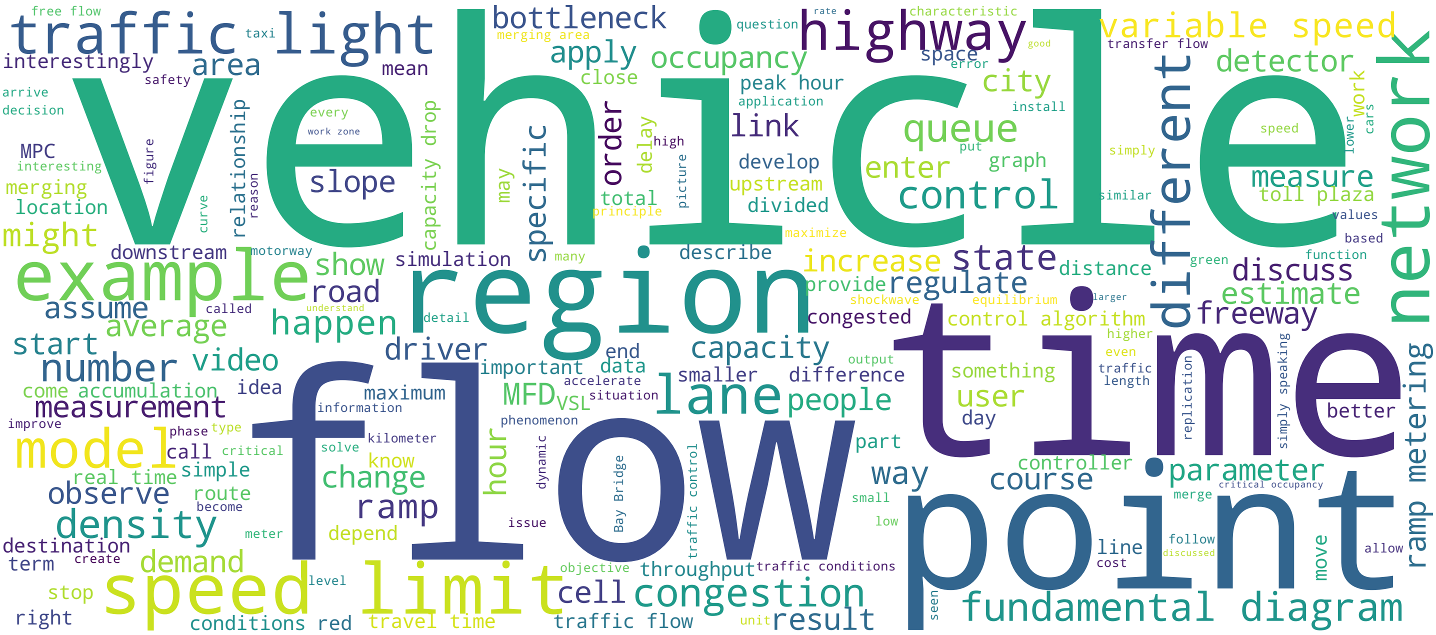
Variable speed limits

Intro to traffic flow modeling and ITS

Dr. Anastasios Kouvelas



Search MOOC

Video

Welcome

VSL, New Zealand (CC0 1.0 by drivertraining via Pixabay)

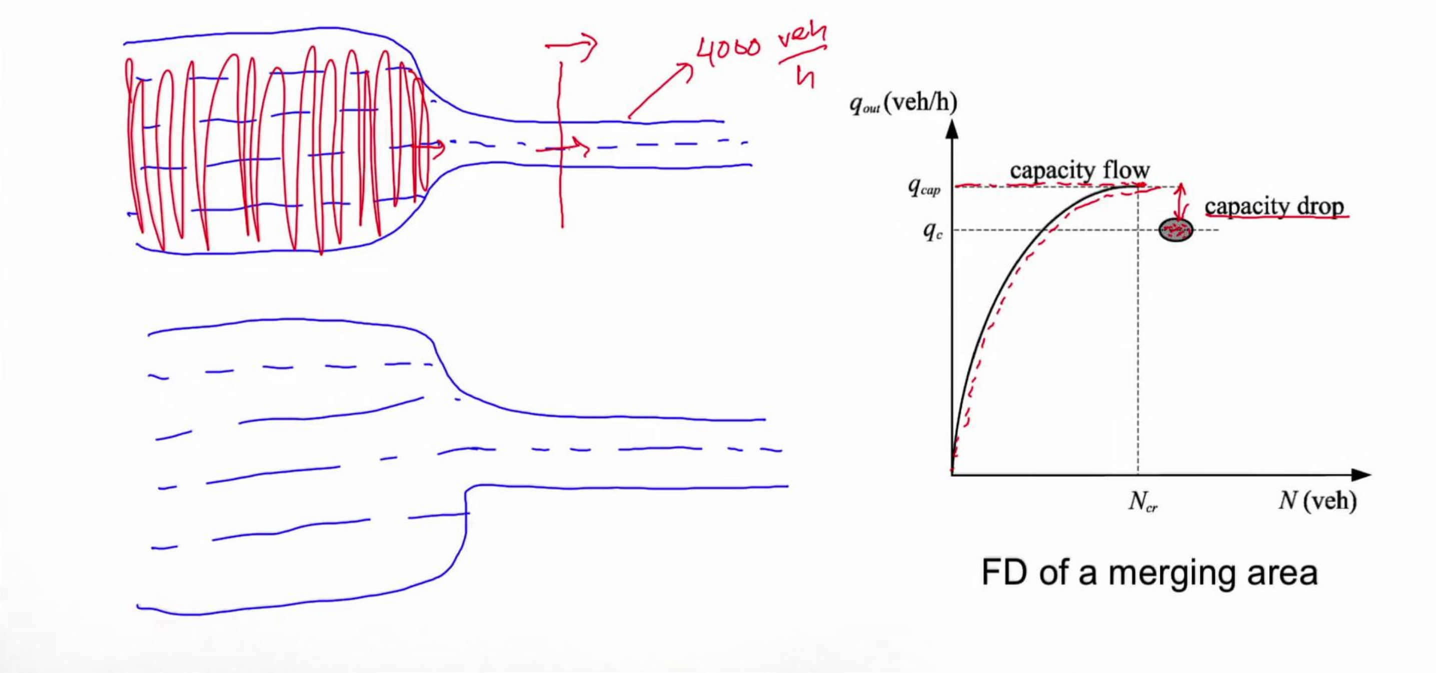
Hello. I am Anastasios Kouvelas. This video is about variable speed limits. In many highways, you must have seen some signs like this one in the picture that define the speed limit. So this is the maximum speed that you can drive and it is enforced by law. Some of these signs can be dynamic so they changed over time according to the prevailing traffic conditions. So, the transport authorities can regulate the permissible speed limit during the day so they can have a different limit for the peak hour and the different limit for the off peak hour. The initial reason for the application of such measure is safety. But have you ever thought that we can use this type of regulation in order to manage traffic and improve mobility. In this video I'm going to provide some reasoning behind this statement and by the end of the video I hope I can convince you that we can use variable speed limit in order to improve congestion in highways and I would like to start with a simple example.

