ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Real-time traffic management

Intro to traffic flow modeling and ITS

Dr. Anastasios Kouvelas

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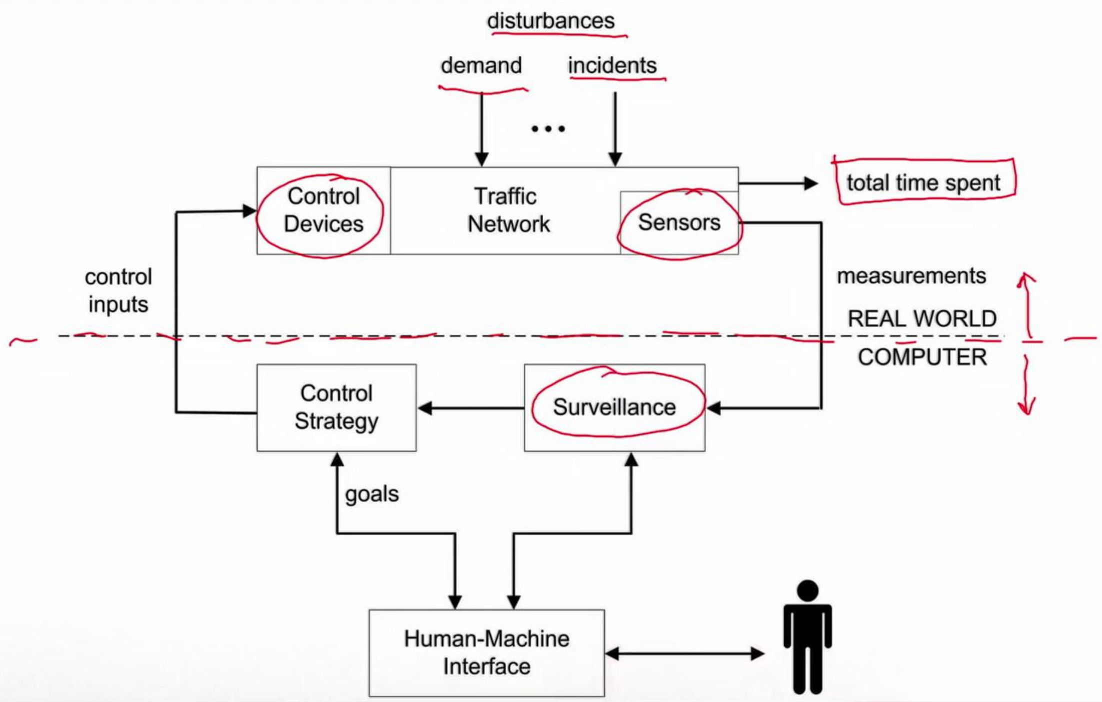
Video

EPFL

Real-time control loop

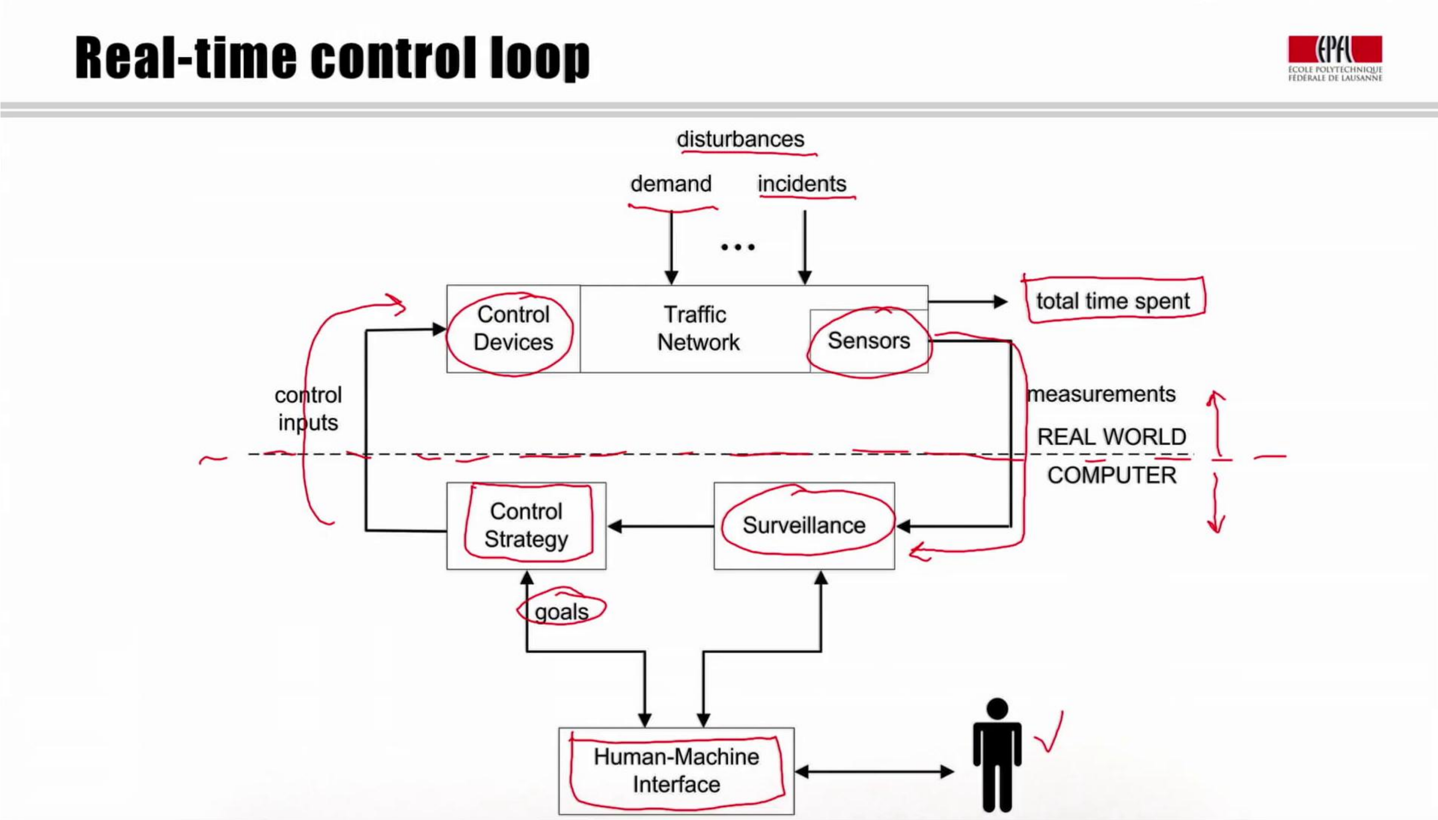


Welcome. My name is Anastasios Kouvelas. And in this video we are going to talk about real time traffic management. Researchers can develop different control strategies but here I would like to discuss what is needed in order to bridge the gap between theory and practice. How can you apply your methodology in the real world? What do you need? I will give you some insights based on my personal experience on field implementations of traffic control strategies. So let's have a look at the real time control loop. I put the line here, a dotted line to separate the real physical world from what happens in the computer? So, in the real world we have a traffic network which has some sensors for measurements and it has some control devices traffic lights for example and it can have demand, some incidents, disturbances. So these are happening in the traffic network. And from this traffic network I can have a way to estimate the total time spent. So, I have this physical world and the somewhere in a traffic control center I have a central computer that can run some algorithms to monitor and control traffic. So, I can collect all the data.

