# DAIPEX

## EINDRAPPORTAGE

**Data and Algorithms for Integrated Transportation Planning and Execution**

TKI DINALOG
Dutch Institute for Advanced Logistics

# SAMENVATTING

Every day, all around the world, transportation companies find that the execution of the transportation plan they carefully built does not follow, well, the transportation plan they carefully built. Rather than a perfect match of the execution with the transportation plan, they observe a relentless stream of disturbances leading to violated time windows, unnecessary waiting time, drivers working overtime, violated driving limits, and underutilized transportation capacity. An important reason for this is that when building a transportation plan one does not know how long traveling from one place to the next will actually take. It on average may take 45 minutes, but it can also take a bit less and it can also take much longer. This situation raises the questions that were the motivation behind the DAIPEX project: How do you best handle uncertainty in transportation? How do you generate a transportation plan that is robust against travel or loading or unloading taking longer than expected? How do you make sure that such a plan is not too expensive? How do you find the right balance between direct cost of a plan and the robustness of that plan? Robustness leads to lower overall cost and thus higher profitability as one for example does not have to pay a penalty for being late or does not have to come back the next day in case a delivery was missed. It also leads to a better service level for customers and thus to better customer retention, which again positively influences profitability. Still if you invest too much in robustness you actually can end up being less profitable, which is easy to see if you imagine the extreme case where you put every shipment alone in a truck and start driving right away.

True to the name of the project (“Data and Algorithms for Integrated Transportation Planning and Execution”) the objective of the DAIPEX project was to get data and develop algorithms for integrated transportation planning and execution, where the focus was on being able to handle the uncertainty in transportation and generate transportation plans that have the right balance between direct cost of a plan and the robustness of that plan. And true to this objective we did precisely that, including building an application that allowed us to test the whole approach on real-life data. The result is that having this data and these algorithms taking uncertainty into account gives an up to 10% cost reduction and an up to 65% reduction in missed time windows.

The DAIPEX project tackled the questions raised above from the following four major angles: Data, Algorithms, Planning, and Execution. Using the broad practical transportation experience in the consortium from Jan de Rijk Logistics, H. Veldhuizen Transport, DHL Global Forwarding, Ernst Opus V, and Quintiq, we realized that there are indeed two, integrated, ways to help handle the issues at hand. One is to be reactive and have great execution. The other is to be proactive and have great planning. We developed algorithms to do continuous Transportation Optimization, capable to 24/7 react to all kinds of disturbances, from travel times taking longer to drivers calling in sick and from service times taking longer to trucks breaking down. For this to work well, you not only need the right algorithms, you also need the right data like where your trucks and your shipments are. All of this was implemented in practice by our partner Quintiq.

Great reactivity brings a lot of value, but has its limitations. If you for example have a transportation plan that puts shipment 1 in truck T1 and shipment 2 in truck T2, and looking at how the execution of the plan goes you ideally would have liked to have that switched, you generally cannot do that once the trucks are underway. So only being reactive is not enough and you need a great robust transportation plan to begin with. To get such great robust plans we started by getting and analyzing travel time data. For this we used the vast amounts of travel time data and the expertise on that data that TomTom has, combined with the expertise from the researchers at Eindhoven University of Technology. TomTom has access to a community of 500 million devices globally. These devices leave so-called

