of status has created huge bottlenecks in the approval process, as their employees now request much more details before approving personally safety related solutions. This has also had a drastic impact in the volume of documents that must be supplied before approval. As a consequence, delivery schedule of European train suppliers haven't been met in the last years. In fact, this movement towards more stringent homologation has been estimated by some specialists as adding as much as one to two years to deliveries. A consequential damage of this change in status and role is that important extra costs have been added to manufacturers or system integrators in an industry known for very low margins. Unless the industry is able to change its processes to adapt to these new demands, the extra costs will be passed to society through higher taxes or more expensive fares.

Safety improvements do not come cheap but whenever new accidents happen, there will always be public outcry for more safety measures. As one of our nine principles is that all transportation means compete against each other, all these measures are pricing out trains in regards to cars or buses. Luckily two important elements should help the railway industry. First and as we will see in the next section, the railway industry has shown resilience to new safety regulations throughout its history and has a strong embedded safety culture. Second and probably more importantly, in a litigation society, no industry can go on forever allowing millions to be killed or injured. The day all vehicles are unmanned, the same safety concepts, and stringent regulation will be applied to the automotive and bus industries, leveling the playing field.

2.2 Safety Concepts

Safety of passengers has always been a key concern of public transport authorities. No politician or operator's President in his or her right mind can show complacency when the life of passengers is involved. On the other hand, car and motorcycle manufacturers have mostly been able to escape costly legal battles, except when class actions were able to prove that the deaths or accidents were due to equipment malfunction. In cases where accidents were due to poor road state or bad signaling, infrastructure owners have been able to escape such litigation, because of the difficulty of proving that such accidents were caused by malfunctioning infrastructure. How can someone pushing his or her way into a train through partially closed doors successfully sue the metro operator for any injuries suffered by his or her act, when someone hitting an icy patch on the road can't?

The reality is that there is a double standard measure. Private transport industry can invoke the act of God principle or the "he took his chance" syndrome. Public transport and especially the train industry must on the contrary plan for all types of

conditions, even if this means increasing tremendously the cost of trains or its railway infrastructure, even though the probability of such event occurring is negligible. As we've just seen, the safety homologation process is becoming increasingly complex, lengthy, and thus expensive, reducing the competitiveness of the railway transport means in regards to private transport. Imagine if car manufacturers had to build in fail-safe systems to ensure braking under any conditions, or equipment redundancy to ensure that any equipment malfunction would automatically be taken over by substituting equipment.

Everyone within the private transport chain, be it manufacturers, infrastructure operators as well as private car owners can still invoke the “fate” excuse to avoid being prosecuted. On the other hand, under the megatrend of a risk adverse society and under the influence of a litigation society, laws have been getting tougher for railway or bus employees responsible for gross negligence involved in accidents. Recently, railway employees responsible for accidents have been trialed and arrested if found guilty. It has not always been that way. At the beginning of the era of train transportation, risks were part of train travel. Today even a small derailment without any onboard passenger is likely to make the newspaper headlines. Is the private transportation going that way?

The first signs of going in that direction are there. Under the assaults of the litigation society, drunk or over-speeding drivers must now respond rightfully so for their acts criminally. Things are changing and we believe that with the new e-mobility technologies, the day isn't far where any car accident involving casualties will be investigated and the responsible party be it manufacturer, infrastructure, driver or car owner, prosecuted. With the emergence of new technologies allowing for driverless cars, this trend will accelerate. In order to understand how e-mobility is likely to influence safety in the automotive industry, let's take a look at the evolution of safety in the railway industry. We could ideally learn how railway safety could help shape a safer automotive environment or at least see how the automotive industry is likely to evolve from a safety perspective in the coming years.

2.2.1 Railway Safety Concepts

Trains being guided by fixed rails are uniquely susceptible to collision, unlike cars or buses. Furthermore, trains cannot stop as quickly as automobiles, and frequently operate at speeds that do not enable them to stop within the driver's sighting distance. Thus safety was from the start one of the top priorities of any new train operation, though fate was at the start an inherent part of the journey.

In the early days of the railway adventure, horse mounted flagmen preceded trains. Hand and arm signals were then used to direct train drivers. To compensate for poor visibility conditions (i.e.: fog, rain, snow), wayside attendants introduced in the 1830s elevated flags and lanterns, which could be seen from far away. However, many accidents still occurred. So much so, that in 1889, England introduced the first safety regulation (Regulation of Railways Act), which forced the application of interlocked block signaling. Almost simultaneously, the USA introduced similar regulation.

Regulation evolved and new technologies were developed, but the three main safety principles that were established at the end of that century are still applied today:

- Locking a section of the railway;
- Making sure that no trains occupy such section; and
- Insuring that the system's integrity is maintained throughout operations.

Block interlocking It is a very simple concept: under normal circumstances, railway sections—known as blocks—can allow only one train at a time. Thus, trains cannot collide with each other if they are not permitted to occupy simultaneously the same section of tracks. However, this is only a certainty if the trains are spaced far enough apart to ensure that they cannot collide, taking into consideration factors such as speed, braking time, etc.

In the early railway days, signalmen were responsible for ensuring that any switch was set correctly before allowing a train to proceed. Early interlocking systems used mechanical devices both to operate the signaling appliances and to ensure their safe operation. Beginning around the 1930s, electrical relay interlocking was used and since the late 1980s, new interlocking systems have tended to be electronic based.

Block signaling This is the second safety principle: signaling to the next train driver (or an unmanned train today) that no train is in that section.

At the beginning of the railway adventure, employees were standing at intervals along the line with a chronometer and used hand signals to inform train drivers that a previous train had passed, as well as when it did so. However, the signalmen couldn't know whether the train had cleared the line ahead, so if this preceding train had stopped for whatever reason, the following train driver would have no way of knowing it before it was too late. Even though drivers were expected to slow down when a train had passed

very recently, accidents were frequent then. With the use of telegraph, it suddenly became possible for signalmen in a station or at an interlocking tower to send a message to confirm that a train had passed and that a specific block was cleared. This safety enhancement became known as the “absolute block system”. Fixed mechanical signals began replacing the hand signals from the 1830s. When a train passed into a block section, signalmen would protect that block by setting mechanically the signal to “occupied”. When an unoccupied message was received, signalmen would move the signal into the “clear” position.

With the 1989 legislation, Great Britain made mandatory the use of block signaling together with interlocking for all passenger railways. Based on these two principles, railway engineers came up afterward with new developments to increase safety on the wayside, on board the train and at the controllers’ level in the station, and more recently within the control centers.

Integrity The next safety issue railway engineers tried to solve was that even though a train might have left a block section, there was always the possibility that a few wagons had separated from the front locomotive. This safety problem which can be described as the “carriage integrity” principle was especially critical for long freight convoy. The other integrity issue that needed to be solved was the integrity of the railway tracks. In long distance freight operations like the ones in North America, freight trains could travel through forest for thousands of miles without meeting anyone. Being able to identify that the tracks weren’t broken was a key issue.

2.2.2 *Safety Procedures*

Things don’t always go as planned. To address issues coming from abnormal or emergency situations, the railway engineers came up with safety operational mode, also known as degraded modes.

Degraded mode safety principles: Under normal weather conditions (not under misty or rainy conditions) trains were allowed at the low speed of 30 km/h, a velocity judged sufficiently low to enable safe braking during sight driving, to overpass signals indicating the line ahead was occupied. This operating mode was called “permissive block”. In order to split or join trains together or even rescue failed trains, the operator had to allow multiple trains to enter in an absolute block. In giving authorization, signalmen needed to ensure that drivers knew precisely what to expect ahead, and act in a safe

manner. In such situation, the signal would remain at “danger” and the driver could pass that signal at low speed.

2.2.3 *Interoperability*

Interoperability is a newer concept not related to safety but more to economics or to a political vision. Convergence of rail networks is promoted by governments. Countries seek to build interoperable networks, and international organizations seek to build macro-regional and continental networks. For instance, the EU has set out to develop interoperable freight and passenger rail networks across its entire area, and is seeking to standardize gauge, signaling, and electrical power systems.

Although interoperability decision isn't made for safety reasons, it has implication for safety. Once the decision is made to integrate various elements of a system, these elements need to work together in a safe way. Physical but also conceptual interoperability needs to be sought to integrate various rail networks.

The most obvious railway interoperability parameter is the gauge similarity. Rolling stock on the network must have wheel sets that are compatible with the gauge, and therefore the gauge is a key parameter in determining interoperability between two lines. There are many other parameters, such as electro-magnetic compatibility, voltage, compliance with control system parameters such as the signaling system, axle load, loading envelope, etc.

2.2.4 *WaySide Safety Technologies*

Railway engineers came up with several technologies to solve the issues of signaling, interlocking, and integrity. On most railways, physical signals are erected at the line side to indicate the drivers whether the line ahead is occupied and to ensure that sufficient space exists between trains to allow them to stop.

Mechanical signal Older forms of signal displayed their different aspects by their physical position.

The earliest types comprised a board that was either turned face-on and fully visible to the driver, or rotated so as to be practically invisible. While this type of signal is still in use in some countries (e.g. France and Germany), by far the

most common form of mechanical signal worldwide is the semaphore signal (introduced as way back as 1842). This comprises a pivoted arm that can be inclined at different angles. Each angle would define a level of risk.

Color light signal On most modern railways, color lights have largely replaced mechanical signals as they can display the same aspects at nights and days and require less maintenance.

Although signals vary widely between countries, and even between railways within a given country, a typical aspect would be (as on roads):

- Green: run to the next line speed;
- Yellow: Prepare to find next signal displaying red; and
- Red: Stop.

The following two technologies were used mainly to help identified cleared blocks:

Axle counter Using axle counting is a simple method of determining the occupied status of a block. These devices located at the block's beginning and end count the number of axles entering and leaving. If the numbers accounting for axles leaving and entering the block are the same, then the block is assumed to be clear.

Track circuit Its principle is a relatively simple alternative: the rails at either end of each section are electrically isolated from the next section and an electrical current runs through both running rails at one end. A fail-safe relay at the other end is connected to both rails. When the section is unoccupied, the relay coil closes the electrical circuit, and is thus energized. However, when a train enters the section, it short circuits the current in the rails, and de-energizes the relay, indicating the same token that the block is occupied. This method does not explicitly need to check that the entire train has left the section. If part of the train is left in the section, this part will continue to be detected by the track circuit.

This type of circuit is also used to detect the absence of trains, both for the purpose of setting the signal indication and for providing various interlocking functions—for example, not permitting switching points to be moved when a train is standing over them. Electrical circuits are also used to prove that points are in the appropriate position before a signal supervising them may be cleared.

Track integrity check Rail breaks are a serious threat to operation and to passengers. Another interesting feature of track circuit is that it can automatically detect some types of track defect such as a clear broken rail, though cracked rails cannot be identified, as current can still pass through. Many companies are working on alternative technologies such as ultrasonic or electromagnetic broken rail detector or similar other technologies. All these technologies have in common that they send a flow in the rail which measures any variation in regards to a normal response time or pattern. These systems are installed either on the trains or on maintenance machines.

2.2.5 Fixed, Semi-Fixed, and Moving Block Principles

As we've seen, railway engineers came up with the concept of block which forbids the entry of a new train before the previous train exits such block. Without changing this safety principle, the engineers worked throughout the years to shorten the spacing between the blocks. Until recently, this spacing was fixed along the tracks and depending on the operational mode, its length was more or less important. With the need to transport thousands of commuters during peak hours, spacing became critical because reducing it meant increasing significantly the operational capacity.

Headway Space between two vehicles, running on the rails, influences directly the system's capacity. It is a direct consequence of the minimum stopping distance required to bring a train to a complete stop. The stopping distance is the sum of the distances a train will run due to the driver's perception and reaction time, and the distance a vehicle will travel from the point when its brakes to when it comes to a complete stop. It is primarily affected by the vehicle's speed and the coefficient of friction between wheel and rail surface.

The railway industry came up with the concept of headway, which translates distance into time. The minimum safe headway measured tip-to-tail (from the front to the end of a train) defined by the braking performance is on a flat section (on a slope, we would need to take into consideration the gravity impact):

$$T_{\min} = L/V + t_r + P_r + kV/2(1/a_f - 1/a_1);$$

where:

T_{\min} minimum safe headway time in minute;

L length of the vehicle;

V speed of the vehicle;

t_r reaction time;

P_r perception time;

a_f maximum braking deceleration of the following train in m/s^2 ;

- a_1 maximum braking deceleration of the leading train in m/s^2 ; and
- k arbitrary safety factor superior or equal to 1.

Let’s calculate the minimum theoretical headway, using realistic values for a light metro operation, with a driver. We can select a 100 m long EMU composed of 4 cars train-set. A speed of 80 km/h (22 m/s) is typical of metro operation’s maximum speed, running between two stations. 1.5 and 0.5 s for reaction time and perception respectively can be considered accurate values.

For a metro car of this length, the average braking deceleration would be around 1.2 m/s^2 , but we could use an emergency braking value of around about 1.38 m/s^2 . A higher value of 1.5 m/s^2 is possible but could cause injuries to passengers who would fall. As railway safety rules require that the minimum distance considers absolute distances (also called “brick wall” stopping), this means that the speed of the leading train shouldn’t be considered. With a safety factor of 1.5, the minimum headway time would be

$$T_{tot} = 100/22 + 2 + 1.5 * 22/2 * (1/1.38) = 18.5\text{ s.}$$

With an unmanned system, the 2 s due to perception and reaction time would be eliminated.

Based on this 18.5 s, the braking distance for such a train configuration would be around 230–250 m.

Calculating operational headway is much more complex than what we’ve just done, as it requires taking into consideration other safety factors such as overlapping distance, as well as integrating an intermediary signaling for safety reasons and the dwell time at stations. To complicate matters even more, some metro operations can consider up to three-signal spacing (the following graph (Fig. 2.1) shows two-signal spacing).

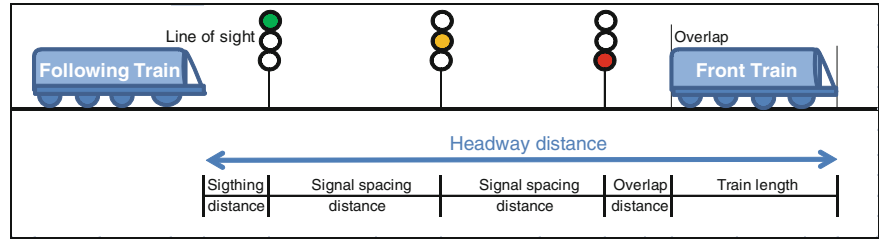


Fig. 2.1 Headway distance considering two-signal spacing. *Source* Author

Fixed block As seen, a fixed block signaling solution allows a single train to occupy a specific block of the railway line. As a train or metro moves along the track, it will occupy blocks which prevent another train from entering that area; mechanical or color light signals provide information to the driver on available blocks and routes. Railway engineers calculate the blocks' length using speed, grades, stopping areas, operational properties of the train, and location of physical elements such as switches and stations. Once the blocks' length has been calculated, signals are physically placed on the line to instruct drivers on scheduling and routing information.

For many lightly operated lines, fixed block length isn't an issue. For these non mass transit lines, railway designers usually favor positioning the blocks at the start and end of the stations. The following operational modes still use mainly such positioning:

- **Timetable:** trains following a schedule; and
- **Train order:** messages sent from a central dispatcher to line side station operator and train crews (regarded as immutable command orders), which control and protect train movements.

However, when system capacity starts to be an issue, as in mass transit operations, designers usually put the blocks with the start and end of the signal levels. The lengths of blocks are then designed to allow trains to operate as frequently and quickly as safely possible. A lightly used line might have blocks many kilometers long, but a busy commuter line might have blocks only a few hundred meters long.

As indicated, the previous headway formula would need to integrate the overlap, additional spacing distances, and the dwell time at stations (necessary time for passengers to hop on and off the metro). When all these distances and additional safety time are factored in, the minimum headway time, in which metros can operate safely with fixed block technology, is around 90 s. As we will see for many mass transit operators, this isn't good enough and this is why technology providers have been trying to introduce a newer technology.

Semi-moving block technology In the early twenty-first century, companies tried to adapt fixed block technology to enable more and more trains to operate on the heavy commuter and metro lines, on shorter spacing distance. With blocking spacing calculated to their bare minimum, operating systems could almost simulate the performance of moving block technologies. However, technology providers are now all proposing moving block technology, which changes the concept of spacing.

Moving block technology One disadvantage of having fixed blocks is that the faster trains are allowed to run, the longer the stopping distance, and therefore the longer the blocks need to be. This obviously decreases the line's capacity (Fig. 2.2).

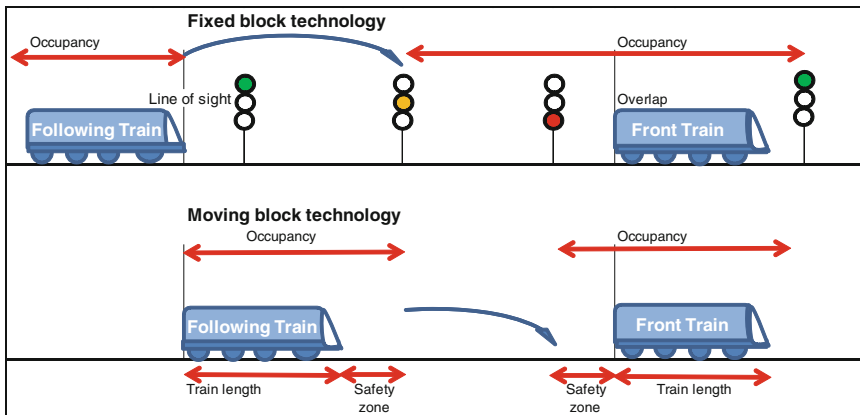


Fig. 2.2 Distance comparison between fixed and moving block technologies. *Source* Author

The spacing concept of moving block system doesn't take into consideration two fixed points on the line but rather a safety zone around each moving train that no other train is allowed to enter. Similar to the calculation of fixed block length, this safety zone is calculated using speed, grades, and the operational properties of the train. An additional buffer zone is provisioned around the train, which can vary depending on the location of the vehicle and its surrounding elements.

Normal operating and worst-case scenarios are simultaneously considered when calculating this safety zone. Normal braking rates are used for calculating safety stopping distances. Other factors integrated in the calculation are positional uncertainty, runaway propulsion, and delays in brake application. A guaranteed emergency braking rate is also applied.

This safety zone, which is calculated in real time by a vehicle on-board controller (VOBC) and centralized computers, depends on knowledge of the precise location, speed, and direction of each train, which is determined by a combination of several sensors:

- **Passive markers along the track:** Track-based transponders are activated by a low-frequency signal, which receives its energy from a passing train and transmits data to the train. Typical data transmitted by fixed balise typically includes the location of the balise, the geometry of the line, such as curves and gradients, as well as any speed restrictions;
- **Active markers along the track:** Track-based transponders are powered from the signaling supply that continuously sends packets of information to passing trains;
- **Train-borne tachometers:** This technology is based upon the principle of detecting rotational wheel speed by means of a pulse produced by a transducer and calculating any deviation of distance between two markers;

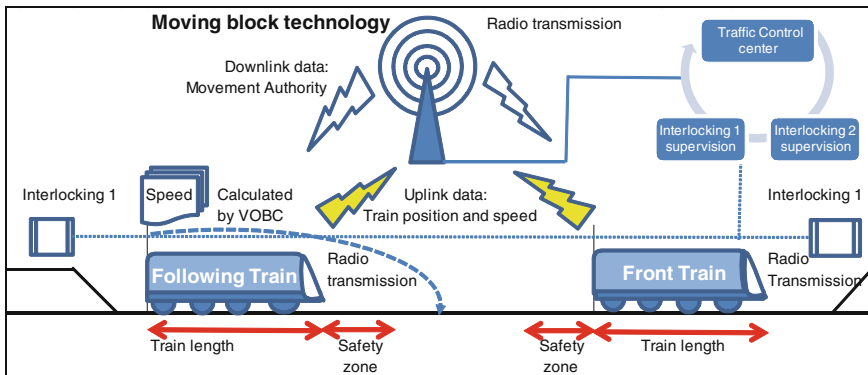


Fig. 2.3 Illustration of moving block transmission technology. *Source* Author

- **Speedometers such as GPS systems:** They cannot be used alone, because they don't work in tunnels (see section on GPS for more technical information); and
- **Wayside signals:** With moving block technology, they are unnecessary.

It is important to mention that the occupancy calculated in these systems must include a safety margin for location uncertainty added to the length of the train. This safety margin depends on the accuracy of the train's odometers and sensing devices.

On a moving block system, the line is usually divided into sections, managed on the wayside by one interlocking equipment. Each interlocking equipment is controlled in real time by a computer at the control center level. As shown in the following illustration (Fig. 2.3), this control center receives and downloads data to all fleet trains. In such a system, the train position and its braking curve are continuously calculated by the train's VOBC, and then communicated via radio to the wayside equipment.

