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DAVID HSU: I'd like to welcome you to another installment or another lecture in my MIT class on urban energy systems. My name is David Hsu, I'm an associate professor of urban studies and planning at MIT, and this week we're going to talk about cities and transportation systems. In our last lecture, we talked about electric vehicles and why certain new technologies are much more efficient than our previous internal combustion engine or fossil fuel using technologies, and how we need to achieve electrification to achieve lower greenhouse gas emissions.

Today, I want to talk about transportation systems. And I want to take a different attack or a different tack on the subject of transportation systems. We'll start with policy analysis. Here's the materials for today. They're all in the syllabus. And what I want to talk about is policy analysis. Quite often what we teach in public policy schools or urban planning schools is fundamentally an economic framing of policy analysis. It's a cost-benefit analysis, or as one of my previous advisors would say, a benefit-cost analysis, because you would want to emphasize the benefits over the costs if we take certain public policy actions.

And so the two main concerns we typically teach in economic styles of policy analysis are efficiency-- what are the highest priority items? This assumes that resources in the public sphere are scarce and we can only basically deploy certain level of resources to address social problems. Of course, we should also question whether or not resources are scarce or what kinds of political economy, let's say, leads to this scarcity. But if you have scarce resources, you would want to establish what the highest priority items are.

And the second main concern that is usually given, I would argue, slightly less emphasis in public policy analysis, is equity: is the distribution of benefits and cost fair? And of course, we want to emphasize that this economic style policy analysis hasn't always included broader concerns. For example, risks, that we know from recent disasters like wildfires in California or of course, the COVID-19 pandemic, that we can have unexpected or low probability disasters. We could argue that they are low probability or fairly rare, but of course, they can also be potentially catastrophic. So there's increased interest in how do you achieve resilience to disasters like wildfires or COVID-19.

Of course, if we talk about equity we can also talk about definitions of fairness or justice. We can talk about it in terms of rights or opportunities or capabilities. Those are all differently distributed or considered or conceived of by different groups. And of course, this leads us to the overall question of what is justice? It's also perhaps fair to say that public policy analysis doesn't always include behavior. We know behaviors can rapidly change, that may be a result of signaling, or culture, or incentives.

But essentially, I would take the approach that our economic framing is within a certain context. We quite often draw on evidence in a similar context, but we also know that behaviors and cultures do change, and those behaviors and cultures actually establish what should be valued in economic systems or markets. Of course, there's non-monetary values. Environmental economists have spent a lot of time trying to establish the non-monetary value of things-- things that simply exist, but may not necessarily be traded in a market economy.

Examples include a particular species, like let's say the desert tortoise or the Grand Canyon. How do you put an existence value on the desert tortoise or the Grand Canyon? People have tried to do it. We can discuss or debate whether or not we think those non-monetary values are, in fact, things that we believe are accurate.

And of course, as I alluded to before, the total budget or resources we have to address social problems. Are we actually taking into account, let's say, future payoffs for investments or even the sustainability of our public policy actions? This brings into question also implementation. We can analyze whether or not things have certain benefits or costs, but of course, if we have a public policy that cannot be implemented, then it may not have any effect. That leads us to questions of who, how, and where our public policy is going to be implemented.

And of course, growth and speed. We often do our policy analysis based on existing data. We may not capture large shifts in systems or situations. And of course, we know that certain technologies are growing faster than others. So are we understanding-- or is our public policy analysis durable or in a technical phrase, stationary? And we assume that our results from one period of time are generalizable to another.

And finally, geography. Similarly, can we assume that our public policy analysis and our public policies work the same in all places? Again, can we generalize the effects of our public policy analyses from one place to another? And so in terms of policy analysis today and for transportation systems, I want to talk about three case studies, and those three case studies will use this as examples of different kinds of policies and other analyses.

The first one is global aviation, which we've talked about in this class more. I think it's an exciting topic for us to talk about because as I've argued to you before, I think it's a cultural blind spot for many committed environmentalists who are relatively high income and educated. We'll talk about the case study from the Mimi Sheller paper on walking, bicycling, and transit in Philadelphia. And we'll just touch briefly on Los Angeles's efforts towards clean air, which led to the California Air Resources Board. That chapter is a great chapter just to reinforce questions about how long does it take or how do we achieve public policy over time.