Notes

Summary

0m 06s

A simple example

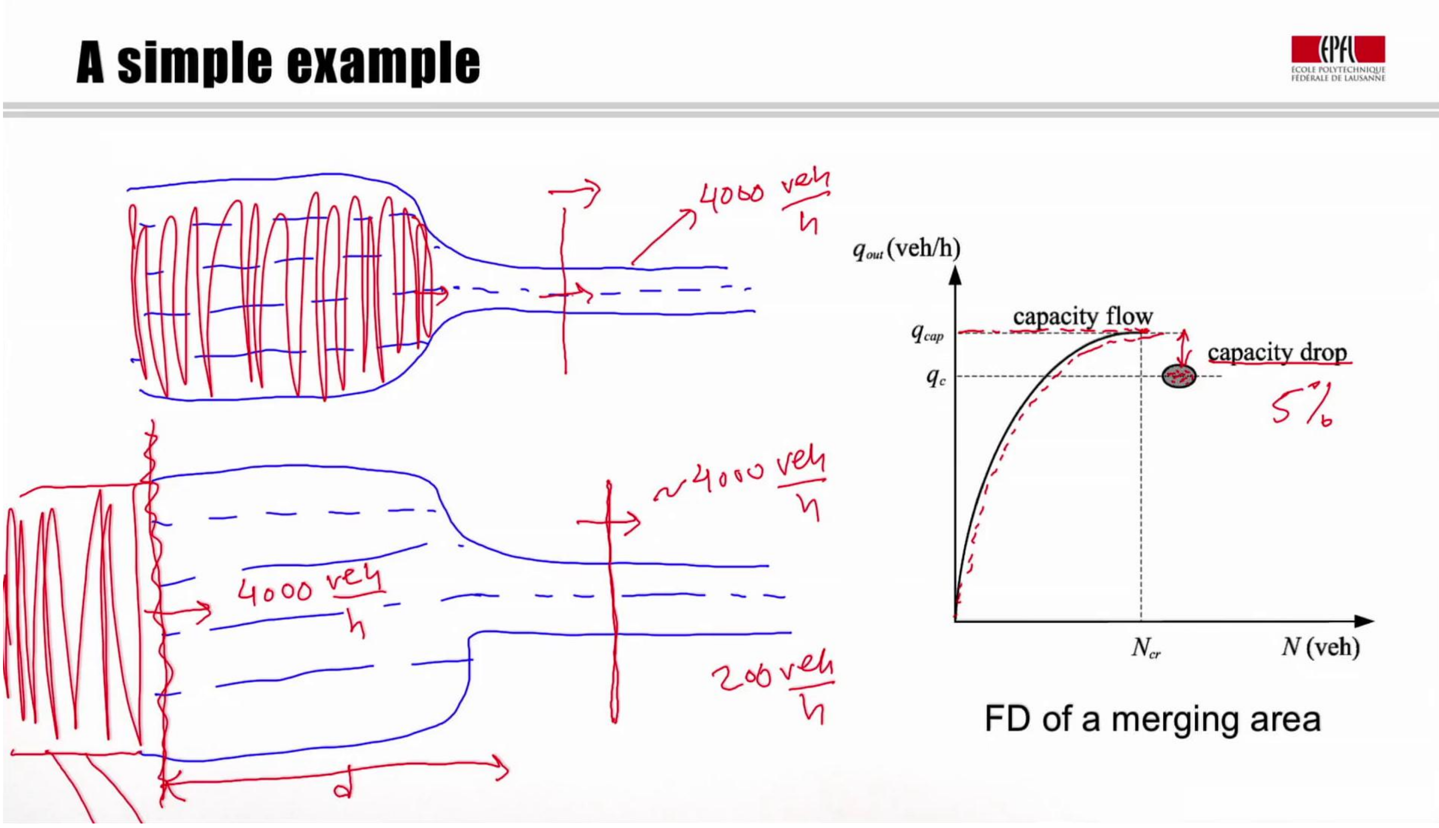


Let's assume that we have a highway that has a physical bottleneck like this. So I have here five lanes that merge into two lanes. So this is my construction a bottleneck and the during the peak hour what will happen here is that I will have many vehicles queuing here and creating congestion and they try to enter this two lanes. And if I go to this point and measure the flow or the throughput of this point I can observe some phenomenon that is called capacity drop in the literature. So let's assume that the the capacity of these two lanes just for the sake of discussion is 4000 vehicles per hour, two thousand vehicles per hour per lane. So this is the maximum flow that I can observe here at this point. And what happens from real data is that I get flow measurements here outflow measurements or throughput measurements in this point. And this increases it reaches some maximum and then when I enter the congestion I get points here which is lower than the capacity of this difference is called capacity drop and this reduces the serving capability of this point. and let's now discuss another scenario, so in the same infrastructural the same bottleneck.

Notes

Summary

1m 22s



So there is an idea that I can go somewhere here upstream and install traffic lights and then I can keep the queue here. So instead of having the queue here I can find the same queue some meters upsetting. And the idea is now that I can regulate these traffic lights and allow for the flow that enters this part to be equal to 4000 vehicles per hour. I can do this through the traffic lights and there is a point here that if I do this the merging of vehicles from these five lanes to two will be much easier. And they have this distance to accelerate and it's a high speed. And then if I go here and take measurements of the throughput again at this point I claim that this can mitigate the phenomenon of capacity drop and I can measure here something close to 4000 vehicles per hour. So if this is true and if we assume that this capacity drop is 5 percent for example and this means that if I can achieve this I can serve 200 vehicles per hour more. Note here that I need this distance d for the vehicles to accelerate and I claim that the merging in this area can be much easier because I have less vehicles and they can improve the throughput of this point. Of course this depends on the topology of the network and if I have for example an off ramp somewhere here. By doing this I may block the off ramp. So we should be careful where we can apply this and we're not.