GPS breadcrumbs saying where the device is and at what speed it is traveling. To date 18,800,000,000,000 breadcrumbs have been collected, with 10,800,000,000 being added every day. This is based on 11,490,000,000 individual trips a year for a total of 271,000,000,000 kilometer, which is 742 million kilometers per day. A way one can get to this data is through TomTom's Traffic Stats application. A first thing we investigated was whether we could use all this data to make predictions on how long a certain trip would take. The idea was that if you can do such a prediction, you can use that when generating a transportation plan. Such predictions however turned out to be very hard to do. Travel times are dependent on the day of the week, the month, the time of the day, on weather conditions, on roadwork. Finding explicit patterns and relations proved to be hard, except in extreme cases like when it is snowing. This makes it hard to make a single prediction, which supported the primary line of research where the Traffic Stats data was used to build time-dependent travel time probability distributions of how long traveling between two points in the network is going to take depending on the time you are traveling. These probability distributions state things like that when leaving at 7:00 on Monday there is a 5% probability that travel will take 43 minutes or less, and a 10% probability it will take 43:46 minutes or less, etc., while when leaving at 13:00 on Thursday there is a 5% probability that travel will take 42:30 minutes or less, and a 10% probability it will take 42:45 minutes or less, etc. The next step was that we developed optimization algorithms that use these travel time probability distributions to build transportation plans. We finally brought everything together and built a prototype application that allowed us to test the whole approach on this real-life travel time data and real-life transportation data we obtained from our logistics partners.

The result we found was that the technology we developed gave an up to 10% cost reduction and an up to 65% reduction in missed time windows. The cost reduction was a mix of distance driven, working time (including waiting time), number of used vehicles, and penalties for being late. This means this is not just about decreasing cost, but also about decreasing $CO_2$ emission, decreasing required working capital, and increasing potential to generate new business. The reduction in missed time windows of course directly translates to increased service levels. Interestingly we found an effect we had not thought of beforehand where, in case being late is rather inexpensive, the algorithms in fact smartly plan for more missed time windows than when calculating with deterministic travel times. This allows to reduce distance driven and/or vehicles used and/or working time which outweighs the increase in penalties for being late. In case being late is expensive the opposite occurs, i.e., the generated plan uses more distance and/or more vehicles to decrease the number of missed time windows, thus leading to the wanted improvement of service levels.

Looking at the future we believe that the combination of Data Science and Optimization as we have investigated, will have a great impact on the logistics industry in the 5-10 years that lie ahead of us. We have shown that there is already a lot of data available, in this case on time-dependent service time and travel time probability distributions, that can be turned into actionable information that can be exploited by Optimization algorithms to generate better plans. We foresee that that data will be supplemented for example by travel time data transportation companies gather from their day-to-day operation, giving information of how long their trucks, with their drivers, transporting their shipments, take to go from one place to the next. More generally, both the Data Science component as the Optimization component will be improved over time, in reliability of the results, in speed, and in broadness of the approach, where for the latter you can think of handling uncertainty around the probability of the size of a shipment when you do not yet have the shipment in your possession or around the probability that a certain pickup shipment pops up in some region, so that you can anticipate truck capacity in a smart way.

## INHOUDSOPGAVE



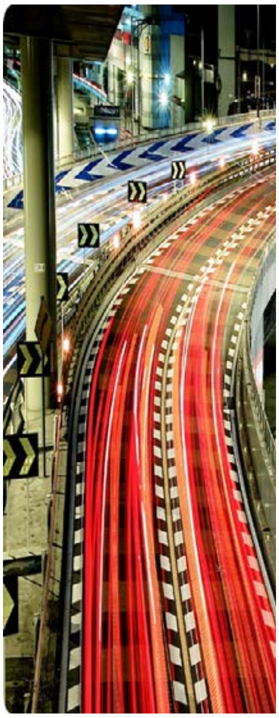
Prof.dr.ir. Wim Nuijten

"Our objective was to be able to handle uncertainty in transportation and generate transportation plans having the right balance between direct cost of a plan and the robustness of that plan."

# AANLEIDING

In the DAIPEX project we attacked the problem that in practice transportation companies often find that their day-to-day transportation execution does not follow the transportation plan they made in advance. Rather than a perfect match of the transportation execution with the transportation plan, companies are faced with violated time windows, unnecessary waiting time, drivers working overtime, violated driving limits, and underutilized transportation capacity. An important reason for this is the uncertainty in travel times and service times, i.e., you do not precisely know how long travel or loading or unloading is going to take. There is furthermore a trend in the industry towards tighter time windows, which makes it even more important to be able to correctly handle uncertain travel and service times. These problems get even more pronounced in Cross Chain Control Centers (4C) as the problem instances to solve are considerably larger, the time to find good transportation plans is reduced as the communication requirement between the different stakeholders in the process increases, and the resulting practical time windows get tighter as more synchronization is required.