So just talk about global aviation for a moment. If you look at the growth of air transport over the last 50 or 60 years, this is from the International Civil Aviation Organization, you can see that they've basically charted a fairly constant upward trajectory. You see minor blips in the upward growth for the 1970s oil crisis, the Iran-Iraq war, the Gulf war, the Asian monetary crisis in the 1990s, the 9/11 terrorist attack in 2001, SARS, and the world recession.

Those all have some effect on the growth in air transport, but if you had to summarize over the last 70 or so years, you could basically say that there's been an uninterrupted growth of air transport. Here I think it says it's a 7.1% growth rate versus 2014. That is in terms of revenue passenger kilometers and freight ton kilometers both have grown fairly relentlessly.

Of course, we're talking about this in 2022. This is one year after the, perhaps, greatest decline in world history in world air passenger traffic. You can see the effect of the COVID-19 pandemic has had the effect that all those previous crises did not have on air travel. We can discuss-- or we will discuss in class whether or not this is a good thing. I'm sure we can agree that COVID-19 was not a good thing. But the question is, after COVID-19, is air travel going to simply resume and go back to the level that it was in 2019, and will it continue to resume its upward growth?

Some forecasts estimated that aviation and transportation will be 30% of our total greenhouse gas emissions in 2050. We obviously cannot sustain that growth if we also want to try to achieve decarbonization. And of course, just to talk about behavior and culture change. Over the last five years, *The Economist* I think up to 2019 or 2020 had a graph of airline passengers in Sweden, and they call it *flygskam,* which I think is not quite the right pronunciation, but it basically translates as "flying shame."

And you can see that the number of passengers at Sweden's 10 busiest airports had declined for a number of years. You can also attribute this perhaps to Greta Thunberg making great efforts to publicize the hypocrisy, perhaps, of flying, and choosing to take a boat to the conference-- climate conference in New York to avoid being charged as a hypocrite. "Flying shame" has been translated to a number of languages. I think this is actually a cultural shift that we may be seeing.

Just to talk about why global aviation is an important factor in climate action or climate change. This Lee et al. 2021 paper is not one that I assigned in the syllabus. But if you have the PDF slides, I encourage you to click on the link. And it's important to note what this paper says. This paper basically argues that the greenhouse gas emissions from plane engines themselves are not their only contribution to radiative forcing or the greenhouse effect. The contrails created at a high atmosphere also result in additional greenhouse gas warming.

In fact, aviation is about 3.5% total of the total radiative forcing, estimates this paper. You might see the oft quoted number of 2%, aviation is only 2% of global emissions. First, I would press you to find out where that number actually comes from. I know industry has circulated that number at various times. But also that number has-- I think is relatively old. But also to point out it doesn't include this relatively large non-CO2 effect. If we considered aviation to be a country, it would be the fifth or sixth biggest contributor to global greenhouse gas emissions.

And of course, that country would be a pariah if it didn't take efforts to try to reduce its emissions. And so just to reinforce this point a little bit about how global aviation is inequitably distributed among the flying population. This is from the Gossling and Humpe 2020 paper. And it basically divides the world population into four income brackets. The low income countries, about 700 million people; lower middle income countries, about three billion people; upper middle income countries, about 2.7 billion people; and 1.2 billion high income people.

What they do is simply take numbers from the World Bank, type in the number of flight passengers per country, they calculate how many passengers there are per capita, and they assume that if every single person who could fly, flew, then they can calculate a theoretical maximum relation. So if you take 0.03 passengers per capita, assume only people take one flight-- you should get to a maximum of only 1.63% of the population has flown.

Of course, in high income countries since we average about two flights per capita in high income countries, they assume that the total maximum flying population is 100%. Obviously, that doesn't actually reflect the number of people who flew. We'll talk about that in a second. But this is just getting to a maximum flying population. And already, you can see that there's a global inequity between who flies or who even could possibly fly. Of the 2.1 billion people who have flown, the maximum-- or 2.1 billion perhaps flights, the maximum flying population includes all the flying countries, and that's approximately 100 times what the maximum flying population is of the low income countries.

Similarly, if you adjust it for the non-flying share of the population, because some people in many countries or even high income countries do not fly, you can calculate this through again and you can find out that roughly 40% of the flying population in high income countries flies. 0.7% of the flying population in low income countries-- I'm sorry. 0.7% of the population in low income countries could be flying.

