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Collaboration in transport of healthcare related materials

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M.Sc. Thesis

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MANAGEMENT SAMENVATTING

Dit onderzoek heeft als doel om te kijken naar de mogelijkheden voor samenwerking op gebied van transport tussen de organisaties: Ziekenhuisgroep Twente, Medlon, en LabMicTA-LabPON.

ACHTERGROND

De betrokken organisaties in dit onderzoek vervoeren materialen naar een aantal dezelfde locaties. De condities voor deze transporten zijn voor elke organisatie verschillend en sluiten aan op de interne werkprocessen. In de huidige situatie is het transport voor de organisaties per organisatie geregeld. Het is onbekend of de huidige vervoerssituatie optimaal is georganiseerd en of de realisatie van een samenwerkingsverband winst op kan leveren. Om inzicht te geven in de huidige situatie en de invloed van verschillende manieren van samenwerking is het volgende onderzoeksdoel opgesteld:

"Het analyseren van de huidige transport processen van materieel, en het identificeren en evalueren van verschillende manieren van samenwerking tussen ZGT, Medlon, en LabMicTA-LabPON met als doel om de totale kosten te verminderen en de kwaliteit van diensten te verhogen."

METHODE

Om de huidige situatie meetbaar te maken is een inventarisatie gedaan naar de verschillende materialen die per organisatie worden vervoerd en de kwaliteitseisen die bij dit vervoer horen. Daarnaast is voor iedere organisatie een inventarisatie gedaan naar de voertuigen die worden gebruikt en de tijden waarop deze voertuigen beschikbaar zijn. Voor elke organisatie is gekeken naar de vaste routes die in de huidige situatie worden gereden en de klanten en locaties die op deze routes worden bezocht. Aan de hand van deze verzamelde informatie hebben zijn randvoorwaarden voor transport opgesteld om binnen de gestelde kwaliteitseisen het materiaal transport anders te plannen; de transportverzoeken waaraan moet worden voldaan.

Om de invloed van verschillende interventies te testen zijn de planningen van het materiaal transport compleet nieuw opgebouwd aan de hand van een "insertie-opbouw" heuristiek. Bij deze heuristiek worden alle transportverzoeken waaruit een route normaal bestaat opnieuw verdeeld over de beschikbare vloot voertuigen. De voorgestelde interventies in dit onderzoek zijn vervolgens aan de hand van verschillende prestatie indicatoren geëvalueerd waarbij nadruk is gelegd op de invloed op de totale kosten.

De interventies die in dit onderzoek zijn voorgesteld zijn, ten eerste, een aantal verschillende methoden voor het opbouwen van nieuwe routes. Hierbij maken we gebruik van verschillende aanpakken om nieuwe routes zo goed mogelijk opnieuw op te bouwen. Ten tweede, het beperken van de samenwerking aan de hand van een classificatie van de locaties op de routes. Hierbij wordt samenwerking alleen toegelaten voor bepaalde typen klanten. Ten derde, het implementeren van tussenlocaties op vooraf bepaalde locaties en tijden. Ten vierde, het weg laten van één organisatie uit het samenwerkingsverband. Ten vijfde, het vervangen van de huidige transport services door een externe partij. Om het aantal combinaties handelbaar te houden is gebruik gemaakt van een groepenindeling van de transportverzoeken en is in fasen de invloed van de verschillende interventies geëvalueerd.

RESULTATEN

Het uitvoeren van de experimenten heeft laten zien dat er ruimte is voor verbetering van het reguliere transport van de organisaties.

Voor de eerste interventie, waarbij we verschillende aanpakken voor het opbouwen van routes testen, zien we dat tijd een belangrijke rol speelt in de opbouw van nieuwe routes. We vinden de beste resultaten wanneer we op voorhand de locaties sorteren op vroegst beschikbare tijd van ophalen en we locaties toewijzen aan voertuigen aan de hand van minimale toename in reistijd.

Voor de tweede interventie, waarbij we de invloed van verschillende vormen van samenwerking op basis van locatietype testen, zien we dat de totale kosten omlaaggaan wanneer we samenwerking tussen de organisaties toelaten voor: alle locaties, grote locaties zoals poliklinieken en ziekenhuizen, en gedeelde locaties. Bij overige vormen van samenwerking, zoals alleen op basis van huisartsen, vinden we een verslechtering ten opzichte van de huidige situatie.

Voor de derde interventie, waarbij we de invloed testen van het gebruik van tussenlocaties, vinden we met het gebruikte model geen verbeteringen ten opzichte van de huidige situatie wanneer we frontoffices als tussenlocaties toevoegen. We concluderen dat het huidige model niet geschikt is om deze interventie te implementeren.

Voor de vierde interventie waarbij we de invloed testen van het weglaten van één organisatie zien we dat ZGT de verbindende partij is die ruimte geeft voor verbetering. Wanneer we ZGT includeren in het samenwerkingsverband vinden we een verbetering in de totale kosten. Dit geldt voor de samenwerkingsverbanden {ZGT, Medlon, LabMicTA-LabPON}, {ZGT, LabMicTA-LabPON}, en {ZGT, Medlon}. Wanneer we alleen samenwerking toelaten tussen Medlon en LabMicTA-LabPON zien we, ondanks de sterkste gelijkenis in motivatie voor transport met behulp van voertuigen, alleen scores die gelijk of slechter zijn aan de huidige situatie.

Voor de laatste interventie zien we dat een volledige uitbesteding van regulier vervoer aan een externe partij een aanzienlijke impact heeft op de totale kosten ten opzichte van de huidige situatie en zien we deze impact niet terug wanneer we kijken naar kwaliteit.

UITWERKING RESULTATEN

Door het aggregeren van de eerder bepaalde groepen kunnen we voor de interventies die positieve invloed hebben een aantal scenario's schetsen voor samenwerking op gebied van regulier transport. Deze scenario's bieden een mogelijkheid tot verbetering ten opzichte van de huidige situatie.

Scenario 1: Samenwerkingsverband tussen de drie organisaties

In het eerste scenario betrekken we alle drie de organisaties in het samenwerkingsverband en zien we, wanneer we kijken naar de totale kosten van het regulier transport, dat we de grootste besparing vinden wanneer we samenwerking toestaan voor alle locaties op de routes.

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Tabel 1 - Reguliere transportkosten voor verschillende typen samenwerking

In de experimenten vinden we de beste resultaten door te sturen op een zo kort mogelijke toename in reistijd. Dit zien we terug in de totale tijd dat voertuigen onderweg zijn. Onafhankelijk van het type samenwerking valt hier winst te behalen voor de organisaties. Bij geen samenwerking valt een nagenoeg gelijke winst op de totale rit duur te behalen als bij volledige samenwerking.

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	100,0%	91,9%	97,7%	86,1%	86,0%

Tabel 2 - Reguliere transportduur voor verschillende typen samenwerking

Voor het aantal kilometers zien we de tendens dat wanneer samenwerking van toepassing is het aantal kilometers dat gereden wordt toeneemt.

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	100,0%	107,7%	105,1%	103,5%	99,1%

Tabel 3 - Reguliere transportafstanden voor verschillende typen samenwerking

Scenario 2: Samenwerkingsverband tussen LabMicTA-LabPON en ZGT

In het tweede scenario betrekken we alleen ZGT en LabMicTA-LabPON in het samenwerkingsverband. In dit scenario zien we de sterkste effecten voor de vermindering in totale kosten.

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Tabel 4 - Reguliere transportkosten voor verschillende typen samenwerking

Voor de totale duur van regulier transport zien we in dit scenario dat er ruimte is voor verbetering van de totale duur van het reguliere transport.

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	100,0%	94,8%	98,1%	85,6%	84,7%

Tabel 5 - Reguliere transportduur voor verschillende typen samenwerking

In tegenstelling tot Scenario 1, zien we in dit scenario dat de kilometers in het geval van samenwerking niet toenemen maar nagenoeg gelijk blijven.

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	100,0%	100,7%	102,0%	98,4%	99,6%

Tabel 6 - Reguliere transportafstanden voor verschillende typen samenwerking

Scenario 3: Samenwerkingsverband tussen Medlon en ZGT

Uit de resultaten sectie blijkt dat een samenwerkingsverband tussen Medlon en ZGT een positieve invloed heeft op de totale kosten. Wanneer we een totaalbeeld schetsen zien we echter dat er geen ruimte is voor verbetering bij een samenwerking tussen enkel Medlon en ZGT. In gelijkenis met de vorige scenario's zien we een verbetering mogelijk in de totale duur van transport. In dit scenario zien we een verslechtering voor het aantal kilometers gereden.

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Tabel 7 - Reguliere transportkosten voor verschillende typen samenwerking

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	100,0%	94,6%	99,2%	89,0%	91,0%

Tabel 8 - Reguliere transportduur voor verschillende typen samenwerking

	Huidige situatie	Gedeelde locaties	Grote locaties	Alle locaties	Geen samenwerking
Reguliere transportverzoeken gedurende een jaar	100,0%	128,9%	127,1%	125,8%	101,0%

Tabel 9 - Reguliere transportafstanden voor verschillende typen samenwerking

Scenario 4: Route optimalisatie binnen eigen organisatie

Ondanks dat Tabel 1 geen verbetering laat zien in de totale kosten, is er binnen de eigen organisaties wel ruimte voor verbetering. Bij het herverdelen van kleine groepen transportverzoeken of het herverdelen van de transportverzoeken die in de huidige situatie aan één voertuig toebehoren, zien we gemiddeld gezien geen verbetering. Echter, in de praktische implementatie is het goed mogelijk om alleen voor bepaalde voertuigen of bepaalde groepen transportverzoeken her te verdelen binnen de eigen organisatie. Een voorbeeld hiervan is het transport in het weekend, voor zowel LabMicTA-LabPON als Medlon is hier ruimte voor verbetering zonder dat sprake is van samenwerking.

AANBEVELINGEN

Gebaseerd op de resultaten van de experimenten en de uitwerking voor verschillende scenario's dienen de volgende aanbevelingen in overweging genomen te worden:

- In het huidige model is vanwege de explorerende aard van het onderzoek en de complexiteit van het probleem gekozen om alleen de reguliere transporten mee te nemen. Voor de praktische implementatie is het van belang dat samen met de transport managers wordt gekeken naar de door het model gegenereerde routes. In de praktijk zijn zaken als irregulier transport, ondersteunende facilitaire taken van de transportdiensten, uitzonderlijke klanten met specifieke eisen, aannames over gelijkheid van voertuigspecificaties en vakkennis van werknemers, etc. extra of anders dan in een gemodelleerde omgeving. Meer onderzoek naar de praktische werkbaarheid van gevonden oplossingen is nodig.
- In dit onderzoek is gekeken naar de mogelijkheden op gebied van samenwerking tussen de organisaties, waarbij de focus op de reorganisatie van het transport is komen te liggen. Daarbij is buiten beschouwing gelaten dat een implementatie van samenwerking vanuit verschillende organisaties ook aansturing nodig heeft. Aansturing van samenwerking is van belang om consensus te vinden voor het maken van afspraken over verantwoordelijkheid, het verdelen van kosten, het aanleveren van

personeel en kapitaal, etc. Men kan aannemen dat er een verschil zit in de complexiteit van aansturing wanneer wordt gekozen voor een samenwerking voor alle locaties, of alleen de grote of gedeelde locaties. Het is aan het management om een inschatting te maken of de beoogde winst op gebied van transport opweegt tegen de kosten voor het aansturen en onderhouden van samenwerking.

- In dit onderzoek is gebruik gemaakt van een insertie-opbouw heuristiek met als doel de transport operatie radicaal te veranderen om de limieten van samenwerking te exploreren. Voor de onderzochte problematiek zijn ook andere heuristieken en algoritmes bekend (beschreven in het theoretische raamwerk hoofdstuk van het onderzoek) om tot oplossingen te komen. De belangrijkste tegenhanger voor de gebruikte methode is de zogenaamde Tabu heuristiek, waarbij vanuit een werkende bestaande oplossing geprobeerd wordt een verbetering te vinden. Het gebruik van een andere heuristiek, zoals bijvoorbeeld de metaheuristiek Tabu-search, kan leiden tot andere oplossingen en geeft meer mogelijkheden voor bijvoorbeeld een interventie als hubs/ tussenlocaties.
- Gedurende dit onderzoek is aangenomen dat er harde tijdsrestricties zijn voor de aankomst patronen van de laboratoria. Zonder het aanpassen van de aankomststroom van materiaal van de laboratoria is samenwerking tussen de bedrijven Medlon en LabMicTA-LabPON niet voordelig. Een herdefiniëring van de vooraf gestelde eisen kan in een vervolgonderzoek leiden tot andere resultaten.

MANAGEMENT SUMMARY

The purpose of this research is to explore the collaboration possibilities in the field of transportation between the organizations Ziekenhuisgroep Twente, Medlon, and LabMicTA-LabPON.

BACKGROUND

The organizations involved in this research partially transport materials to the same locations. Transportation conditions for these transports are different for each organization. Transportation is designed to support internal work processes. In the current situation, transport is regulated by each organization individually. It is unknown whether the current transportation operation is organized optimally and if a realization of a collaboration collective would result in savings. To gain insights into the current situation and test the influence of several ways of collaboration, the following research goal has been created:

"To analyze the current transportation processes of materials, and identify and prospectively assess ways to establish collaboration between ZGT, LabMicTA, LabPON, and Medlon to lower costs and provide a higher level of service."

METHOD

To make the current situation measurable, information was collected on the materials that are transported. Furthermore, for every organization, the availability and the number of the vehicles were collected. All the regular vehicle routes and the customers on these routes were analyzed. Given all the collected information, the constraints needed to sustain the demands of the organizations of the current material transport were created. The constraints and demands translated into the transportation requests that need to be sufficed.