# UITDAGING



The challenge we faced of how to handle uncertainty in transportation planning and execution had two main components. The first was to develop information aggregation algorithms to get actionable information on the uncertainty of travel and service times. The second was to develop transportation planning and execution optimization algorithms that can exploit that information to generate transportation plans that have the right balance between direct cost of a plan and the robustness of that plan. The ultimate goal was to help transportation companies find the right balance in decreasing their cost, decreasing their $CO_2$ emission, increasing their service levels, decreasing their required working capital, and increasing the new business they can generate. Both the development of the information aggregation algorithms and the resulting practical data collection and the development of the optimization algorithms exploiting that data and resulting in efficient and robust transportation plans was new. A further challenge we took on was to build a prototype application that would allow us to test the whole approach on real-life travel time data and real-life transportation data from our logistics partners.

# PROJECTOPZET

We aimed to develop and test information aggregation algorithms and software and transportation planning and execution optimization algorithms and software, guided by an iterative user-centered design (UCD) cycle. The complexity as well as the size of instances the software can handle, are enablers of handling uncertainty in Cross Chain Control Centers (4C), so that it will support the successful practical deployment of 4C. Software is indeed an important enabler for such centers, as they typically do not own assets, but rather coordinate assets of the different participating transportation companies. Consequently, the knowledge that a 4C brings and the software that implements that knowledge is a crucial asset of the 4C. We used the combined research and development knowledge, the combined transportation industry knowledge, and the combined software development knowledge of the consortium. From the public domain we had researchers of Eindhoven University of Technology, both from the Industrial Engineering department and from the Mathematics and Computer Science department. Consortium partners from the private domain were TomTom, Jan de Rijk Logistics, H. Veldhuizen Transport, DHL Global Forwarding, Ernst Opus V, and Quintiq.

## End-user studies

The goal of this work package is to develop practical usage scenarios for transportation planning and execution in 4C taking uncertainty into account. Based on these usage scenarios the approach is to develop a set of requirements for the transportation planning and execution software as well as an evaluation plan. The final aim is to execute the evaluation plan and show benefits in evaluation criteria like cost, CO2 emission, working capital, service levels, and potential to generate new business.

## Framework and integration

The goal of this work package is the integration of the two main components as developed in work packages 3 and 4 and the definition of a framework to govern the development of these components. The approach is to devise standard formats to communicate information between the two components like travel time distribution data, transportation planning data, and transportation solution data, so that all systems and algorithms that adhere to these formats can easily be integrated. The final aim is to effectively integrate the two components as developed in the project.

## 4C transportation planning and execution software

The goal of this work package is the development of transportation planning and execution optimization algorithms and software. The approach is to start by obtaining formal optimization problem descriptions, after which a user-centered design is used to develop and test the algorithms and software that solve the described real-life transportation planning and execution problem. Final aim is to be able to handle uncertainty in transportation and generate transportation plans that have the right balance between direct cost of a plan and the robustness of that plan.

## Transportation information integration software

The goal of this work package is the development of information aggregation algorithms and software. The aim is to develop a Complex Event Processing (CEP) engine that can aggregate transportation related information from data streams, extend CEP technology with the ability to detect and correct inaccurate and incomplete data in a multi-parameter setting, and extend CEP technology with the ability to create views on a data stream in such a way that relevant information to a view can be aggregated, but irrelevant information (in particular information that must not be disclosed) cannot be aggregated.