Notes

Summary

3m 11s

Merging Traffic Control

- Merging traffic infrastructures ($M \rightarrow \mu$ lanes)
- Real-time information:
  - Merging of two highways
  - Motorway on-ramps
  - Toll plazas
  - Motorway work zones
- If arriving flow on M lanes > Capacity of μ lanes
  ⇒ Congestion ⇒ Capacity drop
- Merging traffic control to restore capacity flow

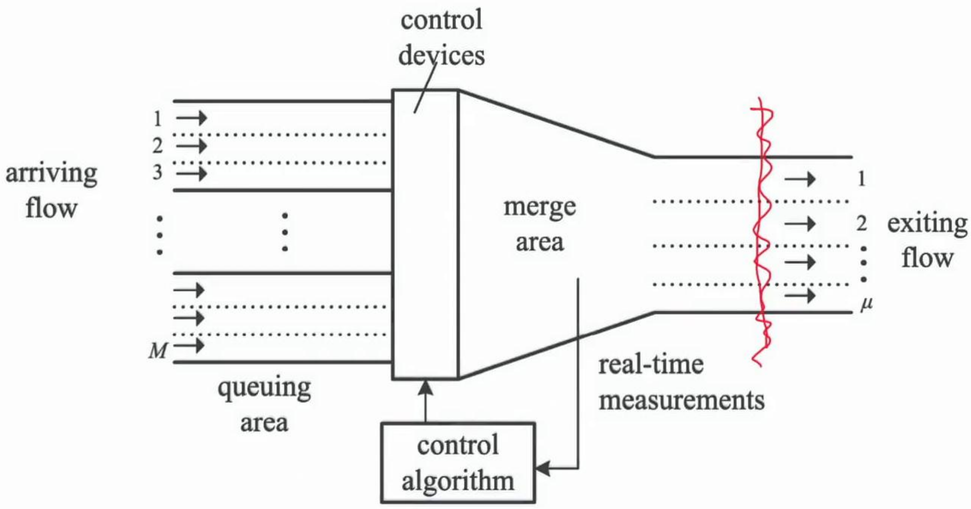
So when we have medicine traffic infrastructure routes where M capital lanes methods into mu lanes with mu much smaller than M. We can apply merging traffic control and what we need it's real time information. For example we can have merging of two highways or we can have a motorway and then on ramp we can have a toll plaza or a work zone. I will discuss this in the next slides and if I have real time information from this point I can do merging control. So the basic idea here is that this M lanes have much higher capacity than mu lanes and this creates congestion. And this has a result as we discussed this phenomenon of capacity drop. And I can demonstrate you through some examples that by applying merging traffic control we can restore the capacity flow.

Notes

Summary

5m 10s

Structure and Elements



Control Algorithm Main Goal

$N \approx N_{cr}$ (or $o \approx o_{cr}$)

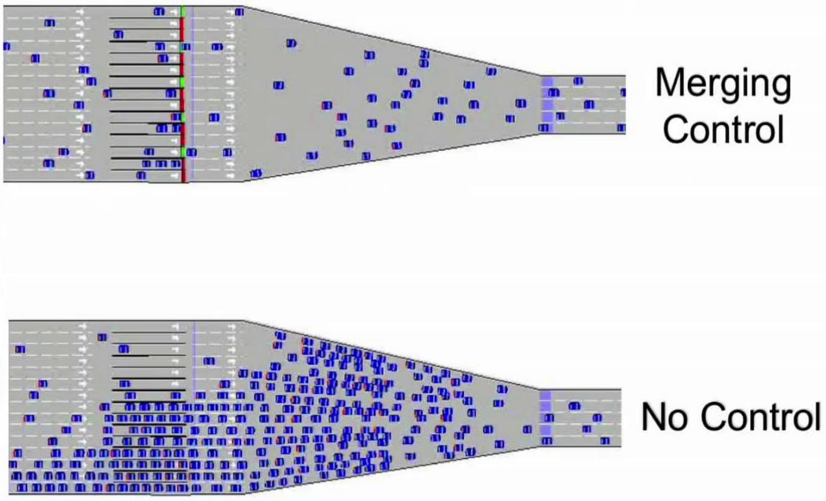
So, let's have a look at the structure of the transport infrastructure that we are discussing today. So we need an area with M lanes that merges into mu lanes and here I can measure the exit flow. So this M must be sufficiently higher than mu and here I have the merge area and we can install here some control devices and develop a control algorithm that can improve the mobility and can maximize the throughput. The objective of this control algorithm is to maintain in this point the occupancy close to the critical occupancy of the fundamental diagram or the number of vehicles that I measure here.

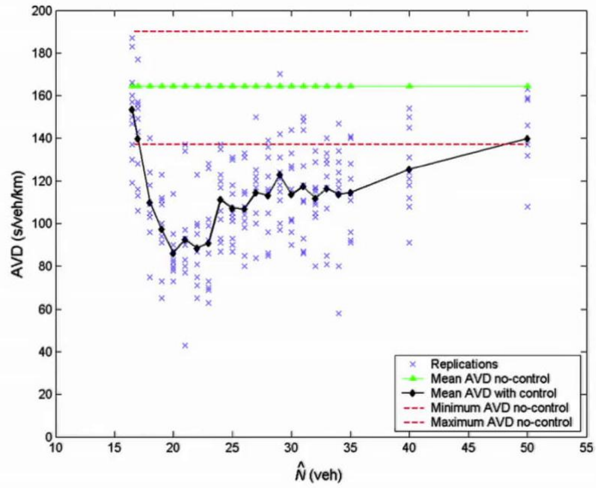
Notes

Summary

6m 12s

Bay Bridge Toll Plaza (San Francisco)





Papageorgiou, M., Papamichail, I., Spiliopoulou, A.D. and Lentzakis, A.F., 2008. Real-time merging traffic control with applications to toll plaza and work zone management. Transportation Research Part C, 16(5), pp.535-553.

