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Editors: Lisa Hudson-Bushart | FFG, Johannes Riegler | FFG

DUT Driving Urban Transitions

EUROPEAN PARTNERSHIP

Co-funded by the European Union

Imprint

Driving Urban Transitions Partnership
Website: https://dutpartnership.eu/
LinkedIn: https://www.linkedin.com/company/dut-partnership/

Design and Layout
Front page: HAUS
Text: Tina Cihal

Photo credit
Front page: In order of appearance: Johannes Riegler, purchased image from iStock, Mariborska kolesarska mreža, Barkarby Science AB, Jan Khur, Julie Hrncirova, Supergrätzl Lichtental

November 2024

Reducing emissions caused by transport using costless optimisations

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Abstract

In this document we present what can be done to reduce emissions and decrease transport cost in urban and suburban areas without having to use major funds for investments. We present our social taxi service, which is dedicated mainly for elderly adults and people with disabilities as an example of optimisations that have been made. We show how to calculate the carbon footprint of transport, why moving to electric or hybrid vehicles may not give anticipated results, and how to avoid actions that can actually make the carbon footprint larger than before. We also show how emissions data can be collected in transport industry or any other company, which uses mechanical vehicles for transportation. We analyse numerous ways to reduce emissions, divided into two major categories – driving and scheduling. We discuss certain computer science problems, including travelling salesman problem and convoy effect, which have a huge influence on transport efficiency.

Key lessons:

1. Learn how to measure or estimate your environmental impact
2. Always assess new solutions in terms of this measurement and take nothing for granted
3. Sometimes best improvements require no investment
4. Your customers can be more flexible if you offer them more sustainable solutions
5. Cooperation with other entities is key to success

Our company is running a transport service dedicated mainly to elderly adults and people with disabilities under the name of „social taxi". The main goal of this initiative is to provide them access to different kinds of services, like healthcare, culture or social events that happen in our towns. Public transport has been improved in the recent years, but for our customers using it is either very inconvenient or even impossible, due to their health issues. We want to bring them out of transport-related social exclusion. We operate in the two biggest towns in Kuiavian-Pomeranian region in Poland – Toruń and Bydgoszcz, serving almost million citizens and also operating in suburban areas, where there is actually no public transport at all.

Urban transformation

All kinds of resources are limited. The more our urban areas become friendly for pedestrians, cyclists, people using micro-mobility devices and public transport, the harder using own cars becomes, so more and more people don't need a car. Is that good news? Of course! But we have to keep in mind that many people, who currently rely on their families, friends and neighbours to get driven somewhere will have bigger and bigger problems with finding someone, who not only has time to drive them, but who also owns a car. Therefore, our services are becoming more and more important every year.

Green transformation

We obviously want to get greener all the time, but our first ideas turned out to be very expensive and ineffective.

We run a fleet of 14 diesel-powered cars with very average fuel consumption. We got an average of about 7.1 litres per 100km of city driving in real conditions (not according to any standards, that tend to give numbers, that are not achievable in real live). Our first idea was to replace diesel cars with hybrid or electric - and it turned out, that the cost of this operation is not the biggest problem. We will explain options, and show you, why those options turned out to be inadequate.

Failure in this field forced us to find other options to achieve similar or even better results at much lower cost. Our achievements were quite surprising for us. We believe that many companies and organisations can benefit from our solutions.

How to calculate carbon footprint in transport ?

The most important and neglected issue in making our businesses more environmentally friendly is actually counting how much carbon dioxide we emit. Without it assessing our actions is just impossible. It might get very complicated if our company uses highly processed materials, but when talking about transport, the most obvious source of emissions is the energy source we use. This makes our calculations rather easy, because carbon dioxide emission is proportional to the amount of fuel used. If we know the amount and type of fuel, we can calculate our emissions.

Here is a simple table showing this:

Fuel type	kg CO_2 per litre
Coal	*3.00
Gasoline	2,34
Diesel	2,69
LPG	1,52
LNG	1,24

* on average, depending on carbon content

We can see two important things: First, the calculations are really simple. If our cars burned 100 litres of gasoline, we emitted 100 * 2.34 = 234 kg of CO2. Second - the less carbon we have in a fuel molecule, the lower is the emission of CO2.