Notes

Summary

0m 05s

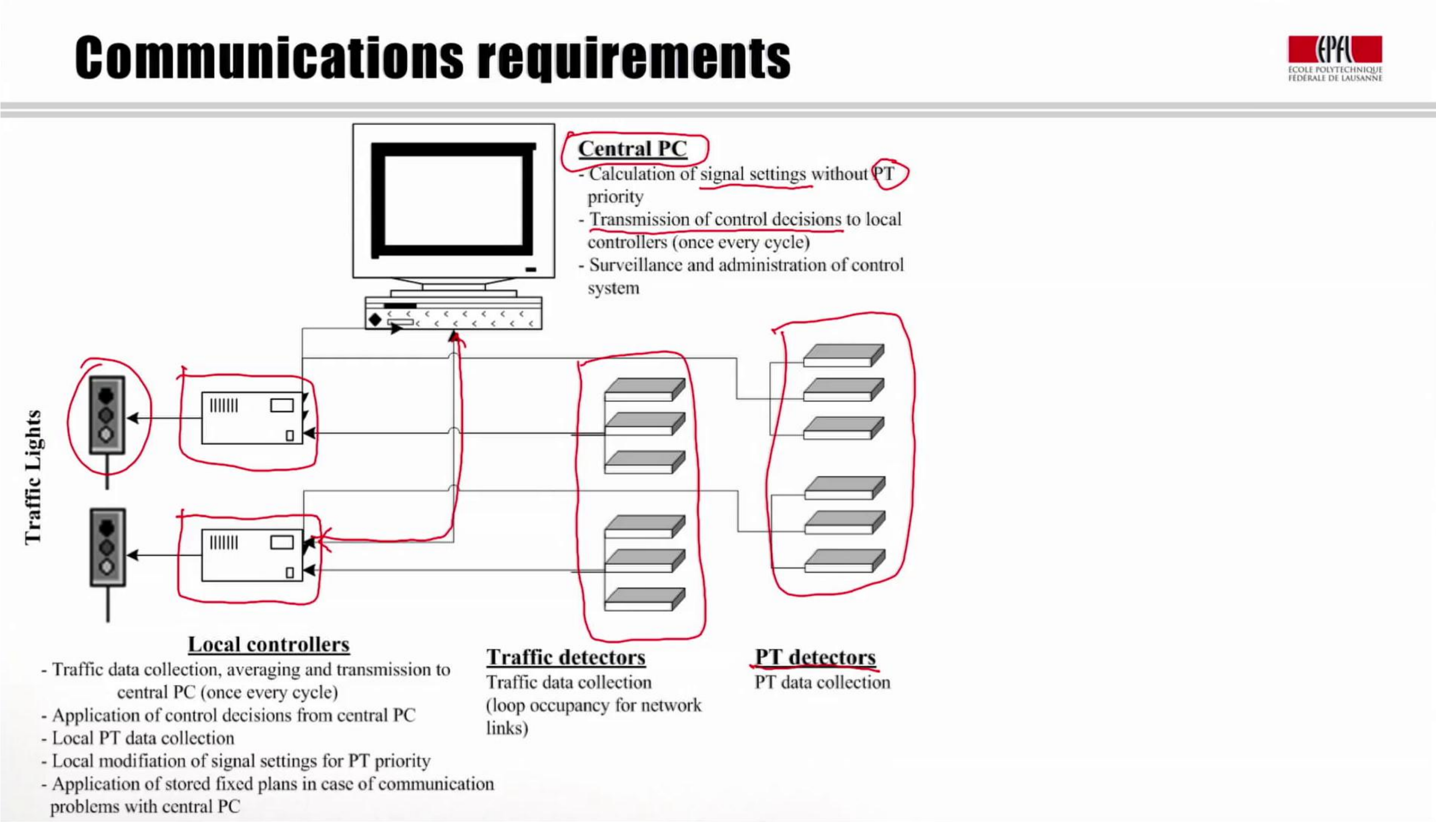


I can run some estimation algorithms and I can have here some control strategies that I have some goals that I'm aiming to. And I can control this system I can compute these control inputs and send them to the control devices and of course I can get feedback from my network which are the measurements. And note here that this central computer has an interface where humans like traffic operators can interface with what is happening in this computer. So a traffic operator that monitors the system and the traffic can make real time decisions and can go and change things in the computer and what is happening in the control center.

Notes

Summary

1m 32s



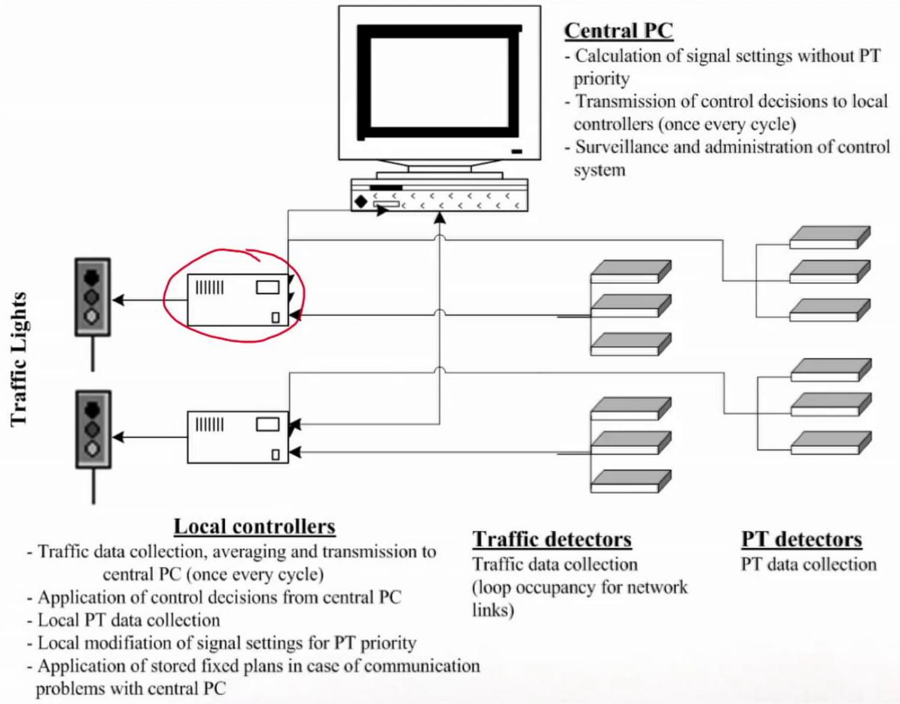
Of course a basic requirement in order to apply real time traffic control strategy is real time communication. I should be able to send and receive data. So let's look at this picture here again we have this central PC but this needs to communicate with traffic detectors which are measuring traffic and they may have some public transport detectors. So this PT stands for Public Transport. I can collect data from public transport vehicles and this data need to be transmitted to the central computer and the inside the computer there are some algorithms that can do some calculations and the computer signal settings or provide priority to public transport. And once these are computed they need to be transmitted back to the control devices. So I have here local controllers installed in my network that I also need to communicate with the central computer so they receive commands and they need to apply these commands to the traffic lights for example. So, all this system has a two way communication. I send data from the detectors to the central computer and the computer does some computations and it sends back to the local controllers some control commands.

Notes

Summary

2m 30s

Communications requirements



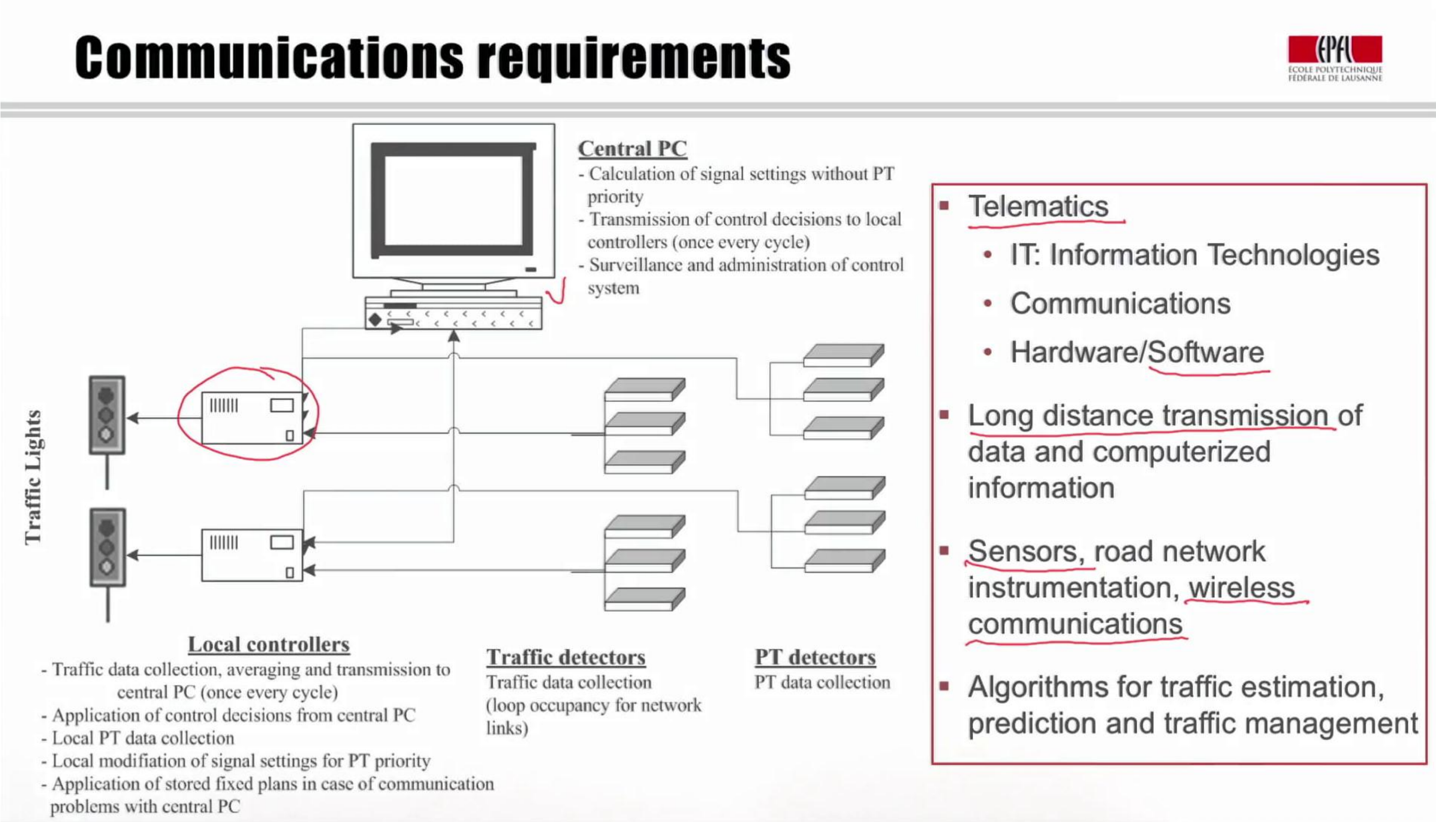
- Telematics
  - IT: Information Technologies
  - Communications
  - Hardware/Software
- Long distance transmission of data and computerized information
- Sensors, road network instrumentation, wireless communications
- Algorithms for traffic estimation, prediction and traffic management

So this communication for example can happen once per cycle so once per cycle I can collect the data and I can send back the commands. But I can also have some local actuations. So I can have some local modifications of the signal plans for example. In this case there is no need for communication with the central computer but I can do this locally. For example I can have a communication only with the detectors and the controller and the traffic light and I can have some micro logic here that does some kind of optimization without communicating with the central computer. So this is the difference between centralized and the local actuation and control. One basic term that we use a lot in real time traffic management is Telematics and telematics has to do with information technologies IT and with communications and it refers to the hardware and the software that is used in this procedure. So, it refers to my algorithms that I do estimation or prediction or control but also to the hardware devices like the controllers for example they are actuators.