And of course, you also get these drastic inequities where high income countries approximately have 100 times more flying population than low income countries regardless of the total population in these income brackets. And so just to reinforce this point, again, it is not just rich countries versus poor countries. It's actually people who are flying more in all these countries. The distributions in table one do not consider that there's a significant share of the population in every country that does not fly, while some air travelers participate in one, two, or multiple trips.

If you can look at all these countries it was quoted in the paper, you can see that the National surveys indicate that in high income countries, between 53% and 65% of the population will not fly in a given year. This actually indicates that a majority-- actually, a fairly large proportion population, almost two thirds of the population doesn't fly in a given year. I want to reinforce this point, because I think in academic settings and educational settings, we tend to assume that most people are like us. They fly all the time. That's actually not the case in many high income countries, also.

To show this again for the United States. This is from the-- I think the Air for America or the Airline Industry Trade Association did a similar survey. And they find that in a given year, 53% of adults do not fly. Either 35% of adults in a given year take one to five trips, and 12% of adults, or one eighth of the population, take about six trips or more. I'll let you think back on your last few years before COVID and think about what your flying behavior has been. This is something I've certainly considered as I've been trying to increase my efforts towards reducing my greenhouse gas emissions.

And most importantly, if you look at the forecast from here to 2050, this is a 2020 paper where they look at 2018 numbers and 2050 numbers. And you can see that this is also quite inaccurately distributed across regions of the world. North America is the lion's share of the emissions now from commercial air passenger transport, along with Europe. It's much lower in-- I guess Asia-Pacific is also quite high.

But on a per capita basis, overwhelmingly flying occurs in North America and Europe, to a lesser extent in the Middle East with perhaps much lower populations. And the population on a per capita basis, even though Asia does have a lot of air passenger transport and is expected to apparently quadruple in this forecast, it is still much lower than North America and Europe.

And so this brings me to the homework problem, just to give you a sense of how we might achieve different transportation modes. This is a figure from MacKay's book, figure 2023, chapter 20. The vertical axis is in kilowatt hours per passenger per 100 kilometers. And on the horizontal axis, you can see the speed in kilometers per hour. As I said to you in the last lecture, mobility is a super power. It gives us the ability to access jobs, leisure, housing, travel.

And so as you think about our transportation modes, you can see that all of these different modes of transportation, the red ones I think all being ground transport, the green ones being ocean transport or water-based transport, and the blue ones being air transport. They all have different energetic implications along this vertical axis and different speed implications along the horizontal axis.

So what I wanted to do the homework was to calculate simply, if you had a choice between traveling, let's say, by train or by turboprop plane, which one you should take and what the energy implications of that are, because energy is closely linked to greenhouse gas emissions. So I asked the homework to compare taking a turboprop plane versus high speed train, assuming that in the United States if you want to take a turboprop plane, you have to go to the airport and check into security, and I think it's a reasonable assumption that it would take three more hours to travel.

So the key to this problem is setting it up so that they travel the same distance. And you can see, you take from the train's perspective, the plane has a higher speed but gets, let's say X number of hours minus three hours to travel. And that is probably the equivalent of distance, because you crossed out the hours, as a train going 200 kilometers per hour, traveling for X hours. And you simply solve for X and you do the algebra.

And you can see that the train, from the train's perspective, it takes 4.27 hours by train and you go 855 kilometers. If you set it up from the plane's perspective, you simply put the three hour difference on the other side. You can see that we're traveling X hours by plane. The train gets a three hour head start. You calculate it through. The plane only takes 1.27 hours but only goes the same distance of 855 kilometers.

So you want to then calculate the energy, you can look back at that graph from MacKay 2023, and look at how much energy required to go a certain distance. So if 38 kilowatt hours per passenger per 100 kilometers to go 670 kilometers per hour for a turboprop plane. And for a high speed train, it requires four kilowatt hours per passenger per 100 kilometers to go to 200 kilometers per hour. And so if you multiply through, you simply take the 38 times the 836 kilometers, you get to 325 kilowatt hours per passenger.