But there is one important factor to consider. Every type of this fuel has a different energy content. One litre of diesel fuel „contains" much more energy than one litre of LNG (liquified natural gas). Most papers present CO2 emissions per kWh, but we believe that it would make this comparison useless, as we cannot directly „extract" energy from fuel. In transport, we need cars. Electric motors are far more efficient than any internal combustion engine, and within this category compression ignition engines (diesel) are more efficient than spark ignition engines (petrol). LNG or LPG emit less CO2 per litre, but their energy content is much lower than petrol or diesel, so emission per kWh is lower, but not in such a spectacular manner.

The most problematic thing is calculating how much carbon dioxide emission we are responsible for, when we use electric energy. It actually heavily depends on where we live (losses on power lines are really significant!), what primary source of energy is in our country (hydropower and nuclear power are not causing CO2 emissions, while coal power plants emit quite a lot of it), and even the time of the day and year (to determine percentage of energy from highly variable renewable sources, like photovoltaics or wind turbines). The only reasonable way is to use an average as a meter.

In the following table we can see average emissions in grams CO2 per one kilowatt-hour (kWh). As you can see, the difference between countries can be as big as 30 times! What works in one country can be useless in another. Therefore, it is crucial to do the calculations yourself in your case and do not rely on copying other ideas without checking if the initial parameters are similar.

Country	gCO_2 per kWh
Kosovo	895
Poland	662
China	582
Germany	381
Unted States	369
Italy	331
United Kingdom	238
Spain	174
Portugal	166
Austria	111
Finland	79
Sweden	41
Norway	30

Initial concept failure?

In the beginning of this chapter, we would like to point out that there is still a probability, that solutions that we rejected, will work great for you. We encourage you to think about your own company or organisation while reading this and the next chapter. Maybe in your context you will find our initial idea much better suited!

Our first concept was replacing our cars with electric vehicles, which seems to be the most obvious way of going green. First problem we encountered was - of course – the cost of this operation. We have 14 cars, which could carry at least 7 passengers each. The cost of new vehicles of this kind was at least 65 thousand euros per car, which would mean a total expense of almost one million euro. We are a self-financing social enterprise offering our services for people with disadvantaged backgrounds, so it was simply impossible to go for this option. Before we started looking for grants, we checked the option more closely.

Our cars consumed on average of about 7.1 litres of diesel fuel per 100 km. This means that per 100 km we emit about 19 kilograms of CO2. Then, we took the cheapest 7-persons electric vehicle for a test drive in similar conditions. It used about 25 kWh per 100 kilometres. In Poland, where we are based, this means an emission of 16.5 kilograms CO2 per 100 kilometres. So, after a 1-million-euro investment in so-called „zero-emission transports" we would decrease our carbon dioxide emissions by only 13%. That is pure nonsense.

However, we did not give up. Our next idea was to take electricity from renewable sources. A photovoltaic farm should work quite well, so we started calculations. Unfortunately, we would need two sets of cars or a huge energy storage system to be able to charge our cars - we serve our customers in the daytime, and not at night. Moreover, we would need an enormous amount of installed photovoltaic power, to cover our demand in the least sunny months - especially in December. We would need about 700 kWh daily, so in December we would need about 7MWp, which is insane. For March to September, it would be much better - only about 2MWp, which is still a lot (about 1-million-euro investment, not taking real estate into account). So, the idea of electric cars was of no use for us.

Reasons for this being:

1. We needed 7-person cars, which are much more expensive than regular

2. Poland has an extremely high carbon emission per kWh of electricity, in countries with lower emissions per kWh (like France or Sweden) it would be much better

3. We work in the daytime, so we cannot charge directly from photovoltaic power (it would be perfect if we operated mainly at night)

4. Poland is quite far away from the equator; with lower latitude (like Spain or Italy) we would get much better photovoltaic efficiency, especially in winter.

How we gathered our data?

Our data gathering consisted of two elements per car:

- driver's smartphone

- Bluetooth OBD2 dongle

OBD2 (On-Board Diagnostic) is a mandatory system in every modern car (diesel after 2003 and gasoline after 2001). It provides engine parameters that can be used for diagnosing engine malfunctions, but we found that some parameters can provide us excellent information about current fuel consumption. These parameters, depending on particular make and model of vehicle were:

- injection time

- injection mass

- air-to-fuel ratio

- air mass

- engine temperature

- engine RPM

- accelerator pedal position

- car speed

We connected our cars to the driver's smartphones using cheap (10 euro) Bluetooth OBD2 dongles. This way, our custom app on the smartphone could gather vehicle information in real-time and send them, alongside with GPS coordinates, to our server.