To test the influence of several interventions, the schedules for material transport were completely rebuilt using an "insertion-construction" heuristic. By using this heuristic, all the transportation requests are redistributed within the vehicle fleet available. Thereafter, the proposed interventions in this research were evaluated using several performance indicators; keeping a strong focus on the total costs.

Interventions proposed in this research are the following: First, several different methods to rebuild new routes. Here, we used various methods to rebuild routes as well as possible. Second, we limited the collaboration by using a classification for the locations on the routes.

In this settinga, a collaboration between the organizations depends on the type of the customer. Third, we implemented hubs at predetermined locations and times. Fourth, we left out one of the organizations of the collaboration collective. Fifth, we evaluated the influence of outsourcing the material transport. To keep the total number of experiments manageable, the transportation requests were divided into groups and the experiments were carried out in several phases.

RESULTS

The results showed that there is room for improvement in the regular transport of the organizations.

For the first intervention, where we used several approaches to rebuild routes, we found that time plays an important part in rebuilding the routes. We found the best results when we sorted the locations on the earliest available time of pickup and we assigned the requests to vehicles minimizing the total driving time.

For the second intervention, where we tested the influence of collaboration based on different types of customers, we saw an improvement for the total costs when we allow collaboration between the organization for the following types of customers: all customers; large customers e.g., outpatient clinics and hospitals; and shared locations. With the remaining types of collaboration, e.g., only collaboration between the small customers such as general practitioners, we see a deterioration of performance compared to the current situation.

For the third intervention, where we tested the influence of the use of hubs, we found no improvements compared to the current situation using a construction-insertion heuristic and front office locations as hubs on fixed times. We conclude that inserting hubs into the routes is not a good intervention when we use an insertion construction heuristic.

For the fourth intervention, where we test the influence of leaving out one of the organizations, we see that ZGT is key to get improvements in performance. When we include ZGT in the collaboration collective, we get an improvement in total costs. These improvements hold for the coalitions {ZGT, Medlon, LabMicTA-LabPON}, {ZGT, LabMicTA-LabPON}, and {ZGT, Medlon}. When we allow collaboration between Medlon and LabMicTA-LabPON, we see, despite the strong resemblance in motivation for transport using vehicles, only scores that are either equal or worse compared to the current situation.

As the last intervention, we see that outsourcing the transportation operation to an external party increases the total costs considerable compared to the current situation. We do see an improvement when we look at the performance indicators for quality of service, but the increase in quality does not justify the increase in extra costs.

ELABORATION OF RESULTS

By aggregating the groups determined earlier, we can examine the effect of the intervention settings that have a positive influence on several scenarios for collaboration on regular transport. These scenarios offer the possibility for improvement relative to the current situation.

Scenario 1: Collaboration coalition between three organizations

In the first scenario, we involve all organizations in the collaboration coalition. When we examine the effect on total costs for regular transport, we find the best improvement when we allow collaboration for all locations on the routes. When we do not allow collaboration, we see that the total costs virtually stay the same. This means that when no collaboration is allowed, we do not improve the current situation by reorganizing.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 1 - Regular total transportation costs for different types of collaboration

In the experiments, we find the best results when we minimize the increase in ride duration. This is reflected in the total time that vehicles are on the road. Independent of the type of collaboration, we can see a decrease in the total duration for all the organizations. With the setting of no collaboration, the profit on total duration is virtually the same as full collaboration.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	100,0%	91,9%	97,7%	86,1%	86,0%

Table 2 - Regular transportation duration for different types of collaboration

For the number of kilometers, we see a trend that when we allow collaboration, the number of kilometers increases.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	100,0%	107,7%	105,1%	103,5%	99,1%

Table 3 - Regular transportation distances for different types of collaboration

Scenario 2: Collaboration coalition between LabMicTA-LabPON and ZGT

In the second scenario, we involve only ZGT and LabMicTA-LabPON in the collaboration coalition. In this scenario, we see the most decrease in total costs compared to the other scenarios.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 4 - Regular transportation costs for different types of collaboration

For the total duration of regular transport, we see that there is room for improvement for the regular transport.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	100,0%	94,8%	98,1%	85,6%	84,7%

Table 5 - Regular transportation duration for different types of collaboration

In contrast to Scenario 1, we see that in this scenario the total number of kilometers does not increase when we collaborate but stay virtually the same.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	100,0%	100,7%	102,0%	98,4%	99,6%

Table 6 - Regular transportation distances for different types of collaboration

Scenario 3: Collaboration coalition between Medlon and ZGT

The results section showed that a collaboration coalition between Medlon and ZGT has a positive influence on the total costs. When we combine these findings in a grand total picture we see that there is no room for improvement in a coalition of only Medlon and ZGT. In parallel with the previous scenarios, we see that there is room for improvement looking at the total duration of transportation. In this scenario, we see an increase in the total number of kilometers driven.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 7 - Regular transportation costs for different types of collaboration

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	100,0%	94,6%	99,2%	89,0%	91,0%

Table 8 - Regular transportation duration for different types of collaboration

	Current situation	Shared locations	Large locations	All locations	No collaboration
Regular annual transportation requests	100,0%	128,9%	127,1%	125,8%	101,0%

Table 9 - Regular transportation distances for different types of collaboration

Scenario 4: Route optimization within an organization

Despite Table 1 showing no improvement in the total costs, there is room for improvement within the organizations themselves. The redistribution of small groups of transportation requests or redistributing the transportation requests that in the current situation are appointed to a single vehicle show no improvement on average. However, the practical implementation of newly constructed routes offers the possibility to only selectively redistribute transportation requests within the own organization. An example of such a situation is the transport on Saturday, for both LabMicTA-LabPON and Medlon there is room for improvement without collaboration.

RECOMMENDATIONS

Based on the results of the experiments and the elaboration of the various scenarios, the following recommendations should be considered:

- Because of the explorative nature of this research and the complexity of the problem, only the regular transports are considered in the model. For a practical implementation, it is of importance to evaluate the constructed routes in conjunction with the transportation managers. In practice, matters like irregular transport, supporting facilitating duties of the transportation services, exceptional customers with specific demands, assumptions about the equality of vehicle specifications and professional knowledge of employees, etc. are additional or different than in a modeled situation. More research is needed into the practical workability of the solutions found.
- In this research, the possibilities of collaboration between the organizations are examined, keeping the focus on the reorganization of the transportation services. The issue of managing the implementation of a newly formed collaboration coalition is not included in this research. Managing collaboration is of importance to find consensus on, among others, making agreements on responsibility, the division of costs, the supply of personnel and assets, etc. One can assume that there is a different level of complexity in managing the transportation operation when a setting for collaboration for all customers is chosen in contrast to only collaborating on large customers. It is up to the management of the organizations to estimate whether the intended profit offsets the additional management costs that come with the level of collaboration.
- In this research, we used an insertion-construction heuristic intending to radically reconstruct the transportation service to explore the theoretical limits of collaboration. There are also other algorithms and heuristics available (described in the theoretical framework chapter of this thesis) to find a solution to the researched problem. The most important counterpart of the method used is the Tabu heuristic, where a new solution is created based on the existing feasible solution, or another newly constructed feasible solution. A metaheuristic solution can be applied to the current situation or to newly constructed solutions found by the model in this research. An intervention, such as the insertion of hubs into the current situation, would be more effective when using an

insertion heuristic and provide more flexibility instead of adding extra restrictions to the solution.

- During this research, it is assumed that there are hard time restrictions for the laboratories. Without adjustments to the arrival stream of materials, collaboration is not beneficial to the coalition between the organizations Medlon and LabMicTA-LabPON. A redefinition of the predetermined demands can lead to different results in future research.

PREFACE

This thesis is part of my master's in Industrial Engineering and Management at the University of Twente. For me, this project has been a long ride with unknown ups and downs and has been a great learning experience, both professionally and personally.

First, I would like to thank the logistics professionals at ZGT, LabMicTA, LabPON, and Medlon for handing me the opportunity to complete my master thesis. Your time and effort were of great importance to perform this research.

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CHAPTER 1 INTRODUCTION

ZGT (Ziekenhuisgroep Twente) desires to explore the possibilities of collaboration concerning the material transport with branch related organizations in the region with similar logistical processes. This report describes the findings for these possibilities of collaboration.

Currently, organizations involved arrange their own transportation. Own transportation is organized such that processing of transported materials can continue without interruption; meaning an equal throughput of materials throughout the day. Transport is arranged such that intra-company costs are minimized. Transportation costs are subject to quality levels of the organizations. Quality levels of material transport need to be met to create profit; so high transportation costs can be justified if quality levels are met. Transportation of materials is essential for running the core business. However, the organizations experienced that not all material transport is used efficiently.

Involved organizations visit locations in the same area by vehicle every day. The organizations have the feeling that by collaborating, their system-wide (inter-company) material transport costs can be reduced. Sharing these costs reductions might increase everyone's profit. In this section, the organizations are introduced and the setup for the research is explained.

1.1 THE ORGANIZATIONS

The research was initiated by ZGT in collaboration with three other organizations. The organizations will be introduced in the next sections.

1.1.1 ZGT

ZGT, freely translated as Hospital group Twente, is a hospital organization with locations in Hengelo and Almelo. The core business of ZGT is to provide patients with medical cure and care. Apart from delivering care directly to the patients within the hospitals, the department of facility management has a transportation service that transports employees, patients, and materials including medicine and medical equipment. The material transportation of this service involves mostly export of medicine from pharmacies and the transportation of goods between the locations of the ZGT hospitals and outpatient clinics.

1.1.2 LabMicTA and LabPON

LabMicTA and LabPON are two private companies that both perform laboratory research at the request of medical specialists and general practitioners. Both companies are in the same building in Hengelo, next to the ZGT Hengelo.

LabMicTA is a company that provides microbiologic research (the full name of the company is Laboratory Microbiology Twente Achterhoek). LabMicTA engages in all tests concerning infectious diseases, e.g., bacterial, viral, yeast, fungal, or parasite-infections. For these types of tests, blood, stool, urine, or other bodily fluid samples are collected.

LabPON is short for “Laboratorium Pathologie Oost Nederland”, which translates to laboratory pathology eastern part of the Netherlands. The company engages in pathological tests that are performed for tissues, and bodily fluids. All samples are prepared for examination and testing in the laboratory; this means sometimes whole organs are delivered to the laboratory. Samples are analyzed for diagnose and results get reported back to the requester of the tests.

LabMicTA also performs the transport for LabPON. Transportation of materials consists mostly of test samples from specialists or general practitioners to the laboratory, but all private clients are accepted. Apart from collecting samples, LabMicTA and LabPON provide and deliver sample collection material such as cups and tubes. Both LabMicTA and LabPON remain owners of the sample collection material but deliver them for free to encourage sales. These sets are delivered when samples are collected.

1.1.3 Medlon

Medlon is a company that provides blood tests for specialists, general practitioners, private individuals, and organizations. Next to blood tests, Medlon also provides urine, stool and sperm tests. In contrast to LabMicTA and LabPON, most tests done at Medlon have test results available on the same day.

Medlon currently has three laboratories, one in Almelo, one in Enschede and one in Hengelo. Plans of Medlon are to close the laboratory in Hengelo. Medlon has 79 blood collection offices where samples for testing are collected. The sizes and opening hours of the locations differ. Offices are often located within healthcare facilities such as hospitals and nursing homes.

Medlon also provides general practitioners with materials such as testing kits. This is part of their assortment of goods and services.

1.2 SIMILARITIES BETWEEN ORGANIZATIONS

Although samples collected can be the same for, e.g., Medlon and LabMicTA, the tests performed on the samples and the other services and products differ such that all parties cannot be called competitors. Roughly speaking, the laboratory organizations can be classified according to their field of expertise: Medlon performing clinical chemical tests, LabMicTA performing microbiologic tests, and LabPON performing pathologic tests. Bengtsson and Kock (1999) would describe the relationship as mainly coexistent. While the laboratories have very similar business models, the business model of ZGT differs. The business model of ZGT is to treat patients. The medical specialists use laboratory work to support their treatment plans. ZGT, therefore, employs a large group of the customers of the laboratories: the medical specialists. However, the transportation department of ZGT does perform transportation of materials by vehicles like the laboratories. Although the organizations deliver different services and products, transport of material is similar. The organizations have their own delivery vehicles (vans) and existing routes of materials to be transported. The majority of the material that is transported (test-samples, medicine) can be transported in relatively small protective boxes, which can be handled by anyone. Furthermore, all organizations also use external couriers to cope with contingency. Finally, all organizations visit locations in the same area.

1.3 PROBLEM DESCRIPTION

The organizations have a mutual presumption that material transport with vehicles can easily be combined between the organizations. The current area of delivery for all the organizations is essentially the same and vehicle capacity is almost never fully utilized. To what extent collaboration is possible is not known. From all organizations, there is a desire to explore the possibilities of collaboration in transport. Most of the locations are the same for the organizations involved. However, there are conflicting interests, e.g., Medlon and LabMicTA as private companies also work with the MST (Medisch Spectrum Twente) hospital in Enschede, which is a direct competitor of ZGT. The current transportation processes have developed over time to support internal processes. The current routes, pickup and delivery times have not been determined by an algorithm but rather by practice over time, common sense, and the adherence of certain preconditions. Locations geographically close together have been put in the same routes.

The current situation is that all parties are responsible for their own transport and try to maximize transport efficiency based upon their own logistics processes. Customers indirectly request transportation of materials, and the capacity of vehicles and transportation workers are determined to satisfy this. However, the demand for transportation is not always the same and increasing or decreasing the capacity of staff or vehicles is not easy. For the organizations, there is a constant balancing game going on between the use of hired staff, use of transportation methods, and the number of materials to be collected and delivered. When own vehicle or staff capacity is insufficient, external parties are usually hired to meet demand.

Regarding the maximum utilization of delivery vehicles and transportation staff, the organizations try to collect and deliver materials on the same rides as much as possible. E.g., new sample collection material is delivered to a location when test-samples are collected for LabMicTA and LabPON. The amount of space needed in a delivery vehicle for the number of test-sample boxes in one route does not exceed loading space. New sample collection material does not require as much space as the collection of the test-sample boxes; generally, the capacity of the delivery vehicle space is not fully used.