Based on the speed and train position data received from the trains, the wayside equipment is able to establish protected areas, called Limit of Movement Authority (LMA), up to the nearest obstacle (i.e., the front train, or whatever obstacles, such as an end of line) (Fig. 2.4).

2.2.6 WaySide Interoperability Technologies

Things that aren't interoperable per nature cannot work together.

Track gauge This was one of the main reasons why track gauge was originally so different from one country to the other, as many countries built different systems in order to avoid invasion, limit freight competition from neighboring countries, or simply adopted the gauge system from their colonial power.

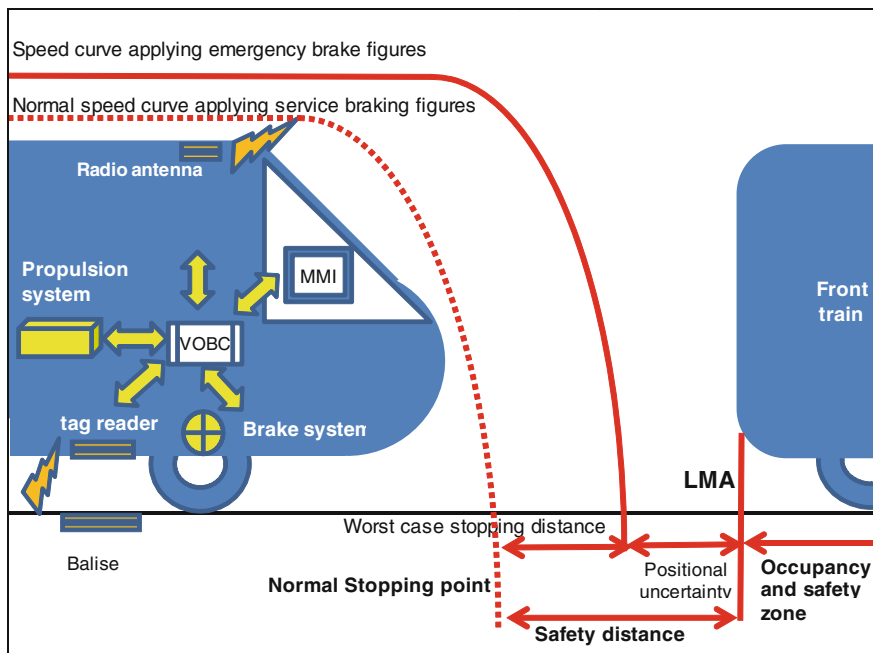


Fig. 2.4 The safety distance concepts for moving blocks. *Source* Author

As incredible as it seems, throughout history many different track gauges could be found, for instance 0.6, 1 m (small gauge), 1.6 m (large gauge). A 3 m gauge track was even contemplated (the Breitspurbahn) by Adolph Hitler's Nazi regime. Today all new built lines tend to adopt the standard gauge, which is 1.435 m system. Interoperability issues can be huge in some areas such as Spain, as one can find small, large and standard gauges alongside. No wonder that for interoperability purposes, Spanish manufacturers introduced in 1968 a bogie with variable gauge wheelsets (variable axle). Such variable gauge technology allows trains to travel across a break of gauge and as the train passes through the gauge changer, wheels are automatically unlocked, moved closer together, or further apart, and are then re-locked.

Overhead electric system Electric trains collect their current from an overhead line system by pressing a device called pantograph against the lowest wire of an overhead line system (contact wire). Metro lines use mainly a brush that is in contact with a connector called third rail. The current collectors are electrically

Fig. 2.5 Picture of a tramway's pantograph in contact with a catenary line.
Source Author



conductive and allow current to flow through to the train or tramway and back to the feeder station through the steel wheels on one or both running rails (Fig. 2.5).

Alternative electrical power transmission schemes for trains include ground-level power supply, batteries, and electromagnetic induction.

There are two main electrical power transmission technologies: AC and DC. Each one may present different voltages and in the case of AC, different frequencies as well.

Example of AC and DC technologies

- 600 V DC;
- 750 V DC;
- 1500 V DC;
- 3 kV DC;
- 15 kV AC, $16\frac{2}{3}$ Hz (16.7 kHz);
- 25 kV AC, 50 or 60 Hz.

Although there are always some exceptions, AC lines are mainly used for main line trains and DC for commuter and metro operations.

Signaling system interoperability Signaling interoperability is mainly an issue on main railway lines (but also sometimes on commuter lines of huge city commuter network). Indeed on metro networks, lines operate independently from one other.

For main lines, the EU specified the use of a standardized signaling system called European Train Control System (ETCS). It is a signaling, control and train protection system designed to replace the many incompatible safety

systems currently used by European railways, especially on high-speed lines. ETCS requires standard trackside equipment and a standard controller within the train cab. In its final form, all wayside information is passed to the driver electronically, removing the need for signals which, at high speed, could be almost impossible to see. It is now a requirement that all high-speed trains within the EU adopt ETCS and many high-speed networks outside the EU have also adopted it.

ETCS is specified at four different levels:

Level 0: ETCS-compliant locomotives or rolling stock interact with wayside equipment that is non-ETCS compliant;

Level 1: ETCS and non-ETCS equipment co-exist on the same line;

Level 2: a dedicated system with wayside train integrity supervision; and

Level 3: works like Level 2, but train integrity is controlled by onboard equipment monitoring distances between trains constantly and fluidly.

Other wayside interoperability issues Most railway lines have different clearance requirements, as well as axle load issues (maximum weight per axle that the line can support). This complicates the life of railway manufacturers who need most of the time to build tailor made equipment for each railway and metro operations.

2.2.7 Train Integrity Technologies

Carriage integrity: In the early railway days, when a train left a block, the driver needed to inform the signalman controlling the block entry, but had no way of knowing if the last convoy's wagon was still attached. This is why railway engineers came up with a procedure: even if the signalman received the message that the previous train had left a block, the signalman of the next block had to make a visual contact to check if he could see the 'end-of-train marker' on the last vehicle, confirming the train's integrity and allowing the next train to enter the block. The end of train marker was usually a red colored disc by day and a red electric lamp by night. In case he couldn't see it, the signalman would ask the next signal box to stop the train and investigate.

End of Train markers Today, the "end-of-train marker" used in freight convoys, usually called end of train device (ETD), is a self-energized electronic device. Introduced in the 1980s under the drive to lower operational cost, it can be divided into two categories: flashing red light and radio-based ETDs, sending back a

message that the end wagon occupies the same position in regards to the head locomotive. Any significant change in distance will automatically give a message to the crew that there is a problem.

For passenger trains, the carriage integrity is today performed by logical sequencing done by the computer-based vehicle system called vehicle control unit (VCU). These VCUs, before entering in operation, will check the vehicles integrity and even establish the train's configuration.

2.2.8 Train Protection Technologies

The consequence of a train driver failing to respond to a signal's indication can be disastrous. As a result, various auxiliary safety systems have been developed. Any such system will necessitate the installation of onboard equipment to some degree. Some of these systems only intervene in the event of a signal being passed. Others include audible and/or visual indications inside the driver's cab to supplement the wayside signals. Some systems act intermittently (at each signal), but the most sophisticated systems provide continuous supervision.

Cab signaling This system communicates track status and driving position data to drivers present in the train cab. The simplest systems display trackside signal aspect, while more sophisticated systems also display allowable speed and dynamic information about the track ahead.

Cab signaling systems range from simple coded track circuits, to transponders communicating with the cab, and communication-based train control (CBTC). In modern systems, a train protection system is usually overlaid on top of the cab signaling system to warn the driver of dangerous conditions, and to automatically apply brakes and bring the train to a stop if the driver ignores the dangerous condition.

Train protection systems All types of train protection systems are based on the desire to eliminate possible driver errors resulting from failing to obey to a visual displayed line side or to an in-cab signal instruction. The development of such technology on main line railways began with the introduction of warning systems and subsequently progressed to instruction enforcement issued by these systems. There are three main train protection systems that will work closely together to maintain a train within a defined tolerance of its timetable: ATO, ATC, and ATP. The combined systems will marginally adjust operating parameters such as the ratio of power to coast when moving and station dwell time, in order to bring a train back to the timetable slot defined for it.

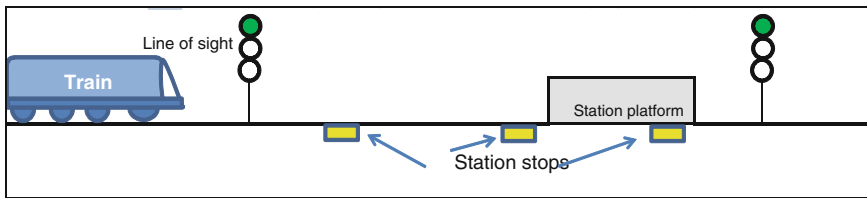


Fig. 2.6 ATO principles. *Source* Author

Automatic Train Operation (ATO) The earliest ATO system on a full metro line was introduced in 1961 on the Barcelona Metro line 2. ATO is the non-safety part of train operation related to station stops and starts. The basic requirement of ATO is to tell the train approaching a station where to stop, so that the complete train is in the platform, after receiving confirmation from the ATP that the line is clear. The sequence operates as shown in Fig. 2.6.

The train approaches the station under clear signals so it can do a normal run-in. When it reaches the first balise (originally a looped cable now mostly replaced by fixed transponders), a station brake command is received by the train. The VOBC calculates constantly and updates the braking curve to enable it to stop at the correct point.

Many operators using ATO systems decide to maintain drivers to mitigate risks associated with failures or emergencies.

Automatic Train Control (ATC) Many modern systems integrate ATC systems that carry out normal signaling operations such as route setting and train regulation. The ATC hardware is divided into two parts:

- **Vehicle on-board control (VOBC)** located on the vehicle and composed of a dual-processor computer that continually monitors the position, speed, and general status of the train; and
- **Vehicle control center (VCC)** located in the operations and maintenance center that directs the train movement, via the VOBCs of a portion of the fleet. The VCC is indeed limited to the control of about 125 trains and normally communicates with trains at least once every second. An important safety feature is that if the communications between a VOBC and the VCC were to be lost for more than 3 s, the VOBC fail-safe mechanism would immediately halt the train by applying emergency brakes.

Automatic Train Supervision (ATS) This system is usually integrated within the ATC system. Its main function is to monitor the system status and provide appropriate controls to direct train operation with the objective of maintaining the intended traffic patterns and minimizing the effect of train delays on the operating schedule.

Automatic Train Protection (ATP) ATP is the safety system which ensures that trains remain a safe distance apart and have sufficient warning to allow them to stop without colliding with each other. ATP systems were first introduced on metros in the late 1960s. Most metro applications use ATP in conjunction with ATO. ATP was also introduced in various forms on a number of main line railways, often in conjunction with high-speed train operation. There are mainly two types of ATP systems:

- **Intermittent systems:** They use electronic beacons (inductive or radio frequency) or short electrical loops positioned within a meter; and
- **Continuous systems:** They use permanently active data transmission and monitoring systems, either through electrical inductive coupling by means of track loops or coded track circuits or by means of radio transmission.

ATP is a predictive enforcement system, which continuously monitors the speed of a train in relation to either a target speed or distance. It intervenes when a train is prevented from passing a Limit of Authority or exceeds a speed limit. This speed limitation will be defined by the line's profile or signal indication. If the allowable speed is exceeded, braking will be applied until the speed is brought within the required limit or the train stopped.

As an ATP system recognizes track condition and driving information of a corresponding train, it permits shorter headway and increases track capacity, by ensuring a minimum braking distance.

Braking system The interface between braking and ATP systems has been designed to automatically authorize trains to brake if they consider that the driver does exceed predefined speed or if the train isn't in a safe mode.

2.2.9 Onboard Operational and Safety Procedures

Operating rules, policies, and procedures are used by railroads to enhance safety. Specific operating rules may differ from country to country and even from railroad to railroad within the same country. Most railway systems around the world use what is known as "speed signaling." Under this speed signaling principle, the signaling elements inform the driver of the speed at which he or she may proceed, but not necessarily the route the train must take. Speed signaling requires a far greater range of signal aspects than "route signaling," but places less dependence on the drivers' route knowledge. This usually takes out the human error factor, which is far safer.

A notable exception is Great Britain, which generally conforms to the "route signaling" principle. Under such procedure, the driver is informed about

which route the train must take beyond each signal. This is achieved through route indicator attached to the signal. The driver uses his route knowledge, reinforced by wayside speed restriction signals to drive the train at the correct speed throughout the portion of the route. This principle requires that drivers be familiar with the route, and in emergency situations drivers might have problem when diverted to other routes. As several accidents have been caused by such situation, UK drivers are only allowed to drive on routes for which they have been trained on and must regularly drive on these alternative routes to keep their knowledge up to date.

2.2.10 Positive Train Control (PTC)

In the USA, PTC is a system of functional requirements for monitoring and controlling train movements to provide increased safety. The American Railway Engineering and Maintenance-of-Way Association (AREMA) describes positive train control (PTC) as having these following primary characteristics:

- Train separation or collision avoidance;
- Line speed enforcement;
- Temporary speed restrictions; and
- Rail worker wayside safety.

The main concept in PTC (as defined for North American Class I freight railroads) is that the train receives information about its location and where it is allowed to safely travel (LMA). Equipment on board the train then enforces this, preventing unsafe movements. PTC systems may work in either dark territory or signaled territory, and may use GPS navigation to track train movements.

2.2.11 System Interoperability Procedures

One of the fascinating differences between the North American and European railway systems is in the priorities given to freights and passenger cars. Actually, if we want to generalize, one could say that priorities are inverted across the two sides

of the Atlantic. In Europe, freight cars must wait on the sideline for the passage of the passenger cars, whereas in North America, passengers must wait several minutes for the long wagon convoy to pass through.

This significant difference (together with the difference in distances, the electrification of the lines, and the type of transported goods) has had consequences on the design of the locomotives which favored more powerful locomotives in the USA running at lower speed, whereas European locomotives can typically go at speeds of 160 km/h but are usually limited in power output.

2.2.12 Grade Crossing

A railway crossing is an intersection between a railway line and a road or path, at the same level. Many accidents occur at these level crossings with cars or even pedestrians. Grade crossing safety systems use either passive solutions, such as signs, or use safer active warnings, such as lights and warning tone. Radar sensor systems or empty space detection by video analytics are some of the new e-mobility technologies implemented to improve safety of level crossings.

2.2.13 Safety Integrity Level (SIL)

SIL is defined as a relative level of risk reduction provided by a safety function. It is defined by a number of quantitative and qualitative factors (i.e., development process and safety life-cycle management). In the European Functional Safety standards, based on the IEC 61,508 standard, four different SIL levels are defined. This standard defines two broad categories: hardware safety integrity and systematic safety integrity. A device or system must meet the requirements for both categories to achieve a given SIL level.

The SIL requirements for hardware safety integrity are based on a probabilistic analysis of the device. In order to achieve a given SIL, the device must meet targets for the maximum probability of dangerous failure and a minimum Safe Failure Fraction. The concept of “dangerous failure” must be rigorously defined for the system in question, normally in the form of requirement constraints whose integrity is verified throughout system

Table 2.10 SIL probabilistic requirements

SIL level	PFD	RRF	PFH	RRF
1	0.1–0.01	10–100	0.00001–0.000001	100,000–1,000,000
2	0.01–0.001	100–1000	0.000001–0.0000001	1,000,000–10,000,000
3	0.001–0.0001	1000–10,000	0.0000001–0.00000001	10,000,000–100,000,000
4	0.0001–0.00001	10,000–100,000	0.00000001–0.000000001	100,000,000–1,000,000,000

Source Standard IEC 61508

development. The actual targets required vary depending on the likelihood of demand, the complexity of the device(s), and types of redundancy used.

The probability of failure on demand (PFD) and the risk reduction factor (RRF) of operational demand for different SIL levels are as in Table 2.10. For continuous operation, it is necessary to use the Probability of Failure per Hour, which we’ve indicated in Table 2.10.

Hazards of a control system must be identified then analyzed through risk assessment. Mitigation of these risks continues until their overall contribution to the hazard is considered acceptable. Certification schemes are used to establish whether a device meets a particular SIL level. Requirements of these schemes can be met either by defining a rigorous development process or by establishing that the device has sufficient operating history to argue that it has been proven in use.

2.3 Communication-Based Train Control (CBTC)

CBTC technology is behind the concept of various technologies, such as

- PTC,
- European Train Control (ETCS),
- electronic train management system (ETMS), and
- incremental train control system (ITCS).

The IEEE defines CBTC as follows:

- Continuous, ATC system utilizing high-resolution train location system, independent of track circuits;

- Continuous, high-capacity, bidirectional train-to-wayside data communications; and
- Train-borne and wayside processors capable of implementing ATP, ATO, and ATS functions.

The advent of digital radio communication technology during the early 90s encouraged the signaling industry to replace transmission loop by radio telecom-based systems for wayside to train communication. CBTC makes use of telecommunications between train and track equipment for traffic management and infrastructure control.

CBTC technology gives a more accurate train position than traditional signaling systems. This results in a more efficient and safe way to manage railway traffic. Metros and other railway systems are able to improve headways while improving safety. Improving headway as we have already seen, allows for capacity increase. Furthermore, CBTC allows for reduced signaling system CAPEX and OPEX by eliminating all mechanical and electromechanical signals along the line.

CBTC systems are designed to be vital standalone systems, which may also have an overlay capability on fixed blocks for migration purposes. A CBTC system must be implemented in a fully fail-safe manner in order to be able to provide vital moving block functionality (Fig. 2.7).



Fig. 2.7 View from a monorail's front car, showing heavy concrete switch beams managed automatically by a CBTC system. *Source* Author

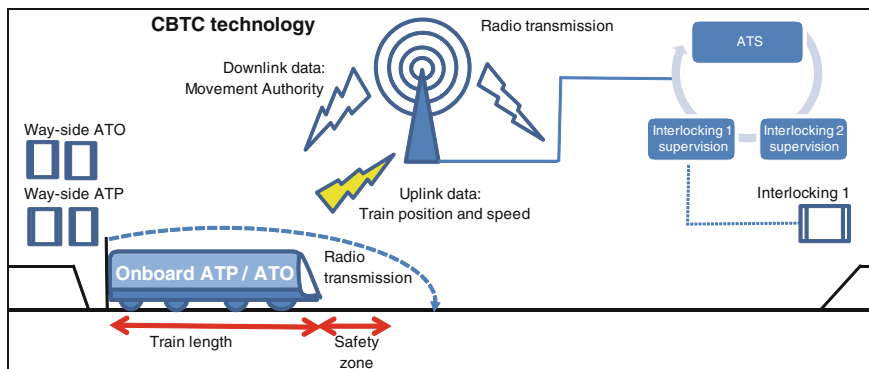


Fig. 2.8 A typical radio-based CBTC architecture. Technical solution may differ from one supplier to another. *Source* Author

2.3.1 CBTC and Moving Block

The CBTC technology was first introduced in 2003, at SFO AirTrain, in San Francisco Airport, and on Singapore's North East Line. In the modern CBTC systems, trains continuously calculate and communicate their status via radio to the wayside equipment distributed along the line. As seen, this status includes, among others parameters, the exact position, speed, travel direction, and braking distance. This information allows calculation of the area potentially occupied by the train. It also enables wayside equipment to define the points on the line that must never be passed by other trains on the same track. These points are communicated to make the trains automatically and continuously adjust their speed while maintaining safety and comfort requirements. So trains continuously receive information regarding the distance to the preceding train and are then able to adjust their safety distance accordingly (Fig. 2.8).

Typical architecture of a modern CBTC system comprises the following main subsystems:

Wayside equipment, which includes interlocking and the subsystems controlling every zone in the line or network (typically containing wayside ATP and ATO functionalities).

CBTC onboard equipment.

Train to wayside communication sub-system.

Onboard ATP system: Subsystem in charge of continuous train speed control and communication with the wayside ATP subsystem;

Onboard ATO system: Responsible for automatic control of traction and braking effort;

Wayside ATP system: Manages all communications with the trains in its area and calculates the limits of movement authority;

Wayside ATO system: Controls the destination and regulation targets of every train.

Communication system: Digital networked radio system using antennas or leaky feeder cable (especially used in tunnels) for bidirectional communication between the track equipment and the trains. The 2.4 GHz band is most commonly used in these systems (same as WiFi);

ATS system: Interface between the operator and the system, managing the traffic schedule according to the specific regulation criteria.

2.3.2 Metro Evolution Toward Unmanned Railway Systems

The evolution of autonomy in the railway environment can be seen as a continuous movement toward more sophisticated systems. Based on the Brussels located International association of public transport UITP, there are five Grades of Automation for trains:

- **GoA 0** is on-sight train operation;
- **GoA 1** is manual train operation where the driver controls many operational functions;
- **GoA 2** is a semi-automatic train operation (STO) where starting and stopping are automated but the driver in the cab can intervene;
- **GoA 3** is a driverless train operation (DTO) where starting and stopping are automated but a train attendant operates the doors and drives the train in case of emergencies; and
- **GoA 4** is an unattended train operation (UTO) where all operations are fully automated without any on-train staff.