We cross-checked these values with odometer readings and fuel bills. These gave slightly different results, but they were proportional with values between -5% to +15%. So, we adjusted them on a single car basis.

This allowed us, to analyse our records retrospectively in order to find out techniques to save fuel.

How can you gather your own data?

Although the equipment we used was really cheap and basic, custom software and analytic skills are not, but you probably do not need them. You can adjust our findings to your cars. Probably all modern cars can display current fuel consumption. If you can find a flat, empty road in a non-windy condition, you can check the consumption of your vehicle at 30, 50, 70 and 90km/h. You can also check the hourly consumption when the vehicle is standing - when engine is cold, warm, AC is on or off, and heating is on or off. Then you can decide which factors are important for you, and which are not.

Two categories of optimisation

There are two categories of optimisation - driving and scheduling. The driving category is much easier to implement but does not give as spectacular results as the scheduling category. We will go into details on this in next chapters.

Driving optimisations

Tires and pressure

One of our models accepts different tire pressure for different load types - between 240 and 300 kPa. Of course, we are unable to inflate and deflate tires all the time, so we need to set an in-between value. Between highest and lowest pressure value we got fuel consumption difference of about 4%, which was just above statistical error. Higher pressure meant lower fuel consumption - so we decided to go towards higher values and set it at 280 kPa.

But at the same time, we tested different tires. Fortunately, since a few years, EU forced tire manufacturers to put an efficiency label on their tires. From our research there is a very noticeable difference between E class efficiency and B class efficiency: somewhere between 0,5 and 0,7 litres per 100km - almost 2kg of CO_2 every 100km!

Currently we buy only A and B class tires. Even if we did not look at a low environmental impact, it is much more economical to buy tires that are more efficient; despite their higher price.

Acceleration and deceleration

It is a quite common knowledge, that rapid acceleration consumes a lot of energy. Some of our new drivers could consume over 70% more fuel, until they were taught eco-driving habits.

On the other hand, very slow acceleration is also increasing energy consumption. Drivers accelerating very slowly, up to 1500 or 1700 rpm, have about 20% more fuel consumption. Why is that? The slower we accelerate, the longer we do it.

Driving speeds and wind speed

One of the most believed misconceptions is that when a car is driving with constant speed, the slower it goes, the less fuel it burns. This is true, but only between about 50-70km/h (depending on the car), which is the most efficient speed. Below this threshold the slower we drive, the more fuel we consume.

In city driving it is usually worth selecting longer but faster routes, as the usual travelling speed is in the optimal range, and there are much less stops than on small, residential area streets.

On the other hand, when driving outside of town, slower routes are usually more efficient than multi-lane motorways. On our cars we have an almost 80% increase in fuel consumption between 90km/h (which is the legal limit outside towns in Poland) and 140km/h (which is the legal limit on a multi-lane motorway in Poland), and most of this increase is between 120km/h and 140km/h.

Therefore, we limit the speed for our cars to 110km/h for minivans and 120km/h for cars.

This huge increase in fuel consumption is caused by aerodynamic laws - aerodynamic drag power is proportional to speed to the cube. That means, that it is unimportant at low speeds, where e.g. rolling resistance is much higher, but gets very important from above 100km/h. Power of aerodynamic drag is almost 3 times higher at 140km/h than at 100km/h.

Really important here is that the speed is considered as airspeed. If we drive 100km/h and get 40km/h of wind facing the front of our car, we get drag that is almost as big, as if we were driving 140km/h with no wind.

We recommend our drivers to reduce speed from 120km/h to 100km/h when going against strong wind on the motorway, which gives us a huge reduction in fuel consumption.

Air conditioning and heating

The more efficient our cars are, the more overhead we have on air conditioning and heating. What we especially want to avoid is a car with the heating completely cooled down and the cooling completely heated up. Therefore, when one driver ends his duty and the next one starts his new shift, we ask them to pass the car on with the proper temperature. It can save us about 1 litre of fuel at every driver's switch.