Next to the maximization of usage of vehicles and transportation staff, timely pickup and delivery are sought, e.g., pickups or deliveries must be made in a certain time window depending on what is transported. In general, this is attributable either to the (cooled) conditions materials need to be transported in or to the urgency of tests. From a quality point of view solely, all organizations strive for transport as fast as possible.

When the companies arrange their transport individually, automatically all the addresses visited are clients of the company. When rides are combined between multiple companies, the addresses visited are not necessarily clients of every involved company. The question that follows from this fact is whether combining rides yields efficiency gains. Apart from the costs reduction incentive for collaboration, there is a desire from the organizations to create long-lasting partnerships. There are all kinds of links between the organizations, both from a historical point of view and from today's practice. The reason the organizations are linked is that parties such as ZGT and, e.g., LabMicTA are largely codependent for their production. Examples of organizational links are: ZGT is a large shareholder in Medlon, the supervisory board of LabMicTA has ZGT employees, LabMicTA and LabPON used to be the same company, and LabMicTA has collaboration with Medlon as a strategic goal in their annual plan (LabMicTA, 2016). Hence, the production processes of the companies are intertwined, and a more efficient way of transportation provides all organizations with a higher level of service. This makes their relation valuable.

1.3.1 Core problem

The transportation processes of ZGT, Medlon, LabMicTA and LabPON are very similar in terms of material transportation by own services and the geographical area where they are active. Furthermore, the production of the organizations is indirectly related. Currently, the organizations arrange their own transport to support their own internal logistical flows. It is not known if the current transportation is organized efficiently and the companies would like to explore in which way and to what degree collaboration is beneficial.

1.3.2 Problem owner

The problem owners are the companies introduced in the previous chapters: ZGT, Medlon, LabMicTA and LabPON. More specifically, the problem owners are the policy makers of these organizations. They are the ones that search for a recommendation regarding collaboration.

1.4 RESEARCH MOTIVATION AND GOAL

The findings from Section 1.3 lead to the following research objective:

To analyze the current transportation processes of materials and identify and prospectively assess ways to establish collaboration between ZGT, LabMicTA, LabPON, and Medlon to lower costs and provide a higher level of service.

1.5 RESEARCH QUESTIONS

To achieve the research goal, six general research questions have been established. In sections 1.5.1 to 1.5.5, these questions are elaborated with sub-questions where needed. The sections provide the structure for the chapters in this research.

1.5.1 Chapter 2: Context analysis

To answer the question of whether collaboration is beneficial, the current performance must be measured to serve as a baseline for possible interventions. We analyze the current methods of transportation and find fitting performance indicators.

RQ1. How is material transport currently organized at all parties/companies and what is their performance?

- 1.1. How are the organizations structured?
- 1.2. What is the current flow and volumes of materials in the organizations?
- 1.3. What materials are transported per organization?
- 1.4. Who are the involved external parties?

1.5. What are good performance indicators for measuring the performance of the current means of transportation?
1.6. What are the current costs of the transportation of materials by vehicles?
1.7. What are (future) restrictions or constraints on the transport per party?

Data required to answer Research Question 1 and its sub-questions will be gathered by performing interviews with operational transportation managers, researching documents provided by the organizations such as schedules and protocols, observations from practice, and by extracting data from the laboratory management systems.

1.5.2 Chapter 3: Theoretical framework

The theoretical framework chapter forms the literary support of the research in this report. A literature study is performed in various databases, to investigate algorithms and methods for ride combination and their applicability for this research. This includes searching for various models and methods, which can contribute to choosing a solution approach for this study. Furthermore, literature about ways of collaboration such as gain sharing or horizontal collaboration is explored.

RQ2. What methods, models and knowledge are available that can be useful in exploring collaboration of the parties involved?
2.1. What models or methods are known?
2.2. Which model(s) or method(s) are best suited for this study?
2.3. What are the different types of collaboration described in literature?

1.5.3 Chapter 4: Modelling

Using the findings of the previous research questions, a literature-based model can be composed to explore the possibilities of collaboration. Performance indicators found in Research Question 1 are used to measure different experimental settings. To answer the research goal properly, a model with quantifiable results should provide insights.

RQ3. How can the current logistical planning and collaboration suggestions be modeled?

1.5.4 Chapter 5: Experimental design

A modeled setting gives the opportunity to test various collaboration interventions. With an appropriate way to model the problem explored in Research Question 3 and with the knowledge about collaboration explored in Research Question 2, different interventions will be tested on their performance.

RQ4. What are relevant interventions for collaboration to test using applicable models?

4.1. What experimental settings do we use?

1.5.5 Chapter 6: Analysis of results

The last section of this research describes the results of various experiments, we measure this performance using the performance indicators found in Research Question 1. Results are analyzed and interpreted for a practical setting. Furthermore, conclusions, a discussion, and the limitations are given.

RQ5. What results do the various collaboration scenarios give and how can they be interpreted?

1.6 RESEARCH SCOPE AND METHODOLOGY

The geographic scope of this project limits itself to the region of Twente. All parties involved have their daily operation within this region. Solutions to the problem might be applicable to other cases, but this case study limits itself to this region and these organizations.

The general scope of this study is to look at the transportation planning of all parties involved, leaving the organizational planning intact. Interventions for collaboration are explored, looking at the financial or quality benefit interventions might provide. We limit the scope to the transportation of materials.

We use a combination of research methods to achieve this, the general outline of the methodology is presented in Figure 1-1. We start by exploring the organizations through interviews, organization’s documents and data. To get a grasp of the theoretical aspects of this thesis we search for relevant literature in the theoretical framework. All the information found is used to create a theoretical model in Chapter 4. By combining a model with different types of collaboration we create interventions in Chapter 5. Subsequently, we calibrate and test the model and the interventions in Chapter 6, ultimately, to give a conclusion and discussion on the research questions.

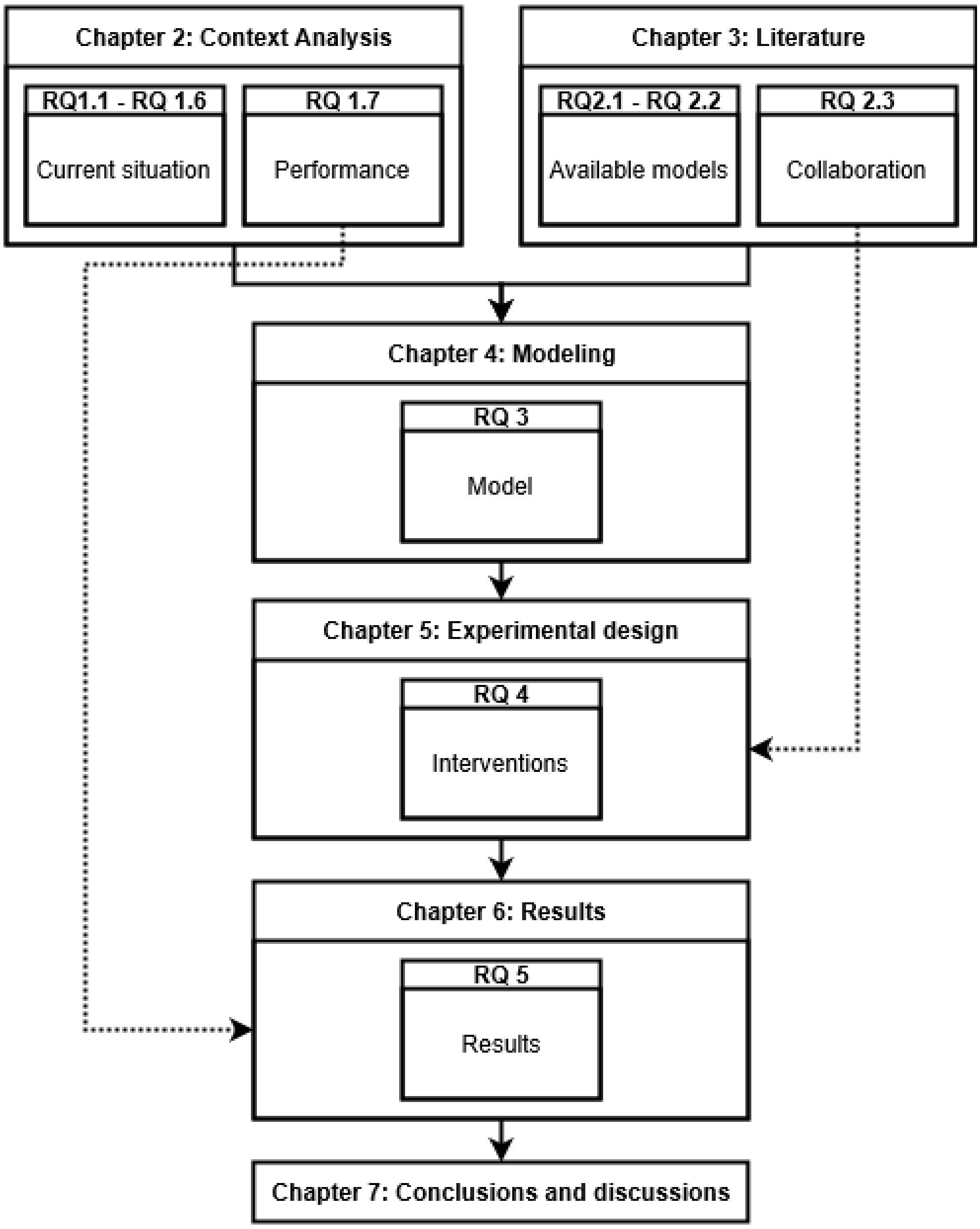


Figure 1-1 Thesis outline

CHAPTER 2 CONTEXT ANALYSIS

This chapter gives a description of the current methods of material transportation within the organizations by answering Research Question 1:

How is material transport currently organized at all parties/companies and what is their performance?

2.1 ORGANIZATIONAL STRUCTURE

To give a clear image of the organizations involved in this study, the locations of all organizations are defined in this chapter.

2.1.1 Medlon

Medlon is an organization that was founded in 2011 by a merger of the privatized clinical laboratories of ZGT and MST. Medlon provides the service to treat thrombosis for the hospitals of ZGT and MST. The organization works for general practitioners and medical specialist and focuses on the medical diagnostics and delivering a service to treat thrombosis (Medlon, n.d.). The organization has multiple locations in the region. A distinction can be made on the type of location.

<u>Laboratories</u>

There are currently three laboratories of Medlon all located in the hospitals in Almelo, Hengelo, and Enschede. All tests are performed at the laboratory locations; generally, all samples collected end up in one of the laboratories. In the future, Medlon has plans to close the laboratory in Hengelo. Enschede has a laboratory with facilities to perform extraordinary tests; for instance, samples can be taken in Almelo, but need to be transported to Enschede to be tested. The laboratories are depicted in Figure 2-1 with a blue marker.

<u>Blood collecting outpatient clinics</u>

Medlon currently has six blood collecting outpatient clinics. These locations are located within hospitals or large healthcare facilities. Outpatient clinics are often opened on office hours contrary to blood collection offices. Blood collecting outpatient clinics use tube mail as a method of transport to the lab in Almelo, Hengelo, and Enschede, these are essentially the same locations as the laboratories. The other blood collecting outpatient clinics are depicted in Figure 2-1 with a purple marker.

Blood collecting offices

Most of the locations of Medlon are blood collecting offices. Medlon currently has 59 blood collection offices. These offices are often only opened in the morning. Blood collection offices are set up to provide patients with a location nearby so that patients do not need to travel far. Patients sent by their general practitioner usually go here. The blood collecting offices and blood collecting points are depicted in Figure 2-1 with a red or yellow marker. The red markers are locations that are on existing routes. Yellow marked locations are not on existing routes.

Blood collecting points

To provide patients with thrombosis treatment close to their homes, blood collecting points are set up. These points are solely for thrombosis treatment. All the blood collected at these points is to be tested for thrombosis treatment. Blood collection points are often opened on 2 or 3 days a week. Medlon currently has 15 blood collecting points.

Stock locations

The main material storage of Medlon is in Enschede. Furthermore, Medlon has a material storage location in both ZGT hospitals.