Completely man managed As expected, railway systems started as entirely managed by personnel. In the Grade of Operation 0 and 1 environments, all operational functions are performed by human being. On the wayside, tracks are switched mechanically by the train dispatchers and the trains are obviously driven by people. The safety functions were firstly ensured by mechanical devices and logic. With electromechanical devices, relay-based logics started to be implemented and safety functions on the wayside started to be controlled by the signaling control center. Similarly, onboard safety was improved with more intelligent electromechanical devices.

Semi-autonomous As more and more intelligence was built into the signaling systems and the train, the track switches started to be operated remotely from the control centers or even from the moving train. In systems, with Grade of Automation 2, drivers were and are still there mainly to make decisions in emergency situations. These systems are still the norm in most regional and intercity lines. Vast majority of metro lines are now going to driverless applications.

Driverless Driverless trains (Grade of Automation 3) were introduced in the 80s. It is probably of no surprise to anyone that the introduction of driverless systems initially happened in closed environments such as airport or small metro applications.

The paternity of such introduction is however still in doubt. The first light driverless metro was built in the North of France in the city of Lille, by the French company called Matra (later purchased by Siemens). The VAL (véhicule automatique léger), which is a light rubber tire metro, was originally built in 1983. However, the first automated people mover (APM) commercial operation opened for service in September of 1980 at Hartsfield-Jackson Atlanta International Airport with an unmanned system. The system was originally built by the American company Westinghouse. As a result of acquisitions and mergers with other companies, the system has been operated and maintained under several brands.

The next technologies that evolved toward autonomous driving were the Light metro, APM, and Monorails. Metros are also going unmanned in the big cities of this world.



Fig. 2.9 A view of a monorail GOA 4 operation front end, without any driver or attendant in the city of Sao Paulo in Brazil. *Source* Author

Today, we see new systems being implemented without the need for any onboard staff to attend the train (Grade of Automation 4). What people should realize is that for the first time in history, they are confronted to a completely unmanned operation, which could also be described as a robotized application (Fig. 2.9).

2.4 Applying Railway Safety Principle to Cars

Does it make sense to apply railway technologies or principles to future automobile design? To answer this question, let's look at Great Britain. There were 1754 road deaths in 2012, which means that around five people died that year on Britain's roads every day. As seen hereafter, the variety of route causes are such that merely maintaining the status quo isn't acceptable.

The following are the most common causes of road accidents due to human factor and must be considered jointly (there is often more than one cause of accidents):

Speeding: Around 400 people (22 %) a year are killed in crashes in which someone exceeds the speed limit or drives too fast for the conditions;

Drink driving: Around 280 people (16 %) die a year in crashes in which someone was over the legal drink driving limit;

Seat belt wearing: Around 300 lives each year (17 %) could be saved if passengers always wore their seat belt;

Careless driving: Around 300 deaths a year (17 %) involve someone being "careless, reckless or in a hurry";

Aggressive driving: a further 125 deaths were involved (7 %);

Fatigue: involves around 20 % of all car accidents;

At-work: Around one third of fatal and serious road crashes involve someone who was working (33 %);

Inexperience: More than 400 people are killed in crashes involving young car drivers aged 17–24 years, every year, including over 150 young drivers, 90 passengers and more than 170 other road users (22 %)

Failed to look properly: 40 % of road crashes involve someone who failed to look properly;

Loss of control: One third of fatal crashes involved loss of control of a vehicle (33 %); and

Misjudge other person or car Path/Speed: One in five crashes involve a road user failing to judge another person's path or speed (20 %).

Source of information¹¹: web page of Royal Society for Prevention of Accidents

¹¹Web page of Royal Society for Prevention of Accident (ROSPA) updated on 15/072013). <http://www.rosipa.com/faqs/detail.aspx?faq=298>.

Obviously, car accident statistics are typical of any given country and might differ from one region to the other in relation to each government's attitude toward such cause of accidents, as well as in function of the media's crucial role in promoting safe driving behaviors. The point is that many of these fatality causes could have been eliminated with unmanned operations, especially had railway safety principles and technology been applied in the UK or anywhere else. The following paragraphs will give ideas about how to adapt railway principles to the car environment.

2.4.1 Automotive Block Interlocking Concept

Block interlocking concept, which forbids vehicles to occupy the same space, at the same moment, will need to be applied to unmanned cars. The issue to solve for automotive system engineers will be how to space cars far enough apart to ensure that they cannot collide.

Fixed block The automotive environment will not use the fixed block concept as road environments simply don't allow for fixed sections.

Moving block We strongly believe that the concepts behind the moving block technology could be applied to the unmanned car environments. Firstly, its spacing concept is well suited for cars as it doesn't take into consideration two fixed points but a safety zone around each moving vehicle in which no other vehicle would be allowed to enter. This safety zone would be calculated using speed, grades, and the car's operational properties. Secondly, an additional buffer zone would be provisioned around the vehicles, which would vary depending on location and surrounding elements. Thirdly, the car's normal braking rates would be used for calculating safety stopping distances, with probably a guaranteed emergency braking rate that could be used in critical situations. The big question will be whether the concept of brick wall stopping will be applied or not, and under which conditions.

This safety zone, which would be calculated by an onboard computer like the one used within the Google cars, would use the define location, speed, and direction of each car through an accurate GPS. In some critical areas, passive or active markers could be used to indicate dangerous curves or gradients, or even in tunnels to give more accurate positioning information (Fig. 2.10).

The block notion will need to evolve because of the fluidity of the road environment, from an exclusively horizontal dimensional concept toward a tri-dimensional space, which will take into consideration length, width and even height parameters. Because of the need to overpass cars or run on parallel lanes, virtual moving blocks will also be calculated to account for the safe zone needed to overtake front cars (Fig. 2.11).

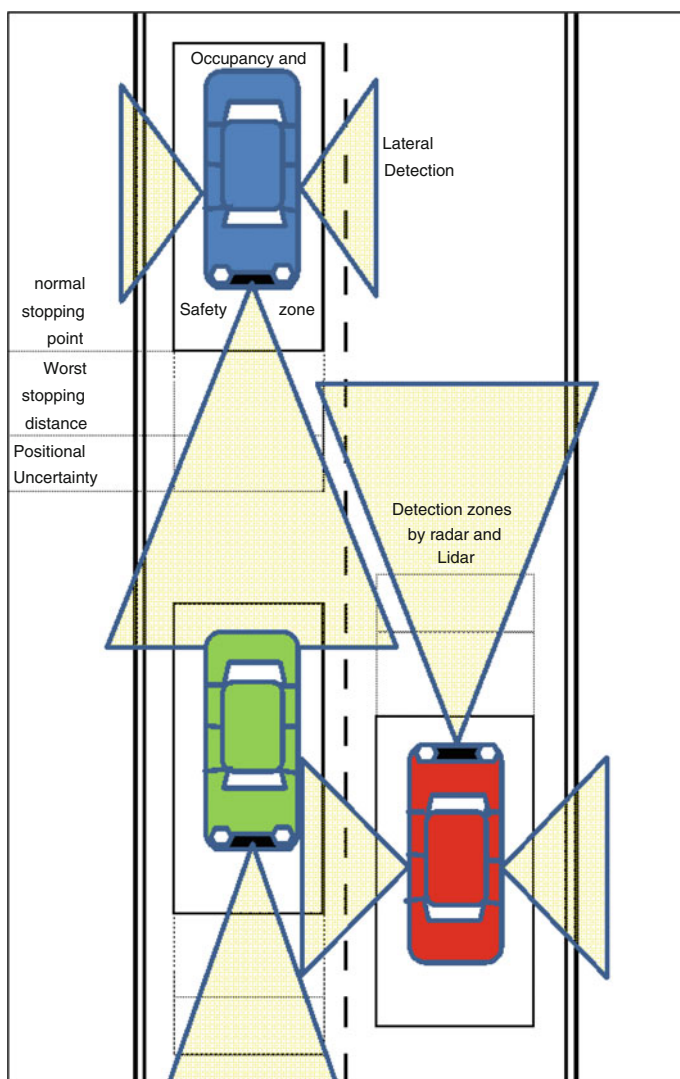


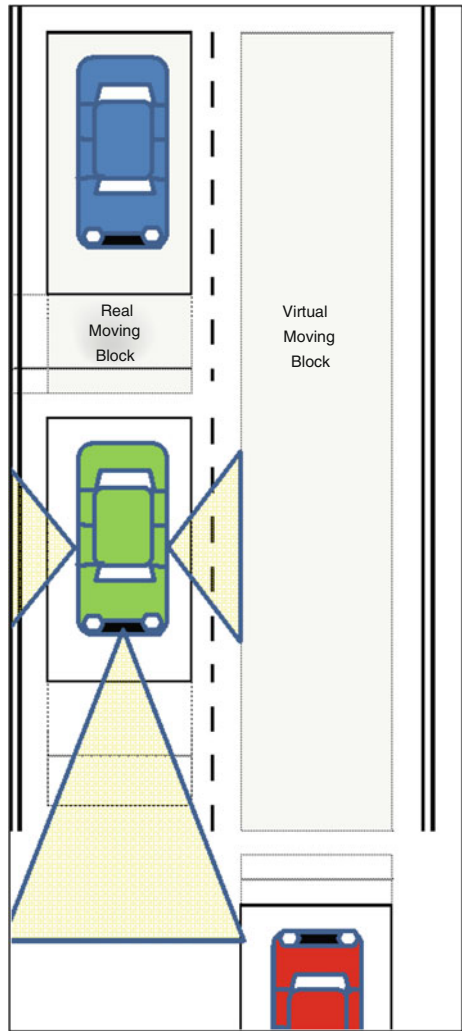
Fig. 2.10 Automotive moving block interlocking with safety zone calculation and detection zones. *Source* Author

2.4.2 Automotive Block Signaling Concept

The second railway safety principle of signaling to the next vehicle that no train is in that block will also need to be applied.

In a railway moving block application, the track line is usually divided into sections that are each controlled in real time by a computer at the control center

Fig. 2.11 Real and virtual moving blocks. *Source* Author



level, with its own telecom transmission system. Would that architecture be replicable in a road environment? This would be important because in a moving block environment, the continuously calculated car position and its braking curve must be communicated to the wayside equipment to establish protected areas (LMA). In a highway environment, we could imagine having such dedicated computers per lane sections. However, in an urban environment besides the complexity and cost of having computers throughout the city areas, the major issue to apply such a moving block concept would be to maintain constant connection of vital functions (the absence of communications between the VOBC and the VCC stops the trains).

Obviously and as we will see in the next sections, engineers are working on a blend of various communication technologies, as well as a mesh network architecture, which would provide fallback solutions in case of technical problems. With cloud computing, information would be centralized without having to dedicate fail-safe computers. However, major differences between railway and automotive operational environments will need to be taken into consideration.

- **Vehicle-to-vehicle (V2V) communication:** Because in a road environment cars can come from all directions, communications between all cars will be required within a calculated perimeter, which will be accounted for in real time according to the cars safety braking distance.
- **Obstacle detection:** Most metro networks are closed environments, reducing uncertainties to the bare minimum. On the contrary, cars (bus or even tramways) do face issues with obstacles such as pedestrian, animals, cars, or even falling objects such as rocks. It is true that long distance detection technology is being tested in the railway environment to prevent accidents but the difficulty is that trains at great speed need very often a kilometer to brake, eliminating the benefits of such technology. Unmanned cars, on the other hand, can brake within meters and as they will need mandatorily to avoid obstacles, they must use sensor technology to avoid crashing on pedestrians, animals, cars equipped with failing V2V equipment, or even working cruises. As we will see in the next sections, sensor technology such as lidar, radar, and cameras will be integrated within unmanned car environments.
- **No dispatching:** Unlike trains, car destination won't be centralized as it goes against the main transportation principle: freedom to go wherever we want.

With these major differences needing to be accounted for, it is unlikely in our view that the automotive concept of LMA will be centralized. Indeed the safety spacing calculation, which is given by a centralized computer in the railway environment, will be calculated by each car individually and shared directly between all cars within a certain perimeter. Additional safety parameters will need to be accounted for, such as direction, safe braking distances of each car, distance and time to reach another car's LMA (especially when overtaking), safety priorities, all non-car detected object, animal or human being, fixed or removable beacons or balises, etc.

Geo-localized messages (see Chap. 5 for more information) will be pushed to the road from the V2C to indicate the passing cars that an obstacle or a special situation, such as a working crew, can be found within vicinity of the location (Fig. 2.12).

2.4.3 *Automotive Integrity Concept*

Is the integrity concept relevant on roads? After all, cars unlike trains are made of a single body shell and no wagon or section can depart from the motorized section. Roads also unlike tracks cannot brake suddenly and derail a car.

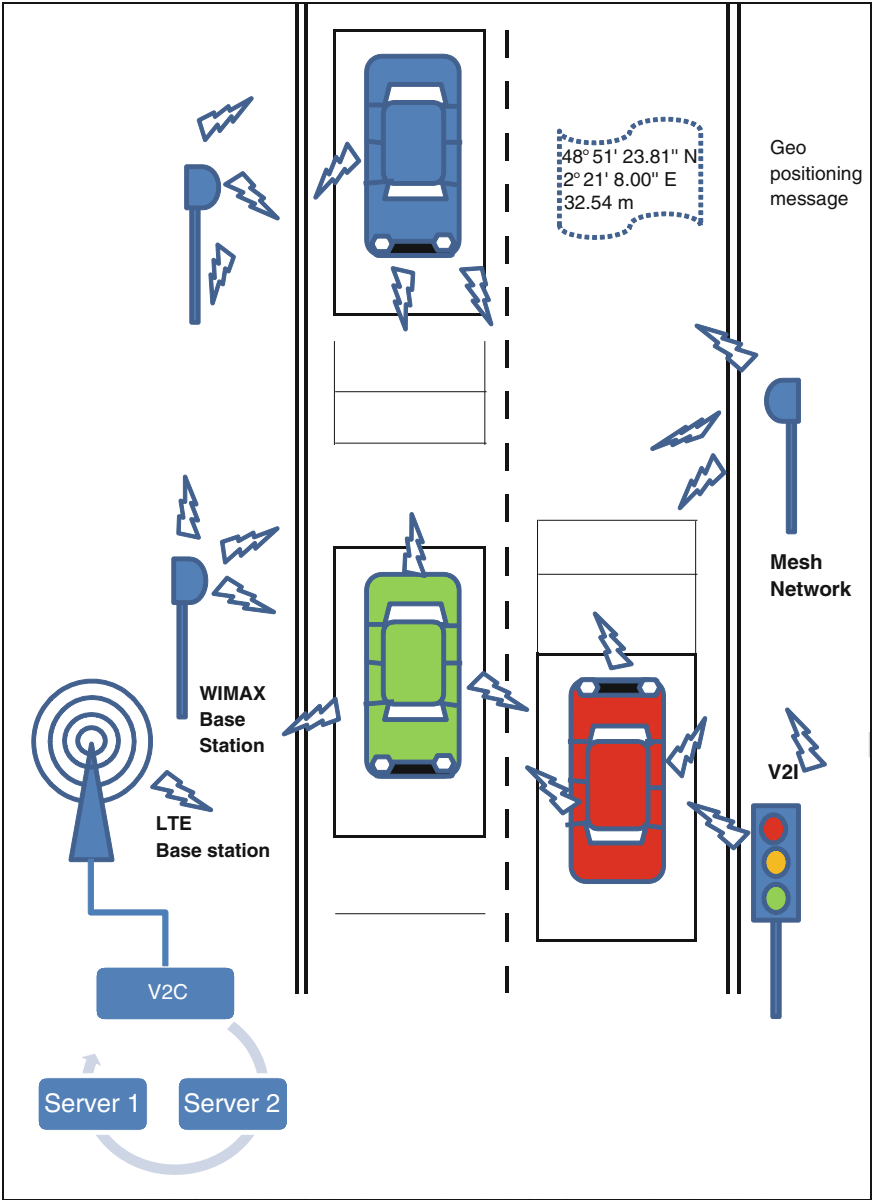


Fig. 2.12 Automotive block signaling with V2V, V2C, and V2I communication through LTE, Wi-MAX, and mesh networks. *Source* Author

Well in our view it is. First, cars don't run alone. Trucks can lose their charge. Cars also can tow a motor home or a trailer, which can separate from the cars. These would need to be accounted for. Specialists could always argue that any separated trailer would be treated as any other road obstacle and be detected by the onboard sensors. True, but the car's VOBC would need to calculate that such element could change lane, roll over, decelerate or accelerate depending on the slope, etc. Secondly and more importantly, in a platooning environment (a convoy of cars that follow each other a 5 m apart), no detection system would give the braking system enough time to avoid such separated trailer. In fact, the integrity concept is extremely relevant in such platooning operation, as the platoon itself could be considered a convoy of attached parts, which integrity would need to be checked regularly (Fig. 2.13).

2.4.4 Automotive Protection Technologies

Unmanned cars will need to integrate some of the protection technologies we've described. Obviously, the equipment and the software will be different, but the basic functionalities will be similar.

ATC The Vehicle On-Board Control (VOBC) continually monitoring the position, speed, and general status of the car will be mandatory. On the other hand, the VCC portion of the ATC will be superfluous as the safety braking distance will be calculated within the VOBC.

ATS It will be needed to monitor the system status and provide appropriate controls with infrastructure equipment, with the objective of maintaining the intended traffic patterns. In fact, the ATS functions will be integrated within the V2C (vehicle-to-cloud) environment.

ATO This non-safety part of train operation related to station stops and starts won't really be necessary in a road environment. Exact stopping distances will be calculated by the VOBC with the support of sensors.

ATP This predictive enforcement system, which continuously monitors the train's speed in relation to either a target speed or a distance, will be required. It will intervene whenever a car exceeds a speed limit (as speed restrainers already do) or when the car infringes the Limit of Authority, calculated in the VOBC, taking into account other cars moving block and safety braking distance.

Braking system If the allowable speed is exceeded, braking will be applied until the speed is brought within the required limit or the car stopped.

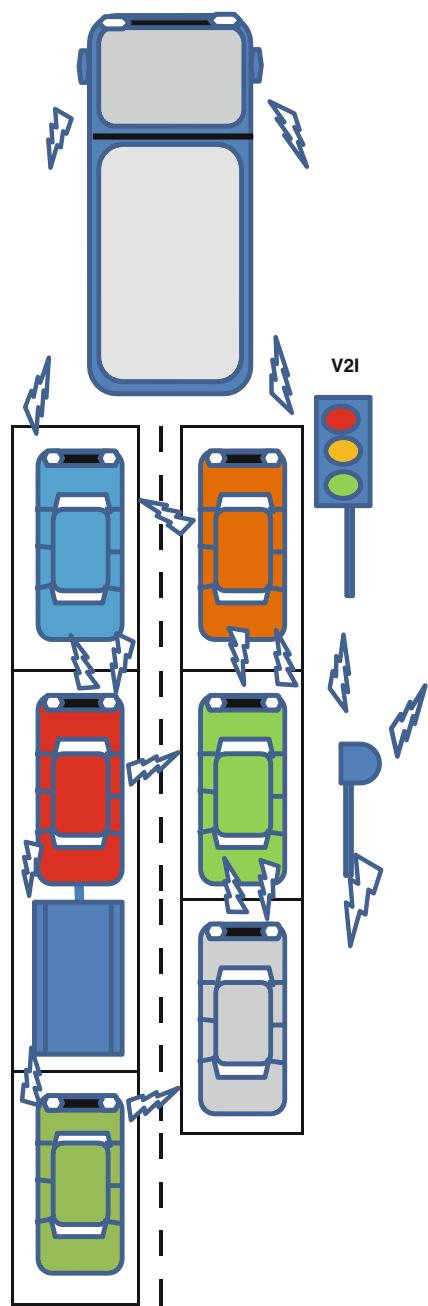


Fig. 2.13 Platooning with illustration of integrity issue. *Source* Author

2.4.5 Automotive System Interoperability

Interoperability for any system is always a key issue to address. Cars will need to communicate with each other, with the infrastructure and the cloud in ways that can be understood by each other, independently from the cars' brand. This means that at least continental standards will need to be applied for cars to be able to travel from one country to the other. As we will see, it is unlikely that a worldwide standard will be adopted, as for instance, we already know that the technology behind the V2V Japanese, American, and European system won't be interoperable.

2.4.6 Other Relevant Automotive Safety Concept

In the previous section, we've seen other concepts such as degraded mode procedures, safety integrity level (SIL). There is no doubt in our mind that these safety concepts and other technology from the railway environment will be applied to the automotive unmanned environment. In fact, in the next section, we will present the car automation level. As the reader will see, the similarities are just striking!