When driving with passengers, we always have AC on when needed. But when the driver was returning from a distant location without passengers - without AC but with open window, we noticed a drastic increase of fuel consumption (over 15%) - so we decided against driving with open windows and AC turned off. In city driving, due to lower speeds it could potentially be the other way around, but we do not have data to confirm this.

Parking

Continuing from the previous section - it is very important to park in the shade when it is hot, and in the sun, when it is cold. During the 15-minute breaks that our drivers have, the difference can be seen on level of 0.2 – 0.3 litres of fuel.

Another important consideration is having parking in a place, that does not require going far to serve your customers.

Car weight

It is widely known that you should not carry unnecessary weight in your car, as it increases your fuel consumption. We did not test this directly but we can compare routes with and without passengers. With 6 passengers, if we are adding about 30% to the weight of the car with driver, the fuel consumption was increased by about 20%.

Scheduling optimisations

Join rides, don't separate them

When we need to drive to several places during the day or week, we should aggregate to achieve two goals:

1. Using a car with warmed-up engine and comfortable temperature inside, which saves fuel and carbon dioxide emissions

2. Possibility of distance reduction

In most cases, when we need to visit many locations from a point, that we will call later our „base", total travelled distance will be higher if we go

Base -> Point A -> Base -> Point B -> ... -> Base

than if we go

Base -> Point A -> Point B -> ... -> Base

It is not only logical, but it can be proven using a theorem called triangle inequality, which states that the first route cannot be shorter than the second one.

Saving distance means saving fuel, saving fuel means reducing carbon dioxide emission.

Travelling salesman problem

What can we do when we have multiple points to visit? Which route should we take? Is there a software for this? Unfortunately, this problem is hard. Actually NP-hard, as we call it in computer science. This means if we have many points to visit, the number of possible routes to check becomes enormous, and there is no other way to do it efficiently because the number of possible permutations of N points equals N! (N! = 1 * 2 * 3 * 4 * ... * N). 10! is over 3 million, 20! - over 2 quintillion.

Does this mean that we cannot find an optimal solution? Yes and no. In a formal sense, it is very hard, but it is quite easy to get a solution that is very close to optimal. It can be easily done with a simple observation.

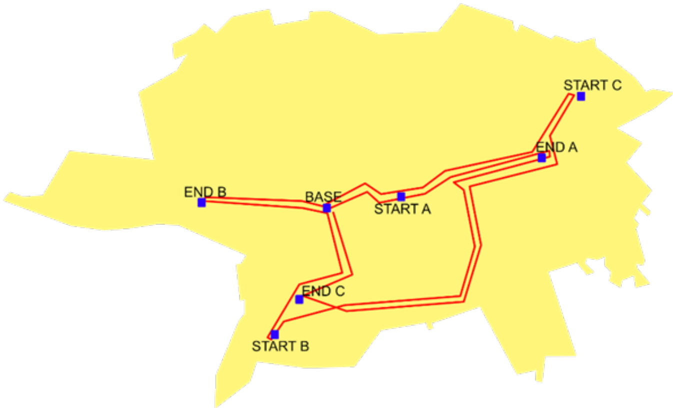
If we have 9 points, we should check about 400 000 routes. But if we can divide our 9 points to 3 groups of points that are close together, we can find best route in every group. It is just 3 routes per group if we ignore one-way roads and assume that route A -> B -> C is almost the same as C -> B -> A. So, we find the best route for all of the 3 groups and between those three groups. This is 12 short routes in total, over 30 times less than standard.

Our task seems to be complicated for a computer, but when we visualize it on map, one can see the close-to-optimal routes, while a random route will be several times longer. So, if we do not want to use sophisticated IT tools, it is usually enough to just have a look.

We would like to point out, how planning is important. Using „first come, first served" methodology is a huge waste of energy.

We present you a simple example of what can happen, if the order is changed.

Here we have 3 simple routes: A, B and C, which start and end at our base. This is a real-life example in Toruń, our hometown.



Changing the order to A, C, B gives us almost a 50% decrease in total used time and distance !

Alternating routes

What we found to be most wasteful were similar transports from one place to another. In our case, it was most visible with driving elderly adults to rehabilitation. It takes about an hour for a patient to do all exercises and later we have to transport them back home. Patients from the same district usually go to the same rehabilitation facility. Initially we drove them, and waited for them. It was very efficient in terms of emissions, but highly inefficient economically because our employees had nothing to do during this hour. We changed it and gave them other routes after dropping the patient off, and them or another driver came back to pick up the patient and drive them home.