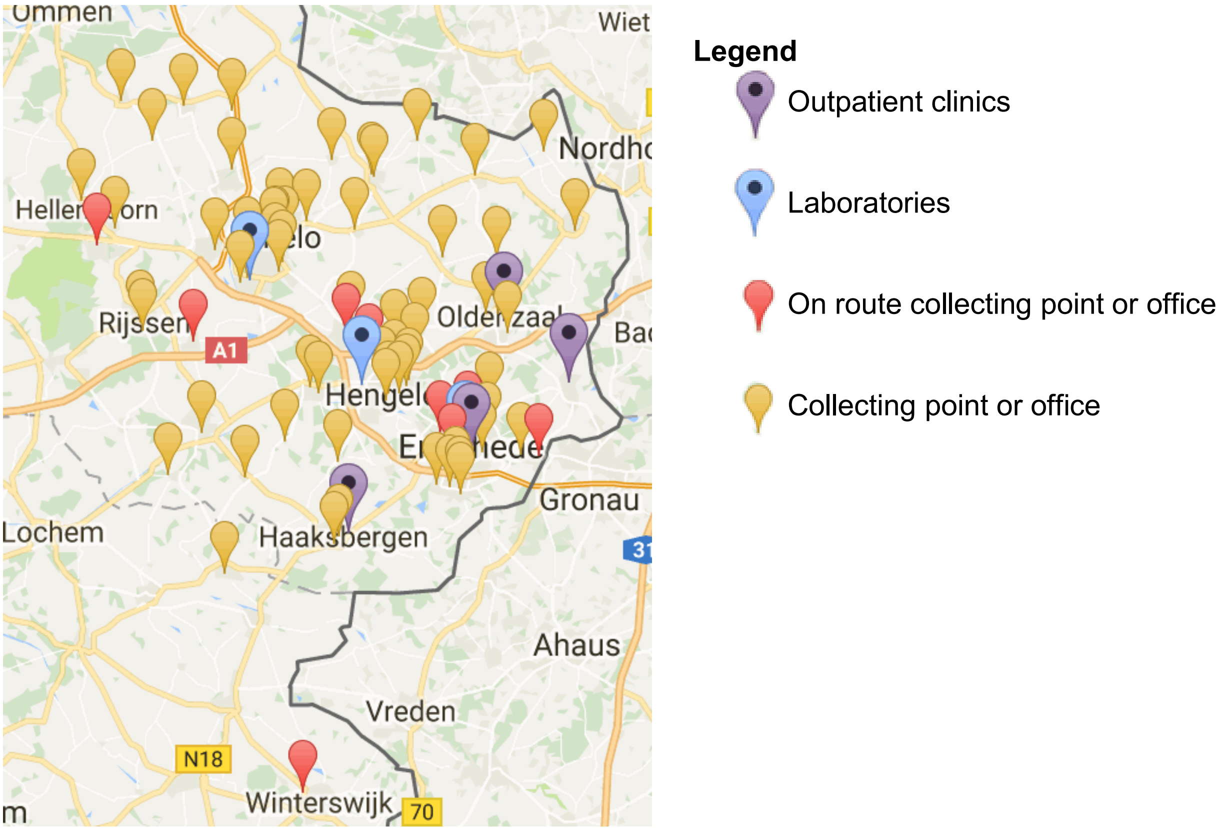


Figure 2-1 Locations of Medlon

2.1.2 LabMicTA and LabPON

Following the invention of antibiotics, the municipal bacteriologic laboratory was founded in 1947 as a precursor of LabMicTA. The “Foundation to promote pathological and anatomical research in Twente and Gelderse Achterhoek” was founded in 1953 as an initiative of municipalities, hospitals and health insurance funds as a precursor for LabPON. Due to technological and scientific advances, both parties grew and both the precursor of LabMicTA and LabPON were located together at the Burgemeester Edo Bergsmalaan in 1966 and 1965 respectively (LabMicTA, n.d.). This location is directly next to the current location of the MST Hospital. The two organizations merged together in an organization known as the regional laboratory for pathology and microbiology in 1970. After 25 years, in 1995 the organizations split into the organizations as we know them now: LabMicTA and LabPON. The split was realized as part of a plan to build basic laboratories in the regional hospitals, but this plan was later revised.

Apart from the split, the companies have always shared a building and infrastructure. In 2013 the hospital moved from Enschede to completely new premises in Hengelo. The offices and laboratories of LabMicTA and LabPON are both located in Hengelo within the same building, only on different floors. The location of the building is directly next to the ZGT hospital; the total distance is only 550 meter (LabMicTA, n.d.; LabPON, n.d.). The location of the laboratories is depicted in Figure 2-2 with a blue marker.

<u>Front offices</u>

Apart from the location of the laboratories and offices in Hengelo, both LabMicTA and LabPON hold a collective front office in collaboration with Medlon and ZGT in the ZGT hospital Almelo since 2014 (LabMicTA, 2016). Because of the success of the front office in Almelo, a new front office in Enschede was founded in 2015 in the Enschede hospital. Front offices are used to collect all material to be transported to the laboratory in Hengelo and prepare them for transport. A task force to create plans for a front office in SKB Winterswijk has been started in 2015 but has not been realized yet. Locations of the front offices are depicted in Figure 2-2 with a purple marker.

<u>General practitioners and healthcare centers</u>

LabMicTA is responsible for the transportation of materials for both LabMicTA and LabPON. There are daily routes that stop at 157 general practitioners or healthcare centers. Aside from the own apply for samples to be tested, locations of general practitioners or healthcare centers function as a collection point for any private customer. All locations have their own pick-up time for when the transportation service of LabMicTA collects the samples. Locations of the general practitioners and the health care centers which are on existing routes are depicted in Figure 2-2 with a red marker. Other clients of LabMicTA in 2016 have a yellow marker. Yellow marked locations are not on existing routes but presumably drop off their samples at red marked locations before pick-up time or send their samples by mail.

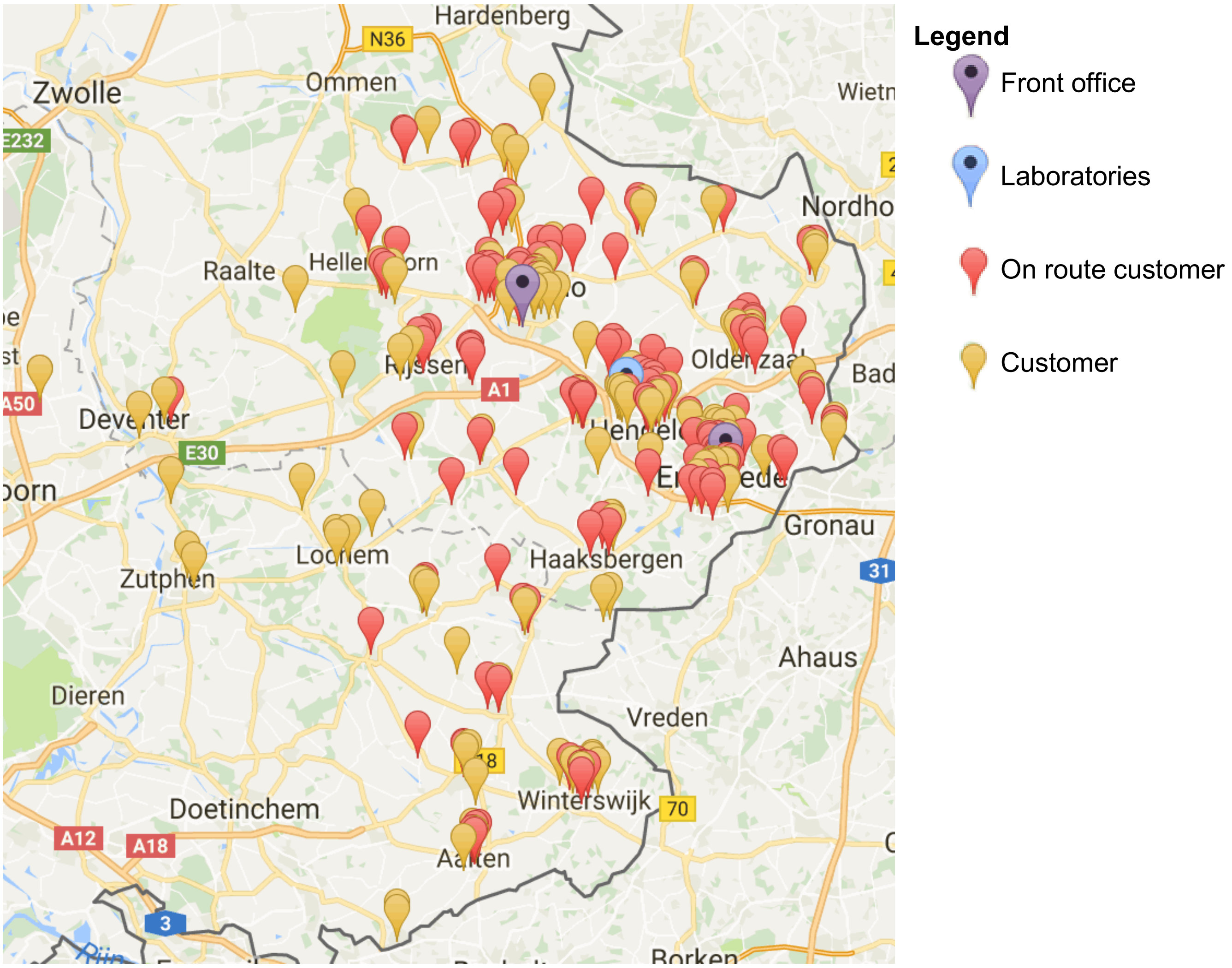


Figure 2-2 Locations of LabMicTA and LabPON

2.1.3 ZGT

Ziekenhuisgroep Twente is an organization with two general hospitals and six external outpatient clinics. The hospitals are in Hengelo and Almelo and are depicted in Figure 2-3 with a blue marker; outpatient clinics are in Geesteren, Ootmarsum, Goor, Rijssen, Nijverdal, and Westerhaar are also depicted in Figure 2-3 with a purple marker. These outpatient clinics hold one or more specializations and many specialists working at the outpatient clinics also work within hospital locations.

Figure 2-3 Locations of ZGT

2.1.4 Concluding organizational structure

This section answered Sub-Research Question 1.1: *"How are the organizations structured?".* We have seen that every organization has multiple types of locations each with different characteristics in the material transport process. By answering this question, we can use the information found to distinguish different types of locations when building a model in Chapter 4.

2.2 CURRENT FLOW AND VOLUMES OF MATERIALS

This section describes the flow of materials between locations together with volumes and a description of the proceedings carried out on locations regarding transport.

2.2.1 Flow of materials Medlon

Diagnostic materials

Diagnostic materials are either clinical or outpatient clinic samples. Clinical samples are taken from patients who are hospitalized in one of the hospitals where Medlon is active. These samples are not included in this study because they don't have to be transported by vehicles. Outpatient clinic samples are taken from the patients in blood collection outpatient clinics, blood collection offices, blood collection points, or from the patients' homes.

In the blood collection outpatient clinics of Almelo and Enschede, samples are transported by a tube system to the laboratory. The other outpatient clinics have no laboratory and have regular transport picking up the samples daily. As can be shown in Figure 2-4 the blood collection outpatient clinic (Purple marker) is very close (and connected to) the laboratory (Blue marker).

The blood collection offices and points were created to be close to patients as part of a service. This way, a patient does not have to travel far to get a sample taken. When an office or a point is opened for that day, a laboratory worker drives to the location with a Medlon car or with its own transport. Laboratory workers are responsible to keep up the stock of sample collection material and package material at blood collection offices or points. Materials are often taken from one of the material storage locations the day before. An example of the route of a worker is shown in Figure 2-4. The green line shows the worker going to a blood collection point and returning to the laboratory when the blood collection point is closed. Mind you, the green route is traveled by a Medlon car or own transportation, not by a transportation service vehicle.

At the location, laboratory workers register patients in GLIMS, the laboratory information system, and print barcodes. This is also the moment samples get a location stamp. Next, samples of the patients are taken. Some blood collection offices or points are on the route of the daily regular transport and have the samples that were taken by the laboratory worker so far, given along with the regular transport. Locations that are on existing routes have a red marker in Figure 2-4. The red line shows a route of regular transport with vehicles of the transportation service. Most of the blood collection points or offices are opened in the morning hours (differing per location). This is a custom because patients are often not allowed to eat before their samples are drawn. Laboratory workers work until all patients at the offices or points have been served. After their shift, the laboratory worker takes the samples collected with them in their Medlon car or their own vehicle to the collection points in Almelo, Hengelo or Enschede or starts collecting samples from patients at home.

Medlon also provides services at home, when patients are unable to come to a collection point or offices. Instead of a collection office or point workers get assigned an area. They visit all the patients within the area with a Medlon car or their own transport and then return the collection points in Almelo, Hengelo or Enschede. During the visits to patients at home workers often visit blood collection points to assist in taking samples. Samples taken by assisting workers are only for thrombosis treatment. An example of such a route is depicted by the blue line in Figure 2-4.

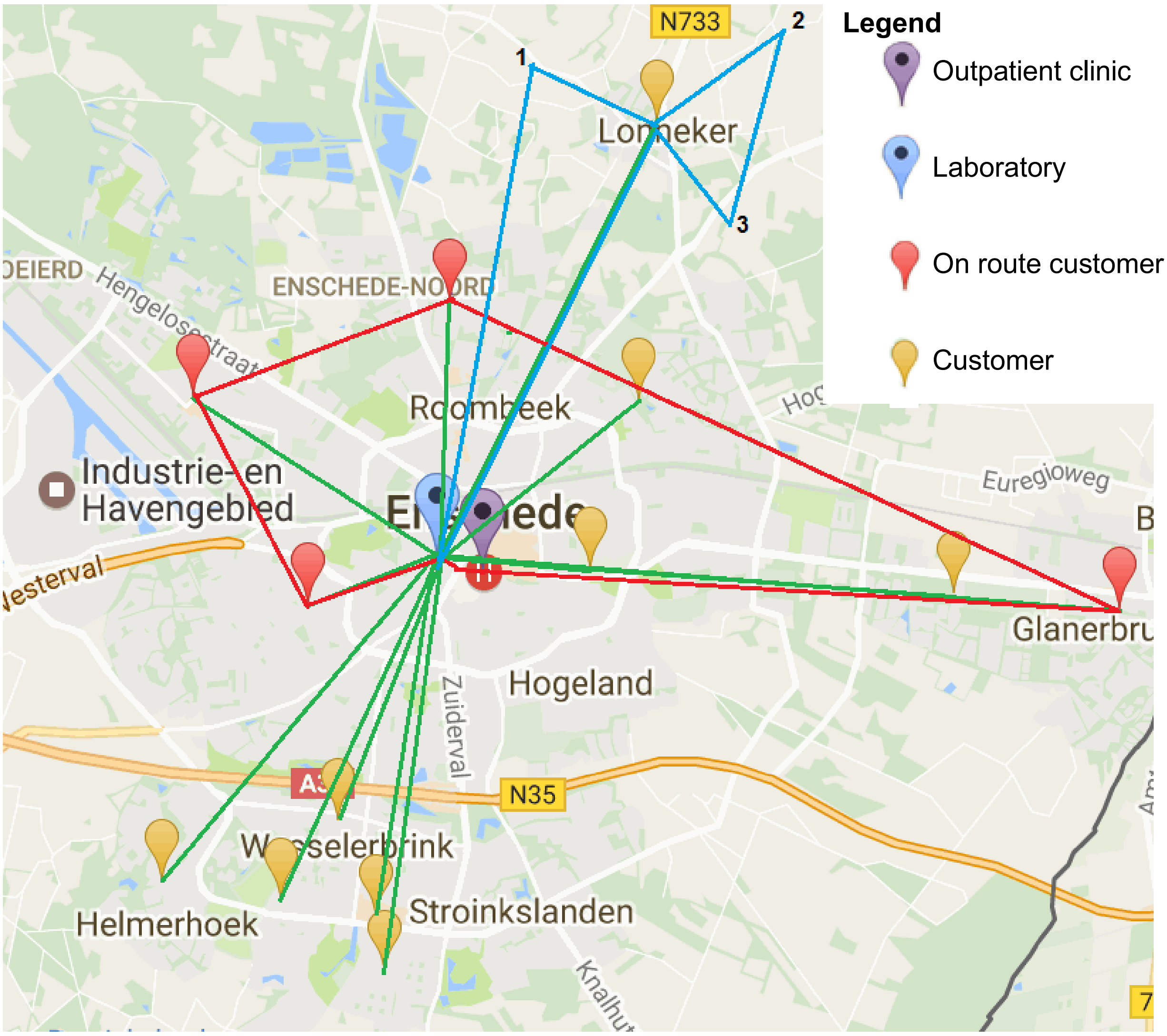


Figure 2-4 Example flow of material Medlon

Redistribution from the collection points of diagnostic materials

Redistribution of samples takes the most time of the transportation service with delivery vehicles. Outpatient clinic samples collected at the collection point of Hengelo all get redistributed to Enschede. This redistribution is done by the regular daily transport. An example of one of the daily routes is shown in Figure 2-5. The red line shows material destined for