2.5 Automation Level in the Automotive Environment

For every 30 s, someone somewhere dies of a car crash, and ten more are seriously injured. This hideous number doesn't show the complete picture. In the rich world, the number of crashes per driver has been constantly dropping. Higher vehicle standards are a big reason for falling death rates in the rich world. Restraints on drivers and investment in safety programs, be it through better infrastructure, awareness campaigns on seatbelts or new technologies, have also helped slashed road deaths in rich countries. Newer technologies such as alcolocks, which prevent drunk-driving and self-driving cars, will make roads in the rich world even safer.

However, additional safety measures must be taken in developing and poor countries, if we want to avoid WHO's hecatomb prevision that expects deaths to more than triple in the very poor countries.

Experience in the Rich World has shown that roads can be made safer cheaply and simply. Some of the recent safety measures such as dedicated cycle roads, count-down lights at crossings and strict vehicle standards are pricey, but if the road designers and investors would only earmarked a small fraction of the road cost for safety improvement, it would dramatically improve the fatality statistics. For instance, roads need pedestrian paths but 84 % of the worldwide roads have none. This measure is easy to address.

Roads with fast traffic need well designed junctions and crossings. For very poor countries that can't invest in central barriers of concrete or metal, allocating space between the opposite lanes can dramatically help stop head-on collision. Installing rumble strips on hard shoulders can also be a good way of alerting drivers that they are moving from their lanes. Ensuring that courts and police enforce laws against speeding and driving under alcoholic or drug substances as well as bringing ticket money also can reduce significantly all the road tragedies.

All these measures make a big difference and should be contemplated everywhere. However, we will maintain the focus of this section on the e-mobility technologies that can also reduce significantly the number of fatalities. We will try to present these technologies that can address some of the main causes of road accident as described in the previous section.

2.5.1 Reducing or Eliminating the Human Factor in Driving

One of the more interesting lessons we can learn from the evolution of safety in the railway industry is that the human factor is one of the main causes of accidents and eliminating it altogether will improve accidents statistics. As the car manufacturer Volvo puts it, most accidents are caused by the four D's: distraction, drowsiness, drunkenness, and driver's error. Another crucial lesson learned from the railway industry is that safety improvements can come from three different areas: system, vehicle, or infrastructure. In railway industry, three industries have originally pushed these three options: signaling companies, train manufacturers, and railway operators. Governments, through regulations and even more essentially through norms and standards, have also played a key role in improving safety. Let's understand what the concepts behind automated cars are.

2.5.2 Level of Car Automation

We've seen that there are different levels of automation within the metro or train for CBTC signaling technologies (as well as safety levels). As for the train industry, the automotive industry has come up with an almost similar classification. In the United States, the National Highway Traffic Safety Administration (NHTSA) has established an official classification system. However, there is still no worldwide standard and thus the following is an explanation based mainly on this classification.

Level (0) Non-Automated The driver completely controls the vehicle at all times. There is no automation at all. While most current vehicles can be included in this category, vehicles with warning systems that assist drivers also fall into this category. Vehicles equipped with these technologies will not assume control for any driving tasks, but will provide additional information to the driver and/or warn the driver of situations requiring immediate attention.

Navigational global positioning system (GPS) is an example of a currently available e-mobility technology, which provides information useful to the overall task of driving. V2V communications and Lane Departure Warning (LDW) are also two examples of warning technology, alerting the driver when the vehicle begins to drift out of the lane of travel.

Level (1) Automation-Assisted Individual vehicle controls are automated. This category still leaves the driving authority with the driver. However, under limited normal driving or crash imminent circumstances, technologies in this category will take control away from the driver (Fig. 2.14).



Fig. 2.14 Picture of an active lane-keeping shown on the dash board. *Source* Author

An example of this type of technology is the Electronic Stability Control. This system uses automatic computer controlled braking of individual wheels to assist a driver in maintaining control in critical driving scenarios in which the vehicle is beginning to lose directional stability. Another advanced example of automation-assisted driving is a lane-keeping system that will actively steer a vehicle back toward the center of its lane when the system detects that the vehicle is drifting into an adjacent lane or is on a collision course with a vehicle in an adjacent lane.

Level (2) Monitored Automation This category is the first in which technology will share the driving responsibility with the driver. However, in this category, the human driver is expected to intervene at any moment (e.g., lane markings disappear and the vehicle can no longer position itself in the center of the lane). Thus, the autonomous technology is only able to assume the responsibility of driving when the conditions permit.

For example, some vehicles on the market today are available with automatic parallel parking systems. This type of technology differs from automation-assisted driving technologies because the driver gives a general command to the vehicle (e.g., “park in this space”) and the vehicle performs that command by assuming entirely the steering control and making the necessary steering calculations. Another potential example is the combination of adaptive cruise control with lane-keeping. The combination of these two technologies would potentially enable vehicles to proceed on the highway with little or no input from drivers.

Level (3) Conditional Automation In this category, the driver can fully cede control of all safety-critical functions in certain conditions to the onboard computer. The driver doesn’t need to keep constantly an eye on the road. The car senses when conditions require the driver to retake control and provides a “sufficiently comfortable transition time” for the driver to do so. Level 3 is full automation in certain situations (most likely for highway driving).

In 2014, several automakers, like Audi, BMW, Nissan, and Mercedes targeted self-driving capabilities by roughly 2020. Others are more bullish. Tesla and Ford for example, targets respectively 2016 and 2017 to market such cars. For speed lower than 60 km/h (38 mph), Mercedes Benz’s “intelligent drive” kit can already allow drivers to relax and enjoy, while their car accelerate, steer and brake autonomously.

Table 2.11 Comparison between car and rail automation level according to UITP and NHTSA classification

Level of train automation (UITP)		Level of car automation (NHTSA)	
Level	Description	Level	Description
GoA 0	On-sight train operation	Level 0	Non-automated
GoA 1	Manual train operation	Level 1	Automation-assisted
GoA 2	Semi-automatic train operation	Level 2	Monitored automation
		Level 3	Conditional automation
GoA 3	Driverless train operation	Level 4	Full automation
GoA 4	Unattended train operation	Level 5	Unmanned

Source Author

Level (4) Full Automation The car performs all safety-critical functions for the entire journey, with the driver not expected to control the vehicle at any time. However, level 4 will maintain the possibility to shift control to a human driver. This vehicle would integrate various technologies from the previous three categories to perform all driving tasks.

Level (5) Unmanned This is an unmanned system where human control won’t be allowed at all. The only driver input would be the destination. Level 5 driving encompasses all of the systems necessary for the vehicle to perform automatically and independently all driving tasks in all driving scenarios.

2.5.3 Similarities Between Level of Car and Train Automation

Table 2.11 shows how similar the principle of automation level for cars and trains are.

2.6 Personal Rapid Transit (PRT)

Before being accused by Nay-Sayers of being over-optimistic about the future of unmanned vehicles, let’s present a car technology which is already completely driverless: the Personal Rapid Transit system.

PRT is a public transport mode based on small automated vehicles operating on a network of specially built and segregated guideway, arranged around a network of small stations. The principle of a PRT is very similar to the concept of a network of

taxis running on dedicated and exclusive lanes. Like taxis, they offer relative privacy, though one could expect to share the PRT car with a few other passengers. They also allow for relative fast access to the specific final destination station.

2.6.1 PRT References

PRT technology has been around for a few years but isn't well known from the general public. The main reason is that the industry has a record of failure due to various project problems, such as financing issues, cost overrun, regulatory conflicts, flawed designs, etc (Fig. 2.15).

As of 2014, two PRT systems were already operational.

- Since 2010, 13 pod cars continue to shuttle students along an 800 m stretch between a station and the university in Masdar, UAE; the air-conditioned vehicles have a maximum speed of 40 km/h. The entire system was originally designed to run up to 5000 trips per day, with each of the 810 vehicles.
- Since May 2011, a 21-vehicle Ultra PRT system at London Heathrow Airport links the business car park, by a 3.8 km route to the terminal. The driverless cars can reach speed of 40 km/h and carry up to four passengers and their luggage. Since its opening, the PRT system has carried in around 2 years more than 700,000 passengers from the Terminal 5 Business Car Park across to Terminal 5 itself.

Unfortunately, it is true that there is still today no city-wide deployment, but this is due more to the fact that no Public authorities (except for Masdar city) have already committed to building PRT, because of the risks associated with being the guinea pig. But these two applications have shown that PRT can work. With the right political support for financing the project and provided a large technological railway or car manufacturer would embrace such market, things could be very different. In the mean time, the small PRT developers are facing a bleak future as they don't have the financial strength required to sustain the R&D and marketing costs to build such a market.

However, if this market were to integrate technologies being developed for driverless cars, this market could pick up and grow tremendously. The fundamentals are there. To use an image, PRT is the convergence of smart infrastructure with smart cars (which could become much smarter with the integration of driverless car technology), as well as the convergence of automotive and railway technologies and concepts.



Fig. 2.15 Heathrow Airport car park operational PRT system. *Source* Picture of ULTra PRT POD at Heathrow Airport car park During a trip to the airport 2012-02-16; *Author:* Moshrunners; file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license

2.6.2 Smart Infrastructure

All PRT suppliers have been highly influenced by rail transit technologies and concepts. For instance, technologies like fare systems, guideway, track and station design, as well as concepts of system safety, reliability, operations, and maintenance are originated mainly from the railway environment.

PRT station PRT stations are similar in many aspects to subway stations. The fundamental difference is scale. Indeed, PRT stations must have the same functionality than mass transit but must be designed for only a small numbers of passengers. In order to make the PRT network attractive, the system usually positioned stations close together. However, and unlike metro stations, the station's vehicle access isn't positioned directly on the main lane. The station uses one- or two-way section connected to the main lane by the same junction (vehicles come back and forth through the same junction) or by two junctions positioned in parallel to the main lane. Each station might have multiple berths, for several passengers drop-off or hop on, or for vehicles storage. When user demand is low, surplus

vehicles can be configured to stop at empty stations at strategically placed points around the network. This enables an empty vehicle to quickly be dispatched to wherever it is required, with minimal waiting time for passengers.

Switching As mentioned, many concepts from the railway industry have been adopted by the PRT system designers. Switching, which is one of the main railway features, has been used to ensure guideway clearance for most PRT systems. However, and as we will see on the section dedicated to self-driving cars, conventional steering technology with mounted sensors could become an interesting alternative to switching. There are two PRT switching concepts:

- Track switching like in railway system; and
- Vehicle mounted switching.

Each approach has its advantage and inconvenient.

Track switching increases the vehicle reliability by reducing the number of small moving parts in each car and weight. It also increases the overall system safety using successful tested rules from the metro industry. On the other hand, vehicle switching allows faster switching, reducing the headway time and distance between vehicles, as well as obviously simplifying the guideway infrastructure. Because of differences in switch setting between two cars, it increases the minimum distances required between consecutive junctions.

Dedicated guideway As for trains, the notion of dedicated lanes is extremely important in PRTs. It allows control of the environment like in the railway industry, eliminating potential hazardous situation, resulting from mixed traffic.

Furthermore, all PRT systems use segregated lanes with no possibility for pedestrian or other cars to cross the guideway. Many use over-pass to avoid this potential conflict with pedestrians, animals or car crossing. Masdar's system ambition has been limited because it attempted to dedicate ground-level to its PRT system, which led to expensive buildings and roads. Many guideways have a loop shape for easier reinjection of cars into the system.

Power and telecom equipment Most designs use the guideway to distribute power and data communications, including the vehicles.

Signaling system Unlike railway signaling system, which uses fixed traveling concept, PRTs use a unique flexible signaling concept. In most metro operations, the vehicle rides from the first station on one side of the city to the last station, stopping at all operating stations on the way. Even when there are exceptions, such

as when metro cars make shorter shuttle trips between two intermediate stations of the more busy section of the metro, all the cars defined as such will have the same fixed sequence of stopping.

On the following (Fig. 2.16) railway design, a metro vehicle would usually go from station 1–7 and back from station from 7 to 1. In case of shorter carousel (planned trip), the metro could in principle use the switch situated at the end of station 3 and 5 to short circuit stations at the extremities of the line. We say in principle, because this configuration would create operational problems and not be favored by operators and passengers.

PRT systems apply an operational principle based on point-to-multipoint travel. For instance, passengers might decide to go directly from the first to the last station, by passing all intermediary stations (Fig. 2.17).

On the design here above we show two configurations where the vehicles can use 3 park lanes either with no parallel line to the main guideway or with a parallel line to inject more easily the parked cars (at station 3 and 5).

Thus in theory, if there was a network with sufficient guideway length and closely spaced stations, passengers could easily board in a station and take relatively direct routes to their destination without stops. Once again, this is only

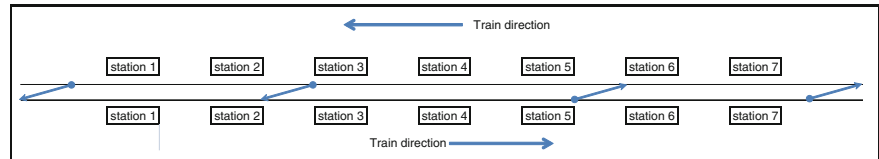


Fig. 2.16 Train carousel with intermediary switching possibility. *Source* Author

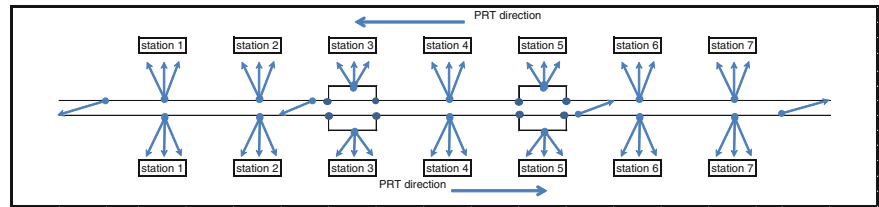


Fig. 2.17 PRT carousel with intermediary and station switching possibility. *Source* Author

possible because the stations aren't directly on the main lane, thus vehicles are never blocked by other vehicles stopped on the main guideway at stations.

Running gear Most designs enclose the running gear in the guideway to prevent derailments.

Fare system As for trains, PRT would be working with reliable ticketing system.

Supervision and monitoring system Onboard computers communicating with the control center main computers eliminate the need for human control. Errors from human drivers are eliminated increasing the public's safety. Other public transit safety engineering approaches, such as redundancy and self-diagnosis of critical systems, are also included in PRT designs. The monitoring PRT system places the cars in moving Slots (block) that go around the guideway loops. Real vehicles are allocated a slot by the trackside controllers. Traffic jams are prevented by placing north/south cars in even slots and east/west vehicles in odd slots. At intersections, traffic in the systems can interpenetrate without slowing.

2.6.3 (Reasonably) Smart Cars

PRTs have adapted automobile technology to carry comfortably from 2 to 4 passengers. Using many standard components of automobiles such as electric motors, batteries, tires, axles, wheels, and body components, the automotive sector possesses all of the needed competencies to efficiently design and manufacture these types of vehicles.

Most PRT vehicle designs are based on electric cars. Some systems adapted the concept from the metro of wayside conductors rather than batteries. However, with the increase in battery capacity, future PRTs are likely to use that technology. For instance, Ultra the Heathrow PRT uses batteries which are recharged when at stops.

2.6.4 PRT Operational Characteristics

Headway distance It is the space between two vehicles running on the guideway and influences directly the system's capacity. Existing rail regulations usually apply to PRT systems. Thus, railway safety principles are typically applied and headways are calculated in terms of absolute stopping distances. This stopping distance is the

Table 2.12 Braking distance in meters of PRT cars (with 0.5 s perception and reaction time), according to speed

Speed in km/h		10	20	30	40	50	60
Braking distance	With 0.5 s perception + Reaction	2.0	5.0	9.2	14.5	21.0	28.6

Source Author

sum of the distance a car will run due to the driver’s perception and reaction time and the distance necessary for stopping the car (Table 2.12).

The braking distance is one of two principal components of the total stopping distance and is defined as the distance a vehicle will travel from the point when its brakes to when it comes to a complete stop. As we’ve seen in an earlier section, it is primarily affected by the vehicle’s speed, the coefficient of friction between tires and road surface and negligibly by the tires’ rolling resistance and vehicle’s air drag.

The second element is the perception-reaction time required to hit the brake. In cars involving a driver, 1.5 s is considered for legal purposes. In PRT system 0.5 s can be used, as this process is linked to communication between control centers and cars and don’t involve human beings. A coefficient of kinetic friction of 0.7 can be used to calculate such distance, but this is under normal condition (under rain it would need to be lowered). The following table gives the braking distance in meters required for different speeds under normal road conditions.

The minimum safe headway measured tip-to-tail defined by the braking performance is as follows:

$$T_{\min} = L/V + t_r + kV/2(1/a_f - 1/a_l)$$

- where
- T_{\min} minimum safe headway time in minute;
 - L length of the vehicle;
 - V speed of the vehicle;
 - t_r reaction time in minutes;
 - a_f maximum braking deceleration of the follower;
 - a_l maximum braking deceleration of the leader; and
 - k arbitrary safety factor superior or equal to 1.

However, using an absolute stopping distance (also called brick wall stopping) for safety reasons and thus not taking into consideration the speed of the leading

Table 2.13 Safety time PRT cars (with 0.5 s perception and reaction time and safety factor of 1.5), according to speed

Speed in km/h		10	20	30	40	50	60
Braking distance	With 0.5 s perception + Reaction	2.0	5.0	9.2	14.5	21.0	28.6
Safety time in second	With safety factor of 1	2.8	3.0	3.6	4.3	5.1	5.9

vehicle, as well as considering a safety factor of 1 for a 4 m car, we would have the following minimum safe headway in seconds (Table 2.13).

PRT system engineers have calculated that two-second headway is sufficient. It is true that computerized control theoretically allows for simultaneously multiple vehicles braking. However, such short headway is controversial, because it would consider the following:

- A system reaction time of around only 0.01 s without any perception time;
- A brake failure of around 1 m/s of the lead vehicle; and
- An average speed of 30 km/h.

The problem from a safety perspective of this approach is that usually, the authorities making the safety case use the most pessimistic scenario. This pessimistic scenario would need to consider rainy conditions, a leading car or object at complete stop at full speed of around 60 km/h (and not the average speed of 30 km/h). Indeed most PRTs' speeds are in the range of 40–70 km/h though a few PRT designs have operating speeds of 100 km/h. Having said that, the UK Railway regulating body has evaluated the Heathrow design and accepted in principle one-second headways, pending successful completion of initial operational tests at more than 2 s. The jury is out there to conclude on this required safety time.

PRT system Capacity This headway calculation is fundamental because system capacity is inversely proportional to headway. System capacity in terms of vehicle and in terms of passenger is, respectively,

$$N_{\text{veh}} = 3600/T_{\text{min}} \quad \text{and} \quad N_{\text{pas}} = P \times 3600/T_{\text{min}}$$

where

N_{veh} the number of vehicles per hour;

P the maximum passenger capacity per vehicle; and

T_{min} minimum headway

Using a four-passenger per car vehicle capacity and 2 s of headway, the theoretical PRT capacity with one lane would be 1800 vehicles and 7200 passenger/car. However, most estimates assume that vehicles will not generally be filled to capacity, due to the point-to-multipoint nature of PRT. At more typical average car occupancy of 1.5 persons per vehicle, the maximum capacity is 2700 passengers per hour (see Chap. 4 on megacities for more information on capacity calculation).

PRT promoters argue that the theoretical minimum PRT headways should be based on the mechanical time to engage brakes, and these are much less than half a second. Moving from two to one-second headways or half a second would respectively double and quadruple PRT capacity, making it more attractive and financially interesting. However, one shouldn't forget that in simulations of rush hour or high-traffic events, about one-third of vehicles on the guideway need to travel empty to resupply stations with vehicles in order to minimize response time. This would obviously reduce capacity proportionally.

Travel speed PRTs have an advantage in terms of journey time in regards to normal buses or metros. Given their point-to-multipoint travel nature, nonstop journeys are about three times as fast as those with intermediate stops. This is not just due to time savings for accelerating and stopping. Scheduled vehicles are also slowed by boarding and exiting.

2.6.5 Cost Characteristics

Most of the PRT initial investment is in the guideway, with most estimates falling in the \$10–\$15 m range per kilometer line, excluding rights of way or system infrastructure, such as storage and maintenance yards and control centers.

A design with many modular components, mass production, driverless operation and redundant systems should in theory result in low operating costs and high reliability. However, this isn't the case currently and will only be known once a full scale PRT is in operation. According to Ultra, the Heathrow pod integrator, it took six years to develop this PRT and costed £30 m (50 M US\$), which at a little over 13 M US\$ per kilometer corroborate this costs per kilometer.

2.6.6 PRT Versus Unmanned Cab

In chap. 6, we will see the new business model of hailing companies such as Uber against which most European taxi drivers were protesting in June 2014. Furthermore, we describe a future where there will be no taxi drivers left but where PRTs will become predominant. Will it be through unmanned taxis with a multipoint-to-multipoint model (current taxi model) or point-to-multipoint model (current PRT model) is still a question mark. What is also sure is that because of the investments made by the big IT players and car manufacturers, unmanned cabs are likely to have more intelligence on board the car than on the wayside. The main reason for this is that unmanned cars need to ride in non-segregated lanes and PRTs don't have this capacity today, as they rely on switching technology just like the train industry. We believe that the automotive industry cannot reduce this driving flexibility if unmanned cars are to prevail in the future.