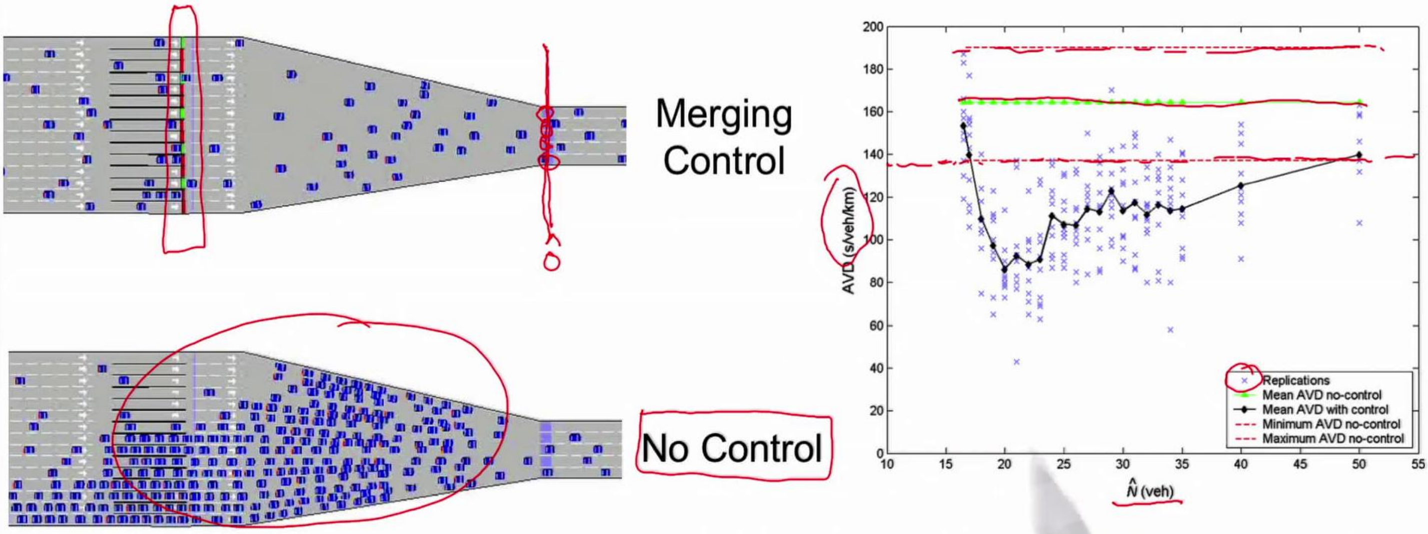
I can measure the flow or the number of vehicles and this needs to be regulated close to the critical number of vehicles and I would like now to show you a real case study that the transport infrastructure has similar characteristics to what I described before. And this example is the Bay Bridge Toll plaza in San Francisco. So this is a bridge that connects the East Bay to the city of San Francisco. In this area I have several highways that come from the East Bay from Oakland Berkeley and meds here in the toll plaza where I have twenty lanes and then they lead to the Bay Bridge which starts here and has only five lanes and this is the managing area. Look here there are some tolls where drivers need to stop and pay the fee to cross the bridge and then some distance something like two hundred meters. Now authorities have installed these traffic lights. The basic reason of the installation is safety. When drivers merge from twenty lanes to five this is not an easy task and many accidents can happen. So by putting these traffic lights you can make the merging easier by regulating the traffic lights. But apart from safety these traffic lights can be also used to optimize traffic conditions and I have some simulation results here on the right.

Notes

Summary

7m 06s

Bay Bridge Toll Plaza (San Francisco)



Papageorgiou, M., Papamichail, I., Spiliopoulou, A.D. and Lentzakis, A.F., 2008. Real-time merging traffic control with applications to toll plaza and work zone management. Transportation Research Part C, 16(5), pp.535-553.

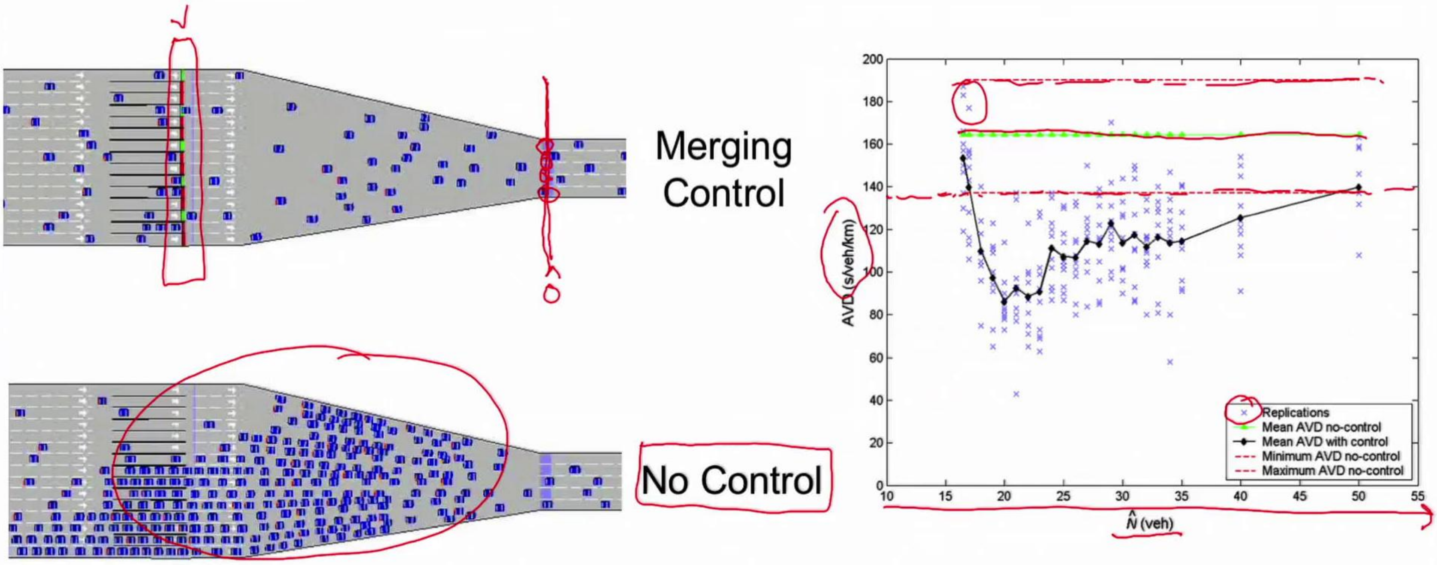
So if I do not do any control I have a situation like this so vehicles they need to find their way to merge and enter the bridge and in the other case I can do some control here in the traffic lights and try to regulate the occupancy at this point. So I have detectors here that can measure their occupancy so I can try to regulate this occupancy close to the critical occupancy. So this graph on the right demonstrates many different simulation replications. A lot of replications with different random have been run and these are the results. So this line here corresponds to the minimum delay for the no control case that replication with a minimum delay. And this, the units here is second per vehicle per km. So it's like close to 140 seconds per vehicle per km. and this line is the maximum delay. That replication with a maximum delay and the green line demonstrates the average delay of the no control case. Again no control cases here when I do not have any traffic lights and with the blue points here I have different replications and the respective delays for different values of N hat. So N hat is the set point for the number of vehicles that I measure here at this point and I can see all the range of results.