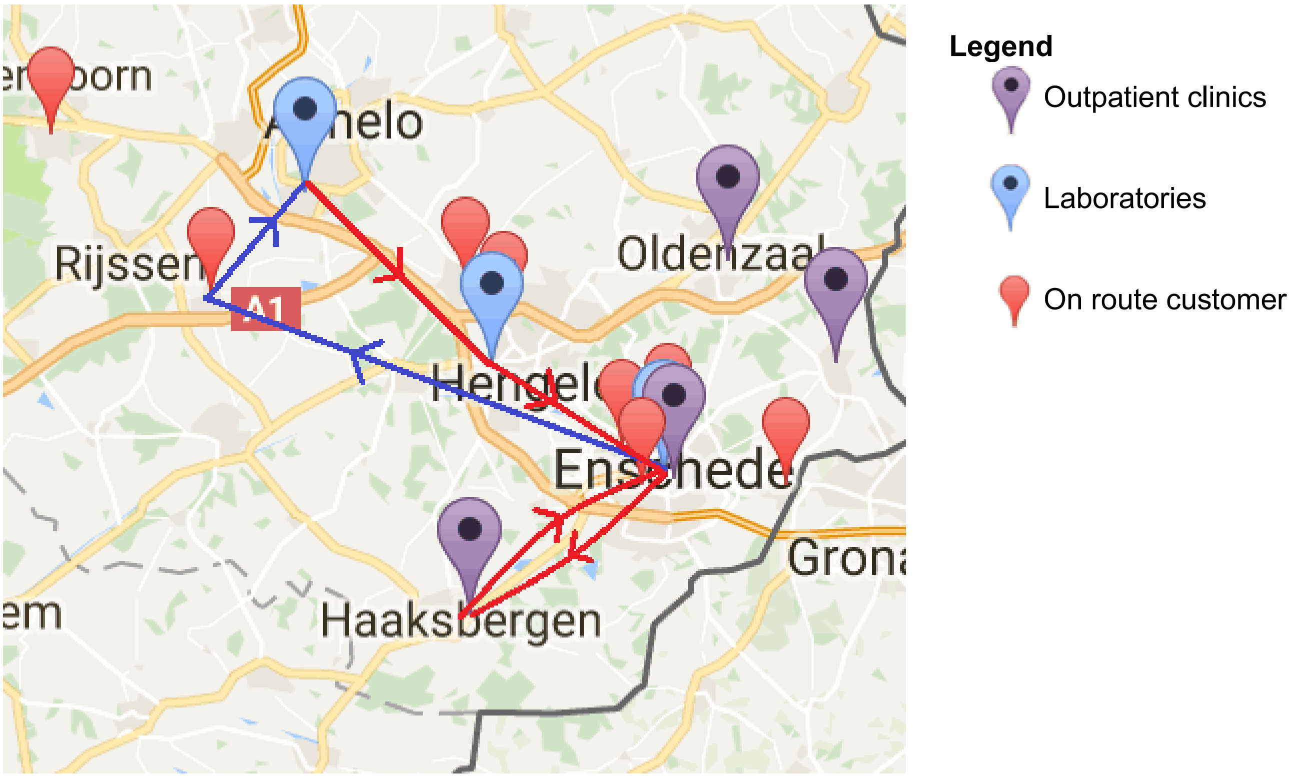


Figure 2-5 Redistribution route Medlon

Enschede, the blue line shows material destined for Almelo. In Almelo and Enschede the samples collected by laboratory workers are first put into a machine called the MPA, short for: Modular pre-analytics system. This machine makes different samples out of the original samples taken and sorts them for further analysis per machine. When outpatient clinic samples cannot be analyzed in Almelo they get redistributed to Enschede and vice versa. This redistribution is taken care of by the daily regular transport.

Non-diagnostic materials

Every two weeks, the storage locations of sample collection materials are replenished from the main storage location in Enschede. Either material is shipped to the main storage location in Enschede and then distributed by the own transport of Medlon or material is directly shipped to the laboratory storage rooms in Hengelo or Almelo. As mentioned before, the laboratory workers who go to blood collection points or offices and the laboratory workers who visit patients at home take care of their own supply of sample collection materials. This is done from the storage room in Almelo, Hengelo or Enschede depending on the location where the laboratory workers drop off their collected samples.

Medlon provides cooled test kits for general practitioners. These kits cannot be delivered by mail due to transportation conditions. Cooled test kits are delivered by the own transportation service of Medlon as much as possible but are delivered by external transporters when no own transport is available.

2.2.2 Volumes of materials Medlon

It was not possible in this research to collect annual data on diagnostic samples. The largest possible time window in one dataset was one month. In consultation with the Medlon planning manager data from representable months was taken.

Diagnostic material

In 2016 Medlon collected approximately 725,000 samples. Of all samples collected by Medlon, a rough distinction can be made into three sources. The hospitals in the region harboring blood collection outpatient clinics produce a large part of the samples handled and tested by Medlon. Another source that creates a large part of samples is the blood collection offices. And finally, the workers that collect samples from the patients at home form a large group of samples. An overview of the number of samples collected in January is shown in Table 2-1. A noticeable record in the table is the number of samples collected by workers from patients at home after working in a blood collection office. Workers start working at a blood collection office in the morning, and when work at the office is finished, workers continue to collect samples from patients at home before returning to the laboratory. Furthermore, the applicant “Care homes” form a large group of samples. These care homes do not have a blood collection office or point, but a worker going to the care homes performs likewise services as the workers who visit patients at home. Since a lot of patients who have their samples collected live together in a care home, they are mentioned separately in the data and thus in the table. Applicants under the category “Other” are the laboratory itself and small healthcare facilities such as the municipal health services or fertility clinics. A weekly trend is shown in Figure 2-6, it can be shown from the weekly trend that the busiest days for Medlon are Monday and Tuesday; this is confirmed by the Medlon planning manager. A daily trend is given in Appendix A. What can be shown from the daily trend is that most of the samples taken at blood collection offices are registered in the morning at 9 AM while the other peak in samples forms around 11 AM.

Redistribution of diagnostic materials

Approximately 28800 samples are redistributed from Almelo to Enschede each month based on data from April 2017 with regular transport.

Non-diagnostic materials

The volumes of non-diagnostic materials are transported by workers of Medlon is unknown.

Applicants in January 2017	**Number of samples**
Blood collection office	21,967
ZGT Almelo	6,213
MST Enschede	5,679
ZGT Hengelo	4,987
SKB Winterswijk	4,800
MST Oldenzaal	2,831
MST Haaksbergen	2,172
MST Losser	1,085
Care homes	5,512
Home collection	3,159
Home collection after collection offices	704
Other	2,079
Total	61,188

Table 2-1 Samples collected by Medlon in January 2017

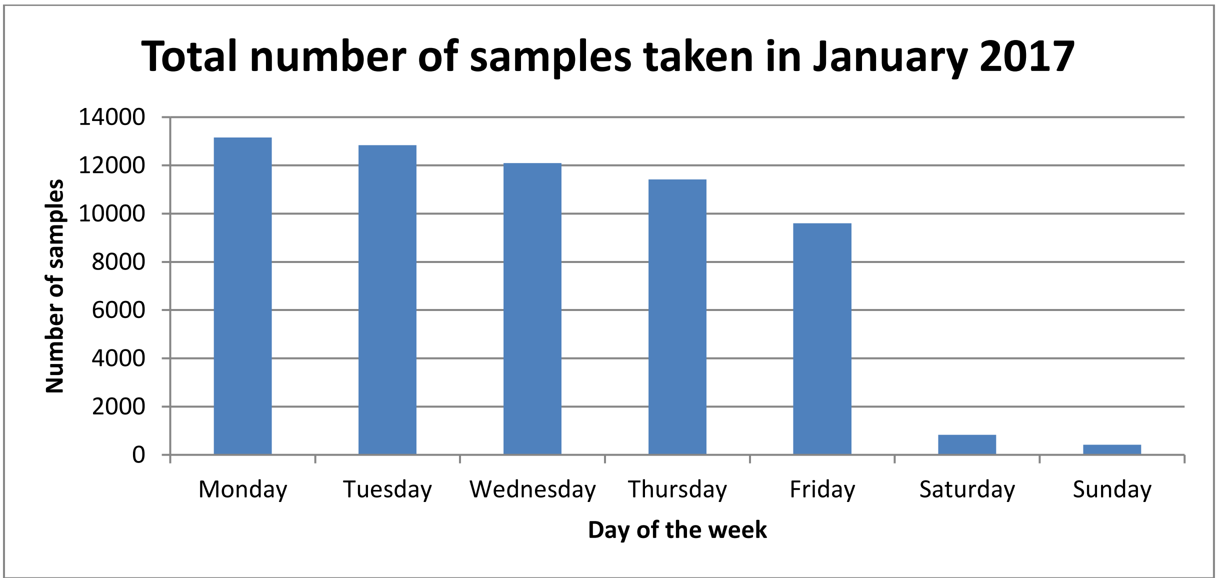


Figure 2-6 Medlon number of samples per day of the week

2.2.3 Flow of materials LabMicTA and LabPON

Diagnostic materials

For all the diagnostic materials to be transported by LabMicTA and LabPON there is a one-way stream that always ends in the laboratories of either LabMicTA or LabPON. The only exception for diagnostic materials coming from the laboratories are the radioactive iodine-125 samples, these materials are collected in SKB Winterswijk and after diagnosis, need to be transported back to Winterswijk. All the other samples are either picked up by a specialized service to be destroyed in a central point in the Netherlands. Most pathology samples are not destroyed but stored at the laboratory itself by regulation. This is done for future diagnosis when, for example, a pathologist performs diagnosis on family members of the current patient or when a patient needs another diagnosis after a period to draw conclusions.

It can also occur that a certain test cannot be performed at the laboratories in Hengelo and the samples need to be transported to other laboratories in the Netherlands or Europe. This kind of transport is not included in this research.

Daily transport picks up transportation boxes from the front offices and general practitioners or healthcare centers. The front offices serve as collection points for all the requests coming from the specialists in the hospital. Both types of locations serve as a collection point for other customers, not along the daily routes.

Non-diagnostic materials

Resupply of the front offices and the general practitioners or healthcare centers is done from the central storage location in Hengelo. As mentioned before, LabMicTA and LabPON provide specimen collection materials and packaging materials for free to general practitioners to encourage sales. Next to the specimen collection materials, all mail for on-route general practitioners and healthcare clinics are delivered by own vehicle transport to save costs on mail.

2.2.4 Volumes of materials LabMicTA

Diagnostic material

LabMicTA performed a total of 163,161 tests in 2016. Most of the tests performed by LabMicTA were for general practitioners in the region. Next to the general practitioners, the hospitals in the region, such as MST Enschede and ZGT Almelo were large customers of LabMicTA. One client that is notable aside from the hospitals, is the community health service. Most of the tests performed for this client are STD tests. A system reported overview of the number of tests performed in 2016 is given below in Table 2-2. Customers among the category "Other" are refugee centers, working conditions inspectors, midwives, etc. all with several tests lower than 1,000 a year. Furthermore, an overview of the total number of samples per weekday is given in Figure 2-7. The annual trend for LabMicTA in 2016 is shown in Appendix B. What can be shown is that the number of tests has a general drop in May and tends to go up at the end of the year, especially for general practitioners. During a week, Monday and Tuesday are the busiest days on the total number of tests.

Applicants in 2016	Number of tests
General practitioners	49,522
Hospital MST Enschede	43,305
Hospital ZGT Almelo	31,380
Community health services (GGD)	10,266
Hospital SKB Winterswijk	11,113
Hospital ZGT Hengelo	7,374
Other hospitals	2,851
Nursing homes, Care homes, and home care	2,265
Private clinics	870
Other	4,215
Total	163,161

Table 2-2 Total number of tests performed by LabMicTA in 2016

<u>Non-diagnostic material</u>

There is no data available for the volumes of non-diagnostic materials. The only assumption that can be made is that for every sample that is collected materials must be transported to the collector.