2.7 E-Mobility Technologies Reducing Fatalities

The human factor is the main cause of accidents; drunk driving, seat belt wearing, speeding, fatigue, in-car distraction (eating, not fixing the road, phone, and e-mail), and wrong perception or judgment are a few of these causes. The human factor isn't, however, the only cause. Bad weather conditions (i.e., rain, fog, and ice) and poor road states (pot holes, dirt) also kill several people and injure many more. We will analyze the e-mobility technologies that are being developed to try to reduce such problems. Let's start by presenting a technology that actually allows recording of all bad driving behaviors or equipment malfunctions—the black box—that has been already installed in our cars for a few years.

2.7.1 Black Box

People are mostly familiar with black boxes in airplane. In the last decade, event data recorders (EDRs), as they are called in the railway industry, have been introduced and are now recording safety-related information such as speed, acceleration, braking, door closing, etc. Black boxes are now gaining momentum in the automotive market as well. Despite obvious privacy issues, black boxes have been used by car accident investigators and insurance companies to reconstruct the events before accidents occurred. Countries such as Canada have used, as early as October 2003, black box information to charge drivers responsible of dangerous driving, involved in-car crashes with fatalities. The reality is, and although most people aren't aware of their onboard presence, event recorders are already installed on around 80 % of all new cars. Originally, car black boxes were installed to

determine the cause of airbags activation, but now their use has changed to enable recording of metadata such as speed, acceleration, braking events, and other safety-related measures. Fortunately, they can also identify if a malfunction happened and caused an accident.

Lately, new types of black boxes coupled with video cameras installed on the windshield have made their market introduction. These digital video recorders (DVRs) can associate image, with positioning through GPS, as well as performance of the car through the event recorder. Thus on top of the safety-related measure of the event recorder, these DVRs also record the car's time, location, and direction, as well as the driver's view which makes it helpful for a number of hard-to-prove situation involving accidents (i.e., someone crossing a lane on a red light).

How does DVRs work? It basically records constantly images on which metadata (i.e.: speed, positioning, braking data, etc.) is inserted for a specific period of time. There is yet no rule for how much time they can record but for instance in the Public Transport a rule of 20–32 days is usually applied to maintain some kind of privacy protection. Video footage isn't destroyed but overwritten by newer video and sound streams and metadata on a First In First Out basis. If a car hit is felt by the system, the last 30 s are tagged and secured in a safe area where it cannot be erased.

If cars have already been equipped for so long with black box under the form of EDR with limited information recording, why do people suddenly want to add more information? There are several reasons to this.

The obvious reason is that DVR technology has evolved tremendously and prices have gone down allowing its diffusion on the mass market. Digital technology has allowed camera miniaturization as well as a significant reduction in mechanical parts always prone to problems linked to vibration. Being cheap, easy to install and use is a great argument for potential consumers.

Secondly, GPS have now become generalized in many new cars. Thus adding such information is simple.

The third reason is legal. In litigation society, having information that the other party doesn't have is clearly an advantage and a powerful motive to install such DVR. In the USA especially this is a strong selling argument. In Russia, where law enforcement is more fragile, DVRs have also been extremely popular as they enable fighting false accident claims. Even countries like France or Belgium, where black box video information can't be used as element of proof in courts are changing their views and starting to follow countries like America or Russia.

The fourth reason is financial. Many insurance companies are pushing for car black box installation. In many countries insurers are still imposing their own black box system, as there isn't yet a global standard.

Though DVR technology might be different, all motivations are identical: reward the good driving behaviors by reducing the insurance costs. These new insurance policies are still at an early stage with big insurance companies like AXA still testing their own black box and deciding on its commercial policy.

The last reason, which also explains greatly why insurance companies are reducing their insurance premium, is that it works. In the United States, studies on the use of black box have shown a reduction of more than 50 % in the accident rates of cars equipped with such systems.

For all these reasons and considering that car fatalities are under scrutiny of an increasingly risk adverse and pro-litigation society, the question isn't if these DVRs will be installed on each car but when. Civil right privacy concerns will be again a big issue.

Privacy advocates need to be wary, though they won't be able to impede, in our view, such inevitable trend. By installing black boxes, insurance companies will be entitled to have access to many details of the car owner's private life and will be able to use this information against their clients. But things will get worst for privacy advocates, the day DVRs become mandatory. Indeed today this information is used as forensic evidence. The justice uses it in case of accidents involving fatalities. People use it in court when it suits them. However with the event of more powerful telecommunication network such as 4G, any car will become a supplier of real time information about the driver's behavior. Ford's CEO Alan Mulally said in 2013:

"We have GPS in your car, so we know what you're doing".

Navigational systems can now transmit real time information about a car's location, as well as details about the vehicle's performance, such as speed, acceleration, etc. The US Government Accountability Office reported in 2011 that all carmakers collected location data and shared it with third parties that provide services to the car owner. Many automobilists are happy to provide such information to service tracking providers such as General Motors' OnStarTM system.

But the question is how long it will be before the companies that own such system decide granting access to advertising companies selling geo-positioned promotions? As we will see in the connected city chapter, companies such as Google aren't investigate in driverless technologies for the sake of it because they

see a huge market opportunity for ads. Furthermore, how long will it be before vehicles' speed is fed to local law enforcement?

In our view, in a couple of years, all car speed and safety-related driving patterns will be fed back into central systems. This is the only way that driverless cars can dominate the road, and dominate they will.

2.7.2 Drink Driving: Alcohol Ignition Interlock

More than 10,000 people die in the US each year in alcohol-impaired driving crashes, accounting for about a third of all deaths.

An alcohol ignition interlock is an equipment, which measures the level of alcohol in the body. It requires a driver to blow into the device and register a blood alcohol reading that is below a predetermined level. If the driver exceeds the level, the vehicle will not start. In some countries such as the US, such equipment must be installed on frequent drunk driver's car. In case of offense, the data recorded by the device can be uploaded to the driver's Department of Motor Vehicles or even to a court system, depending on the State's law. Some groups, such as (MADD) support ignition locks for first-time offenders.

2.7.3 Seat Belt Wearing

In 95 % of accidents, wearing your seat belt will save your life. All newer cars are equipped with alarms that indicate when front drivers don't buckle up.

A Seat Belt reminder system, which is based on weight sensed by the front seats, usually sends a noise signal but doesn't stop the car. This system is usually not connected to back seat belts and rear passengers can still decide to buckle or not, even if legally they are obliged to do so. In the UK, one third or rear passengers don't wear their seat belt. The problem with backseat passengers is that backseats are also used to carry things. Thus alarms for unbuckled passengers are more complicated to manage.

Would it be reasonable to envision as for drunk driving, locking the ignition if not wearing your seat belt? From a technical perspective, this would be extremely simple. The same alarm could be used to stop the ignition, though the issue for back seat passengers would still remain. As we've seen, air bags are connected to the EDR, which records all safety-related measures. Thus using this information to stop ignition would

be simple. An alternative choice would be to send the information through the EDR to the police force to inform them that car occupants haven't buckled up.

However, sending this information would be in most cases useless. Indeed, not wearing seat belts is a choice. People can always buckle up their seat belt without actually being secured by it. No technical solution could solve this problem easily.

2.7.4 Real-Time Limitation on Over-Speeding

Newer GPS give more than geo-positioning and time information. They can calculate speed and overlay this speed on a map where legal upper limits can be dispelled. Integrating a physical speed restrainer in the car, which would automatically be triggered after an acceptable over passing tolerance of let's say 20 %, would be extremely easy to do.

2.7.5 Real-Time Information on Over-Speeding

As we've just seen, it would be extremely easy for car manufacturers to supply through GPS all speeding information with an acceptable level of accuracy to the nearby police radio receiver. Integrating the acceptable tolerance of 20 % for over passing, any driver could be fined at the control center directly without even having to be arrested.

2.7.6 Automatic Car Parking

Some cars already have systems that assist with parking, but these are not completely autonomous. These systems can identify empty parking space and steer into it, while the driver uses the brakes. The Volvo system, however, lets the driver get out and uses a smart phone application to instruct the vehicle to park. The car then drives off, maneuvers into a parking place, and sends an information message to the driver on where it is. The driver can collect the car in person or use his phone to call it back to where he dropped it off.

In the past, designs for automatic car parking relied on car parks being fitted with buried guide wires that vehicle needed to follow. That, though, creates a chicken-and-egg problem: car park operators will not invest in such infrastructure until there is a sufficient number of suitably equipped cars and conversely drivers will not want to buy self-parking cars if there is nowhere to use them. This means that for autonomous parking to work most of the technology will have to be in the car itself.

2.7.7 *Fatigue*

Some of the luxury brands newest safety systems try to address each of the four D problems that cause most accidents, especially trying to keep the driver alert.

Volvo uses cameras, lasers, and radar to monitor the car's progress. If the car crosses a lane line without a signal from the blinker, an alarm sounds. If a pattern of tiredness emerges, an icon on the dashboard flashes and the words "Time for a break" is showed. To instill better habits, the car rates the driver's attentiveness as it goes, with bars like those on a cell phone. Mercedes goes a step further: its advanced cruise control won't work unless at least one of the driver's hands is on the wheel.

2.7.8 *Wrong Perception or Judgment*

With all of the distractions inside of a car today, rear-end collisions have become far too common. Nearly, a third of all car accidents where someone was killed or injured in the United States involved a rear-end collision. Most often, the driver in the rear is at fault for tailgating, following too closely, or not paying enough attention to see that the driver in the front car has stopped or is slowing. Most of these accidents could be avoided if drivers would systematically respect the minimum inter car distance. This distance which we transform into time is around 2 s under normal weather conditions. Unfortunately, many drivers don't use such precautionary measures nor do they add the recommended additional 20 % reduction under rainy or misty conditions. Without such measures, drivers are often caught hitting the brakes at the last moment, creating a possible chain of accidents with nearby cars. Companies are working on technology which would alert other drivers and prevent most of these accidents.

For instance, Ford in 2013 tested equipment that could provide early warning to other motorists when brakes were applied hard. The broadcast signal illuminated a warning light in the dashboard of following vehicles, even if they were out of sight or not directly behind the braking vehicle.

Obviously, receiving in advance an alarm informing us of a nearby potentially dangerous situation such as hitting the brakes or abruptly changing lanes would significantly reduce this cause of accidents.

2.8 The Advent of Vehicle-to-Vehicle Communication Technology

In a move that signals a great technological leap forward for the automotive industry, the US Government announced in February 2014 that it will take steps to require all new cars to communicate with each other. New regulation is expected before President Obama leaves office in 2017. This is the first step on a series of automotive evolution that will ultimately lead to unmanned vehicles, resulting from internal electronics integration with external infrastructure, communications, and database systems.

Similar to trains with radio technology, cars that would communicate with each other need some basic wireless technology. The communication blends multiple networking technologies including dedicated short-range communication (DSRC), 4G/LTE cellular wireless broadband, mesh networking, and accurate geo-positioning. All these technologies that we will describe in more detail later on form a system that goes under the name of VANET (for vehicular ad hoc network).

2.8.1 VANET

As the word VANET describes it, this system is composed of elements (nodes) that spontaneously join and self-organize to form a network in an Ad Hoc mode. These elements can be vehicles, communication base stations, traffic lights, security panels, etc. This system is characterized by rapid but predictable network topology changes, one-time interactions between these elements, and partially available connectivity. Intermittent communication can be a real concern, especially in rural areas, where economical reality won't allow for the systematic implementation of telecom access points. Because of this connectivity issue, several telecom technologies are likely to be involved and integrated within the cars: 4G, GSM, UMT, WI-MAX, and a specific technology to VANET called WAVE (Wireless Access in Vehicular Environments) also known under its standard name: IEEE 802.11p.

We will only describe in more details this WAVE technology, as the other ones are already well known and not specific to transportation (check study¹² for more information on WAVE technology). We will also introduce the draft standards being introduced to ensure that all these heterogeneous technologies work together.

¹²Smart Vehicles, Technologies, and Main Applications in Vehicular Ad hoc Networks; Author Anna Maria Vegni, Mauro Biagi and Roberto Cusani.

2.8.2 *Wave Technology*

For those familiar with wireless technology, the WAVE technology is derived from the IEEE standard 802.11 (i.e., similar to the wireless technology people use in their home). The IEEE 802.11p standard uses channels of 10 MHz bandwidth in the 5.9 Gigahertz (GHz) band in the USA. In Europe, the EU has allocated the 30 MHz of spectrum in also the 5.9 GHz band to road safety applications. Unfortunately, these European and American (but also Japanese) dedicated short-range radio (DSRC) networks aren't compatible.

IEEE 802.11p requirements:

Communication distance: These radio emitters need to be able to communicate over a distance allowing for sufficient safety braking distance, preventing dangerous events. The IEEE 802.11p range can reach up to 300 m, which gives around 10 s of go-ahead at highway speed (sufficient as we've seen in the section on PRT headway).

Communication connections: between cars themselves or with the roadside infrastructure, communication must be extremely short. Thus, the technology must work without lengthy association and authentication procedures. IEEE 802.11p amendment defines a way to exchange data through that link without the need to establish a basic service set, such as an access point and associated stations. For that purpose, IEEE 802.11p enabled telecom stations may start sending and receiving data frames as soon as they arrive on the communication channel.

As several technologies will need to work together seamlessly, an international body working group (ISO TC204/WG16) produced a series of draft standards, known as CALM (continuous air-interface, long and medium range).

2.8.3 *CALM Technology*

The objective of the CALM standards is to develop a network terminal ensuring seamless connectivity between cars and roadside systems for several of these technologies we've already mentioned. This is an EU initiative. The USA has its own initiative known as vehicle infrastructure integration (VII).

2.8.4 LTE Technology in VANET

LTE or 4G is a standard for wireless communication of high-speed data for mobile phones and data terminals. LTE's would be well suited for periodical communication with cloud computing servers to store information from cars and their environment.

Indeed, 4G provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s and Quality Of Service provisions permitting a transfer latency of less than 5 ms in the radio access network. Furthermore, LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams as well as scalable carrier bandwidth from 1.4 to 20 MHz.

Many experts believe that when driverless cars start hitting the road, 5G will also be implemented (around 2020). With 5G communication will come 100 times faster than 4G with much lower latency and ability to connect 10 bn devices around the world.

2.8.5 Mesh Network Infrastructure

Network infrastructure will need to sustain various mobile communications between information sources and transaction stations on the roadside and mobile radio units, as well as between portable and mobile units. The envisioned network is based on mesh technology (for more information see Chap. 5). Wireless mesh architecture infrastructure is, in effect, a router network minus the cabling between nodes. It's built of peer radio devices that don't have to be cabled to a wired port, like traditional WLAN access points do. Mesh architecture sustains signal strength by breaking long distances into a series of shorter hops. Every mesh node (small radio transmitters that function in the same way as a wireless router) can send, capture, and retransmit signals to intermediate nodes (other cars, smart traffic signal, etc.) that not only boost the signal, but cooperatively make forwarding decisions based on their knowledge of the network, thus performing routing functionalities (Figs. 2.18 and 2.19).

Such architecture may provide high bandwidth, spectral efficiency, and economic advantage over the coverage area. Mesh network is important because, most access points would be in locations with no easy cable/fiber access. Moreover, fast deployment in rapidly changing urban landscape is desirable and mesh structure can easily be fixed on traffic lights, light poles, highway bridge structures, without the needed physical interconnections.

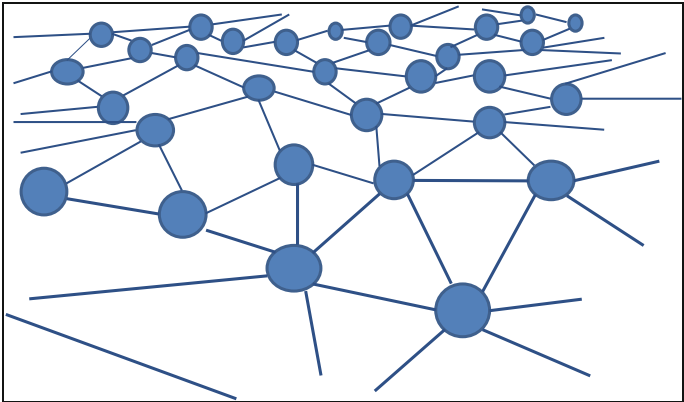


Fig. 2.18 A mesh network routing architecture. *Source* Author

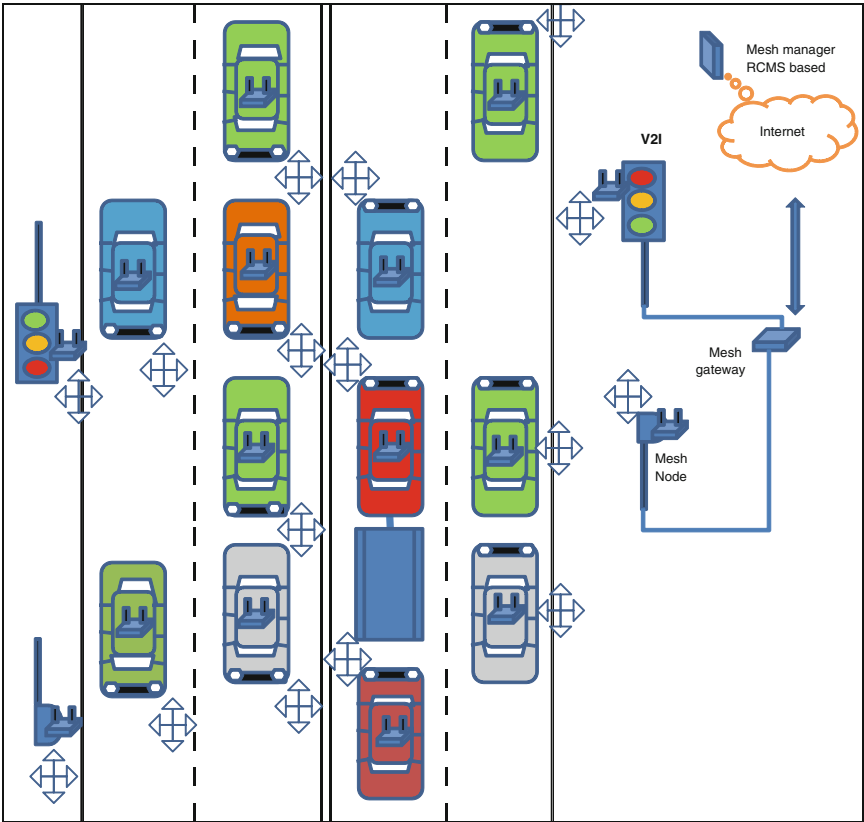


Fig. 2.19 Vehicle Ad Hoc Network composed of mesh nodes communicating through the 802.11p standard and interfacing through a mesh gateway with managing system in the cloud. *Source* Author

- **By-pass functionalities:** Cars need to be able to communicate even when intermittently blocked by passing vehicles. Mesh networks can use the hundreds of other nodes around to adjust to find a clear signal.
- **Fallback options and robust message networks:** If one network is down, alternatives need to be identified and strengthened to reliably propagate messages between networks. For example, if an accident were to cause V2C communications to be broken, a car may still have access to a V2V communication network. An emergency signal message could potentially be sent through V2V to a vehicle nearby, and then between cars and infrastructures until reaching its destination.

2.8.6 Vehicular Application

There are typically three types of application that can be regrouped within the VANET systems:

- **Infotainment:** Though this isn't the real objective of VANET, it should bring commercial opportunities and higher comfort levels for passengers;
- **Traffic management:** These applications will focus on optimizing the car flow by reducing traffic jams. Such applications would include enhanced navigation and mapping system, traffic light flow regulation, lane merging information, accident real-time information, speed regulation, etc.; and
- **Road safety:** These applications have the objective to reduce fatalities (NHTSA reports say that it would reduce vehicle crashes by 81 %) by providing drivers with information about road hazards and dangerous driving behavior or situations. The most obvious application is the anti-collision system.

2.8.7 Anti-collision System

Since V2V is still a concept with several thousand working prototypes, all description of how V2V will work is uncertain.

Most likely the anti-collision systems will integrate a visual interface included within the front board, forewarning the driver of a potential dangerous situation. V2V warnings might come to the driver as an alert, perhaps a red light that flashes in the instrument panel, or a combination of orange and red alerts for escalating problems? The direction of the risk might also be identified on the front board. In a second generation, for which prototypes already exist, cars are likely to brake or even steer around hazards. All the basic information

required for providing this anti-collision system with the required input already exists in most cars.