Notes

Summary

8m 52s

Bay Bridge Toll Plaza (San Francisco)



Papageorgiou, M., Papamichail, I., Spiliopoulou, A.D. and Lentzakis, A.F., 2008. Real-time merging traffic control with applications to toll plaza and work zone management. Transportation Research Part C, 16(5), pp.535-553.

And with this black curve I see the average delay for different number of vehicles for the set point. So it is clear from this picture that for most of my simulation results I can see that the control case is much better than the no control case. Of course there are some outliers but on average I can do much better. So it is clear that the traffic lights that meter the flow here apart from the safety implications they can also have positive effects in the traffic throughput. And I refer you to this paper if you want to have more information about this experiment for the Bay Bridge toll plaza.

Notes

Summary

10m 33s

Control devices

- Traffic lights (appropriate switching)
- Physical barriers (toll plaza)
- Variable speed limits

So, what are the control devices that we can use in these merging areas. The first option is to install traffic lights and here someone should define some appropriate switching for the lights but we can also use these physical barriers that exist in the toll plaza in order to meter the flow of vehicles. And because we cannot install traffic lights everywhere in a highway or a physical barriers, another way to implement something like this is by the use of variable speed limits and i will discuss this in the next slides. So instead of putting traffic lights I can try to have the same effect by regulating the speed limits.

Notes

Summary

11m 21s

Control devices

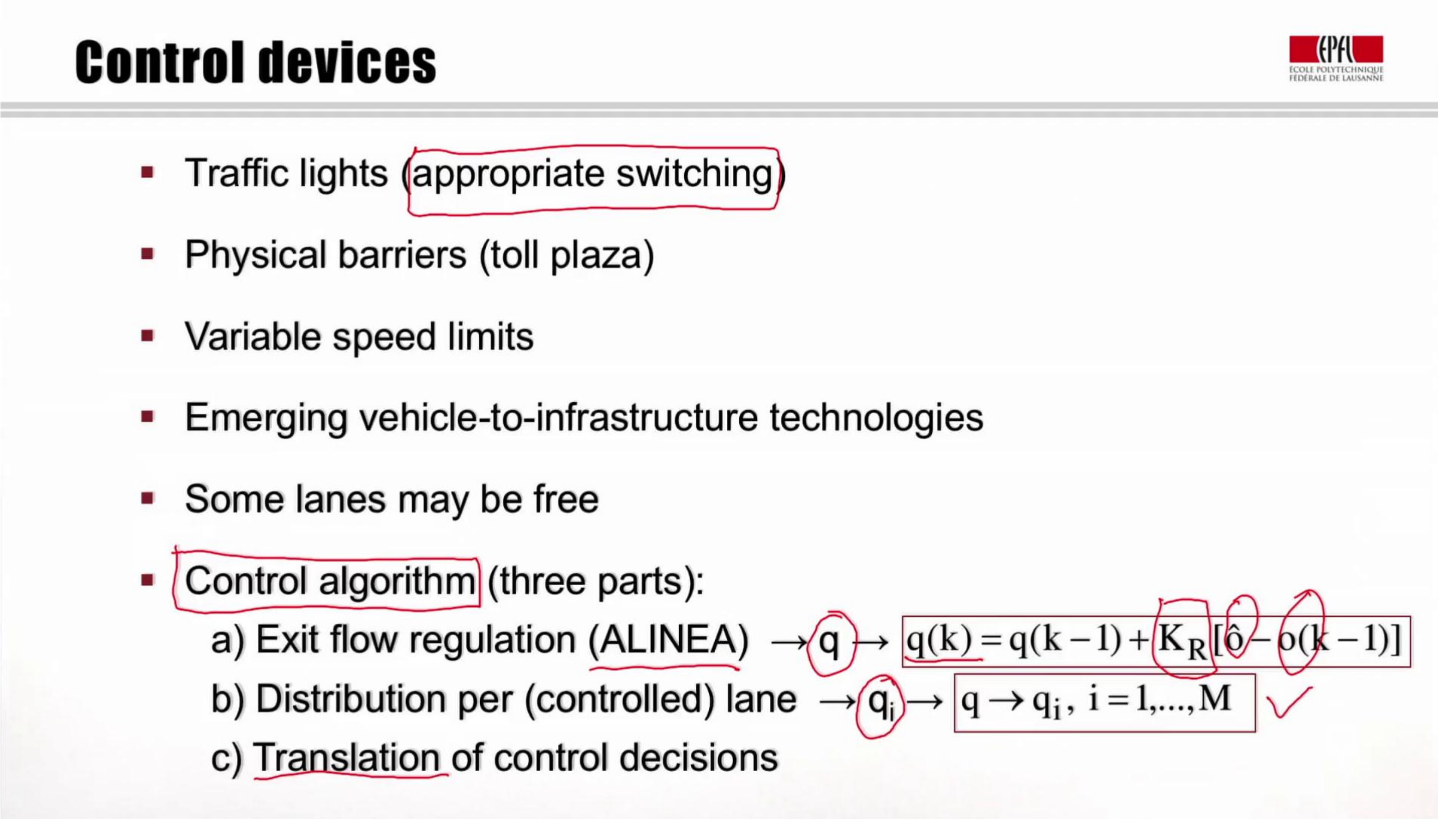
- Traffic lights (appropriate switching)
- Physical barriers (toll plaza)
- Variable speed limits
- Emerging vehicle-to-infrastructure technologies
- Some lanes may be free
- Control algorithm (three parts):
  - a) Exit flow regulation (ALINEA) $\rightarrow q \rightarrow$ $\boxed{q(k) = q(k-1) + K_R[\hat{o} - o(k-1)]}$
  - b) Distribution per (controlled) lane $\rightarrow q_i \rightarrow$ $\boxed{q \rightarrow q_i,\ i = 1,\ldots,M}$
  - c) Translation of control decisions

And I would like to give you an example if I have a highway and I have an active bottleneck somewhere and the congestion growing I have vehicles coming from upstream that enter the congestion and build up the queue so I can go further upstream even five kilometers upstream and apply some low speed limit. So I can delay these vehicles and they're in the queue and degrading the infrastructure. And nowadays there are other emerging technologies like vehicle to infrastructure communication. So if I have some communication like this I can enforce these variable speed limits. Another option is that if I have many lanes merging into a smaller number of lanes I can have some lanes closed. And let's discuss now the control algorithm that I can apply in a merging area so it can be a simple feedback regulator like ALINEA which calculates the flow that I will allow from the traffic lights. And this is given by this equation where I have the critical occupancy and the measurement of occupancy and I try to regulate this close to the critical with this gain they are. So this equation gives me the flow that my traffic lights should allow to pass which is queue of K for time interval k.