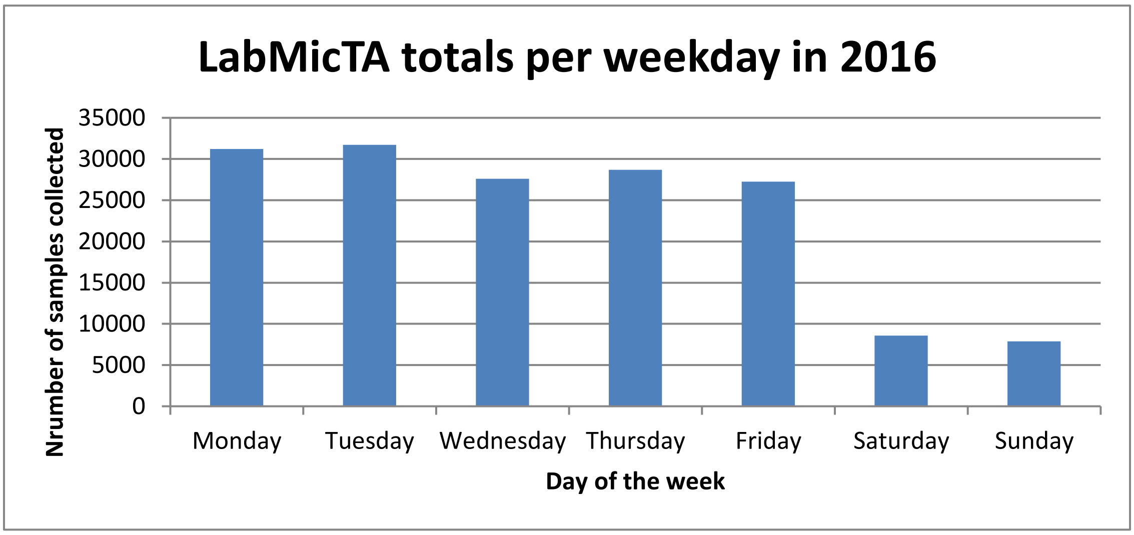


Figure 2-7 LabMicTA totals per weekday in 2016

2.2.5 Volumes of materials LabPON

Diagnostic material

LabPON performed 112,267 tests in 2016. Most of the tests performed by LabPON were either from hospitals in the region or from general practitioners, see Table 2-3. Applicants in the category of "Other" were tests and revisions of LabPON itself, the Deventer hospital or the Laurentius hospital in Roermond. The weekly volumes of LabPON in 2016 are depicted in Figure 2-8 LabPON totals per weekday in 2016. What can be shown from the weekly trend in is that contrary to Medlon and LabMicTA, Monday is not a peak day and Wednesday counts the highest number of samples collected. An annual trend for 2016 can be found in Appendix C.

Applicants in 2016	Number of tests
General practitioners	36,328
Hospital MST Enschede	29,292
Hospital SKB Winterswijk	11,055
Hospital ZGT Almelo	16,345
Hospital ZGT Hengelo	18,585
Other	662
Total	112,267

Table 2-3 Totals: tests performed by LabPON in 2016

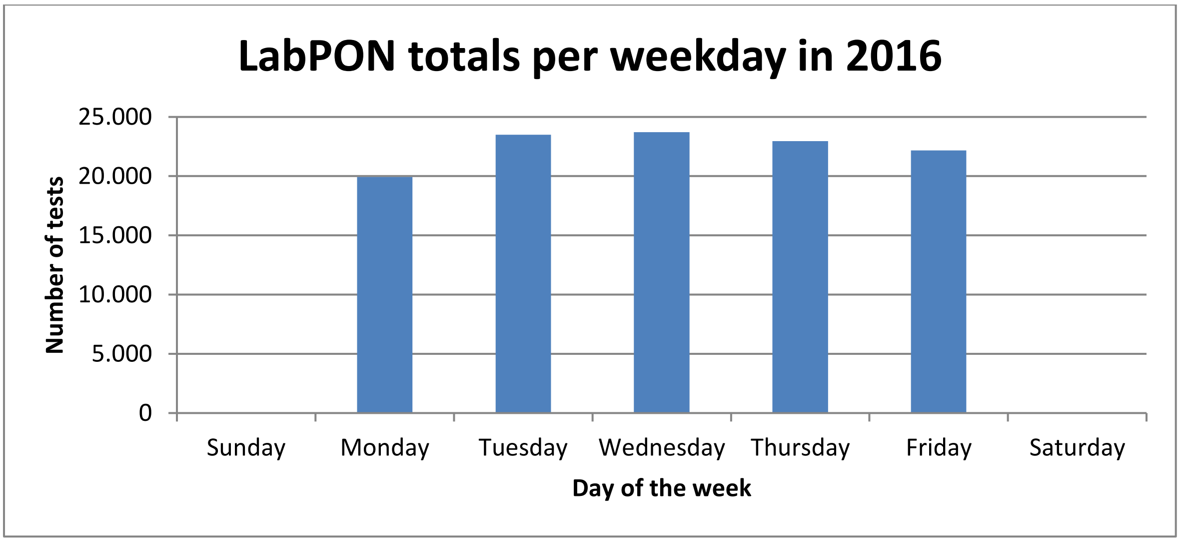


Figure 2-8 LabPON totals per weekday in 2016

General practitioners

Of the 36,328 tests performed for general practitioners, 26,777 tests were cytological tests to screen for cervical cancer as part of a population survey. Rules concerning the population survey of cervical cancer have changed as of 2017 (van Haaren, 2016). There has been a change in standard procedures and from now on only five laboratories in the Netherlands have been selected to perform the screening tests. LabPON is not part of this group. So, if we would take 2016 as a projection of the number of tests performed for general practitioners in 2017 this would result in only 9,551 tests. This is 26.29% of the total number of tests in 2016.

LabPON has 166 different postal codes where 411 of their general practitioners are located. Of those 166 different postal codes, 119 are located directly on an existing route. The next 20 postal codes are located near the fixed route and have a drop-off point. The other 27 postal codes of the location of the general practitioner are not near or on a route. When we correct the data of 2016 for the new rules of 2017 concerning cervical cancer screening locations have an average of 50.86 tests per year with a standard deviation of 52.39.

Non-diagnostic material

Similar to LabMicTA, there is no data available for the volume of non-diagnostic material of LabPON. The only assumption that can be made is that for every collected sample material must have been delivered at some point in time.

2.2.6 Flow of materials ZGT

ZGT transports the most diverse materials of the organizations. When analyzing what the transportation service of ZGT transports, diagnostic materials are (generally) only transported between the locations of Almelo and Hengelo. The rest of all transport includes non-diagnostic materials. Initially, the transportation service of the ZGT was set up to transport materials between locations of ZGT when needed. A regular transport commutes between the locations Hengelo and Almelo seven times a day.

In parity with regular businesses, the facility department tries to make a profit by performing transportation services for other parties than ZGT itself. The transportation service provides a lot of transportation for the clinical pharmacy of ZGT. For the clinical pharmacy, there are three types of customers to be distinguished as locations for the transportation service in 2016. These customers are patients living in CarintReggeland care homes, the Röpcke-Zweers hospital in Hardenberg, and patients needing medicine delivered to their homes.

Transportation of medicine to patients at home is referred to as “Alpha rides”. The transportation to CarintReggeland group care homes and the hospital in Hardenberg are fixed locations. These locations are depicted in Figure 2-9. All CarintReggeland care homes have a red marker. The Hardenberg hospital is marked black. In their daily routines, ZGT visits Hardenberg daily. Three times a week Hardenberg is visited twice on a day. Rides to CarintReggeland are separated into a routine in Hengelo and a routine outside Hengelo. It is known beforehand what CarintReggeland care homes need to be visited each day. There is a fixed route for CarintReggeland care homes, but care homes are skipped if no drugs need to be delivered. Which patients need to be visited in an alpha ride is only known the day prior to the transport. Alpha rides are therefore not fixed. There were 43 different places in Overijssel and Gelderland where Alpha rides needed to be delivered. Information regarding what location needs to be visited is provided by the clinical pharmacy.

As of 2017, the ZGT started to transport sterilized and used operating tools for the jaw outpatient clinic in Hardenberg. Next, the transportation service also started to provide transportation for Medlon between Hengelo and Almelo.

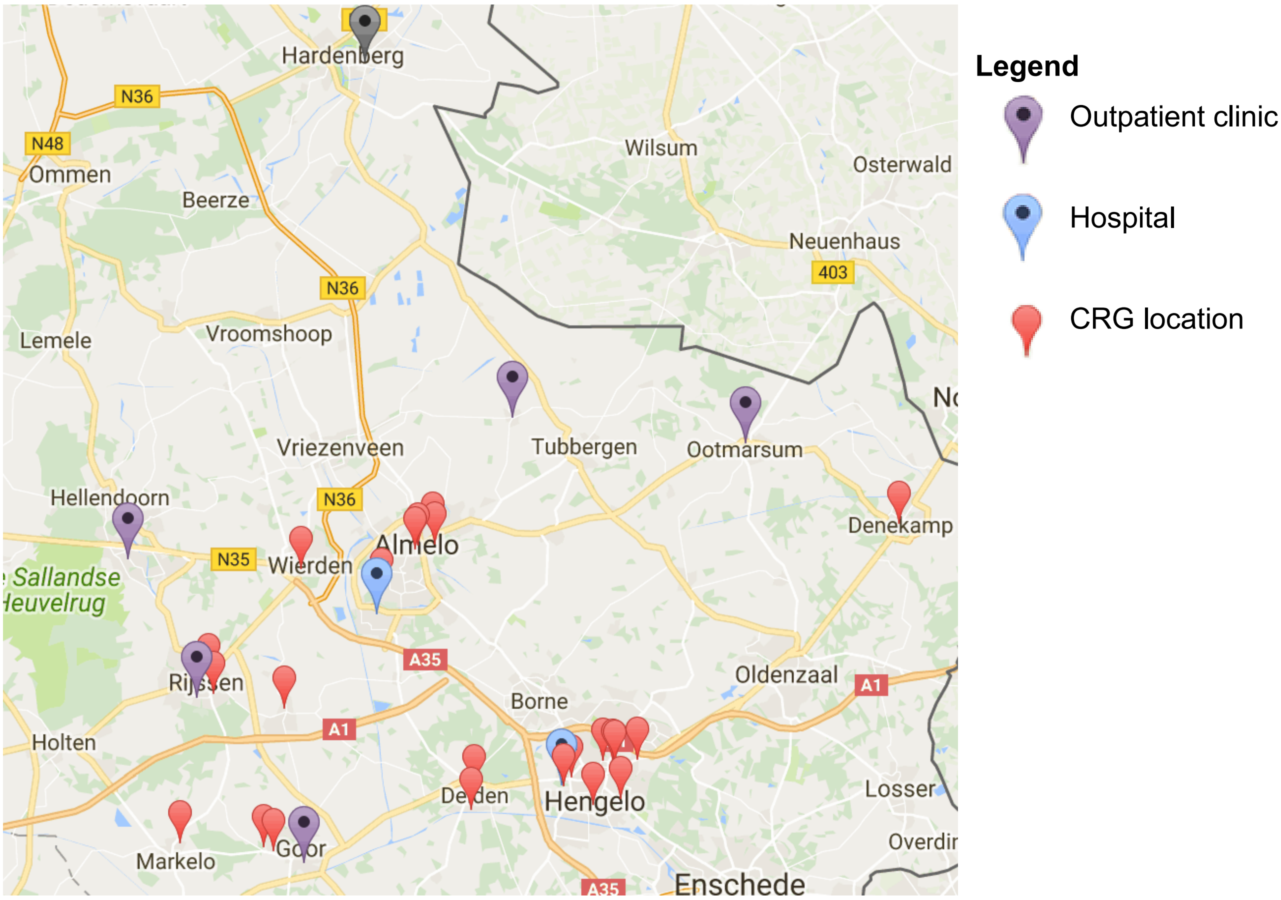


Figure 2-9 Fixed locations of customers ZGT in 2016

<u>Irregular rides</u>

Besides the regular rides that are planned, there are irregular rides that are requested. These rides are usually to other outpatient clinics in the area to deliver material needed by a specialist such as a CD with scans of a patient. These rides are unplanned. When ZGT does not have sufficient capacity to perform irregular rides or when rides are too far, an external courier is hired.

2.2.7 Volumes ZGT

There are no records available of what ZGT transports in a ride. However, the locations visited are registered per day. Table 2-4 provides the locations visited by the ZGT transportation service in 2016. Furthermore, Figure 2-10 provides an overview of the weekly number of transports to different locations. What can be shown is that Tuesday and Friday are the busiest days. The annual trend is shown in Appendix D and shows a drop in May and a rise towards the end of the year for the CarintReggeland transports. Other transports project a steady curve throughout the year.