As seen for trains, cars will need to provide other cars with basic safety information. The EDR, though much simpler than a Train Control Unit, can already provide most of the mandatory information, such as speed, position, direction of travel, car steering angle, car weight, braking conditions, and even loss of stability. All this information will be provided by the onboard equipment except one: the position of the car.

2.8.8 *Accurate Geo-Positioning*

Everyone has already been aboard a car with GPS. The GPS is a satellite navigation system that gives geo-localization and indicates time. In order to work properly, it needs a direct access to at least four satellites. Three satellites can work but data isn't accurate enough for precise 3-D location (latitude and longitude are still available).

How do GPS work?

Using information from satellites, it basically triangulates its position in regards to the satellites. The satellites transmit a signal of their own location in orbit, with a time signature. The receiver compares the time a signal was transmitted by the different satellites with the time it was received, which gives its location. The receiver uses the signals overlap to do this triangulation. However, as the size of the waves transmitting the signal can be large, their overlap can be several meters, thus limiting geo-positioning accuracy. Furthermore and as most drivers have experienced, GPS can stop emitting geo-positioning information. In fact, GPS satellites transmit a low-powered radio signal that travels by line-of-sight. This means it will pass through clouds, glass or plastic but will not go through most solid objects such as buildings or trees. Furthermore, it can be impacted by atmospheric turbulences or electrical interferences. This is especially problematic during storms and when passing through tunnels.

So there are two fundamental issues to solve with GPS for V2V communication to work properly: geo-localization precision and satellite losses.

Geo-localization precision GPS accuracy was on average around 15 m. While this could be sufficient to indicate where you are in relation to a road junction, it isn't accurate enough to tell you to stop especially if you are in a traffic jam, 3 m apart

from the neighboring car's bumper. Furthermore, certain atmospheric factors and other sources of error can also affect the GPS receiver's accuracy. This is why GPS haven't really been used for signaling by railway industry so far. Less than 5 m can separate two tracks and thus, with this level of accuracy, it was impossible to detect if the train was on the same track heading toward a collision or if the trains were just passing by normally.

GPS receivers with WAAS Newer generation of GPS and new safety concept can solve most of these problems. Newer GPS receivers with Wide Area Augmentation System (WAAS) capability can improve accuracy to less than 3 m on average, though the nominal value is 7.6 m. In North America, measurements of the system at specific locations have shown that GPS can provide accuracy level of 1.0 m laterally and 1.5 m vertically. Similar correcting systems exist in Europe (EGNOS) and Japan (MSAS).

PTC initiatives: In order to see how this problem could be solved for cars, let's look at the GPS based railway initiatives. The American signaling program called (PTC) manages to overcome these limitations by using the Nationwide Differential GPS (NDGPS), which comprises of a network of ground-based reference stations, in order to serve as a closer point of reference. The concept behind PTC works by the train receiving information about its location and along which lines it can safely travel. Onboard computers receive the GPS data and can control the movement of the train automatically, preventing any movement that is unsafe according to up-to-date travel information. Using the NDGPS also prevents areas of poor signal, such as tunnels, from significantly impacting the system.

Galileo GPS Europe's answer to the American GPS is called Galileo. When completed by 2019, 30 satellites will be able to give an accuracy level of around 4 m for horizontal and 8 m for vertical positioning. Furthermore, GPS and Galileo will be interoperable.

DGPS Users can also get better accuracy with Differential GPS (DGPS), which corrects GPS signals within an average of 3 to 5 m.

When looking at initiatives in the railway industry, we can conclude that the GPS level of accuracy will enable in the future (around 2017 -2018) a sufficient level of precision for V2V communication to work.

Satellite loss As we've all experienced, GPS can lose satellite signal. In a V2V system, this can be complicated as the exact car's position in regards to the other cars is geo-located. However, in such case, an alarm is likely to indicate the driver that her car's position isn't accurate enough and should be more careful. This loss will, however, be more complicated in an unmanned vehicle environment.

Dead reckoning It is a GPS feature available on many high-end GPS models that help cars keep track of their position after losing their satellite signal. It works by still being able to monitor a vehicle's speed and course of direction, though less accurately than through true satellite guidance. Some systems measure the average speed for a stretch of road based on recent car data and calculate the position based on projections. Other systems may use a digital compass and a connection to the car's sensors to help define the car's speed and direction.

Active markers We've seen that these tools are often used in railways to give basic information about geo-positioning. Most likely in critical area such as tunnels, they will be used to compensate for the absence of satellite access.

2.8.9 V2V Operational Mode

V2V operational mode relies on trust. For experienced drivers, putting their life into the hands of their car's onboard computer won't be easy. They should. After all, millions already do with unmanned trains and as we've seen reducing the human error factor in transportation can only increase safety. However, it is true that passengers will need to trust their car but also the nearby vehicles in a few different ways:

- Firstly, the driver must trust that the received signal comes from the car directly in front or on its side;
- Secondly, he is trusting that this car is accurately reporting its state, and not sending wrong messages; and
- Thirdly, she is trusting that the received signal isn't trying to hack into the car's system or being sent by malicious people.

Operationally, the following six components that would be deployed in vehicles equipped with V2V would need to be working together:

1. An appropriate blend of telecom technologies, such as DSRC that receives and transmits data through antenna, other telecommunication technology, and a mesh network;
2. GPS receivers providing vehicle position and time to DSRC radio and supplying timekeeping signal for applications, as well as accurate and updated maps;
3. An onboard communication network that incorporates the existing network that interconnects components in the vehicle;
4. An electronic control unit that runs safety applications;
5. A driver-vehicle interface that generates warning issued to driver; and
6. A memory that stores security certificates, application data, and other information.

A ruggedized communication security system, which will check the proper functioning of these six components, will need to provide and verify V2V security certificates to ensure this trust between vehicles.

2.9 Intelligent Wayside Technologies

Infrastructure may sound boring in regards to smart cars, but these new e-mobility technologies will demand that Public Authorities decide how to promote such technologies and define the role they should play in their implementation. Unfortunately, and as we will see in Chap. 6, there is a huge deficit in public spending for infrastructure. In many countries, Governments, States, and municipalities are broke and can barely afford to maintain the transportation infrastructure they already have. No public authorities will look favorably at having to invest in new infrastructure and pay the maintenance of such new equipment. However, without clever infrastructure, the concept of V2V and unmanned cars can run into trouble. In fact, we could probably say that smart vehicles are only as intelligent as the infrastructure that surrounds them is.

In this section, we will look at which key infrastructure should be made more intelligent and who could pay for it. However, in the last instance, if no one can pay for it, there is always the possibility to ensure that the required functionality be performed directly by the car and paid by the owners themselves.

In order to make complex concepts easy to remember, marketers have come up with additional acronyms. V2I and V2C are used to indicate Vehicle-to-Infrastructure (V2I) and V2C communication, respectively. Under V2C, we include all the telecommunication backbone and network. Under V2I, we include all the road equipments that will provide real-time information.

2.9.1 *Vehicle-to-Cloud (V2C)*

We've just seen that continuous wireless component is a key success factor of V2V. V2C, which incorporates this wireless system, includes two elements:

- **Cloud computing:** This portion can be hosted by servers from big IT providers. As we all know, this hosting capacity is growing exponentially and this is now a service which can be sold easily; and
- **Wireless communication link:** We've seen that V2C will be based on a mesh network with base stations or LTE tower positioned in key areas of cities or roads (i.e., junctions).

The interesting aspect of mesh networks that we've seen is their ability to reassemble themselves to fit changing environments. Moreover, the more connection points, the better. Indeed, one of the driving forces behind mesh technology is Metcalfe's Law, (quote from Bob Metcalfe one of the Ethernet inventor) that says that the value of a network grows as its number of connection points increases. Imagine wireless traffic relaying information from car to car until reaching its destination. More cars would just mean more capacity to transmit data. It should also be noted that some network companies such as Cisco are working on newer network technology, which would allow for decentralized data processing, directly within the networks, increasing reaction responses.

Some infrastructure providers would also need to support this V2V initiative. One area which will be critical is parking lots.

2.9.2 Intelligent Parking

Some companies have already developed small wireless sensors that can indicate if a parking space is occupied or not. Like balises for the railway industry, these magnetometers that are glued to the road or buried a few millimeters under the pavement can detect when a car arrives or leaves.

In 2014, San Francisco will implement the largest mesh network for monitoring 6,000 parking spaces. The city hopes that displaying information from the sensors on Web maps, smart phones, and signs on the street will reduce the traffic and pollution caused by circling cars.

2.9.3 Intelligent Traffic Systems

Intelligent lighting systems based on sensors or cameras as well as centralized computer making adjustment to help car flow can be found throughout the world. V2I, however, will enhance this capacity by giving additional information that ordinary sensors cannot.

By leveraging and installing wireless transponders and smart embedded sensors, cars will feed safety information into highways and roads. Such information would include static road hazards like curvy roads, flooding areas, low bridges, changing road conditions such as construction, minimum and maximum speed, as well as

traffic input such as density, flow, volume, and speed. Furthermore, information at cross sections will also be available under V2I, such as average car speed and time wasted at such junction. However, the main advantage of such technology is that the information flowing from the lighting system to the car could synchronize automatically the vehicle's speed to reduce the braking needs.

One could also imagine that in areas with low car density, information flow from the car could reduce the lighting's stopping period, enabling the vehicle to avoid stopping altogether. It could even eliminate altogether the need for lighting systems, in areas with no pedestrian. As a matter of fact since 2012, computer scientists from the University of Texas have been developing smart intersections designed for self-driving cars. If successfully applied, their technology will insure that onboard and intersection computers communicate directly and synchronize safely the required car speed at intersections without the use of any traffic lights or stop signs.

2.9.4 *Distributed Intelligence*

How many people have been stuck for hours in a traffic jam, wishing someone or something would have given it an advanced warning of an accident or works lying ahead? On many toll highways of this world, dedicated radio services now give such information. However, not everyone wants to listen to elevator music or to what happens 300 km from their current car location. Furthermore, getting alternative route information is often difficult. With new GPS technology, things have improved as they often provide real-time road status and alternative roads. However, such services are often limited and alternative routes often end up taking more time than just staying on the road.

V2V intelligent traffic management should help. Traffic information already exists on many highways and main city arteries, centralized in control centers. Often traffic reports are relayed to radios or to GPS real-time service provider, and even sometimes, displayed simple electric panels on the road. However, V2C technology will extend these services to all types of road. Cars will be able to send messages to cloud servers informing everyone about the road condition and potential hazardous situations they've encountered, through the means of geo-localized messages (giving a latitude, longitude, and vertical position). Any cars passing by will be able to get such information in quasi real-time and intelligent mapping will then be able to select and display the best alternative route.

2.10 Driverless Cars

Marketers have come up with several names to characterize cars that can run without the need of a driver: self-driving, driverless, unmanned, autonomous, robot car, etc. All these names describe the level 4 or 5 of automated cars. Independently from how we name them, these cars rely on four basic principles: Data acquisition through sensors, data treatment through onboard computers and software programs, two-way communication, and interface with the car's drive train equipment.

2.10.1 Data Acquisition

Unmanned cars need to sense their environment in all potential conditions:

- Exterior and interior environments, such as tunnel;
- In all spectrum of light, from daylight to night; and
- In all weather conditions, be it fog, rain, snow, or even sand in the desert.

In order to sense all these conditions, a mix of several technologies will be required. These are a few of the technologies currently used by Google and that could equip these cars, if their unit cost can be reduced significantly.

Lidar It is a laser radar system, which measures the distance by illuminating elements positioned in front of the laser beams. Lidar uses a spectrum of ultraviolet, visible, or near infrared lights, to picture objects in all conditions. It can target a wide range of materials, including metallic and non-metallic objects, rocks, rain, human beings, etc. In fact everything that can be found on a road can be picked up by a lidar.

Google driverless car used till 2014 for testing a 64-beam laser mounted on the top of a car, which unit price was \$70,000. The laser provided three-dimensional depth. Each beam flashed around ten times per second, scanning more than 1 million points in concentric waves. This laser could detect a 30 cm long object crossing a road 50 m ahead of the car.

Radar Google's car integrates also radar technology, which is an object-detection system that uses radio waves to determine the range, altitude, direction, or speed of objects. The radar has twice the range of the lidar but doesn't have the same precision.

Cameras Finally, it also integrates vision through cameras. Cameras are used for identifying road signs, signals, colors, and lights.

Data fusion All views from these three technologies are then integrated, combined, and overlaid by the digital maps and Street Views™ that Google collects throughout the world. The result is a clear 3 D model of the road.

Once the system gets a clear view of its environment, it still needs to understand what it is seeing. The difficulty is that roads, unlike metro lines, aren't controlled environments. Kids, animals, and other cars can rush from the side or run in front of the car. Luckily, driving is mostly simple: follow the front car within the two delimitating lines, with a defined interspacing. This is especially true on highways. The complication is managing the remaining stuff, especially in urban environments.

2.10.2 Data Treatment

How can computer treat such complicated stuff? The answer is by writing appropriate algorithms. The difficulty is what is an appropriate algorithm and how do you make sure you aren't missing any critical set of rules or interpreting it erroneously? To illustrate such risk, let's take an example from the science fiction writer Isaac Asimov, who set the three laws of robotic¹³, a very appropriate example for a robot car:

- *A robot may not injure a human being or, through inaction, allow a human being to come to harm;*
- *A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law; and*
- *A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.*

Mr. Asimov described in his book *Robots and Empire*, a 0 law created by a robot which modifies the three first laws:

- *A robot may not harm humanity, or by inaction, allow humanity to come to harm.*

Obviously, this is pure science fiction but it shows that if software engineers rely too much on self-learning programs, it can create rules that are difficult to validate through scenarios or testing.

Let's take a more practical example to illustrate how testing and self-learning engines can be useful. Anyone who has accelerated with a rear wheel drive car, when hitting an icy patch may have experienced its car rear end trying to

¹³The novel *Robots and Empire* from Isaac Asimov; published by Doubleday Books in 1985.

come around. In order to redirect the car in the road axle, one must turn the wheels in the direction of the spin. This move is counter-intuitive and anybody who hasn't gone through this experience will turn the wheel in the opposite direction of the spin, ending crashing in snow banks, hopefully without injury. A self learning system would do the error once but would either define its action plan or identify the issue for the software engineer to solve.

If we take the example of the spinning car rule, we could create an algorithm replicating the following scenario: "if"

- the car is rear wheel drive (x1);
- Sensors have identified a quick spin (x2);
- ice has been detected by vision (x3);
- temperature is lower than 0°C (x4); etc.,

"than do":

- turn the driver's wheel in the same direction as the spin(y1) if there is any wheel;
- use engine braking to decelerate (y2);
- if using ABS brakes, maintain a steady pressure on the brakes (y3);
- if not using ABS brakes, do not maintain steady pressure, apply light stabs, hold, release and press again (y4);
- Brake at speed under 10 km (y3);
- etc.

After setting such rules and the necessary interface with sensors and drivetrain, one needs to drive the car and test by trial and error that the rules don't make the car crash. This is a slow and demanding process. Luckily, software engineers can take advantage of self-learning software programs. Other logic models can be used, such as fuzzy logic to integrate and understand uncertainty. In other words, software engineers can combine learning and rule setting to come up with the best algorithms.

Many set of rules can be tested according to several scenarios. For instance, simulations based on accidents documented by the US National Highway Traffic Safety Administration can be applied. Many accidents in rural areas are due to collision with wild life. If a deer crosses in front of the car what rules should be applied? Should the car try to avoid it or hit it? Is the previous rule true in all conditions or it needs to integrate speed? How much advance warning does it need?

As we see, driving hours and experience with self-teaching systems will optimize these algorithms. Having worked on these rules and having been able to fine-tune them will give companies with an early start, a clear advantage. For instance, we all heard that the IT company Google's unmanned cars have been accident-free for a few years now. This proves that their algorithms are working. It also proves that they are safer than normal vehicles, as statistically after more than 830,000 km, and human drivers would have already had an average of two crashes.

2.10.3 Financial Barrier to Adoption

One of the barriers to adoption is cost. In 2010, the cost of Google's self-driving technology was \$150,000, of which as we've seen \$70,000 was just for the lidar. Obviously, such price is dissuasive but some suppliers believe that mass production could reduce quickly the lidar to less than 1000\$. Computational processing, which is still another large component of the overall price, will experience the usual exponential cost reduction.

Many specialists in the automobile industry believe that Google's idealistic approach to the driverless cars won't bring the price of all these technologies down far enough to make it attractive to the mass market. So many car manufacturers together with their OEMs are looking at ways to consolidate and simplify the hardware. Miniaturization, sensor fusion, and integration of controllers are a few approaches considered. Better optical systems that could replace Lidar and radar technologies are also envisioned.

Whatever the solutions that will prevail, one thing is certain, cost will go down. How quickly is still a question mark, but according to a recent study¹⁴, price for the self-driving technology will add between \$7000 and \$10,000 to a car's price in 2025, a figure that will drop to around \$5000 in 2030 and about \$3000 in 2035, the year when the report says most self-driving vehicles will be operated completely independent from a human occupant's control. Some other reports suggest that by 2030, the price of the additional technologies will fall under \$1000, at which point the autonomous option will cost probably less than the annual savings in insurance.

If costs come down, the next most important barrier is legal. In our opinion, and though these legal issues are real, they will be tackled in time to allow the advent of unmanned cars. The fact is that some US States such as Nevada, Florida, California and Michigan have already legalized self-driving cars. The UK has also legalized their use on public roads in 2013. As economical interest and proof of safety will prevail, more and more countries and States

¹⁴Emerging Technologies: Autonomous Cars—Not If, But When; Source IHS Automotive forecasts; Date January 2, 2014. <http://press.ihs.com/press-release/automotive/self-driving-cars-moving-industrys-drivers-seat>.

will legalize self-driving cars. Though legal concerns are legitimate, we see them more as a resistance to change than a road blocker. After all, the railway industry as gone unmanned and this is a market with stringent standards and heavily regulated. In our view, legal issues won't stay in the way of all the forces advocating for autonomous vehicles, such as:

- Fewer accidents, reducing overall risk and liability, which will cause insurance companies to favor self-driving cars;
- Significant reduction in the number of deaths and injuries, bringing undeniable social benefits;
- Greater convenience and possibility for elderly citizens to continue using their cars, leading to strong consumer demand;
- Market differentiator, giving a huge incentive to manufacturers to sell profitable new options; and
- Drunk driving reduction and increase in alcohol consumption, making alcohol companies, bars and restaurants strong supporters, especially in country with 0 alcohol tolerance for drivers.

Simply put, the money is with the forces for autonomous vehicles. Insurance companies, liquor companies, vehicle manufacturers, customers, and governments will all want the benefits of self-driving cars.

2.10.4 Legal Barrier to Adoption

As mentioned, a few states and countries have accepted the principle of driverless cars. Unfortunately, this is more a permission to test vehicles rather than the real legal foundation for a society composed of a fleet of driverless vehicles. In fact, the efforts by the Nevada State to pass the first law authorizing the use of autonomous cars in June 2011 were reported to be highly supported by Google, in order to legally conduct further testing of its driverless technology. However, this law still limits the use of unmanned systems. Although the law acknowledges that the vehicle “operator” (this will replace world driver, at least till there is no operator at all) doesn't need to pay attention during operation, he/she must not have disturbing activities such as sending text messages and requires a person behind the wheel at all time. In California, the law demands for a car operator behind the steering wheel to take over in case of sudden car failure.

2.10.5 Legal Responsibilities

With all these legal limitations, what is required for the advent of unmanned system? First, let's look at what are the implications of a car crash for ordinary car drivers.

Current liabilities There are three potential causes to an accident: issues linked to cars, problems with the infrastructure, or an act of God. Let's focus on the two first causes, as the latest is actually invoked in cases where there can't be any proven liability. In case of car accidents, there are five potential liable Parties:

- One or both drivers;
- Car owner of one of the cars who didn't maintain the car's physical integrity;
- A mechanic who had recently serviced one of the vehicles badly;
- One of the car dealers; or
- One of the car manufacturers.

According to David Chung, a partner of an American law firm (April 2013¹⁵).

There are numerous factors which would be taken into account in order for the Court to determine who is liable. Depending on circumstances, multiple parties may be liable where more than one party is found to have materially contributed to the incident resulting in the injury or damage. Where multiple parties are culpable, they would share the liability in the proportions determined by the Court... Who is liable is a question of fact.

People or entities can also be liable for infrastructure issues. Bad road conditions due to failure to maintain decent driving conditions, or unexpected events causing fatalities, such as construction work not being properly announced and trucks or people being where they shouldn't be, are also potential liable parties. Obviously, in an era without drivers, one of the most frequent liable parties—the driver—will disappear, but new actors will be introduced.

Liability for Driverless Cars According to Mr. Chung's view on principle of law: "relationships of trust give rise to duties of care."

In unmanned trains, passengers trust that the system will perform correctly. Similarly, passengers using self-driving cars will trust that all elements will operate flawlessly to avoid any accidents. Thus, in this e-mobility era, passengers will be off the hook for any liability, as they would trust that someone or something else is in control.