Notes

Summary

4m 04s

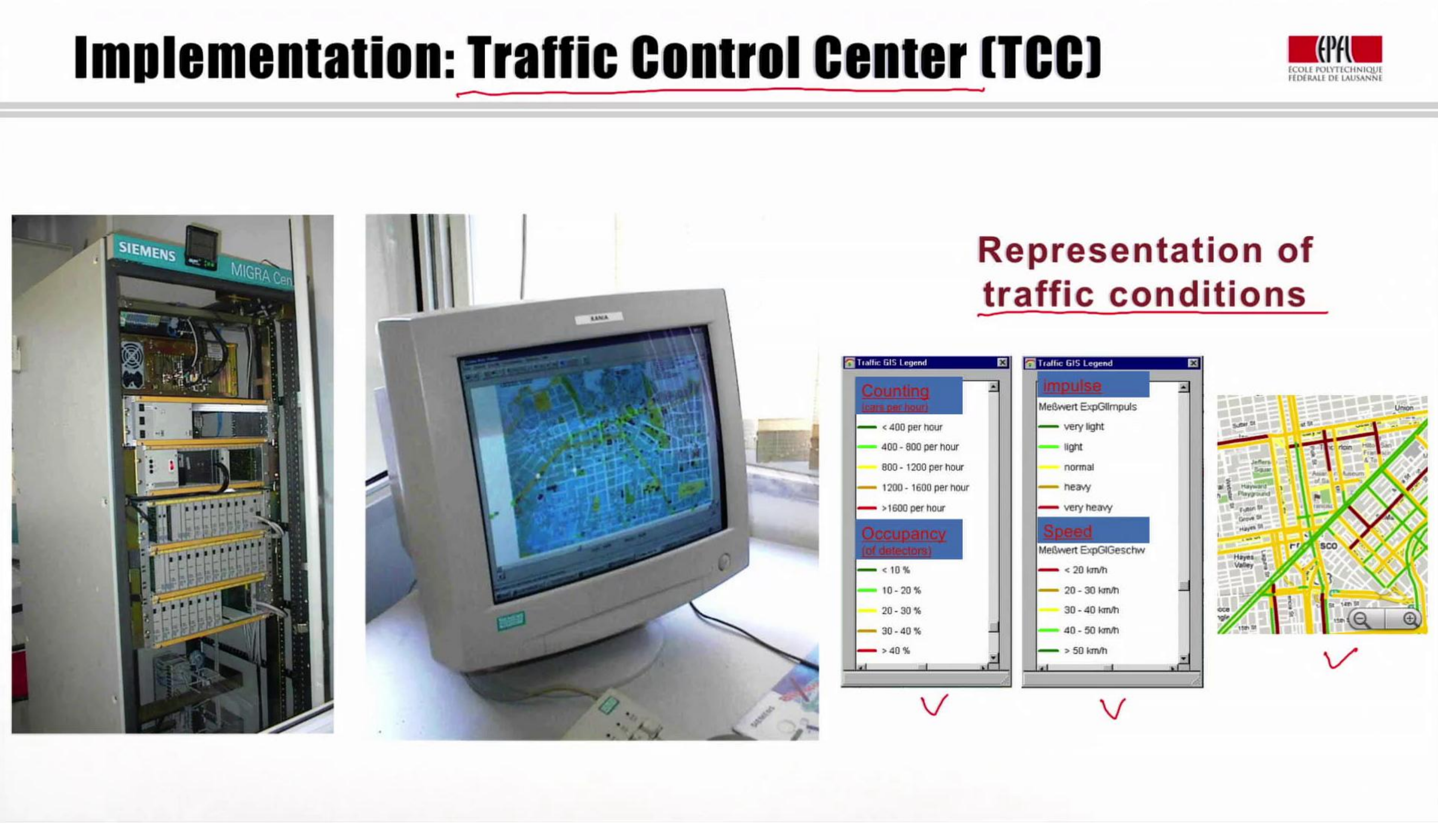


So telematics refers to long distance transmission of data or computerized information and it includes also the sensors that are installed in my network all the infrastructure and I can have wireless or wired communications and as I said before part of the telematics are the algorithms that are installed in this central computer and this algorithm can do estimation, prediction, control and many other tasks.

Notes

Summary

5m 24s



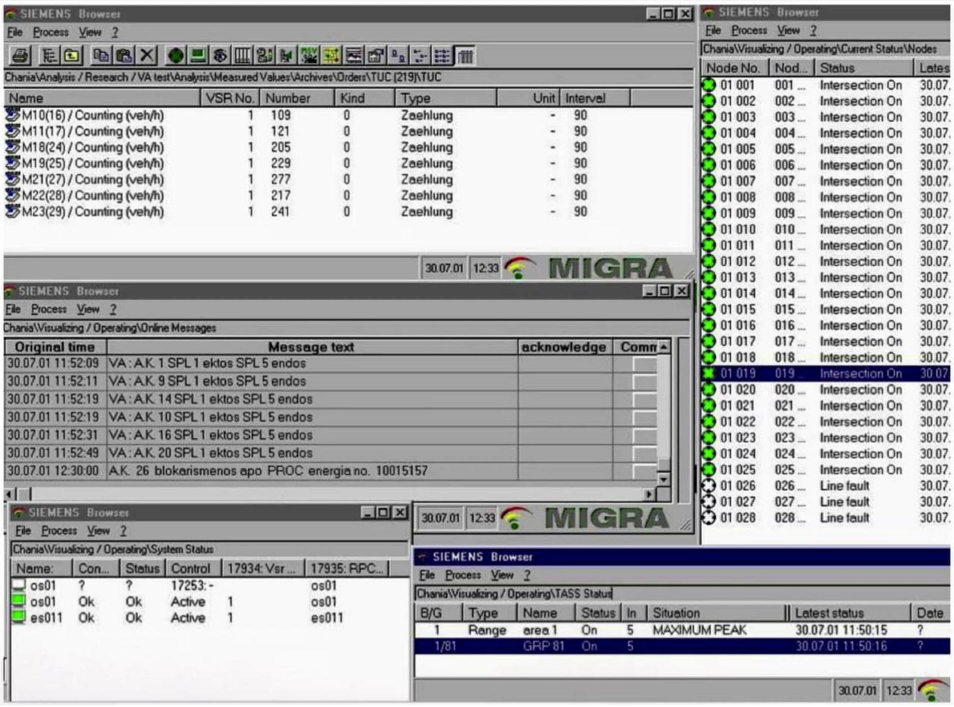
So, all this infrastructure is needed in order to apply a real time traffic management strategy. So, I need the infrastructure the hardware, the controller, the traffic lights, the communications but I also need the smartness of my system which are algorithms optimization and control algorithms that I built and installed in the central computer and I can run in real time given that they are provided with the correct amount of data. So, all this implementation of the control strategy happens in a traffic control center. So, this is a control room with engineers and the transport planners and traffic operators that they can monitor in real time what is happening in their transport system and they can also interfere if needed. So here I have some pictures from traffic control center in Chania in Crete where I did an experiment. So this pictures are maybe 10 years old. Nowadays you can see much more modern control centers with all the equipment and the traffic operators that work in these control rooms. They have access to all the data from the network so they can have access to the traffic conditions in different forms. So, something like this or like this about the speed of the network and where there is congestion and they can have a map with all the different traffic conditions.

Notes

Summary

5m 56s

TCC – Traffic Operator User Interface

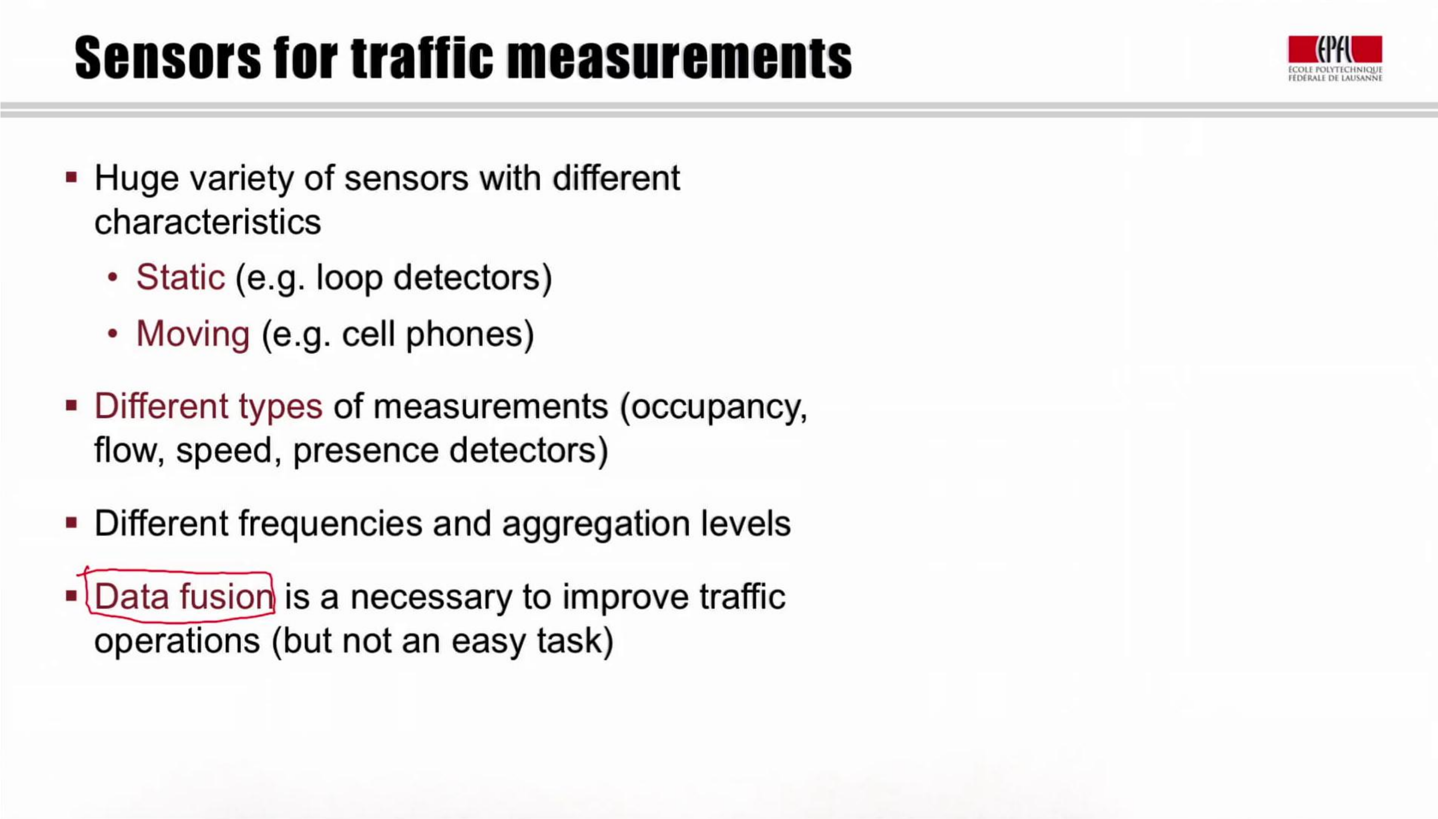


So, a traffic operator can monitor in real time the congestion in the network. And he can intervene if something goes wrong. And this is a picture of a traffic operator user interface. So, inside the computers in the control room there are software installed that can give you access to the data of the network and what is happening in your network. So the traffic operator can monitor all the state of the network and you can take actions if needed. There are different software that show different kind of information.