Type of location	Number of rides
CarintReggeland Total	5,038
Hospital Hardenberg	492
Alpha rides	657
Extra work	317
AB-Koeriers Extra work	31

Table 2-4 ZGT Number of rides to the type of location in 2016

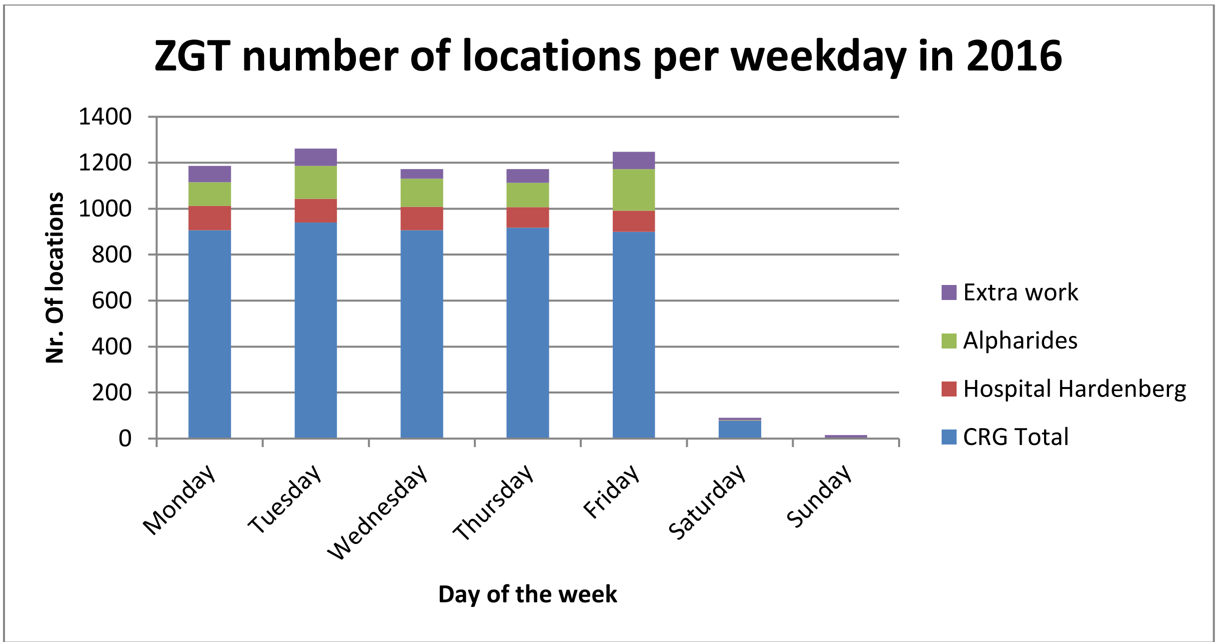


Figure 2-10 ZGT number of locations per weekday in 2016

2.2.8 Concluding flow and volumes

This section answered Sub-Research Question 1.2: *"What is the current flow and volumes of materials in the organizations?"*. We have elaborated the flow of materials between locations of the organizations and have seen that the flow of materials differs between the organizations. When one would compare the flow of the organizations, there is not a clear direction in which the materials are transported overall. The flow of materials is often location specific and is not easy to generalize based on the i.e. type of location. This might pose a problem when modeling the problem.

The information gathered on the volumes of the organizations show similarities to what is available per organization. All the organizations have little to no information on the volumes of the non-diagnostic materials. Furthermore, it shows that the weekly volumes show similarities between the organizations, peaking on the first days of the week.

Although the annual trends sometimes show specific patterns throughout the year, the routes on which these volumes are collected are predetermined and suffice the demand for transportation on these differing volumes. Next, the flow of the materials is often location specific but again the predetermined routes suffice the demand for materials. We conclude that the predetermined weekly routes provide the information needed to suffice the demand in flow and volumes of the organizations throughout the year.

2.3 MATERIALS TO BE TRANSPORTED

Material transported by vehicles of the organizations can be separated on many conditions, e.g., whether the material is of human descent or a product like a sample kit. For the purpose of this study, it is important to separate the materials on special conditions in which materials must be transported.

2.3.1 ADR

A large part of the materials transported between locations in this research are materials of human origin or are considered toxic or dangerous. In the Netherlands, such materials must be transported according to the ADR which stands for “Accord Européen relative au transport international des marchandises Dangereuses par Route”. This is an agreement between 39 countries to transport dangerous materials internationally by road. The ADR is a UN document. In the Netherlands, this agreement is an attachment of the VLG (Regeling Vervoer over Land van Gevaarlijke stoffen) that is in turn part of the law WVGS (Wet vervoer gevaarlijke stoffen).

The ADR uses UN-numbers of materials to determine what type of materials must be transported according to what rules. In the ADR, human or animal materials intended for investigation or diagnosis are classified as “Biological Substance, Category B” and get the UN-number UN3373 that stands for “Diagnostic substances”. Most blood or urine samples fall in this category of transport. Examples of other UN-numbers are UN3291 that stands for “Clinical waste” and UN2814 that stands for “Infectious substances affecting humans”. The ADR states that all materials that are categorized as UN3373 need to be packaged according to P650, short for Packing Instruction 650.

All UN3373 materials that are to be transported are treated as contagious to ensure safety. P650 states that packaging always must consist of three components: a primary recipient such as a sample tube, a secondary packaging that can be hermetically sealed and a third outer packaging that needs to be rigid. These outer packings are the transport boxes handled by the vehicle drivers.

Transport boxes used by the companies in this research are bought at specialized companies which ensure that the right quality levels are met. Quality levels for ADR approved transport of UN3373 materials are drop tests from different angles from a minimum height of 1.2 meters. After these drop tests, the primary recipient cannot leak. Furthermore, when the primary recipient contains a fluid, such as blood or urine, the primary or secondary recipient must be able to endure an internal pressure of 0.95 Bar (De Rijck, 2015).

Radioactive material

Other materials that are transported by vehicles in this research are radioactive or nuclear materials. According to the ADR and the Dutch law, transport of such materials need to be under the supervision of the driver at all time when not in a locked space. Furthermore, radioactive boxes need transportation documents with them stating the UN-number of the material transported. Examples of UN-numbers are UN2910 for boxes with a limited amount of radioactive content and UN2908 for empty radioactive packaging. When an exchange of these materials occurs between companies, the transportation documents need to be signed (Autoriteit Nucleare Veiligheid en Stralingsbescherming, n.d.).

Transportation of radioactive materials on the road also comes with consequences for the vehicle in which the transportation box is loaded. The maximum amount of packages with radioactive content that can be loaded in one vehicle is 50 (Gevaarlijkestoffen.net, n.d.). Furthermore, the vehicle must have appropriate warning signs (depicted below in Figure 2-11) on the sides and the front and back depending on the level of radiation, two fire extinguishers, and a bag of tools.

Figure 2-11 ADR signs category 7-I, 7-III

<u>Cytostatics</u>

Another type of material that has its own transportation regulation is cytostatics. Cytostatics are materials that are used in cancer treatment and reduce allover cell growth and thus tumor size. Although cytostatics are meant to treat cancer patients, ironically, they are cancerous too, and thus should be handled with care. There are many types of cytostatics and for the ADR they fall into class UN2811 with danger class 6.1 which means "Poison" depicted in Figure 2-12. All cytostatics transported in this study fall into subcategories lightly toxic or toxic. There are some exceptions concerning the danger class of cytostatics, UN3077 falls into danger class 9 that are "Miscellaneous dangerous substances" and UN1170 fall into class 3 that are "Flammable liquids". According to Baarsma (2013) hospitals will often over classify cytostatics when they need to be transported by external parties since the classifier of the materials is responsible for classifying correctly.

Figure 2-12 ADR signs category 3, 6, 9

Drivers transporting materials subject to the ADR generally must be in possession of an ADR certificate. There is an exception when the amount of material is very little, this differs per ADR class. There is a point system to determine the maximum amount in kilograms or liters of transported material. The cargo cannot exceed a score of 1000 points and ADR classes have different factors to calculate the total score (van Baal & de Baas, 2014; *Informatieblad 1000-puntentabel*, 2017).

2.3.2 ZGT

The materials transported by the vehicles of ZGT are very diverse. Some transports handled by the facility department are regular, others are at request.

Regular transport

Every day there is a vehicle driving seven times between the location of Almelo and Hengelo. This transport includes cytostatics and nuclear materials and needs to be handled ADR accordingly. Although cytostatics and nuclear materials are included in this transport, other materials can be included as well. Other regular transports by ZGT vehicles include medicine that needs to be transported from the hospital to pharmacies and medicine transported to care homes of “CarintReggeland” group within and outside Hengelo. Furthermore, ZGT handles the transport of sterilized equipment of a jaw surgery outpatient clinic in Hardenberg. Finally, ZGT drives “Alpha rides” were medicine is transported directly to patients’ homes. The term “Alpha rides” refers to the drugs that are transported: TNF-α-inhibitors. These types of drugs need to be handled with care and are transported under cooled conditions. Shaking the drugs too much or a temperature that is too high, too low, or too variable will make the drugs inoperative.

Non-regular transport

Non-regular transport by ZGT can also be done at the request of specialists and vary composition. These transports include CDs with patient information such as scans, machines, chairs, oxygen bottles, etc. Some of these transports are to be considered emergency transports.

2.3.3 LabMicTA and LabPON

LabMicTA and LabPON have a clear distinction in the materials transported by the company’s vehicles. The materials arriving at the laboratory are generally all samples for diagnostics and the materials going are almost all resupply in transportation boxes, new recipients of samples and outgoing mail for the locations along the routes.

Diagnostic samples

Most laboratory samples handled by LabMicTA and LabPON are categorized as UN3373 and thus need to be transported accordingly. All materials that are to be transported are treated as contagious to ensure safety. P650 states that packaging always must consist of three components: a primary recipient such as a sample tube, a secondary packaging that can be hermetically sealed and a third outer packaging that needs to be rigid. These outer packings are the transport boxes handled by the vehicle drivers.

Packaging is always done at the collection location by either the driver of the vehicle or by someone at the pickup location, depending on the content of the transport box. Stickers are used to mark which boxes are not to be opened by the driver. Boxes from the mortuary and boxes with radioactive content are boxes that cannot be opened by the driver of the vehicle and come with extra regulation.

Radioactive boxes transported from and to the laboratory contain iodine-125 or I-125 used in cancer treatment. In the case of LabMicTA and LabPON, the exchange is between a hospital and LabPON and thus between two companies.

From a jurisprudent point of view, there are no regulations concerning the temperature of samples when transporting them over roads. When transporting samples through other means, internationally by air, a stricter widely used agreement is used called IATA, short for the International Air Transport Association. Stricter rules include testing packaging under different temperatures and more rules regarding the outer packaging. Still, no temperature related laws apply. The focus of the ADR and IATA agreements is to contain the sample when transported, not to guarantee the quality of the samples. Interviews with managers of LabPON and LabMicTA brought forward that approximately 360 packages are sent by mail, which could have been taken along the daily route every month. These packages follow the regular mail path and there is no supervision from LabMicTA what these samples have been exposed to. For instance, samples could be in a mailbox all weekend on a hot summer day. LabMicTA and LabPON have plans to get NEN-EN-ISO15189+C11 accreditations for their laboratories and thus such transport by mail will eventually cease.

Transportation of materials categorized as UN3373 can vary in the temperature levels they need to be transported in. Most of the samples are transported at room temperature, which is defined as a temperature between 15-25 degrees Celsius. Other samples transported are to be transported under cooled conditions. To create cooled conditions, ice packs from “Techniice” are used, which can maintain a temperature of -13 degrees Celsius (Techniice, n.d.). Icepacks are put in the transport boxes together with the primary and secondary packaging.

All transport boxes used by LabMicTA and LabPON are UN verified and are bought at the company “Transposafe”. LabMicTA uses different colors of transportation boxes to indicate what kind of samples are transported in which boxes. For instance, boxes with a blue lid are used for cytology samples. So apart from different transportation conditions, samples are put together by specialism. Boxes look like the image depicted in Figure 2-13.

Figure 2-13 Example of a sample transportation box

2.3.4 Medlon

Similar to the transport by LabMicTA, a clear distinction can be made in the materials transported by vehicles of Medlon in diagnostic materials and the resupply of blood collection posts and points, and the delivery of materials ordered by general practitioners, with diagnostic material, generally being picked up and distributed further and other materials being delivered when collecting diagnostic materials.

Diagnostic material

Like LabMicTA, material transported by vehicles of Medlon is subject to ADR since the diagnostic material of human origin is transported by road. This means that transport by Medlon of UN3373 materials must be under P650 instructions. It is no surprise that Medlon uses the same transportation boxes for their UN3373 materials as LabMicTA and LabPON as shown in Figure 2-13. Although boxes are bought at the same company, different types of transportation boxes can be distinguished. Medlon uses three different types of transportation boxes that have the same contour but differ in height. In resemblance to LabMicTA, boxes have different colors and or are marked with stickers to indicate what samples are to be put in what boxes depending on the clinical chemical field of expertise. Medlon basically has three different temperatures at which material needs to be transported: room temperature, cooled transport between 2 and 8 degrees Celsius, and frozen transport at -20 degrees Celsius. In contrast to the other transport temperatures, the -20 degrees Celsius samples are packed in different transportation boxes. Here an outer packaging of polystyrene is used instead of a hard-plastic case.

Recipients packing materials and medical tests

Medlon sells recipients and packing material for specimens to specialists and resupply their own locations. When possible, materials are taken along the transport route. When these materials cannot be taken along an existing route, postal services are used to deliver the ordered materials. Next to recipients and packaging, Medlon also sells medical tests that need to be transported under cooled conditions. Since cooled transport cannot be guaranteed by postal services, these test kits are transported either by own transport or by an external courier "Kamphuis Koeriers".

2.3.5 Concluding materials to be transported

This section answered Sub-Research Question 1.3: *"What materials are transported per organization?".* We can conclude that the content of packaged materials differs a lot between the organizations. A clear distinction can be made between diagnostic and non-diagnostic materials, but for cooperation to be established this should not matter for handling the materials. If the materials themselves are packaged accordingly and if time windows of transportation are not exceeded, there should not be a validation of quality standards that need to be met. If needed, registration of transportation comes naturally while handing over packages.

To cooperate on material transport, the organizations must be able to comply with the applicable legislation of the ADR. In practice, the drivers of the organizations must be certified to transport the materials of all other organizations for cooperation to be possible. Likewise, all the vehicle must be equipped to handle any occurring cargo.

2.4 WHO ARE THE INVOLVED EXTERNAL PARTIES?

In the first two sections, we already described the organizations directly involved in this research. However, there are multiple external parties involved in the transportation processes of the organizations. These external organizations are described in this section.

2.4.1 External parties

When a lack of capacity in own transport occurs or when materials need to be delivered or collected, external transportation services are used. Situations where external parties are used, are: materials need to be transported out of the region, emergencies (e.g., a test needs to be performed during an operation), or when all own transport is in use and there is still material to be transported, and finally as backup for illness of drivers or vehicles broken down or in repair. Every company uses different external couriers besides their own resources, see Table 2-5.