## Management

The goal of this work package is to guarantee the scientific, non-scientific and administrative coordination of all activities of the project, to ensure the timely realization of all project objectives, milestones and deliverables, to coordinate the production and delivery of project reports, to ensure the achievement of appropriate quality standards, and to ensure that the legal contractual obligations are met in accordance with the consortium agreement.

# RESULTATEN

The central results of the DAIPEX project were the development of information aggregation and optimization algorithms capable to handle uncertainty in transportation planning and execution. The combination of these algorithms can generate transportation plans that have the right balance between direct cost of a plan and the robustness of that plan. We built an application and used that application to test the approach on real-life travel time data and real-life transportation data. The result of these tests show an up to 10% cost reduction and an up to 65% reduction in missed time windows. The cost reduction is a mix of distance driven, working time, number of used vehicles, and penalties for being late. This means the benefit is not just about decreasing cost, but also about decreasing CO2 emission, decreasing required working capital, and increasing potential to generate new business. The reduction in missed time windows of course directly translates to increased service levels.

These results add clear value to the strength of the transportation and logistics sector in The Netherlands, in reducing cost and CO2 emission, but also in improving service levels. As there are no assumptions made about circumstances that may hold only in The Netherlands, the results are applicable across the globe, strengthening our combined competitive position. Note that our partner Quintiq has already implemented and deployed transportation execution optimization in practice, including getting the data for proper execution like the position of one's trucks and shipments. That technology is ready for deployment thus.

We succeeded in reaching over 160 companies with the DAIPEX message, both nationally and internationally, where project partners TomTom and Quintiq were very active and where they confirmed the broad industrial interest in the issues DAIPEX investigated and the results we obtained. We reached these companies, and many academics in addition, in over 90 presentations. The connection with industry is confirmed by the fact that 8 DAIPEX students and researchers are now working in industry, where 4 were hired directly by one of our project partners.

We calculated the potential value per customer per year in the following way. A transportation and logistics software and services project costs on average between €200K and €2M. The ROI period for the range of results we found in the DAIPEX project is on average 6 months. That means the benefit for a customer is on average €400K-4M per year. The estimated spend for travel time data per customer is €150K per year. Applying the same factor of 2, this is only interesting if the benefit for the transportation company is €300K or more. This brings us to a value of €700K-4.3M per customer per year. Note that in this number we are not including the value for the software and services vendor or the travel time data vendor.

DAIPEX has raised the interest of the Innovation Committee of Transport en Logistiek Nederland (TLN), which is the main

| MAATSCHAPPELIJKE RESULTATEN | |
|---|---|
| CO2 reductie | 5-10% |
| Kostenbesparing | 5-10% |
| Vermeden vervoerskilometers | 5-10% |
| | Up to 65% reduction in missed time windows |

| SECTOR RESULTATEN | |
|---|---|
| Gecreëerde toegevoegde waarde | €700K-4M per customer per year |
| Bereikte bedrijven | 160+ |
| Bereikte MKB bedrijven | 40+ |
| | 8 |

| WETENSCHAPPELIJKE OUTPUT | |
|---|---|
| Master thesis | 7 |
| Wetenschappelijke publicaties | 9 |
| Wetenschappelijke seminars, workshops, presentaties etc. | 90+ |

Dutch employer organisation in transportation and logistics, having 5500 company members. They are interested in doing a valorization project, implementing the DAIPEX results for their members. Supply Chain Planning and Optimization software vendor Quintiq and travel time data provider TomTom are also interested in continuing this path towards a commercial version of the algorithms and software developed in the project. That valorization project would start with the DAIPEX Transportation Planning application. The standard formats we developed to communicate information like travel time distribution data, transportation planning data, and transportation solution data, make that different systems, like different TMSs of different transportation companies, can easily be connected to the application. This cooperation between TKI DINALOG, TLN, and commercial partners would open up the benefits DAIPEX has shown are reachable to the transportation and logistics sector in The Netherlands.