The real game changer was when we were able to have several patients from the same neighbourhood having rehabilitation one after another. Except for the first and last ride the plan was pretty simple. When driving the patient from their home to the rehabilitation facility, the driver picked up another patient from the rehabilitation facility and drove them home. Then, the driver picked up another patient from the same neighbourhood, and drove them to the rehabilitation facility. This way we had almost 100% of car utilization. Alternation was the key - while one patient was exercising, the previous one was driven home, and the next was driven to rehabilitation facility. This gives us about 60-70% increase in efficiency, which means lowering emissions by about 70-80%.

This resulted in low emission and low cost for us. There was only one problem. We had no impact on the scheduling. And this solution works only if we have similar rides on a regular schedule.

Group and cooperate

In some cases, you can group rides yourself. In our case, many our customers just wanted to get somewhere and an exact hour was not very important. In this case, we could do the scheduling ourselves. First, we did it manually, later we used an AI algorithm to do it more efficiently. However, there is a large group of customers, that want to be somewhere on a specific time for an appointment. Those customers could not change the timing by themselves.

The only solution here turned out to be a cooperation with institutions that our customers are driven to. Before we started talking to them, we needed to figure out, what could be a „selling point" for us because we wanted something from these institutions, initially thinking, that we are giving nothing in exchange. We were wrong about it. What we actually offer is bringing patients on time, making sure they come to the appointment, and if someone cannot get there, we can call the next person on the list and potentially bring this person instead. It seems, that this is much more convenient for rehabilitation facilities (and similar institutions) than we expected.

We highly recommend talking with institutions regarding cooperating – it can improve your efficiency, because it is quite likely, that you can increase their efficiency too.

Rescheduling to Avoid the Convoy Effect While Preventing Starvation

When managing a large number of tasks, where the order of execution is flexible, it is common to aim for an efficient schedule. To optimise the average execution time, the general strategy is to prioritise shorter tasks first and leave the longer tasks for later. This approach is effective even when the specific task times are unknown - just choosing the closest or shortest task is often the best option.

However, one challenge with this method is the risk of task starvation. In a situation where new tasks are constantly being added (which happens frequently in real-life scenarios), a very long task might get postponed indefinitely because shorter tasks are always prioritized. This is known as the convoy effect, where the long task is stuck behind a "convoy" of shorter tasks.

To prevent this, we can make a small adjustment to the scheduling process. Instead of only considering the task duration, we also factor in how long the task has been waiting. Specifically, we reduce the task's duration by 10% of the time it has already spent in the queue. For example, if a task is expected to take 30 minutes but has been waiting for a while because shorter tasks keep getting prioritized, we will treat it as if it takes slightly less time—essentially shortening its "effective" duration—making it more likely to be executed sooner.

Time from adding a task	Task length taken to choose shortest one
When added	30 minutes
30 minutes later	27 minutes (= 30 min – 10% * 30 min)
1 hour later	24 minutes (= 30 min – 10% * 60 min)
1.5 hour later	21 minutes (= 30 min – 10% * 90 min)
2 hours later	18 minutes (= 30 min – 10% * 120 min)
2.5 hours later	15 minutes (= 30 min – 10% * 150 min)
3 hours later	12 minutes (= 30 min – 10% * 180 min)
3.5 hours later	9 minutes (= 30 min – 10% * 210 min)
4 hours later	6 minutes (= 30 min – 10% * 240 min)
4.5 hours later	3 minutes (= 30 min – 10% * 270 min)
5 hours later	0 minutes (= 30 min – 10% * 300 min)

As you can see, as time passes, task will get more and more priority. After five hours it will be prioritized before every new incoming task, even 1 minute long. Of course, you can adjust this 10% constant to your needs – it can be 5% or 30%, but from our experience 10% is a good starting point.

Future of our project

From the beginning we used genetic algorithms that are one of the branches of Artificial Intelligence. Currently we are exploring this topic very intensely, because the AI impact on any optimisation problem can be huge. However, we need to be very agile and still use both AI and standard algorithms to keep costs at bay. We are also working on transforming our project to social franchise to make it possible to use our findings, experience and software not only in one region of Poland, but more globally.