Notes

Summary

7m 33s



So, let's now discuss what kind of sensors do we use for traffic measurements. So there is a huge variety of sensors with different characteristics. And first of all we have static sensors like loop detectors so that I will discuss in the following. But nowadays we have also moving sensors like cell phones. So, everyone today carries a cell phone and if you have your GPS enabled you can give your location to the operator and your speed and the traffic operator can infer traffic conditions based on measurements like this. And this sensors of course provide different type of measurement. They can provide occupancy flow, speed. We also have detectors that report presence or non-presence. So, depending on the kind of sensor we can have Bluetooth sensors for example we get different measurements. From a Bluetooth sensor you can take travel time from point A to Point B and maybe some average speed for this area. Another difference is in the frequencies and in the aggregation levels of the measurements that we get from different sensors. And I would like to discuss here what do we call “Data fusion” which is something necessary that we need to do in order to improve our traffic operations.

Notes

Summary

8m 13s

Sensors for traffic measurements

- Huge variety of sensors with different characteristics
  - Static (e.g. loop detectors)
  - Moving (e.g. cell phones)
- Different types of measurements (occupancy, flow, speed, presence detectors)
- Different frequencies and aggregation levels
- Data fusion is a necessary to improve traffic operations (but not an easy task)
- Emerging technologies (i.e. connected vehicles, new automation systems)

Inductive loop detectors

- The most widely used sensors (for traffic management)
  - magnetic field
  - easy to install, inexpensive
- Measurements:
  - time occupancy (%) 0–100
  - flow (number of vehicles)
  - speed (for double loops)

So if we have data from different sensors we can fuse this data in order to get a better picture of what is happening in our network. But note that this is not a very easy task because of the different nature of measurement. So in order to combine these measurements you need some traffic flow theory. And of course today there are emerging technologies like connected vehicles or new automation systems that can provide new sources of data and can revolutionize the way transport systems work. I would like now to discuss a bit about the "Inductive loop detectors" as they are the most widely used sensors that we have for traffic management. So this sensors, they are some magnetic cubes that we install in the pavement that create a magnetic field and they are easy to install and the inexpensive. Most of the measurements that we have nowadays in real time for a traffic management come from loop detectors and the type of measurements that we get from these inductive loop detectors is first time occupancy. So this is the percentage of time that the detector is occupied or not. So this is a number between 0 and 100.

Notes

Summary

9m 43s

Sensors for traffic measurements

- Huge variety of sensors with different characteristics
  - Static (e.g. loop detectors)
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And for example if I measure for a time interval of one minute and the detector is occupied for 30 seconds and not occupied for the other 30 seconds, the time occupancy measurement is 50 percent. The other measurement that we get from loop detectors is “Flow”. So, they can tell us the number of vehicles that have passed through them. So we get flow measurements and of course we can get speed. But this comes usually from double loops where do we have double loop detectors installed. But we can also estimate the speed even from single loop detectors. There are methodologies to do that.

Notes

Summary

11m 14s

Field performance measures

Estimation of number of vehicles in a link:

length

$$\boxed{\chi_z}(k) = L_z a_z o_z(k) \qquad a_z = \mu_z/(100\Lambda)$$

lanes

$o_z(k)$

$q_k(k)$

So from this detectors I can measure occupancy for every link Z and for every cycle K and flow for every link Z and for every cycle K, should give him this measurement of occupancy and flow how can I compute some metric for my network? So I provide here a relationship that transforms time occupancy to space occupancy. So this is the time occupancy measurement which is between zero and one hundred and this is the space occupancy of link Z. So I assumed that in it a link I have one detector installed for this example. So here I multiply with alpha which is given by this and here µz is the number of lanes of the link. So this is the number of lanes. And one hundred is here in order to divide occupancy with one hundred and the make this percentage is a number from zero to one. The capital lambda here is the average vehicle length. So, I have a vehicle length some average value that I use and so if I multiply the occupancy with alpha and with Lz which is the length of the link the physical length of the length. And here again is the number of lanes and lambda capital is the average vehicle length. This is a way to transform time occupancy to space occupancy.

Notes

Summary

12m 00s

Field performance measures

Estimation of number of vehicles in a link:

$$\chi_z(k) = L_z a_z o_z(k) \qquad a_z = \mu_z/(100\Lambda)$$

Total Time Spent (veh·h): $\mathrm{TTS} = \sum_{k=1}^{K} \sum_{z\in S} C(k)\chi_z(k)$

Total Distance Travelled (veh·km): $\mathrm{TDT} = \sum_{k=1}^{K} \sum_{z\in S} C(k)q(k)L_z$

Space-time mean speed (km/h): $\mathrm{MS} = \frac{\mathrm{TDT}}{\mathrm{TTS}}$ $\quad \frac{km}{h}$

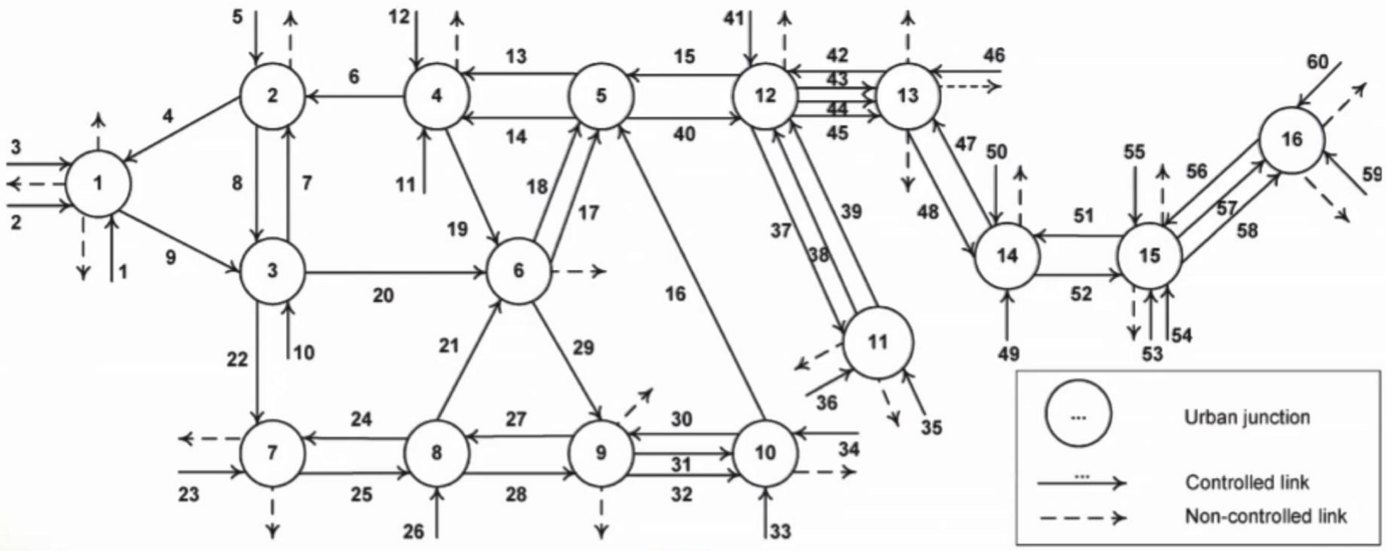
So, I know now how much of my space in link Z is occupied or not and if I have this space occupancy which is something like density if I sum this over all links and over all time periods and here C of K is the cycle of period K and if I do this sum I can get the total time spent in the network. And if I have my flow q of k for link Z here and I sum over all links and all time periods and multiply again with cycle. This is the cycle in seconds or hours and this is the length of the link. I get the total travel distance for all the links and for all the times. Remember that these two equations that TTS and TDT are equivalent to the one I used in simulations when I ran simulations. So all I need is the density and the flow and from this I can estimate the total time spent and the total distance traveled. So this is in vehicle hours and this is in vehicle kilometres. And now if I divide TDT with TTS I have this mean speed of the network in km per hours. So if I have this data from loop detectors I can estimate the mean speed of my network for any time interval and for any aggregation in space. It depends on the summations, the time and the space that I want to use.

Notes

Summary

13m 47s

Case study: Chania, Greece



Real-time traffic management: Chania CBD, 16 signalized intersections, comparison of TASS and TUC strategies.