Once again comparison with trains will be useful to understand litigation changes brought by e-mobility technologies. The segmentation, we've used between, cars, infrastructure and even act of God isn't appropriate anymore.

¹⁵David Chung, Driverless cars, whose liability; March 4, 2013.<http://www.bennettphilp.com.au/content/driverless-cars-whose-liability>.

We need to think in terms of system integration and the different elements that are likely to be part of this system.

Using an analogy with railways, we will have potentially six subsystems that could be subject to liabilities:

1. Manufactured vehicle;
2. Onboard signaling system, which will include the five or six elements (the drivers interface might be made redundant) that were described in the V2V operational modes;
3. Car-to-wayside communication, including V2V, V2C, and V2I;
4. Control center, which will host network information;
5. Road infrastructure provider, which will take responsibility for infrastructure signaling as well as road physical conditions; and
6. Car operator or owner.

2.10.6 Vehicle Manufacturer Potential Liabilities

For the sake of this exercise, we will suppose that manufacturers (i.e., Mercedes Benz, General Motor, and Toyota) won't be integrating the onboard signaling system. We believe that as long as these vehicle manufacturers don't supply the onboard signaling system, they won't be associated with taking over the car operation from the driver. Thus, car manufacturers' overall liability will remain more or less the same, as it is the case for train manufacturers of unmanned system. However, there is a caveat to this, which is that train manufacturers must build some intrinsically safe equipment. An example in the railway industry is that whenever a pressure lost in the hydraulic braking system happens, the brake inherently will be applied, as the pressure maintains the brake apart from the wheel. This also most likely means that redundancy might have to be added to critical-related safety equipment. It also means that in case one of these intrinsically safe equipments fails, the car will need to stop in a safe mode.

2.10.7 Onboard Signaling System Provider Potential Liabilities

In most unmanned railway systems, the onboard, wayside, and control center system are integrated by the same supplier. With initiatives such as ERTMS level 3, the EU has pushed for train interoperability between different railway systems, showing the path for decoupling between trains and the railway infrastructure. This

shows that system integration of very complex systems can be achieved as long as Governments and the major players of an industry elaborate interoperable standards. This needs to be the model followed by the automotive industry.

Let's assume for a moment that Google decides to position itself as a signaling system provider. This would mean that any car manufacturer (i.e., Chery from China) could install on one of its car model Google's signaling systems composed of the five or six V2V operational elements we've already identified, plus probably the sensors, as the signaling system wouldn't be able to work without them. As this system would replace the human factor from driving, it would in fact be responsible for all wrong decisions made, as the driver is today. Currently, in most countries, the consumer protection laws would impose obligations on the signaling supplier to compensate any person suffering injuries or damages, as a result of such wrong decisions. Although responsibility coming from software problems discovered after a product is sold is less clear cut than for a faulty product, there are legal precedents, especially with cars, as recent quality recall events have shown.

2.10.8 Telecom Provider Potential Liabilities

As we've seen, a critical element of self-driving cars is the possibility to communicate with other cars and the infrastructure equipment, as well as getting useful road condition information from a hosting data center.

In signaling systems, when the system aren't dedicated to the railway network, telecom providers (i.e.: for GSM-R, a railway GSM standard) are rarely the cause of accidents. The worst case scenario is usually that the signaling system cannot perform according to requirements and the trains must stop. Though not good for the train operator's image, these events are usually manageable.

What would happen if a complete mesh network in one of the most crowded arteries of a megacity would fail? Could the other technologies take over without resulting on an oversaturation of the entire telecom network? Would telecom companies be liable for such massive traffic jams? In our view, probably not, as long as they could reestablish the networks within reasonable delays. Furthermore, as there will be a blend of telecommunication technologies, there will probably be a fallback telecom technology that could be used.

2.10.9 V2C Hosting Centers

The hosting servers would need to store real-time information coming from cars and road operators and send it back on a geo-localized basis. What would happen in the case that they store the wrong information, are hacked (as it recently happened), or worst aren't able to send an emergency geo-localized message? On the same principle of trust, they would be most likely liable for any accidents or damages resulting from such error or omission.

2.10.10 Road Infrastructure Provider

Today, road operators are very rarely liable for accidents. Accidents resulting from road problems, such as potholes or bad signaling, are usually blamed on the driver or bad weather conditions. With unmanned system, this will change.

In railway environments a derailment caused by a broken rail or a faulty fastener cannot be invoked to avoid litigation. Even bad weather conditions cannot provide legal protection. In fact in unmanned system, weather condition monitoring will be mandatory.

Whenever a metrology equipment detects dangerous conditions, it will require that cars automatically reduced speed or stop operation altogether.

2.10.11 Operator or Car Owner

We must make the distinction between a car owner and a fleet operator of unmanned cars. The car owner will still be responsible to ensure that the car is in perfect working order. Thus, the owner will need to ensure that the car goes to the garage. This means that a mechanic could still be responsible for a crashed car, if he failed to inspect and repair all faulty parts. In cases of parking or traffic tickets, the owner of the car would most likely be held responsible for paying the ticket, even if the car and not the owner broke the law.

Would driverless car fleet operators' legal status be similar to the taxi owners' status? We aren't sure that they would only be responsible for ensuring that the provided cars are in working orders.

Railway operators are usually involved in accidents inquiries. Whenever blame cannot be pinpointed to faulty manufacturer's equipment, signaling or infrastructure providers or to an act of God, they can be convicted.

2.10.12 Suggestions to Minimize Legal Barrier to Adoption

Even though driverless cars will be much safer than conventional cars, there will be a time when a faulty electrical contact, a broken piece of equipment, an erroneous piece of software, or an integration problem will generate an accident. In such case, a lawsuit will follow or even class actions could take place if several accidents can be associated with one of the players. Although driverless technology stakeholders have the same basic obligations to offer safe products and may have the same set of legal exposures if they fail to do so, it won't be a simple problem to identify the guilty party. How do you apportion blame between different integrated subsystems, if there is no real system integrator?

In the article¹⁶ on liabilities published in April 23, 2014 "Who Is at Fault When a Driverless Car Gets in an Accident?," Mr. John Villasenor explains that current product liability law is the fruit of decades of precedent that established responsibilities whenever making or selling products. Plaintiffs in products liability lawsuits can choose from various "theories" of liability when seeking to recover damages.

- **Negligence:** it occurs when manufacturers fail to design safe products;
- **Design defects:** it occurs when a characteristic of a product creates a hazardous situation, due to a flaw in its product design; and
- **Breach of warranty:** Because marketing and selling products create explicit and implicit warranties, products liability also involves contract law.

However, the main difference in our view is that any individual product can work flawlessly but still cause an accident when interfacing with other technologies.

This is why in railway systems, an independent entity reviews the system's safety case and will give its approval to operate, usually after a period of testing. This is doable in confined environments, but much more complex in an application the size of a country. Will safety agencies need to guarantee the safety case of all urban and rural country roads? It is unlikely.

¹⁶Who Is at Fault When a Driverless Car Gets in an Accident? Author: John Villasenor (Published on April 23, 2014 in the Atlantic).<http://m.theatlantic.com/john-villasenor/>.

In our view, all subsystem suppliers will need to follow standards and that in the end no entity will give a safe to operate label for the system, but will for each individual equipment or software of this system.

As robots cannot be charged with crime, the trial lawyers will probably in the end go after the richest company, creating a real risk that innovating companies will shy away from developing unmanned technologies. There are solutions to avoid such situation. One of the easiest ways to reduce barrier to adoption is to maintain legal status quo. This means passing on risks to car owners. Manufacturers, signaling, and infrastructure providers might lobby consumers and their insurers to take on risks associated with their driverless vehicles as a purchase condition.

Would consumers agree to take on the risk? For material damages, there would be a good case for consumers to accept such liability, especially if insurance car companies decide to implement a no-fault policy and reduce their policy costs proportionally. As the number of accidents would dramatically decrease and more importantly their severity, it would probably make financial sense also for insurance companies to promote such a program. However, the issue about criminal liabilities would remain as it is unlikely that consumers would accept such risk.

Governments should introduce laws promoting self-driving cars as it is in their best interest to reduce significantly their citizens' fatalities and injuries. A law imposing V2V to all new cars, like the US Government is contemplating, is a move in the right direction. After a transitional period, it could even make sense for governments to outlaw all conventional cars. Although this would create a legal foundation for the unmanned industry, it wouldn't be sufficient to avoid litigation risks. In fact, some entity would still need to cover potential litigation costs. In our view, what would make the most sense would be for Governments to take over the liability for injuries and damages. In fact in many countries, they already do. Injuries in many countries are paid by the public health insurance. Governments could establish a public fund to compensate the victims of accidents involving autonomous cars. In our view, the funds would quickly be compensated by the \$billion reduction in health care costs. It would also be in the interest of insurance companies to participate in such funds. Car accidents would still happen and thus people would still require car insurances, but on the other hand, insurance companies would see the bills for heavily injured people reduce drastically, as the severity of accidents would diminish tremendously.

2.10.13 *Technical Suggestions to Minimize Potential Litigation*

The best suggestion to minimize the impact of litigation is still to reduce risks of potential accidents.

Semi-autonomous cars As seen, we are expecting car manufacturers to propose a progressive approach to self-driving cars. Cars that still require a driver behind the steering wheel are easier to build and potentially cheaper. However, according to some experts, this semi-autonomy may be the worst of all worlds. Drivers pay less attention to road conditions even though cars aren't really built to take control. Drivers would be likely to take over the controls only in emergency situations. How would he or she be able to assess a critical situation in the blink of the eye? In most cases, reflexes would be slow or not to say inexistent if the passenger was taking a nap. This is why Google in May 2014 announced that they will get rid of the human factor altogether. The new car that Google will build in around 100 units will have no steering wheel, pedals, or controls, just a stop and go button (Fig. 2.20).

Brick wall safety concept In our view, an unmanned system cannot allow for uncertainty to threaten passengers' life. Unmanned train system calculates at all time a safety time/distance that is required to ensure complete stop before hitting the train in front of it. In order to avoid class actions (at least at the beginning of this technology implementation), cars would need to follow this same principle. By applying this brick wall safety concept described previously, cars will always be in a position to avoid bumper-to-bumper accidents. To reduce the need for much longer car interspacing, the signaling system should be in a position to shorten the



Fig. 2.20 Picture of Google unmanned car, which Google intends to manufacture. *Source* Picture of the Google car; Copyright of Google Inc., which allows for the unaltered use of its content

necessary additional time required for this safety concept, by eliminating the human perception and reaction time.

Safer than human being concept In order to protect entities against mass litigation, unmanned cars should be at least safer than vehicles with drivers. This will be the case. For instance, accidents resulting from a change of lane should be eliminated as cars will constantly monitor the presence of other vehicle on the right or left side, either through V2V communication or sensor detection. However, we all know that on a non-segregated lane, some unfortunate events cannot be prevented. For instance, someone falling on the street or deciding to jump in front of the car will not be avoided by self-driving cars. A deer deciding to run in front of a car or a dog running to the cars will most likely be hit. But the point is that a “driven” car wouldn’t be better at avoiding these crashes. Most likely, humans would be worst, as they always need longer perception and reaction time than robot cars. This should in our view limit mass litigation, though wouldn’t avoid criminal enquiries in case of fatalities.

2.10.14 When Will It Happened?

The Nay-Sayers probably believe that it is too complicated or people love too much driving for it to happen. Our belief is that, as for unmanned train systems, self-driving cars will be a common feature of our life pretty soon. It won’t be something that will come over night and as we’ve seen there will be a progression in the class of automated cars.

As we don’t have a crystal ball, let’s check what the car manufacturers are planning to sell and show what industry experts are expecting.

- BMW in its upcoming i3 electric car model, is planning to introduce traffic-jam features, which will let their car accelerate, decelerate, and steer by itself at speeds of up to 40 km/h. It will require though that the driver leaves at least one hand on the steering wheel.
- Mercedes S-Class cars are already equipped with a system that can drive autonomously through city traffic at the same speed. This speed of 40 km/h is important because it allows for less regulation. Mercedes also claims that some of its technology can detect if a driver is getting drowsy, though it only uses sound alarms to warn the driver. In its S-Class, Mercedes is also planning to include several sensors. A 3-D camera could be positioned on the windshield. Short- and long-range radars would also be installed on front, rear and side of the car. Furthermore, twelve ultrasonic sensors will enable close object detection.

- In 2011, Volvo already declared that by 2020, no one would be killed or injured. It has recently introduced cars, which can take preemptive action, such as tightening the seat belts, charging the brakes for maximum traction, and, even in extreme circumstances stopping the car. It is planning to launch in 2015 technology it refers to as “driver assist”, intended for the highway. It will utilize radar and cameras to enable the driver to sit back and enjoy the trip. This equipment recognizes front and behind spacing, limiting the possibility for other vehicle to get near it, as well as detecting lane marking.

Year	Prediction
2014	Volvo will feature Adaptive Cruise Control with steer assist which will automatically follow the vehicle ahead in queues
2015	Audi plans to market vehicles that can autonomously steer, accelerate, and brake at lower speeds, such as in traffic jams [88] Cadillac plans vehicles with “super cruise”: autonomous steering, braking, and lane guidance. This technology will likely spread to other GM models in following years Nissan expects to sell vehicles with autonomous steering, braking, lane guidance, throttle, gear shifting, and, as permitted by law, unoccupied self-parking after passengers exit
2016	Toyota plans to roll out near-autonomous vehicles dubbed Automated Highway Driving Assist with Lane Trace Control and Cooperative-adaptive Cruise Control
2018	Google expects to release their autonomous car technology
2020	Volvo envisages having cars in which passengers would be immune from injuries Mercedes Benz, Audi, Nissan and BMW all expect to sell autonomous cars
2025	Daimler and Ford expect autonomous vehicles on the market

Market forecasts of research institutes vary also enormously. We’ve picked the results of five different institutes, so that readers can decide by themselves what the future looks like.

- In 2014, HIS Automotive a research company reported that by 2025, self-driving cars sale would account for only 230,000 units. This first group of autonomous cars would most likely have Level 3 capability (limited self-driving functionalities).The market shares of this technology would raise to 9.2 % in 2035, as completely unmanned vehicles would become available. 7 million of those 11.8 million self-driving vehicles sold that year would rely on a mix of driver input and autonomous control, with the remaining 4.8 million vehicles completely unmanned. IHS expects that by 2050 e-drive cars will outnumber conventional cars on the

road. By then, the majority of cars sold will be unmanned, with conventional car sales becoming increasingly rare.

- The company Navigant Research is more bullish about sales of autonomous vehicles. According to their 2014 report, self-driving vehicles will grow from fewer than 8000 units sold in 2020 to 95.4 million in 2035, representing 75 % of worldwide car sales. By that time, North America is forecasted to account for 29 % of worldwide sales of level 4 and 5 self-driving cars. China will represent 24 %, while Western Europe will account for 20 %.
- Strategy Analytics research company, meanwhile, expects autonomous cars that are highly automated (but not exactly self-driving) to have a market share of around 15–20 % in 2025–2030.
- Expert members of the Institute of Electrical and Electronics Engineers (IEEE) estimated that up to 75 % of all cars will be autonomous by 2040.
- ABI Research forecasts that self-driving cars would become a reality by 2020 and that 10 million such cars would be sold in the USA by 2032.

2.10.15 Self-driving Market

Predictions on how quickly unmanned vehicle technology will be adopted is complicated and very different from one expert to the other. Estimating how much this market will be worth is even more complex. To do so, we first need to separate the cost of the unmanned technology per se (what we called the signaling technology) from the car itself to assess correctly the self-driving market opportunities. We need also to add infrastructure opportunities, be it on the wayside or in the cloud.

Signaling price As we've already seen for batteries and other technologies such as computers, incremental decreases in cost are mostly dependent on the rate of adoption of that technology. The automotive industry being worth so much, any significant system sales will immediately impact costs. Thus and according to industry experts, the price premium for this electronics technology, which should add around \$10,000 to a car's price in 2025, will fall drastically. This amount, which would be initially installed on premium cars, would then drop to around \$5000 by 2030 and about \$3000 in 2035 when no driving feature would be required anymore.

Two ownership models for self-driving cars Such predictions rely on the principle that unmanned cars will continue to be bought by the passengers as they are today by drivers. This is most likely to happen in the early development of this technology. Self-driving cars are likely to be an important selling feature in the early years,

which will affect sales cars positively. The question is if the number of unmanned cars will grow initially and then peak, due to new business models enabling passengers not to own their car but to use it whenever necessary, as a taxi.

Some industry experts are saying that sales of cars will be affected tremendously by such models. For instance, Columbia University's The Earth Institute forecasts the reduction of United State's fleet of vehicles by a factor of 10. Price water house Coopers forecasts a collapse in the United States of the number of vehicles from around 245 million to just 2.4 million.

However, and as we will see in Chap. 7, younger generations tend to be less interested in car ownership, and these estimations remain very optimistic or pessimistic, depending on one's appreciation of the car role in modern society. In our view, people will continue buying cars as this is part of the social status. People don't need a Ferrari nor do they need a watch anymore, but they still buy both luxury items. Furthermore, passengers will most likely still want to feel "at home" in their car and not share it with others. Mercedes Benz President Dieter Zetsche in fact presented his unmanned car at the CES stating that (Fig. 2.21):

the car is growing beyond its role as a mere means of transport and will ultimately become a mobile living space.

So how much money are we talking about for this market? If we do the math for 2035, a point in time when the market will be already reasonably mature, we would have 95 million cars x \$3000 = \$285 billion. Needless to say that is probably one of



Fig. 2.21 In January 2015, Mercedes presented its version of a driverless car at the CES show in Las Vegas (Picture of the F015 driverless concept car, Copyright of Mercedes Benz and kindly lent for this book)

the biggest opportunities for any given market. Furthermore, this excludes the infrastructure market, which would benefit to telecom companies such as Erickson, Cisco, and Huawei, as they stand to gain from the million of wireless routers and wireless equipment that will need to be installed. In fact, Machina a consulting firm¹⁷ suggests that this market will be worth \$422 billion by 2022, a significant portion coming from new connected services, which don't even exist today.

2.10.16 Testing the Driverless Application

There are already some driverless car systems being tested on both sides of the Atlantic.

From 2014, driverless taxis will be carrying passengers during demonstration projects in five European cities, during six to eight months. The EU project CityMobil2 brings automated vehicles to designated roads inside the city centre.

In the United States, the Michigan University in partnership with several car manufacturers (Toyota, GM, Ford, Bosch, Xerox, Econolite) has started the construction of a new city dedicated to testing unmanned vehicles on a 12 ha field. This area called Mobility Transformation Center, will integrate four lanes, signaling, junctions, lighting systems, buildings, pedestrians and building areas. In fact most real life conditions will be possible to emulate.

2.11 Security

Security issues are very different from a private or public transport perspective. In private transportation, the usual risks are having your car stolen or being high jacked. In the future when cars will be driverless, new security threats will happen such as hackers getting access to your car's computer and creating malfunctions on the vehicle's equipment, causing a crash. In public transport, on top of the risk for the passenger of being robbed, mobbed or even assaulted by a gang of angry hooligans, there is the risk of people vandalizing the infrastructure as well as terrorists putting a conventional or dirty bomb, a lethal virus or a poisonous gas in the station or on board a train driving at 350 km/h. The answers to such threats can vary tremendously from one risk scenario to the other but will always need to contemplate three main factors:

¹⁷Report written by analysts Machina Research, "Connected Car Industry 2013" and commissioned by Telefónica SA.

- **Human factors:** how do staff, police, guards, dog patrols, and even passengers react in a threatening situation;
- **Technology:** there are as many technologies as threats that can be thought of. Most technologies come from other areas with few adaptations to the transportation sector. Lately, some technologies have been adapted to the specific needs of Public transport; and
- **Procedures:** what are the reactions that need to be taken in function of different threat scenarios.

Experience has shown that it is the association of these three factors that can achieve the best results. These factors can be applied to the main principles that we've regrouped under four areas:

- **Reassure and Deter:** Through police patrolling or random checks, police may be able to deter potential thieves to organize and assault passengers. By being visible often, law enforcement officers can deter but also reassure passengers. Surveys on security technologies such as CCTV have indeed shown that they can play a reassuring role with the public and can deter people from committing crimes, since they know that their acts can be recorded;
- **Detect, record, and alert:** When a crime is committed it must be detected
- **Assess; confirm;** and
- **Investigate; review; identify; show evidence during trials.**

2.11.1 E-Mobility Security Solution

Defense or security industry specialists might argue that the security solutions are just an extension of existing technologies applied in buildings, casinos, airports, or even on the battlefield and shouldn't be included within these e-mobility technologies. We believe on the contrary that the very nature of public transport networks—characterized by many access points, frequent stops, large geographical areas, many passengers and large fleets of moving vehicles—requires specific security solutions. In the public transport environment and unlike in airports, security Personnel cannot search passengers systematically at specific checkpoints. Furthermore, unlike street, building, or large infrastructure surveillance, public transport security systems must be designed with stringent electromechanical and anti-vibration standards. Additionally, the integration of security systems, such as CCTV on board the train, with the wayside communications infrastructure and potentially into a command and control center, adds incremental complexity not found in other systems. This complexity requires new software and telecommunication technologies, which are part of this e-mobility revolution.