For high speed train, it is four times 856 or 34 kilowatt hours per passenger, because you cross out the 100 kilometers in the bottom. You can see that it's roughly a 10x or exactly a 9.5x difference between the two. And you can see it because they use the exact same distance, the key numbers here are the 38 and the four.

So this brings us to Mackay's question in Appendix C, which is, can we improve planes? And he argues in this chapter that engine efficiency can only be boosted a tiny bit by technological progress. The shape of the plane is already highly efficient, and argues that there's little that can be done to improve the transportation efficiency of planes. I will defer to my colleagues in Aero-Astro or students in that area. It looks like there are some possible ways to try to improve the efficiency of planes.

So this reminds me of this headline I saw last year on CNN. This is the long-awaited Celera 500L bullet plane. You can see that it's taken a number of measures, the bullet shape, the small, stubby wings, the placement of the engines are all designed to increase efficiency, It's got this turboprop in the back. And this article says that it gets 18 to 25 miles per gallon compared to two to three miles for a comparable, small, and presumably private jet.

So just to calculate these in a rough way. Assuming it uses gasoline or at least energy-- the density of gasoline, though this probably used as a particular fuel for a private jet, we have the 10 kilowatt hours per liter we used for gas engines in the previous lecture. We divide it by 2.5 miles per gallon, inverting the miles per gallon factor. And we get to a figure of 961. 961 kilowatt hours per 100 kilometers.

If you calculate that like we did last week for the internal combustion engine of an SUV. The only change we made here is we use the same energy density of the fuel, but we've made this SUV 22 miles per gallon-- that seems relatively generous. And you get to almost a factor of nine less. 109 kilowatt hours per 100 kilometers.

And for the Celera 500, which is quoted to get 18 to 25 miles per gallon, you can do the exact same calculation, because we know that 18 to 25 miles per gallon encompasses our 22 miles per gallon for SUV. So we get the exact same number. These are rough estimates. The reason why we do these is to simply to try to compare the modes. And if we assume they all carry about six people, you could divide this energy use by six to get kilowatt hours per person, per kilometer.

If you wanted to compare this new calculation to our previous calculation for the turboprop plane and the high speed train, you can see that the private jet is a very high number or amount of energy per person to go this 856 kilometer trip. The turboprop plane is roughly one fourth of what the private jet is. The Celera or a six person SUV is about half of what a turboprop plane is. And of course, the high speed train is still much lower than all of the other modes.

So this is to say that we have different passenger capacity. We have different speeds, certainly for all these modes. But this also calls into question what kind of infrastructure do you want to build to achieve these different modes. If you want to decarbonize and reduce our greenhouse gas emissions, we are going to have to change how we take some trips. And you can see some countries, like China, have essentially tried to eliminate their short haul aviation market by building high speed train network.

Their high speed train networks are out-competing many of their short haul aircraft. And so apparently the short haul aviation industry has gone away in China. And in parts of Europe, some universities now say that you can't take a plane to a conference if it's within, I think, 500 kilometers, because the argument is you can get to that conference just as quickly by train. And we are seeing a growth, as one of our students sent in an article, of short haul aviation in Europe.

But I would argue that Europe, especially has actually a lot of opportunities to try to eliminate short haul aviation flights. So this brings me to the O'Leary chapter on aviation. And it's just worth noting what the history of policy actions are on aviation. In 1997, the Kyoto Protocol asked all countries to reduce their greenhouse gas emissions by 5%, from 1990 to 2012. The Kyoto Protocol was never brought before a vote to the Senate by the Clinton administration in the United States because they thought or knew that it would fail in the Senate.

When President Obama became president in 2008, one of the initiatives to try to limit greenhouse gas emissions would be Waxman-Markey bill, which apparently included provisions for aviation, but that actually did fail in the Senate, even though it passed the House. In 2012, the European Union introduced an emissions trading scheme, but preemptively in 2011, the US Congress passed a prohibition act for the United States never to join into the same trading scheme as the European Union.

And in 2016, the EPA found that under the Clean Air Act, greenhouse gas emissions did endanger human health, which is what the Clean Air Act protects against. At the same time in the International Civil Aviation Organization developed CORSIA, a carbon cap and offsetting scheme for 2020. In 2017, they adopted a CO2 standard for aircraft, essentially kind of a greenhouse gas emissions limit for planes. And in 2017, the EU decided this only applied to intra-EU flights.