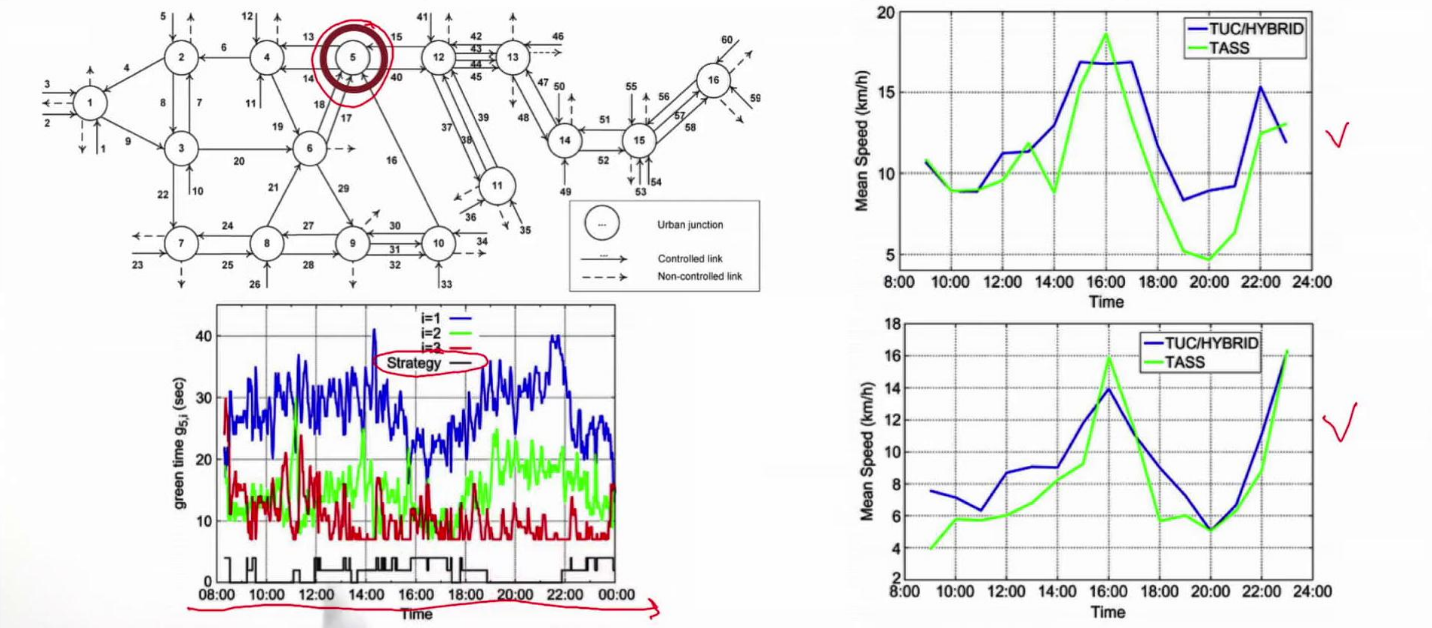
So this is how I can take that performance of a control strategy in the real world. And I would like to show you now an example a field implementation that we did in the city of Chania in Greece. This is in Crete Ireland and we applied in real time a control strategy to regulate the traffic lights of the CBD. So the CBD of the city of Chania includes 16 signalized intersections that you can see here on this picture. And we developed this control strategy that is known as TUC strategy and we applied it in this network for some months.

Notes

Summary

15m 29s

Field results: TUC vs. TASS



Kouvelas, A., Aboudolas, K., Papageorgiou, M., Kosmatopoulos, E.B., 2011. *A hybrid strategy for real-time traffic signal control of urban road networks.* IEEE Transactions on Intelligent Transportation Systems, 12(3), pp.884-894.

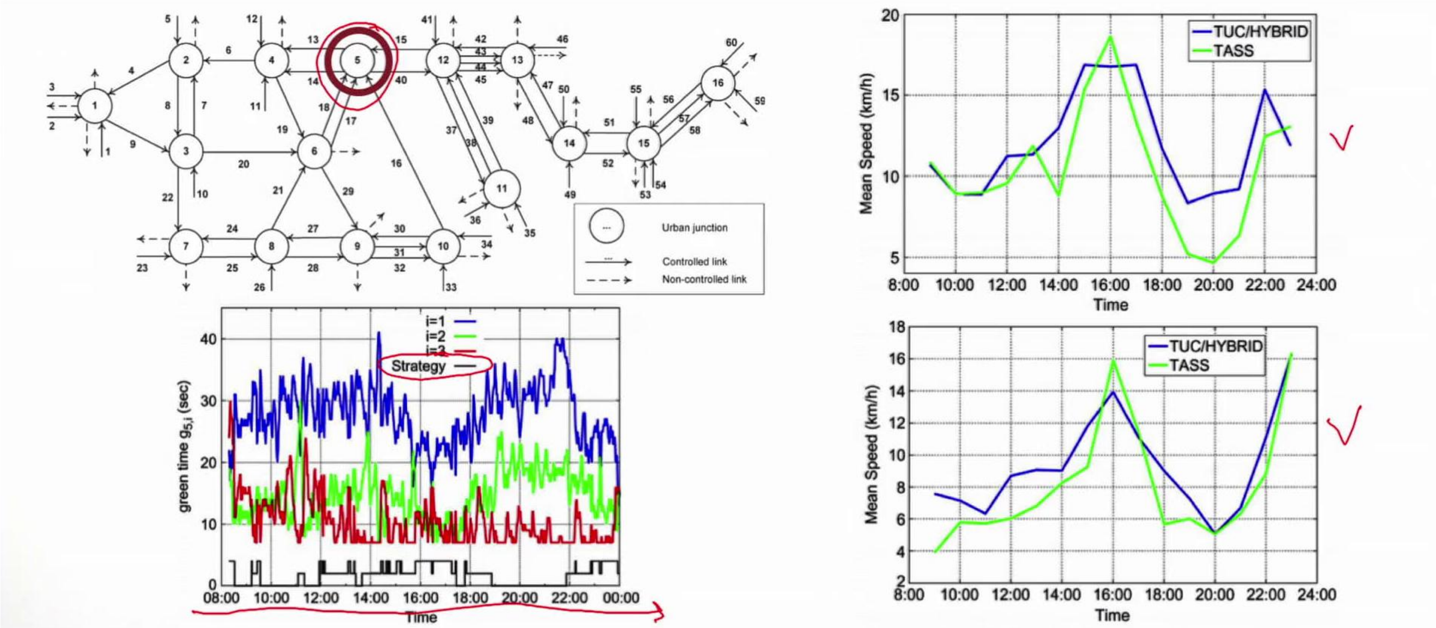
And we compared it to the system that they already run in this city which is a traffic responsive system and it's called the TASS and these are some results of the field implementation that you can find in this paper here below where we compare the two strategies. So in these two plots on the right you can see the mean speed of the network for two different days. So with the blue color is the TUC strategy and with the green color is the TASS strategy. And again this means speed comes from the formula that I showed in the previous slide from data from the detectors. So by getting the data and by comparing similar days like a Thursday with the next Thursday we can see how the mean speed of the network looks over time. And here I focus on this intersection number five of the city which is in the center of the city. And I demonstrate here in this plot from 8:00 in the morning to midnight. How the duration of the green times changes. So this intersection has three stages and I control them in real time and with the three colors here I can see the duration of its stage. So this is time varing in every cycle I have a different green time based on real time measurements that I get from my network as a feedback and with the black color here I can see the strategy that is actuated.

Notes

Summary

16m 14s

Field results: TUC vs. TASS



Kouvelas, A., Aboudolas, K., Papageorgiou, M., Kosmatopoulos, E.B., 2011. *A hybrid strategy for real-time traffic signal control of urban road networks*. IEEE Transactions on Intelligent Transportation Systems, 12(3), pp.884-894.

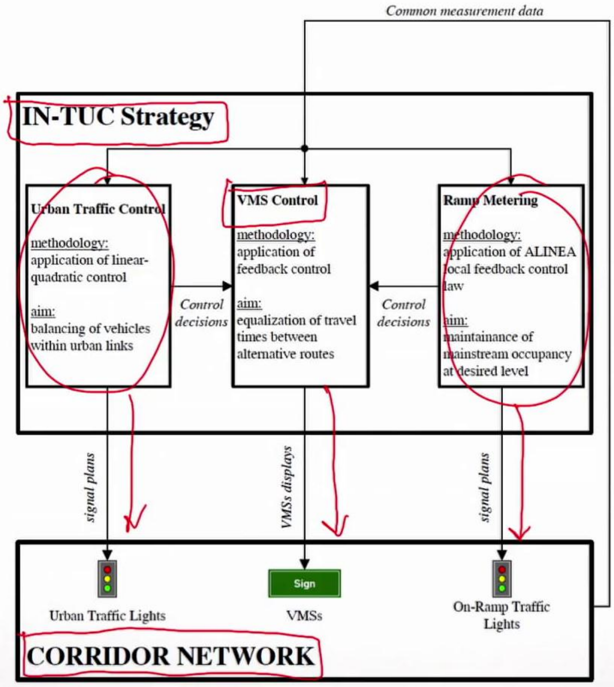
But this is a detail of the implementation where we are using a hybrid strategy so it contains from one to the other over time. You can look at this paper if you want to have more details on this field application.

Notes

Summary

17m 57s

Integrated Corridor Management (ICM)