## RESULTATEN WAAR HET PROJECT TROTS OP IS: (WE ARE PROUD …)

1 That we developed information aggregation algorithms and software capturing uncertainty in transportation by creating actionable time-dependent travel time probability distribution information.

2 That we developed algorithms that provide speed visualizations of time and location dependent stochastic travel times, derived from aggregated GPS vehicle data, capable to distinguish traffic patterns and states.

3 That we developed information aggregation algorithms and software that provide service time probability distribution information, derived from biased human provided log data.

4 That we developed optimization algorithms and software capable to exploit service time and travel time probability distribution information to generate transportation plans that have the right balance between direct cost of a plan and the robustness of that plan.

5 That we built a prototype application that allowed us to test our whole approach on real-life service time, travel time, and transportation data.

6 That we showed that the combination of the developed algorithms gives an up to 10% cost reduction and an up to 65% reduction in missed time windows. Inside this we are proud that the cost reduction includes distance driven and thus helps decrease $CO_2$ emission.

7 That we reached over 160 companies in over 90 presentations with the DAIPEX message, confirming the broad industrial interest in the issues DAIPEX investigated and the results we obtained.

8 That we generated technology with a potential value of €700K-4M per customer per year.

9 That we produced 9 scientific publications and 7 Master thesis. From the students that helped produce that output, 4 were directly hired by project partners, giving these partners well-educated employees and the students a great start of their career.

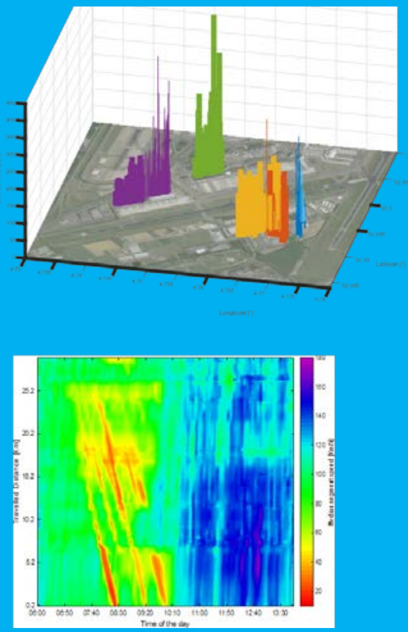
10 That we raised the interest of the Innovation Committee of Transport en Logistiek Nederland to do a valorization project, implementing the DAIPEX results for their members.

## Stochastic service and travel times

Part of the DAIPEX project was to develop information aggregation algorithms to obtain reliable location specific stochastic service times derived from human based logs, which contained inconsistencies, errors, and biases. This data was obtained from our project partners like from Jan de Rijk Logistics. Furthermore, new algorithms were developed to obtain time-dependent stochastic travel times, from aggregated GPS data, provided by TomTom, instead of the more commonly used probe data. This data allowed for a space/time visualization of speed profiles, which allows us to study patterns in real world traffic flows. The time-dependent stochastic travel times were used in the optimization algorithms and transportation planning and execution software as developed inside DAIPEX.

a)

b)



*a) Service times distribution per location and b) Space/time visualization of speed.*

## DAIPEX Transportation Planning Application


DAIPEX Transportation Planning Application

We built the DAIPEX Transportation Planning application that allowed us to test our approach on real-life travel time data we got from TomTom and real-life transportation data, including service time data, we obtained from our logistics partners. It allowed us show the described 10% cost reduction and 65% reduction in missed time windows. The core of the application is based on the Quintiq software, more precisely on Quintiq's Logistics Planner product. The standard formats we developed to communicate information like travel time distribution data, transportation planning data, and transportation solution data, make that different systems, like different TMSs of different transportation companies, can easily be connected to the application. This makes it easy to use the application for different customers than the logistics partners in the DAIPEX project. The Quintiq software is furthermore configurable, making it easy to adapt the application to different circumstances should the standard formats not suffice or should you want to change the GUI for example. The application runs via hosting and as such does not require the installation of the Quintiq software. All this makes that it can be used for future studies and as such is a logical departure point for the valorization project that TLN is interested in executing.