This section is dedicated to the new IP technologies that are unique to public transport and will not describe, access control, biometrics, baggage screening, and

other security technologies that are either applied without any changes or rarely used in such environment. Thus, it will mainly focus on CCTV systems and highlight how they will evolve to better tackle the central challenge of public transport security, which is to balance passenger security concerns with accessibility, convenience, and affordability. It will argue that the integration of fixed and mobile assets can better manage security threats. Finally, it will give an insight into how bundling digital CCTV images with other public transport system technologies will improve both the operational performance of the public transport system and increase the situational awareness of security decision-makers. The concepts and ideas coming from the following section were inspired by a report¹⁸ on the benefits of CCTV within Public Transport, written by the Security and ITSI committees of the UITP in 2010, in which the Author had the honor to participate.

2.11.2 End-to-End Security Solutions

Each public transport operator has a unique set of risks and vulnerabilities, and security solutions for metros, commuter lines, light rail vehicles, buses, or intercity operators will vary substantially. That said, the level of sophistication that an operator wants for its solution will depend on its experience to date with security systems already installed, and the likelihood of future disturbances in its system.

Although some public transport operators are still looking for simple security solutions to implement in their existing networks, more and more operators are looking for end-to-end solutions where all subsystems, fixed or mobile CCTV, access control, employee/visitor systems, GPS, passenger information system, etc. are integrated into the operational control center. This fundamental trend can be explained by the development of the e-mobility technologies as well as by the need to align with professional security strategies being implemented to address these various public transport risks and vulnerabilities.

2.11.3 Technological Trends in Security

As seen for safety risks, security threats are event driven. In other words, a perceived risk is always linked to a location (within a bus, on a station platform, etc.) at a given moment (when there is a crowd, after a football game, etc.), involves

¹⁸CCTV: a Tool to support Public Transport Security; Factors to consider before installing or upgrading; UITP 2010, co-authors M. Babington, L. Barr, D. Bernard, K. Clark, G. Dunmore, B. Hart, N. Koide, T. Kritzer, G. Lucisano, J.C. Pinero, A. Silva Neves, K. Takemoto, J.P. Van Keymeulen, S. Van Themsche.

someone (criminal, bomber, suicidal person, etc.), and something harmful (bomb, gun, toxic gas, fire, knife, etc.).

There are three fundamental security strategies that can be implemented to manage these events:

- **Proactive (Prevention):** Stop the event before it occurs;
- **Reactive (Preparedness & Response):** Act to limit the impact of the event, if the previous strategy failed; and
- **Forensic (Recovery):** Get information to put the system back in operation immediately.

Obviously, from a security point of view, the proactive measures are much better. Stopping terrorists before they explode their bomb is better than finding who did it afterward. From a security perspective, this is the challenge technology providers are facing: going from current forensic approach toward a reactive and ideally proactive phase. Today's reactive and proactive approaches are better addressed by human beings. They can more quickly understand a situation and with good training and adequate policies define the right action to be taken. However, as more and more information is gathered (i.e., through CCTV, access cards, biometrics), human beings have difficulty coping with the amount of data and need more and more automation software for audiovisual and metadata data processing.

Railway operators are becoming aware of these human limitations and are selecting e-mobility technologies based on their track record and cost:

- **IP networks:** Use of Internet Protocol networks onboard vehicles and in fixed environment networks enables the use of standardized software and hardware technology. This quickens the passage from analogue to digital technologies, which as a consequence will push the convergence of images, audio and data;
- **Open software platform:** Open based software, such as SOA solutions, delivers a universal mechanism to interconnect all applications from different systems. This distributes real-time information from disparate data sources and provides powerful new means of unifying different databases across networks;
- **Increasing processing power:** This enables the possibility to perform demanding processing tasks such as video and audio analytics closer to the network's edge, such as within the train or at the camera level;
- **Video analytics (intelligent/smart systems):** Emergence of software using algorithms enabling patterns detection. By enabling a computer to search for events, the images generated by CCTV or sound detection system can become useful input data for these algorithms and detect events;

- **Broadband communication:** The increasing ability of wireless broadband communications to support transmission of images with sufficient bandwidth; and
- **Bundling of CCTV** with other operational requirements: Another trend is for security features to be bundled with safety, control, maintenance, and other operational features in the system.

2.11.4 Limitations of Analog Security Systems

Security Personnel in major transport networks is not physically able to get access to critical information quickly enough. Indeed, within a medium-size metro network environment, there are more than 1000 fixed cameras, with views centralized at one or several operational control centers. It is thus extremely difficult to detect an event before it occurs (especially during rush hours), or react quickly upon it when it is identified. Good training of security Personnel and scorecards of highest risk locations usually helps detecting hazardous situations, but this is expensive and becoming more and more complex with each new camera added to the system.

In the onboard environment, the situation is even worse where the absence of physical connection impedes security Personnel from viewing live images. Videos are simply stored on a hard disk caddy to be retrieved manually if needed and reviewed usually in the days following the incident. This forensic role is furthermore supported by watermarking technology, which ensures that video sequence can be used as evidence in court.

Having said that we will now see that IP technologies are shaping the security solutions which are being implemented in the railway environment:

- Digital cameras and Video Recorders;
- Audio, video, and metadata integration;
- Increased processing power;
- Increased storage capacity; and
- Emergence of new standards, especially compression technology.

2.11.5 IP Cameras

Analog cameras, which are quickly fading from the market, used digital system to transform light into bits of information and then encoded it back into an analog

signal for coax transmission. However, this process created limitations, from which IP cameras are free.

Furthermore, analog cameras at high resolution (4CIF) had a significant problem with interlacing. Images would become blurry whenever there were lots of movements, which obviously is the norm in metro environment.

IP cameras (also called network camera) employ progressive scan technology that better suits depicting moving objects clearly. This more advanced image capture technology means that the whole image is captured at one time, thus providing crystal clear images.

Analog cameras couldn't either provide resolution above television standards (NTSC/PAL specifications), which corresponds to 0.4 megapixels at 4CIF. Operators are now requiring much higher resolution. An IP camera's higher resolution provides more detail and can cover larger areas. Furthermore, in the IP camera system, images are digitized once and stay so with no unnecessary conversions and image degradation.

Network camera technology enables PTZ control over the same network that transports the video. With a Network Dome camera, the PTZ commands are being sent over the IP network, resulting in major cost savings and greater flexibility. What's more, network cameras can integrate input and output signals such as alarms and controlling locks.

2.11.6 Integrated Audio

For many public transport applications, audio has become increasingly important. With an analog system, audio is not possible unless running separate audio lines to the DVR. A network camera can solve this by capturing audio at the camera, synchronizing it with the video or even integrating it into the same video stream, and then sending it back for monitoring and recording over the network. The audio can also be fully bidirectional to allow communication over speakers.

2.11.7 Compression Technology

Compression technology is based on the assumption that a video frame contains a large amount of redundant information that can be eliminated without a great loss in perceived picture quality. Compression methods are effective up to a certain point, beyond which the image quality quickly degrades.

The technology for compressing video pictures has evolved over time, from its origin as a storage system of still photographs on computers (JPEG) where the compression ratio was only 8 to 1, to the current MPEG-4 standard, where compression technology using wavelet can ensure a compression ratio of 100 to 1. Thanks to such compression technology one day of recording requires only 14 GB, a hard disk capacity, which could easily be found in a hardware store.

It is foreseen that in the near future, MPEG-4 technologies will maintain their leading position in the public transport environment, extending their reach by integrating functions such as H.264 (or MPEG-par 10). Other compression technologies are emerging from the mass media market but at this point in time, it is difficult to say what will replace the MPEG-4 standard in the public transport environment.

2.11.8 Wayside IP CCTV Solutions

There are several benefits to installing an IP CCTV system. The most important is that it shifts the security infrastructure responsibility from security experts to the IT departments. In other words, the IP CCTV network becomes one subsystem of the entire IT department. This improves operational efficiencies tremendously by leveraging the IT department's technical expertise, vendor relationships, and support processes to reduce the costs of deploying and maintaining a video system. It also helps standardizing equipment (i.e., storage and servers) across departments and vendors, which results in lower maintenance costs.

IP CCTV benefits are:

- **Infrastructure cost reduction:** as it permits the use of inexpensive, standard network cabling to power cameras and transmit video instead of more costly coaxial cables. It also reduces the amount of cable and conduit required by eliminating separate power and signaling cables and aggregating cable runs to network switches located throughout a facility.
- **Ubiquitous access to video:** Whether local or remote, security enforcement personnel can access video from anywhere on the network, with all the access policy controls of the organization's other IT services.
- **Leveraging established network infrastructure:** Public transport operators can leverage the use of established, highly secure network infrastructure, proven network connectivity and health monitoring tools and robust storage systems to provide a high degree of confidence that video is available when needed.

- **Unlimited storage capacity:** Operators can allocate more storage for video with longer retention requirements.
- **Synergies with other departments:** Security department can also share video investment with operations and marketing for non-security applications thereby increasing overall return on investment.

2.11.9 Integrated Security Event Management Systems

New open software platforms will strongly influence IP CCTV network technology development and largely influence the design of future CCTV architectures. SOA and event-driven software platforms will create a powerful environment for service-led event-driven networks, in a wired and wireless world. New SDP technology such as VoIP and SIP, or specifically designed for images such as IMS, will, when integrated within the Next Generation Network, enable security suppliers to provide any new service (i.e., any security application) defining it directly at the service layer without considering the transport layer. In other words, any security service will become fully independent from its environment. High-level application technology such as UPnP (Universal plug and play) will allow public transport operators to easily and quickly integrate technology coming from different suppliers. We will describe in detail these technologies in Chap. 5 Connected cities.

Reactive security strategy All these software technologies when combined enable an integrated security event management system, which provides the shift from a forensic approach toward a reactive security strategy. In this strategy, key decision-makers have a complete awareness of what is happening on their various networks, including their mobile networks comprising each single bus, tram, or train.

Proactive security strategy We've mentioned that the best security strategy was proactive, as it is always better to detect any criminal act before it is perpetrated. Such an integrated security platform, including the operator's rules and policies, will become a tool to inform security Personnel about potential threats. Not only will they be informed about the nature of the potential threat, but also they will be able to have a complete view of the situation through devices such as PDAs or 4G cellular phones. The potential for video analytics in the public transport is only limited by our imagination. The applications will be totally dedicated to the specific reality of the public transport environment.

2.11.10 Total Integrated Public Transport System

The convergence of voice, images, and metadata is ineluctable. Telecom and network equipment providers are investing tremendous efforts and resources for this to happen. There are few other market sectors other than public transport where these forces will have such a strong impact on the business fundamentals of the industry. Systems that are seen as independent today, such as security (CCTV, access control, biometrics recognition, bomb sniffing devices, etc.), signaling, passenger information systems, train control, remote control, global positioning, remote maintenance, and more generally other applications involving operations and marketing, will share the “services.”

People counting is a good example of how CCTV will affect public transport operators. In the medium term, operators will be able to count how many passengers are in their system by using cameras. Too many passengers in the station will require a flow control where, for instance, train headway could be reduced or passenger flow could be controlled at the gate. In order to do this, the exchange of data (services) will be needed between the security system and the signaling. Passengers on the platform could be automatically informed of the next train arrival schedule or alternative lines. The same application will be able to give valuable information for the operator’s marketing department where they will be able to know statistically where people embark and in which station they get off. Operational functions such as train control will be informed automatically of passenger load. According to passenger load thresholds, power would be decreased by switching off air conditioning or auxiliary equipment, resulting in a significant reduction of energy consumption.

As demonstrated through the above example, Operational Control Centers (OCC) will become even more the decision-making center of all the different systems converging probably physically in one master room. Every potential stakeholder involved in a crisis situation will have in the OCC all the elements to take a coordinated decision to avoid criminal or terrorist acts or limit their impact.

2.11.11 Video Analytics

Video analytics are basically algorithms that are applied to the bits of information coming from cameras (or microphones in the case of audio analytics). Computer vision, speech, facial, and object recognition are some of the areas where algorithms are being developed. It also makes heavy use of digital geometry and signal processing. Most of these systems work on the principle of pattern recognition.

Pattern recognition It can be defined as the act of analyzing raw data and taking an action based on the category of this data. Pattern recognition aims to classify data based on either a priori knowledge or on statistical information extracted from the patterns. The patterns to be classified are usually groups of measurements or observations, defining points in an appropriate multidimensional space. This is in contrast to pattern matching, where the pattern is rigidly specified.

The classification or description scheme usually uses one of the two following approaches:

- **Statistical pattern:** Recognition is based on statistical characterizations of patterns, assuming that the patterns are generated by a probabilistic system; and
- **Syntactical pattern:** Recognition is based on structural interrelationships of features and not only on simple numerical feature vectors, as used in statistical classification.

Although video analytics are being developed for defense and general security purposes, software engineers are designing analytics to meet the specificities of the railway environment. Furthermore, because of the mobile aspect of train or buses, computational power must be considered a constraint that doesn't really exist in fixed environment.

Indeed, applying these algorithms can require enormous computational power. The amount of memory or computer time required can become astronomical when the issue to identify goes beyond a certain size. To take into account memory capacity and data power, security system designers in railway environments will need to consider where they place the system's intelligence: centrally or in a distributed manner.

2.11.12 Distributed Intelligence

Although some experts believe that the best strategy is centralized intelligence, we think CCTV networks in railway environment will evolve toward distributed intelligence. There will be for each operator a unique design on where to apply intelligence. This means that some video analytics will be positioned within the cameras. Most likely, every intelligent piece of software which can be affected by the quality loss during compression or which will try to reduce noise will be put there. Some intelligent pieces of software in the metro onboard environment will most likely be included within the DVRs. By doing this, the operator will be able to both register the audiovisual information (for legal reasons) and tag information

linked to alarms. It will also be able to prioritize this information and make sure that it is sent to the security personnel by interfacing with the train control system.

Like in any distributed architecture, there might even be some pieces of video analytics that will be split between different devices. This strategy (that exists in other areas such as automation) improves response time by giving the order to process information only if a state is found in both elements of the CCTV system.

2.11.13 Video Analytics Limitations

Video analytics' objectives are to help security Personnel detect a risky situation or take a set of actions based on the detected abnormal patterns judged risky. As for any good security Personnel, detecting the real risky situation and not a false alarms will define the quality of the analytics. In other words, the operator, whenever assessing the quality of a piece of video analytics, will need to define his acceptable level of false positives and false negatives (as in all statistical tests, there will be a trade-off).

- **False positive rate:** It is the proportion of negative instances that were erroneously reported as being positive; and
- **False negative rate:** It is the proportion of positive instances that were erroneously reported as negative.

Threshold values within the video analytics solutions can be varied to make the test more restrictive or more sensitive; with the more restrictive tests increasing the risk of rejecting true positives, and the more sensitive tests increasing the risk of accepting false positives. With these limitations in mind, new video algorithms are being developed and deployed in public transport. On the wayside, a certain quantity of software applications coming from the retailing and defense industries are being deployed with an acceptable level of accuracy. In the mobile environment, suppliers are trying to cope with issues such as vibration and extreme changes in lighting conditions.

Fig. 2.22 Through a mix of solutions such as sound analytics and anti-intrusion detection, public transport authorities should be able to reduce graffiti and vandalism.
Source Author



2.11.14 Video Analytics Technologies

A few simple video analytics are now starting to be deployed onboard trains and buses, which we've described hereafter. However, the possibilities of creating analytics that can be applied to the public transport environment are only limited by our imagination. For instance, gunshot detection, abnormal behavior detection, and arm detection are a few of these technologies that could emerge in the midterm. They will most likely be developed in the military or law enforcement environments first and then be modified to the specificities of the public transport, we've largely described previously (Fig. 2.22).

- **Camera obstruction detection:** This is a major issue for railway operators, where vandals or muggers paint or break the cameras before committing their crime. In order to limit false positive and negative levels, some manufacturers are merging two functionalities within the DVR:
 - Watchdog functionality, which monitors constantly the state of the cameras and makes sure that power is being absorbed by the cameras (and thus make sure that the problem is not linked to camera electrical malfunction); and
 - Video analytics function that monitors variation in the quantity of light being recorded.

- **Area obstruction detection:** This piece of software detects objects that may interfere with the use of fire exits or other user defined areas intended to be kept free and clear for health, safety or other operational reasons. This capability allows operators to define both the area to be monitored as well as the length of time an obstruction remains in place before triggering an alarm.
- **Anti-intrusion detection:** Cameras using infrared technology detect any people passing by or objects moving within the set perimeter, especially during low-light situations such as night time. New video analytics using conventional cameras are also being developed, basically creating virtual limits, within which any presence is automatically detected. This type of technology is being implemented to monitor restricted areas such as tunnels and depots.
- **Empty vehicle detection:** One operational issue is to detect passengers within a train (especially in driverless applications) before going to the depot. Very often people hide in the train in order to graffiti or vandalize the assets. Video analytics that can detect people within the trains are being developed to cope with this problem.
- **Unattended baggage detection:** This video analytics detects any unattended object located in a specific area. An alarm is triggered according to a set period of time.
- **Automatic target acquisition:** This piece of software enables zoom-in on suspicious persons or vehicles, and tracks it across the full scene in a separate view, as if there were an additional PTZ camera trained on the scene.
- **Automatic car plate recognition:** This piece of software positioned aboard a bus or a tram can detect plate numbers and automatically processes cars that are running or parked irregularly, for example in a bus lane. It uses Optical Character Recognition (OCR) in which the pixels on the digital image of a license plate are transformed into ASCII text.
- **Facial recognition:** The purpose of this video analytics is to recognize people by comparing selected facial features from the image and a facial database. A newly emerging trend in facial recognition is three-dimensional face recognition.
- **Profiling:** The purpose of this video analytics is to recognize a category of population based on criteria, such as gender, race, color of the skin or hair, etc. It can use the same type of algorithms as facial recognition but rather than comparing it to a database of faces (personnel, convicted criminals, missing persons, etc.), it basically compares fixed patterns (color, height, shape, etc.).
- **People counting:** Designed originally for the retail sector, people counting video analytic capabilities are now providing marketing and operations management with another level of storing traffic intelligence

and reporting. Dedicated cameras mounted above entrances, exits or other areas of the station count passengers as they enter and leave an area. The feature provides aggregate counts from multiple points of entry. In the onboard environment, this function is provided by infra red sensing technology positioned on top of the door entrance. Manufacturers are working on video analytics that can substitute infra-red sensors.

- **Loitering detection:** these analytics provide an alarm when a person or group remains in a controlled area for a prolonged period of time. Alert times can be adjustable according to different scenarios, such as squatting, trespassing and soliciting.

2.11.15 *Security for Cars*

As we indicated before, security is mainly a public transport issue. This isn't to say that carjacking or car thefts aren't important issues. It has more to do with the fact that, besides panic buttons or hidden balise in the car emitting a geo-positioning signal, there wasn't much exciting security technology brought to the market. However, with e-mobility technology, things will change.

As the e-mobility revolution will rely more and more on computers to run, they will get hacked. In fact, some people are already able to get into car systems using Bluetooth or other limited wireless technology. However, when V2V and later on unmanned technologies will be in every car, a new potential security risk will emerge: cyber terrorism. Hackers could not only take possession of someone's car if they were able to pass through fire walls and other IT security systems, but also they could actually send wrong signals from their own cars. Indeed, malicious drivers could send fake signals such as wrong speed, interspacing, and braking information.

The point is that any disruptive technological revolution will bring benefits and new risks. With e-mobility, cyber terrorism is unfortunately coming to the headlines.

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Company or Brand Names Stated in the Chapter

- UITP (Union International des Transport Publics)
- Matra (technology later purchased by Siemens)
- VAL now part of Siemens' portfolio of product
- Westinghouse Electric Corporation
- Volvo Group/AB Volvo
- Audi AG
- BMW
- Mercedes Benz is a Trademark of Daimler AG
- Google Inc.
- Ultra Global PRT
- Uber Inc.
- Axa S.A.
- Ford Motor Company
- OnStar™ system: trade mark of General Motors
- Street Views a trade mark of Google
- General Motors Company
- Toyota Motor Corporation
- Chery Automobile Co. Ltd
- Model i3 brand from BMW
- Model S-Class: Trademark of Mercedes Benz
- HIS Automotive
- Navigant Consulting
- Strategy Analytics
- ABI Research
- PricewaterhouseCoopers
- Ferrari S.p.A.
- Erickson
- Cisco System Inc.
- Huawei Technologies Co. Ltd.
- Robert Bosch GmbH
- Xerox Corporation
- Econolite

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The Choices between E-mobility and Immobility
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