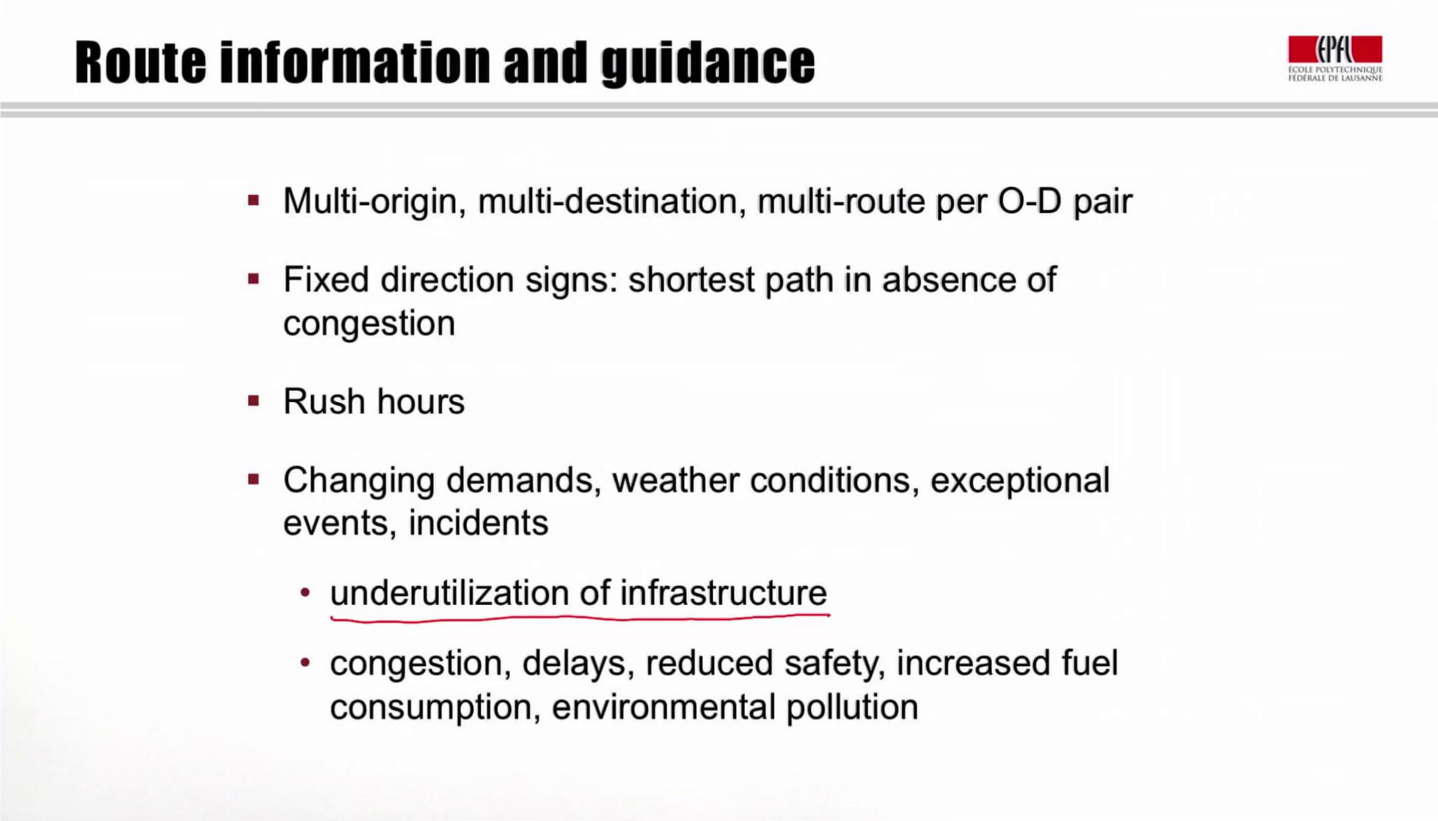
- Coordinate highways and arterials
- Traffic lights, ramp metering
- Variable Speed Limits (VSL)
- Variable Message Signs (VMS)

And I would like to talk in this light the bit about what we call “Integrated corridor management” or ICM. So the idea is that I can have a corridor that consists from some urban network from some highway and from other means of transport for example. And I want to monetize the traffic conditions altogether. So here I can combine traffic lights and ramp metering. I can try to coordinate the highway traffic and the traffic in the areas and I can apply variable speed limits or variable message signs all together implemented in one strategy. So there are attempts like this in the literature and I provide here a flow diagram for this IN-TUC strategy which does this integrated corridor management. So there are different components that deal with the highway with a thorough urban traffic network with viable message signs that I may have installed here and control different parts of the infrastructure. But the idea here is that I combine everything together in one strategy that manages the whole corridor. So ICM integrated corridor management is quite popular nowadays in Europe and also in the US.

Notes

Summary

18m 13s



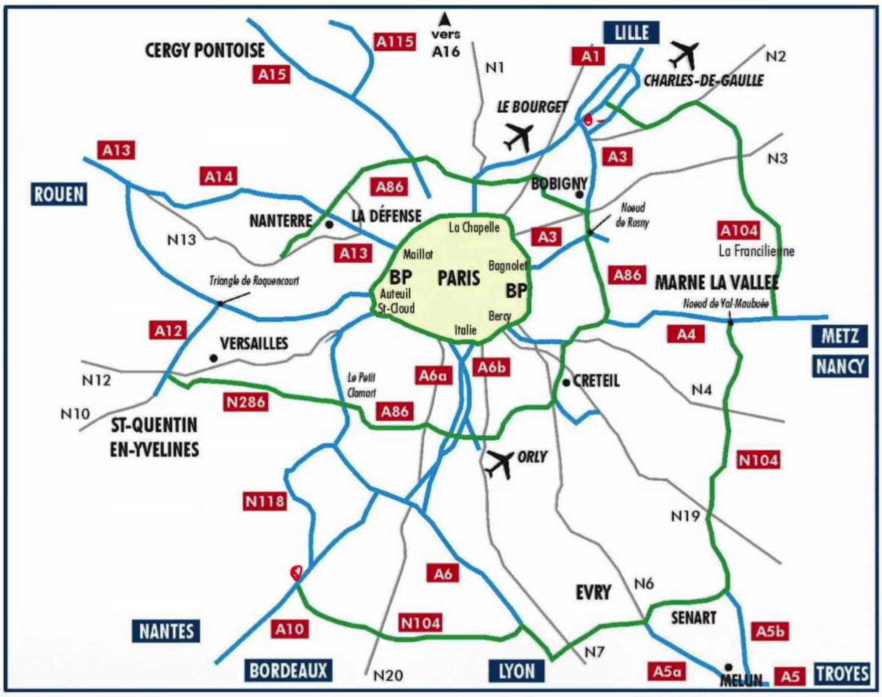
Instead of studying its system separately like the Urban Network or the highway network I can study them together. So let's talk now about real time a route information and guidance to the drivers. So I imagine I have a complex network with many origins and many destinations. And there are many routes between any O-D pair. So if you want to go from point A to Point B there are too many different alternatives. So of course in every city there are some signs that give you the shortest path in absence of congestion but when we are in the rush hours and we have a lot of congestion you can do much better than the shorter stuff maybe. So it depends also on the change of the demand on the weather conditions or in some exceptional events that they may have or in some incidents. So there is a need for real time route information and guidance to the drivers. If I do not do this route information I have underutilization of the infrastructure and I have this congestion that creates delays and other negative effects in my transport network.

Notes

Summary

19m 52s

Paris freeway network (redundancy!)



So let me give you some examples. This is the highway network around Paris. So you see that there are many different options. If I want to go from one point here to one point here for example so this is what we call a redundant network because I have too many alternatives. So a user that is driving here if he doesn't have any information he doesn't know which path to choose or which route to take. And usually he may take the shortest path for example but during the peak hour that there is a lot of congestion there may be another path available with shorter travel time.

Notes

Summary

21m 15s

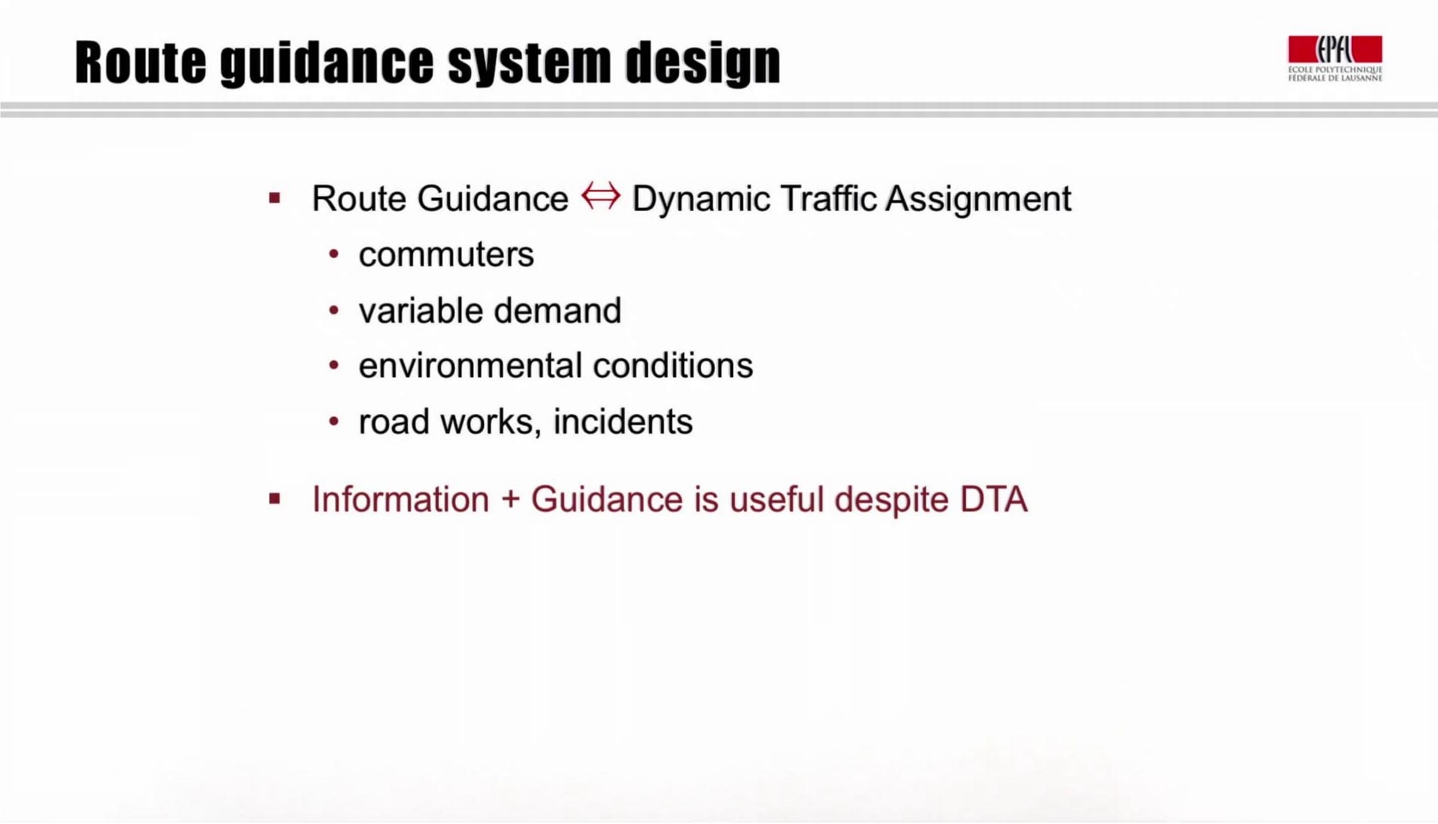
Los Angeles Metropolitan Area

Another network that I like to demonstrate as an example is the Los Angeles metropolitan area. Again I have a grid of highways too many highways that intersect and there are too many options to go from any point to any point. So drivers in LA for example without any real time information they don't know what is the most beneficial route in terms of travel time.