# ERVARINGEN

Despite the fact we had to bring in new people to replace people in the project that took on different responsibilities, both at Eindhoven University and at industrial partners, by pulling together we managed to keep the project on track. We had an issue on Intellectual Property and as such had a delay in getting the Consortium Agreement signed. This slowed down some of the work as the IP situation was not clear, but the issue was constructively solved together with TKI DINALOG, confirming the great cooperation between project partners and TKI DINALOG throughout the project.

## Open innovatie

We had a fruitful and constructive cooperation in the project, where the interaction between scientific researchers, logistics partners, travel time data vendor, and supply chain planning and optimization software vendor led to a stimulating environment where theory and practice came together. Especially these different competencies that the partners contributed helped in the cooperation. In terms of cooperation with other TKI DINALOG projects, there was a direct knowledge exchange with the 4C4More project, as DAIPEX partners participated in that project. We used results from the SALOMO project when establishing the usage scenarios and we included the Extended Single Window project as related work. We also cooperated with the DAVINC$^3$I project on multimodal transport leading to several joint publications.

## Dinalog en Topsector Logistiek

TKI DINALOG played a controlling and steering role in the project. The regular reporting moments helped to measure and realize the state of the project and to determine whether and where extra or different effort was required. TKI DINALOG played a crucial role in forming the project consortium, as they suggested to merge two separate proposals (on information aggregation and transportation planning and execution) to form the DAIPEX project. In terms of influence and follow-up of the project we mention that we shared data aggregation experience with the GET Service European FP7 Project, leading to the spin-off company Synfioo. Furthermore, DAIPEX knowledge on data aggregation will be used in the ISOLA NWO project. The DATAS NWO project in turn is a follow-up of the DAIPEX project with respect to data aggregation. Through DAIPEX Quintiq became aware of optimization under uncertainty, which influenced their messaging in that area. Finally, the interest of TLN to do a valorization project will have a positive influence on 4C and as such on an important topic like reducing CO2 emission.


Eindhoven University of Technology

## Data and Algorithms for Transport Planning and Execution

The goal of the DAIPEX project is to develop algorithms and software that can handle time-dependent, stochastic, planning problems, based on high-volume information. The challenges in this project comprised both in developing algorithms to obtain reliable stochastic service and travel times, but also in using this stochastic, time-dependent information in optimization algorithms. The service times were derived from human based logs, which contained many inconsistencies and biases. The described challenges led to the development of new algorithms to obtain travel times, depending on the time of day, from aggregated GPS data, instead of the more commonly used probe data. Also, new optimization algorithms were developed that take time-dependency and stochasticity into account. The research was done in partnership between industry partners, Jan de Rijk, Veldhuizen, DHL, Ernst Opus V, TomTom, and Quintiq and researchers from two different groups at Eindhoven University of Technology. This pushed us to strike a balance between industry demands and the development of sound, relevant research. For the industry, the developed algorithms give an up to 10% cost reduction and an up to 65% reduction in missed time windows. On the academic side, we produced 9 scientific publications, 6 conference presentations and 7 Master thesis. The experience that a fruitful balance between the industrial and academic world can be found, will be used in future projects where we will participate.