Notes

Summary

12m 08s



And now the second question is how to split this flow to the different lanes. So it's control Lane has a flow qi. So how do I distribute these two qi's. So one way is to distribute this equally in all lengths but there may be more efficient ways. So I can observe the queues in every lane and do some distribution that can balance the queues in different lengths. And then when they have these q's, the qi I need to find a way to translate these flows to control decisions like green time durations for example. And here I go back to my first bullet where I write that I need to come up with some appropriate sweetening that will help the flow. And this also depends on the specific infrastructure and the specific topology of the network.

Notes

Summary

13m 39s

Variable Speed Limits (VSL)

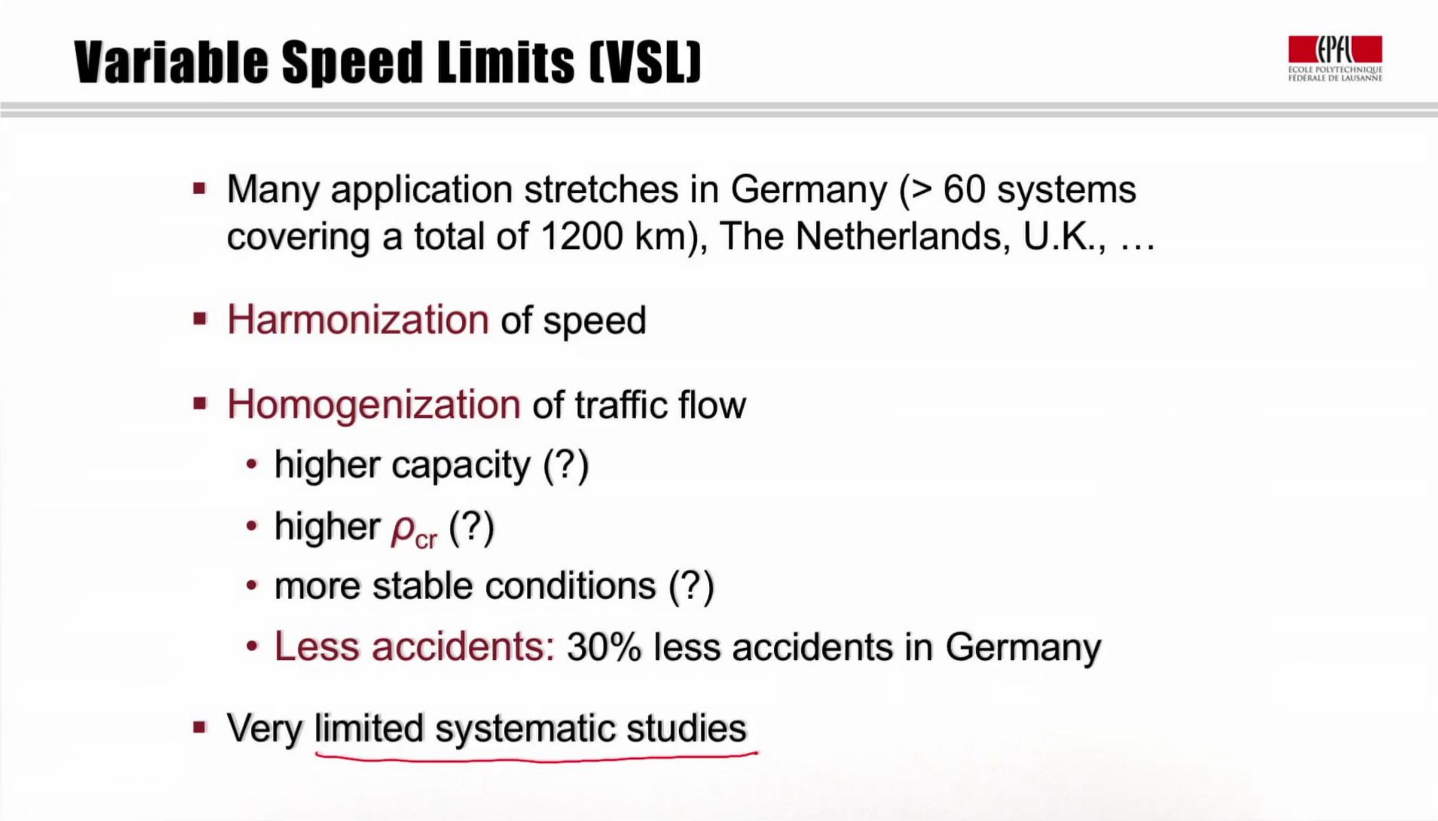
- Many application stretches in Germany (> 60 systems covering a total of 1200 km), The Netherlands, U.K., …

So let's have a review of the available variable speed limits applications nowadays. So in their Germany, there are many applications saying the highways and the during the peak hours you can see speed limits that go as low as 30 kilometers per hour or 20 kilometers per hour. And there are other applications in the Netherlands in UK and in other countries.