Notes

Summary

22m 00s



This is why real time information is important. And nowadays everyone uses smartphones and we all have applications that can tell you the level of congestion in your path and can give you directions on which path to follow and they can reach out to you for example if there is an accident downstream or if there is a special event. So most of the people nowadays when they're driving they use applications in order to get traffic information. So, I would like now to discuss how we can design a system that can provide route guidance to drivers. So in order to solve this problem of route guidance actually this is very closely related to what we call “dynamic traffic assignment” ord DTA. This is basically the same problem when I do it on line I have these dynamic traffic assignment. And if I take care of all the commuters and the variable demand that they have and maybe the weather or environmental conditions and if I have some works in my network or some incidents I can solve this problem and provide to the users the best path to the destination. Of course drivers are humans they are adaptive so drivers they take decisions. Of course drivers are humans and they are adaptive.

Notes

Summary

22m 29s

Route guidance system design

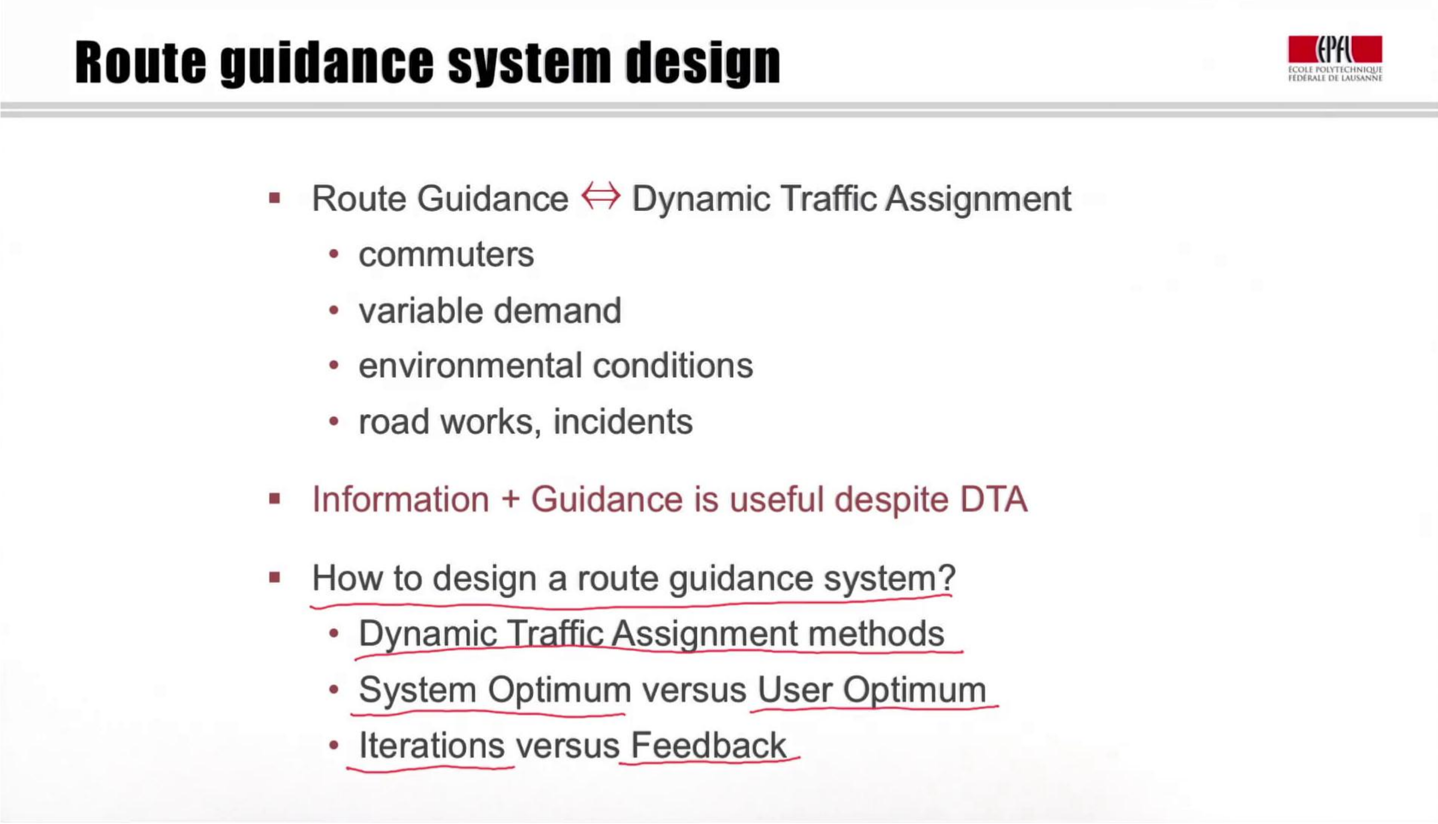
- Route Guidance ⇔ Dynamic Traffic Assignment
  - commuters
  - variable demand
  - environmental conditions
  - road works, incidents
- Information + Guidance is useful despite DTA

So most of the drivers they make decisions according to their own criteria. So when someone chooses to divert from his path and take another path because of congestion or because of a special event, this is what we call again DTA dynamic traffic assignment. But despite that people do this dynamic traffic assignment by themselves. We state here that information traffic information and guidance is still very useful for the drivers.

Notes

Summary

24m 03s

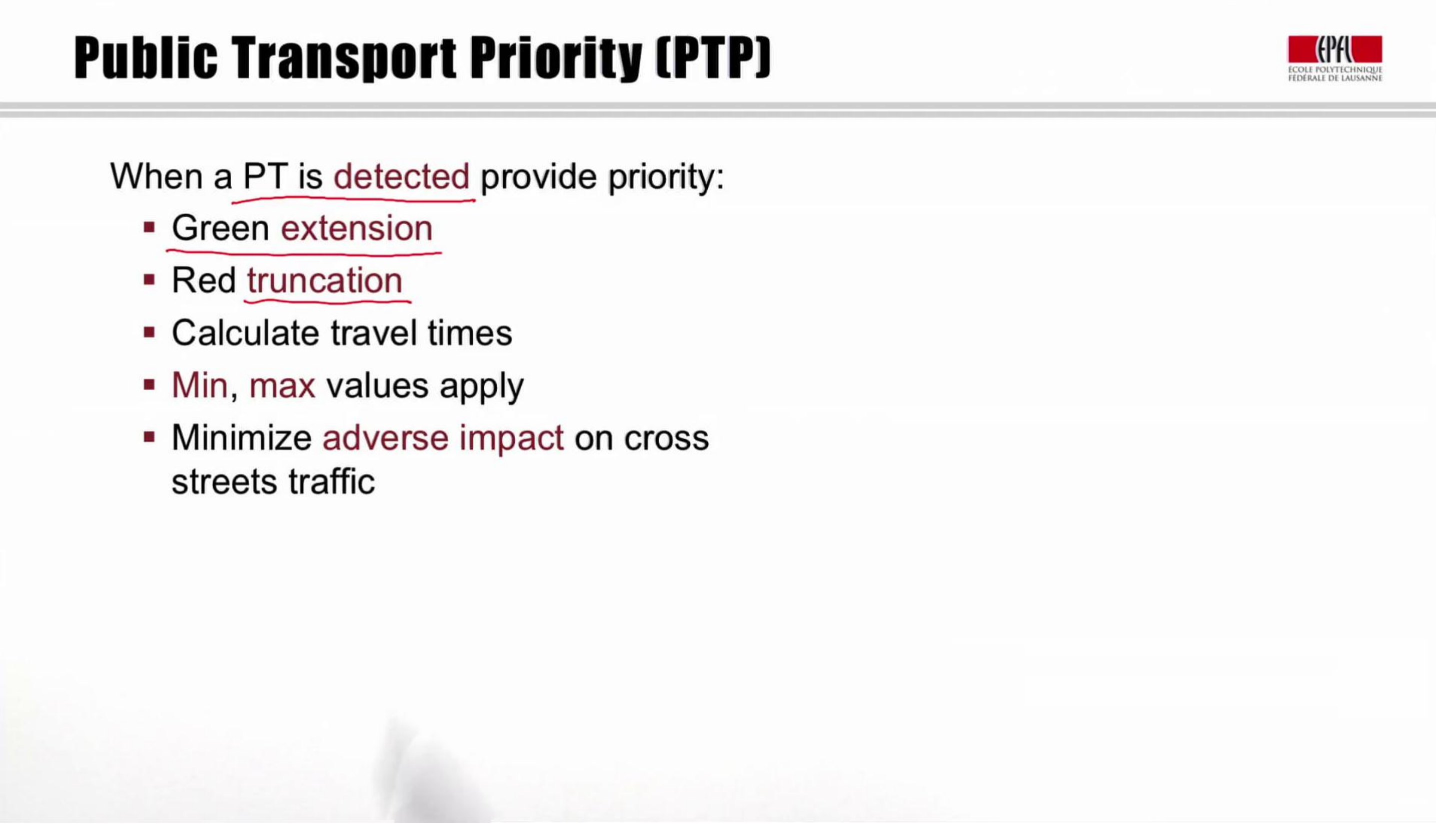


Of course the drivers they can decide by themselves and they can choose their path according to their criteria. But having information about traffic conditions is very important. So how can a researcher can design a route guidance system that can compute good paths optimal paths for their users. So in order to do this we actually use DTA methods. We solve the dynamic traffic assignment problem. So we have too many options for going from A to B. And we need to choose the best path. And in order to do this we usually start the system optimum and user optimum. These are some principles. The system optimum and the user optimum that I can apply to my transport network in order to solve these dynamic traffic assignment problem. And there are many approaches that are based on iterations solutions that you run many iterations until some algorithm converges to some equilibrium. Or on the other hand you can use feedback approaches.