The reason also why I want to focus on global aviation as a policy issue, is that aviation and shipping are not included in the Paris Climate agreements in 2016, which is to say, it's one of our fastest growing sectors of greenhouse gas emissions but we actually don't have an international policy to try to limit these emissions. This, perhaps, brings into a question, is international policy the right way to tackle this problem? The O'Leary chapter I think provides some really interesting ideas for policy options.

The options include improving the efficiency of the vehicles themselves, trying to use biofuels, presumably where those have carbon capture-- that the carbon is captured or utilized or stored. We could try to change our operational measures, increase the efficiency of the system itself to reduce greenhouse gas emissions, or we could simply try to reduce our demand.

And so we translate these various options into US policy options that could include a carbon tax, including aviation emissions. We could specifically increase taxes on aviation, just like we tax other things that have high social impacts, like liquor, guns, and cigarettes. Or we could introduce an emission standard for planes to say that only planes of a certain efficiency are allowed to take flights to the US.

We could require or encourage the use of biofuels for planes. We could try to reduce emissions at airports, such as in airport operations themselves, or reducing taxiing time, that it's like idling for trucks. We could ask airlines to engage in voluntary emissions reduction measures. We could enable or encourage less flying as a demand reduction measure. Individuals could purchase high quality offsets-- this is what MIT is pursuing as a net zero strategy. Or we could try to reduce our freight emissions.

And so this is something I want to discuss in the class when we meet, which is, is aviation a moral or individual issue, and does that actually translate into a policy issue? I would argue there are two schools of thought. The first one argues that aviation is a red herring, a canard or a waste of time for policy analysts to talk about. And some of their arguments are these different lines.

First they argue that our individual emissions or concern about our individual emissions or individual carbon footprints is essentially the product of a corporate marketing campaign from BP or British Petroleum in the 1970s and 80s. That's been well documented. And of course, another line of thought is that 70% of fossil fuels have been sold by 30 or so companies. You can see that news headline in the *Guardian.* And so they blame corporations for these emissions from aviation or other activities rather than consumers.

And of course, there's one other line of thought that individual actions can demotivate people towards larger collective actions. You spend all your time thinking about recycling or bicycling or vegetarianism, you may have less time to participate in larger policy or social organizing. I would actually disagree with that, but some people also have well documented-- Shahzeen Attari at Indiana University has documented how people are very bad at judging the effects of their actions, whether or not they are changing lightbulbs or engaging in energy efficiency, or buying an energy efficient laptop. People just don't really understand necessarily how much implications or how much effect their actions have.

I would argue that we spend a lot of time talking about, let's say, bicycling or vegetarianism or consuming less, then we completely offset that by taking a long flight to another continent. And finally, there's one school of thought that COVID has shown us that individual actions aren't that effective. We didn't reduce greenhouse gas emissions that much during COVID even though we didn't fly and that we need larger policy change. So these are all arguments why policy changes are more important than individual action.

Another school of thought, you may have heard my skepticism about some the arguments, is that addressing aviation or taking individual action is necessary and essential. We can blame fossil fuel companies for selling products to consumers, but we are consumers. Every single day, everything we buy, eat, travel, and essentially use fossil fuels. I would argue that there's a strong equity component, especially for people watching this in North America or Europe where we are relatively rich, developed, and prosperous.

Rich countries consume much more than poor ones. Rich people consume more than poor people, even in poor countries. So there's an equity issue between-- we're arguing that we don't have to take action. Is that a privilege for us to be able to argue that? Another problem is that aviation is going to be very hard to decarbonize. We don't currently have a lot of technological options to reduce the emissions from aviation.

There has been some discussion of electric flying, electric planes. Those will only be able to go short haul distances. I'll talk about that more in the next lecture. But also, on a more important social level, I would argue that most people want to participate. Most people want to try to do the right thing if they know what that is. But another thing is that as advocates, if we're trying to advocate taking action on climate change, there are research findings, again, from Shahzeen Attari's group at Indiana University, that advocates are not taken seriously unless they abide by the advocacy.