Notes

Summary

14m 43s



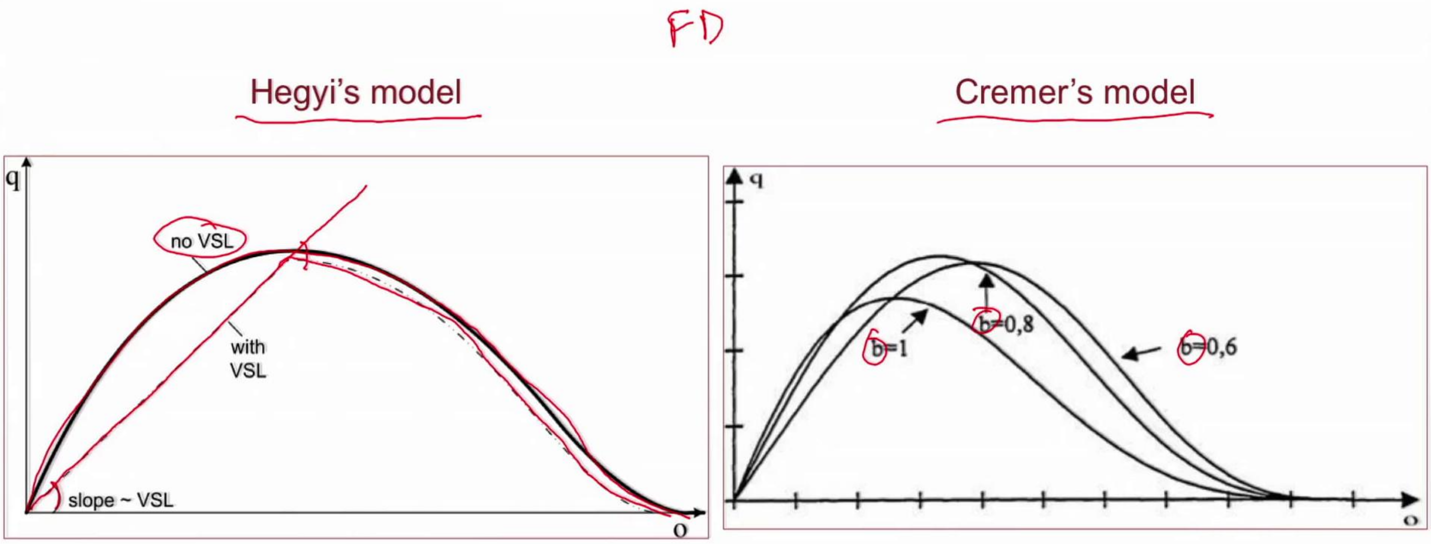
One issue that I would like to discuss here is the compliance of the drivers to the speed limits. This is not a recommendation but rather an enforcement regulation. We can assume that most of the people will comply with the enforced dynamic speed limit but there is no guarantee for this. So the compliance of the drivers is an issue that can be further investigated and it can be different in different countries. So it is obvious that by applying variable speed limits we can achieve the harmonisation of speed in a highway. And this leads to some homogenization of traffic flow. But there are still open questions like: Can we achieve higher capacity for our highway? Or can these variable speed limits increase the critical density of a stretch of a highway? So in other words can the VSL lead to more stable conditions. Nowadays we have evidence that the variable speed limits can improve safety so we have less accident. So we have reports from Germany that after the implementation of variable speed limits they had something like 30 percent less accidents because in highways when congestion starts we have these stop and go phenomena that create many accidents. However until today we have limited systematic studies about the effectiveness of VSL on the traffic flow.

Notes

Summary

15m 10s

Modeling approached

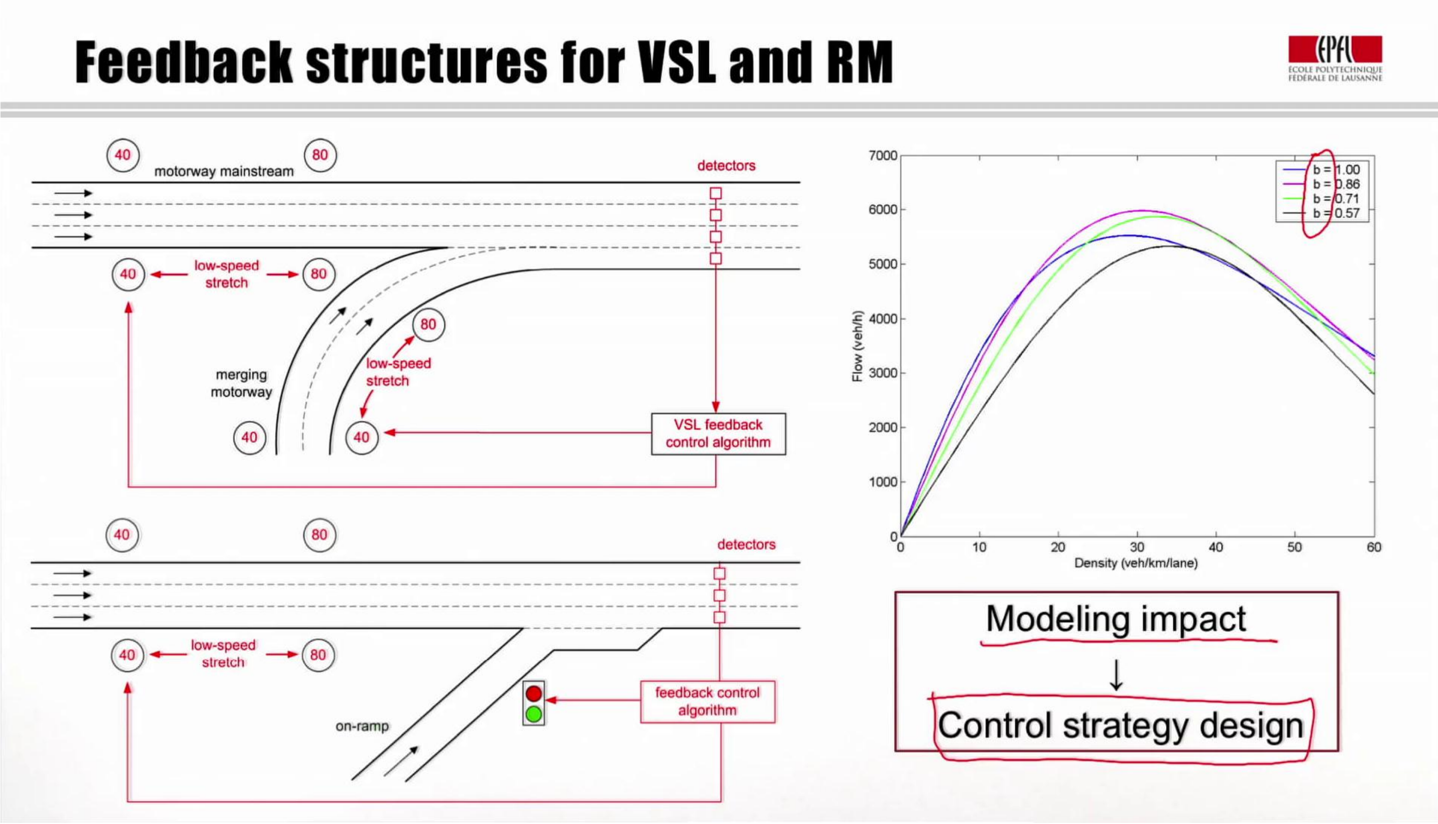


And I would like now to discuss how VSL affect our modelling approaches. So the basic element that we have to tune is the fundamental diagram. And there are different models in the literature and here I provide Hegyi's model and the Cremer's model So how we can modify the fundamental diagram depending on the application of different speed limits. So the idea is that they have this fundamental diagram for a highway for a stretch of a highway which doesn't involve any VSL. And then if I go and apply some speed limit So this is given by this slope. This slope here is the speed so I can model this in my traffic flow model with this fundamental diagram where I put this slope for the speed limit.