## Transportation Planning and Execution Optimization

QUINTIQ

Inside the DAIPEX project Quintiq has researched optimization algorithms to do transportation planning under uncertainty, or as we call it when communicating with our customers and prospects: “Robust Logistics Optimization”. Part of the research was the development of software and testing the software on data as provided by the DAIPEX partners. The research was mostly done around the work of 3 Master students that we hosted at Quintiq, two from Eindhoven University of Technology and one from Utrecht University. These projects allowed us to not only work with the students, but also to cooperate with their university supervisors. The technology we developed inside Quintiq for transportation execution was used as a basis for the transportation planning technology. The incorporation of the time-dependent travel time probability distributions was quite challenging, but did show the benefit our customers can obtain with this technology. One important finding to make selling this to our customers and prospects easier is that the technology can be used to reduce cost, to reduce mileage, to reduce number of required trucks. If the message would only be that one has to invest extra distance or an extra truck to get to the required service levels, transportation and logistics companies would less easily be interested. Being able to show that the algorithms smartly find the best trade-off between cost and robustness and as such can find transportation plans with less distance driven or less vehicles used is important to our customers and thus to us. We have experienced that finding a balance between doing theoretical relevant research and getting practically relevant results is not always easy to find, but if both the academic partners and the industrial partners communicate and cooperate well, that it can be done. Another experience we had was the pleasant and fruitful cooperation through and with Master students. From the 3 students mentioned above we in fact hired 2, and in addition we hired a 3rd Master student from the project who had been working with project partner TomTom. This has been a great extra benefit, besides the developed technology inside the project.

# TOEKOMSTVISIE

We are convinced that the combination of Data Science and Optimization as we have investigated in the DAIPEX project has a great future. This is not only true for the transportation and logistics industry, but holds for any industry out there. It is thus advisable for the transportation and logistics industry to stay in touch with results obtained in other industries, so as to share best practices and benefit from each other. A great way to facilitate that would be to cooperate with the newly formed Jheronimus Academy of Data Science (JADS) in 's-Hertogenbosch / Tilburg / Eindhoven, where cooperation with both JADS's research programs as with the start-up community that is being formed there holds opportunity.

As to exploiting the DAIPEX results, the path that is under investigation of a valorization project where TKI DINALOG, TLN, and commercial partners cooperate should be executed in that or an equivalent way. There is still work to be done to get to commercial versions of the algorithms that were developed and the best way to do that is by having professional software vendors work with actual customers in an actual project. TKI DINALOG can then orchestrate the project where the commercial partners will provide the services and software development expertise and TLN brings the customers to the table, together with their deep knowledge of the transportation and logistics industry.

As explained, there is a potential of multiple millions of euros of benefit per year per logistics company. These benefits can be obtained in isolation, but they are strengthened in a 4C. As such the results support the creation of 4Cs, which if we develop that knowledge and expertise in The Netherlands, we can roll out across the globe. A third group of companies that can benefit are travel time data vendors by providing the time-dependent travel time probability distributions. There's also opportunity for TMS vendors to obtain additional probability distribution information on travel and service times, based on the practice of a company at hand. We finally mention the opportunity for software and services companies in the transportation and logistics industry, an area where The Netherlands is traditionally a very strong player, with multiple very successful, globally operating companies. The DAIPEX results can help to confirm and strengthen that leading position in the world.

***"The combination of Data Science and Optimization will have a great impact on the logistics industry in the 5-10 years that lie ahead of us."***

# PROJECT PARTNERS

## PRIVATE PARTNERS

### TomTom
Travel time data vendor. Brought travel time data and knowledge.

### Jan de Rijk Logistics
Logistics Service Provider. Brought transportation industry knowledge and transportation data.

### H. Veldhuizen Transport
Logistics Service Provider. Brought transportation industry knowledge and transportation data.

### DHL Global Forwarding
Logistics Service Provider. Brought transportation industry knowledge and transportation data.

### Ernst Opus V
Services company. Brought transportation industry and services knowledge.

### Quintiq
Supply chain planning and optimization vendor. Brought software and services knowledge for the transportation industry.

## PUBLIEKE PARTNERS

### Eindhoven University of Technology
University. Brought scientific information aggregation and optimization knowledge and transportation industry knowledge.

## DUTCH INSTITUTE FOR ADVANCED LOGISTICS

TKI Dinalog is het technologisch top instituut van de topsector logistiek ter bevordering van innovatie in de logistieke sector.

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