In other words, we can say that we'll try to reduce greenhouse gas emissions. But if we are not demonstrating that we're willing to do it ourselves, people will actually take our advocacy less seriously. To give you an example, I think every time Prince Harry flies to a climate change conference in a private jet, the first thing newspapers and some people will say is, oh, look, he's flying a private jet. He doesn't even understand what his actions that are resulting in greenhouse gas emissions. Why should we listen to him talking about reducing greenhouse gas emissions or saving the environment?

And of course, from an ecological or physical basis, our consumption expectations cannot grow infinitely unless you believe that human ingenuity will engineer our way out of any environmental problem that we create. So I would summarize these arguments as arguing for individual action, not over policy action, but to complement policy action. I think we can have this debate, but it's also quite possible that we need individual and policy action together.

This brings me to the Sheller paper. And the reason why I assigned this paper, the title is Racialized Mobility Transitions in Philadelphia, Connecting Urban Sustainability and Transport Justice. It's a 2015 paper. It describes Philadelphia, a city I know well, where I used to live. But it's also important to notice that some of the things that they talk on the paper, or Sheller talks on paper, you can simply substitute transport justice for energy and it would tie back to a lot of the justice concerns we talked about a few classes ago.

And so I want us just to put these analogous questions out there for discussion in class. How do we think about our transition to lower emitting transportation technologies? What would we have to do to make these technologies equitable, fair, and just? Sheller does, I think, a really good job of arguing that for transportation transitions already occurring in Philadelphia, like from cars to electric vehicles, or from cars to bicycling and walking, they are not equitably distributed among the population.

You have gentrification happening to Center City. You have young, white people accessing bicycling and walking and subway modes more, and the bus system being relatively ignored. And also, people of color or Blacks not necessarily being seen as bicyclists, or perhaps their bicycling is seen as something necessary or because they cannot afford a car. This is to say that how people use cars, electric bikes or bicycles, subway, light rail, walking and buses, are all quite heterogeneous and distributed. People don't use the same modes, and in many cases, their use of different modes is not necessarily fair, equitable or just.

So the last thing this brings into question, tying us back to cities, is are land use and living patterns implicated in this? The reason why transportation and mobility is a superpower is that it enables us to live in different places and allows us to have different patterns of living. But as we know, cities like Philadelphia and Boston are highly segregated. So if we're talking about transportation and trying to decarbonize transportation, are we willing to tackle our implications for our land use and living patterns if we want to give people equal access to the superpower of mobility?

This brings me to the Mazmanian chapter, again, something we'll discuss in class. This article I've always liked, if only because it simply describes how Los Angeles has been pursuing clean air over a 50 or 60 year period. And it says that the saga to achieve clean air has spanned three different epochs. And the saga of making long term changes in the automobile system or land use or regional governments are all important questions for us to think about as we think about cities tackling climate change.

We need to ask ourselves, what changes do we have to start making now? But the epochs also show you that some of those efforts haven't been sustained over time because some weren't politically popular. The question is, how do we sustain the changes and efforts over a long period of time? As I said in the last lecture, the California Air Resources Board is one of the most aggressive agencies in the world, helping to shape vehicle efficiency standards across the world and for global automakers, as far flung as Korea or Germany.

But even in this chapter, you can see that the city of Los Angeles, the regional air quality management district, the California Air Resources Board, have not always been able to achieve all the things they wanted to, especially in terms of land use. And so on Tuesday, we're going to talk about how to achieve justice, fairness, and equity in different urban modes of transport. And I'll argue that it'll help you to think about the various readings from previous classes to do this exercise.

For all the modes in the slide on the Sheller article, you should be able to argue for the existing status quo or trajectory of the system we have, or argue for radical changes to achieve lower emitting modes of transportation. I'll let you decide which ones are the status quo and what you consider radical changes. But the point of this exercise is to do-- you may have heard this quote, "The test of a first-rate intelligence is the ability to hold two opposed ideas in the mind at the same time, and still retain the ability to function." This is a quote attributed to F. Scott Fitzgerald, though there's many other similar quotes.

What I like about this quote, I never read the second part, which is "One should, for example, be able to see that things are hopeless and yet should be determined to make them otherwise." And so this is the crux of the problem for land use and cities. We know cities are big and hard to change, but we can also see the transportation system is clearly linked to the entire built environment. And it seems like a hard system to change, but we should be determined to make the system change because it dictates so many other aspects of city life. Thank you very much. I look forward to speaking at the next lecture.