Notes

Summary

16m 53s



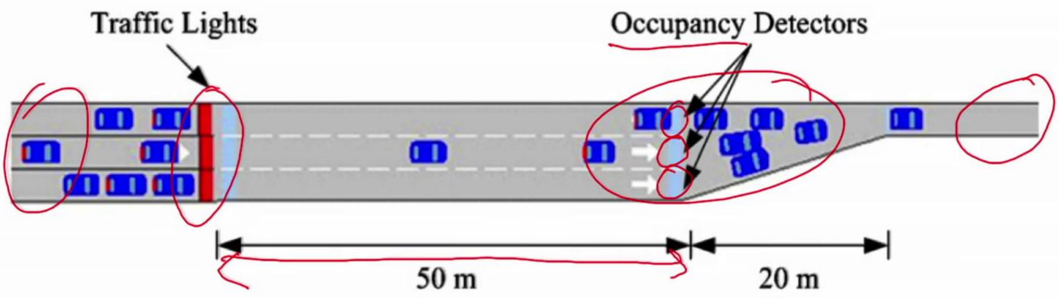
Another way to do it is to introduce some parameter like here beta and by changing this parameter I can get different fundamental diagrams that correspond to different speed limits and in order to design feedback control algorithms for the VSL what I need is to have some detectors here after the merging downstream of the merging to measure occupancy or flow and then I can design some feedback controller that can apply here in this location some speed limit that they can very over time in a dynamic way or here so I have some areas. So here I have a merging of two motorways so in these areas I can reduce the speed and by reducing the speed I delay the vehicles that are approaching the merging area. Also I could develop a feedback control algorithm that can combine Ramp metering and the variable speed limits so I can have a generic control algorithm that can regulate both and coordinate their actions. Again I need measurements from this downstream area. And once again the basic impact that VSL have to the modelling of traffic conditions is the same of the fundamental diagram. So I can design different fundamental diagrams with different parameters that can capture this behavior when I apply variable speed limits. So this is the impact that I have in my modelling of traffic and of course I can use the same principle when I design control strategies for VSL.

Notes

Summary

18m 04s

Highway work zones



Reduced capacity because of work zones → Same principle!

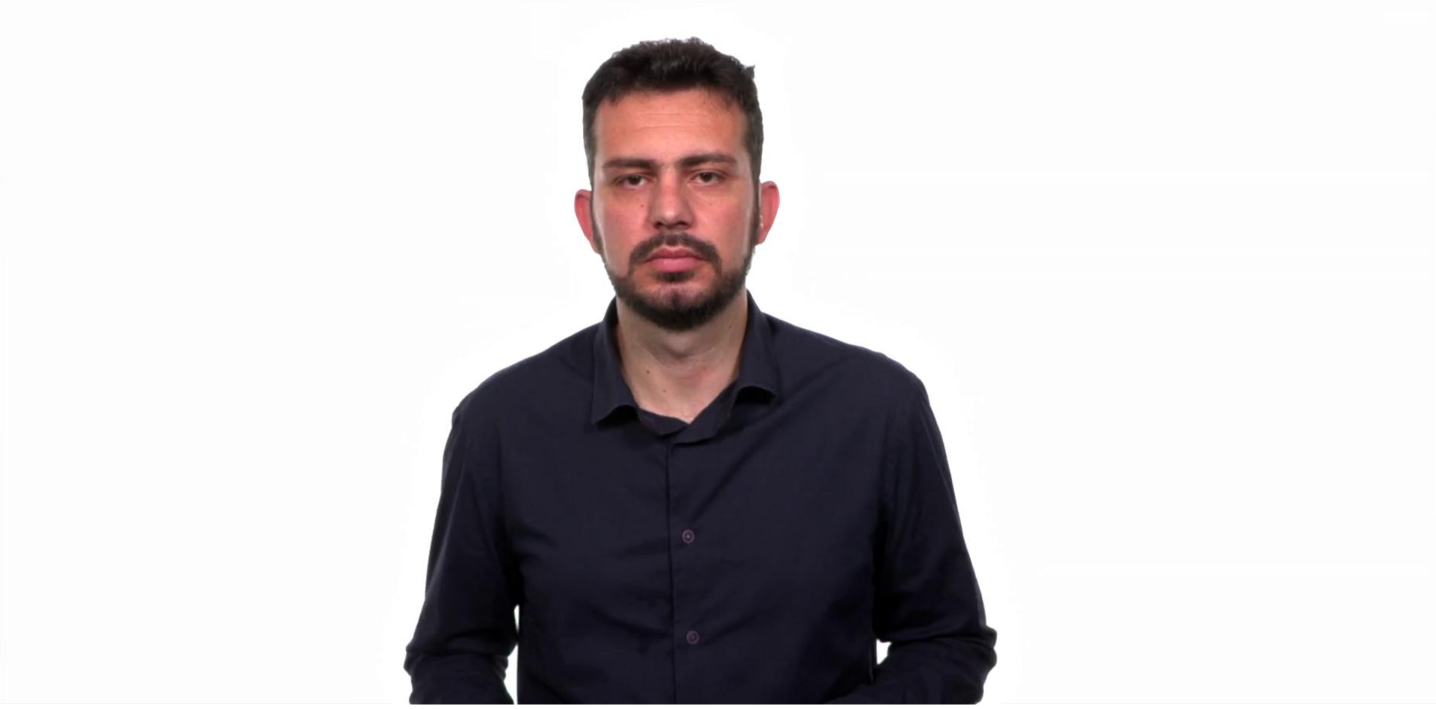
And finally I would like to discuss the work zones that we may have in the highway. So sometimes there are some work that need to be done because of maintainance for example and they can create again bottlenecks. So in this case I have a highway with three lanes and because of some construction or some works I only have one way that I can use. So again I have this bottleneck and I can install some detectors here that can measure occupancy for example and I can install some temporary traffic lights here that can regulate the flow and make the merging of these vehicles easier. Again I need this distance for the vehicles to accelerate. So the same principle that we discussed before applies also in the case of work zones.

Notes

Summary

19m 43s

Variable speed limits – Summary



This video was about variable speed limits. Nowadays we have more and more applications of dynamic speed limits as highway traffic operators understand that this can be beneficial for safety reasons but also for congestion. By applying some smart control strategy VSL can increase the throughput of highway bottlenecks and improve mobility. Thank you for watching.

Notes

Summary

20m 40s