Notes

Summary

24m 36s

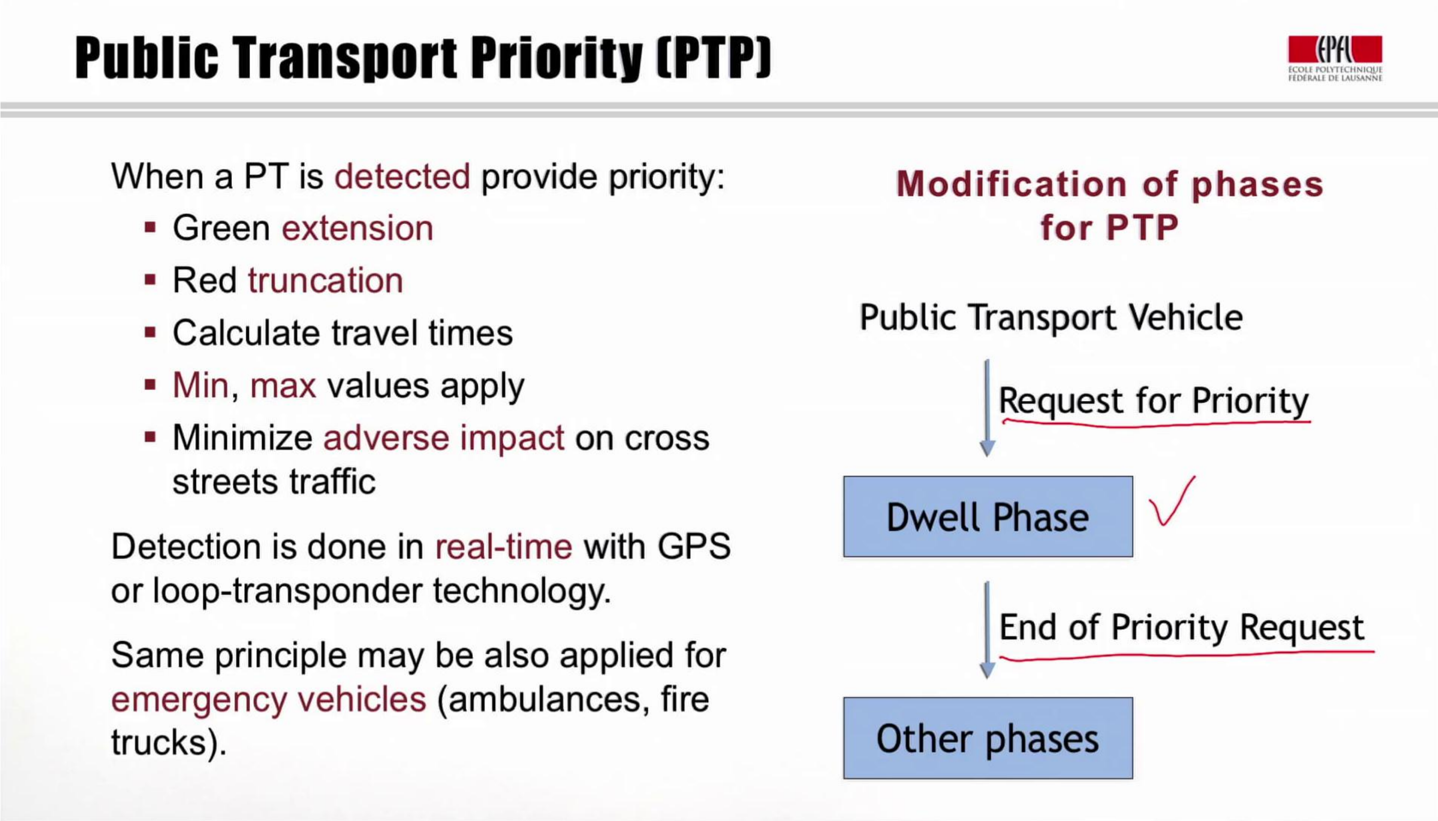


So I would like to state here that when I solve this problem of dynamic traffic assignment I may converge to some equilibrium points that are not always beneficial for my system. It also depends on how many people have access to this information. So there are studies that show that if 100 percent of the drivers they have access to the same information this will lead to an equilibrium point that it may be worse than in the case where 20 percent of the people only have access to this information. So this is a tricky problem to solve sometimes the dynamic traffic assignment problem. Another important thing that I would like to discuss when dealing with real time traffic control strategies is the public transport priority. So when we go to the field and apply some control strategy always the operators are going to ask about public transport. So we usually need to provide priority to public transport vehicles. And let's have a look at how we can do this. So if you have a public transport vehicle detected to approach an intersection we need to provide priority. And if we look at the signal plan this can be done with a green extension I can extend a phase or I can truncate a phase in order to provide this priority.

Notes

Summary

25m 49s

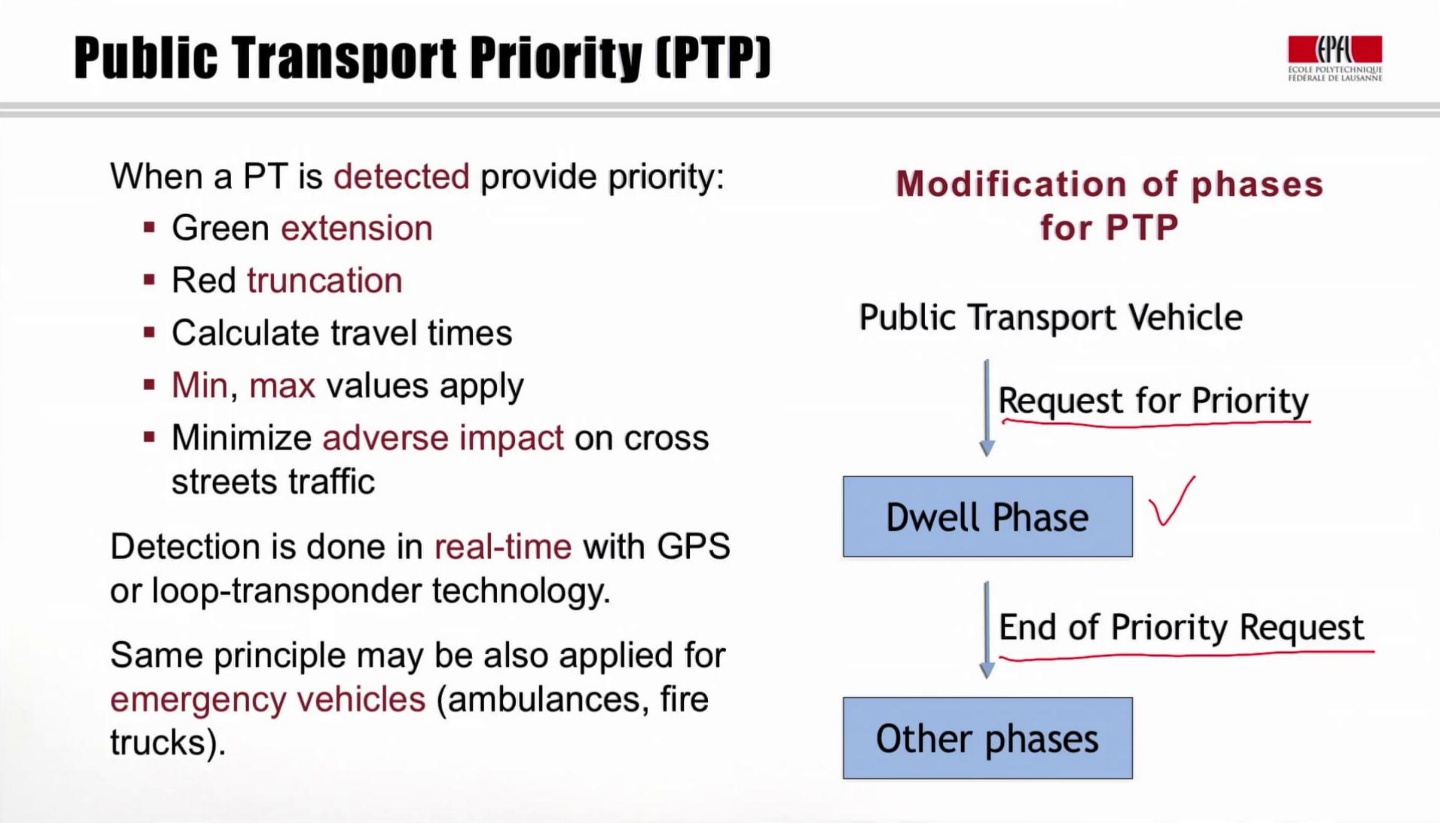


I need to calculate the travel times of the public transport vehicles on line and of course minimum and maximum values apply for the signal phases. And another issue that I should look when I do this priority rules is to take care of the adverse impact on cross Street to traffic so that detection in these cases is done in real time with GPS or any other technology for example “loop transponder technology” so I can detect a public transport vehicle and the apply priority to the signal plan and of course the same principle can also be applied for emergency vehicles. So this is what they do in the US for example when we have ambulances or fire trucks these vehicles they have a GPS and the when and when they are detecting approaching an intersection the signal plan will try to provide them priority. So when I have a detection of such a vehicle I need to modify the phases of my plan in order to provide priority. So I have this request for priority from the vehicle and I need to apply it dwell phase that will try to accommodate the vehicle and then I have the end of priority request and I can continue with my signal plan and with the other phases.

Notes

Summary

27m 19s



So this video provided some basic information on how to apply a control strategy in the field. There are many strategies that try to manage traffic that are developed in the literature but here I wanted to discuss how we can apply them in the real world. So in order to do this we need to have a basic understanding of how a traffic control center works? what type of communication technologies do we need? and how the traffic operators are going to use our methodologies and our tools?

Notes

Summary

28m 47s