Company	Courier
ZGT	AB-Koeriers
Medlon	Kamphuis-Koeriers
LabMicTA and LabPON	MSG-Koeriers, taxies

Table 2-5 External parties per organization

The use of external parties to ensure timely delivery of materials is costly. The organizations use external couriers on a different basis. Medlon uses an external courier to perform some of their regular routes. ZGT only uses external couriers when the regular transport is too busy. Lastly, LabMicTA and LabPON use external couriers to deliver or collect materials out of their service area. Furthermore, LabMicTA and LabPON hire taxies to bring staff or materials from or to operations in hospitals. However, use of taxies is excluded in this study because the focus is on material transport only. How external parties are used exactly is further elaborated in the costs section.

2.4.2 MST, a conflict of interests

A party that has a special position in this study is MST. MST is a direct competitor of ZGT and a large client of Medlon, LabMicTA, and LabPON. MST has multiple outpatient clinics that are on route locations of the transportation services. Furthermore, MST is the other large shareholder of Medlon, next to ZGT. Lastly, the department of facility transportation service of MST provides a small part of the transportation service for Medlon to MST locations from a historical point of view for free. This involvement concerns two regular routes of Medlon and is further elaborated in the costs section.

At the initiation of this study, MST has been approached for participation in this project but declined to collaborate. Although MST declined collaboration, future collaboration is not excluded.

2.4.3 Concluding

This section answered Sub-Research Question 1.4: "*Who are the involved external parties?*". In this section, we have elaborated the involvement of external parties in this research.

2.5 WHAT ARE GOOD PERFORMANCE INDICATORS FOR MATERIAL TRANSPORT?

This section describes argumentation for measuring the performance of the current means of transportation. The urge to explore collaboration between the organizations on transportation of materials is initiated by the mutual observation that vehicles visit the same locations at the same time. Following the creation of a possible collaboration between the organizations, advantages and disadvantages are thought of by the researcher in conjunction with the project initiators and transportation managers. This section first identifies all mutual interests and drawbacks of collaboration and translates these interests into measurable performance indicators.

2.5.1 Mutual interests for collaboration

In this subsection, multiple interests for collaboration are elaborated.

Cost reduction

As mentioned, cost reduction is a major argument for collaboration in the transportation of materials. In section 2.6 total costs per organization are composed of the following factors: The hours of staff needed for the transportation services to operate, the number of vehicles used, the outsourcing of transportation, and the fuel consumption. Each of these factors has a linear relation with the total costs. It benefits all organizations to minimize the level of these factors while complying with the transportation needs of each organization.

Improvement of quality of service

Another argument for collaboration between the organizations is to improve the quality of services. Collaboration could induce faster transportation times. Faster transportation times in their turn induce a better offer to the customers. E.g., if a diagnostic sample can be 15 minutes earlier at a laboratory, the laboratory workers can start to work on the sample 15 minutes earlier.

A small change in arrival time could decrease the total throughput time of a diagnostic sample. Offering customers better throughput times stimulates customer binding and customer appeal.

If visits to customers were to be combined because of collaboration between the organizations, ease of use of either of the organizations' services would improve, since all materials picked up or delivered are handled by a single visit on a regular time to the customer. All transactions are completed at once.

In case of a customer on a regular route, combined visits to a customer result in relatively more visits by the same vehicle driver. This increases the familiarity of the customer with the driver and the organizations and is to be considered as a desirable aspect of transportation. Combined visits of the organizations to customers create an illusion of a single organization offering a wide range of services. This results in less thinking about services of the organizations by the customers and thus increases the quality of services. Another benefit of customers not having to think about the services of the organizations is that competitors are less likely to be considered. Less consideration about competitors increases customer binding.

Use of external parties

Collaboration between the organizations might increase the efficiency of the transportation services of the organizations. While more efficient transportation can reduce the costs of transportation, maintaining the same material transportation budget creates space to outsource less to external couriers.

Environmental impact

Present day it is common knowledge that climate change is a global problem in which an individual or organization must take responsibility. A more efficient transportation of materials can reduce the total number of kilometers driven by the organizations. Driving less kilometer's results in a total reduction of carbon dioxide and other exhaust gas emissions. Furthermore, minimizing the total amount of vehicles used to support the transportation operation results in a smaller environmental footprint for the organizations.

Attraction to other organizations

Given that collaboration is considered beneficial to the organizations, an increased performance of the transportation of materials might increase the appeal for other regional organizations such as MST Enschede or SKB Winterswijk to join. Including these organizations in the group might create a self-reinforcing effect. Logically, the effect is inverted if collaboration has a disadvantageous effect.

2.5.2 Mutual drawbacks of collaboration

In this subsection, multiple drawbacks of collaboration are elaborated.

Co-dependency

The largest drawback for collaboration with other organizations that came up with interviews with transportation managers and project initiators was co-dependency of the other organizations. Arrival times of the vehicles and order durations are important to the organizations. Organizations fear that by collaborating with other organizations order durations or arrival times cannot be guaranteed within a certain time frame because the priority of the transport no longer solely concerns the own organization. In interviews with staff members of the transportation departments, concerns were raised that collaboration might result in more efficient transportation. More efficient transportation was directly translated by the staff members into a decrease in the amount of staff due to collaboration. Collaboration between the organizations, therefore, dismissed the responsibility of the organizations as communal job providers. Furthermore, staff members questioned the applicability of collaboration as it would interfere with other daily responsibilities.

<u>Confusion</u>

Another drawback of collaboration between the organizations is the confusion of familiarity with the organizations. Interviews with operational transportation managers of Medlon, LabMicTA, and LabPON indicated that general practitioners often are confused which organization offers what diagnostic testing procedure. This can result in incorrectly addressed samples that need to be resent to the correct organization. Resending samples is unnecessary extra work for the organizations but is often still performed as an aspect of customer service. Through collaboration between the organizations, this confusion might increase.

2.5.3 Measurable interests and drawbacks

In Section 2.5.1 and 2.5.2, the interest and drawbacks of collaboration are described in unmeasurable concepts or terms, e.g., there is not a measure of environmental impact. However, we can combine multiple measurable indicators to give a score to the environmental impact. Table 2-6 lists measurable indicators appointed to the interests and drawbacks that can be used to calculate a balanced score. The preferred directional coefficient of every measurable indicator is given per interest or drawback to indicate whether we want to increase or decrease the measurable indicator.

Interest or drawback	**Sub- interest or drawback**	**Measurable indicator**	**Preferred linear relation**
Cost reduction	Personnel costs	Staff hours needed	-
	External costs	External hours needed	-
	Vehicles costs	Vehicles used	-
		Kilometers driven	-
	Organization costs	Summation	-

	Total costs	Summation	-
Quality of service	Quality of samples	Duration of order	-
		On-road time of vehicle	-
	Short throughput	On-time arrival of order	+
	Ease of use	Visits per location or customer	-
	Customer binding	Visits per location or customer	-
External parties	Use of external services	External vehicles used	-
		External costs	-
Environmental impact	CO2 emissions	Total kilometers	-
	Environmental footprint	Vehicles used	-
Attraction of other organizations	Overall performance	Combination	+/-
Co-dependency	Quality assurance	Duration of order	-
		On-time arrival of order	+
		On-road time of vehicle	-
	Staff in service	Staff hours needed	+
Confusion	Visits of customer	Visits per location or customer	+

Table 2-6 Indicators per interest or drawback

2.5.4 Concluding performance indicators

This section answered Sub-Research Question 1.5: "*What are good performance indicators for measuring the performance of the current means of transportation?*" Having divided and translated the mutual interest and drawbacks of collaboration, we can find several performance indicators that can be used to calculate different interests or drawbacks. By calculating these values for various interventions of collaboration, we can give a more determined argumentation why and how the organizations would benefit. We can use this information to build a model in Chapter 4 and evaluate the different interventions in Chapter 6.

2.6 WHAT ARE THE CURRENT COSTS OF THE TRANSPORTATION OF MATERIALS?

This section provides an overview of the total costs of transportation by the organizations.

2.6.1 Vehicles

The organizations have a cumulative fleet of 10 vehicles. Information concerning the vehicle capacity of the organizations can be found in Appendix E. For the vehicles, we take an amortization period of three years and we assume a residual value of 40% of the purchase value, service costs of [redacted] and insurance costs of [redacted]. These values are assumed based on numerous variations of options on multiple well-known car-related websites that provide car information based on the number plate, type of car, mileage and the composition of extra options (ANWB, 2017; Autoweek.nl, 2017b, 2017a). The real values are currently unknown and therefore approximated. Other fixed information was found on "kentekencheck.nl" (2017). Business owners are exempted from the taxes in the Netherlands known as "BPM" (Taxes for private cars and motor vehicles) (Belastingdienst, 2017). Furthermore, all the vehicles are owned by the organizations as a legal form. Taxes on the purchases of materials known as "BTW" (Taxes on the added value) is deductible from the taxes paid over the revenue of the organization. This "BTW" - tax deduction is applicable to all vehicle-related costs (Belastingdienst, n.d.). Lastly, business owners can make use of a deduction arrangement for businesses known as "KIA" (Small investment deduction policy). If businesses make investments between €2.301 and €56.024 they can get a tax deduction on the business revenue of 28%. The total vehicle costs range around [redacted] annually with one clear exception for a larger vehicle of ZGT. These costs are solely for owning a company vehicle.

Most of the vehicles are of the Peugeot Partner type. ZGT differs by using slightly larger vehicles of the Citroën Jumpy type. In comparison, the fleet looks similar except for the last ZGT vehicle. The vehicle models used are depicted in Figure 2-14 and Figure 2-15 respectively.

Figure 2-15 Example of a Peugeot Partner **(**"Peugeot Partner Image" 2017**)**

Figure 2-14 Example of a Citroën Jumpy **(**"Citroën Jumpy Image" 2017**)**

Looking at the fuel consumption of the vehicles, the consumption ranges between 10,5 and 23,8 kilometers per liter. The average consumption per organization and the total average are given in Table 2-7.

Organization	Fuel consumption (Kilometer per Liter)
LabMicTA LabPON	21,92
Medlon	20,0
ZGT	13,8
Average	18,48

Table 2-7 Organization fuel consumption

The vehicles within the organizations are exchanged on different routes to distribute the wear. To make an estimate about the fuel consumption per organization, the average fuel consumption per organization is used. The diesel price per liter is not a fixed value. The national bureau of statistics provides insights about the diesel prices over the years. The price differs depending on whether the station is located near a highway and whether the station has an operator. To make an estimate about the annual diesel costs we must assume a value. The assumed diesel price is the average price of 2016 at €1,134 per liter (Centraal Bureau voor de Statistiek, 2017). Fuel costs for the organizations are tax deductible.

2.6.2 Regular rides

The regular rides consist of the existing routes that are the same every week. When we would use 2016 as the basis for an annual classification regarding public holidays the annual kilometers per route are given in

Organization	Route name	Distance on weekday (Kilometers)							Annual distance (Kilometer)
		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	
LabMicTA	1	267,3	267,3	266,3	265,5	267,3	0,0	0,0	67491,3
LabMicTA	2	218,7	218,4	218,7	218,7	218,7	0,0	0,0	55309,6
LabMicTA	3	303,8	302,9	302,0	302,6	303,5	0,0	0,0	76653,4
LabMicTA	4	353,8	352,8	350,5	353,8	372,4	0,0	0,0	90227,8
LabMicTA	5	56,0	56,0	80,5	56,0	56,0	0,0	0,0	15422,5
LabMicTA	Zaterdag 1	0,0	0,0	0,0	0,0	0,0	67,8	0,0	3593,9
LabMicTA	Zaterdag 2	0,0	0,0	0,0	0,0	0,0	82,0	0,0	4345,4
LabMicTA	Zonfeestdag 1	0,0	0,0	0,0	0,0	0,0	0,0	97,9	5874,3
LabMicTA	Zonfeestdag 2	0,0	0,0	0,0	0,0	0,0	0,0	57,2	3433,7
Medlon	NOW	19,5	19,5	19,5	19,5	19,5	0,0	0,0	4921,1
Medlon	Ochtend	126,7	126,7	89,2	126,7	126,7	0,0	0,0	30154,7
Medlon	Middag	144,6	144,6	144,6	153,9	99,3	0,0	0,0	34787,7
Medlon	Zaterdag	0,0	0,0	0,0	0,0	0,0	69,3	0,0	3673,9

Medlon	Kamphuis Borne Goor Hengelo	84,8	84,8	84,8	84,8	84,8	0,0	0,0	21465,8
Medlon	Kamphuis Oldenzaal 1	12,0	12,0	12,0	12,0	12,0	0,0	0,0	3029,7
Medlon	Kamphuis Oldenzaal 2a	12,0	12,0	12,0	12,0	0,0	0,0	0,0	2430,9
Medlon	Kamphuis Oldenzaal 2b	0,0	0,0	0,0	0,0	12,0	0,0	0,0	598,8
Medlon	Kamphuis Avondroute	58,2	58,2	58,2	58,2	58,2	0,0	0,0	14720,8
Medlon	MST Facilitair	79,1	79,1	79,1	79,1	79,1	0,0	0,0	20018,9
ZGT	Taak 22 Pendel	221,6	221,6	221,6	221,6	221,6	0,0	0,0	56073,4
ZGT	Taak 17	30,8	30,8	0,0	0,0	0,0	0,0	0,0	3143,2
ZGT	Taak 17 CRG Buiten Hengelo	94,0	94,0	94,0	94,0	94,0	0,0	0,0	23773,7
ZGT	Taak 14 CRG Binnen Hengelo	23,6	23,6	23,6	23,6	23,6	0,0	0,0	5983,2
ZGT	Taak 21 Rit Hardenberg ziekenhuisapotheek 1	85,9	81,4	81,4	81,4	81,4	0,0	0,0	20821,1
ZGT	Taak 21 Rit Hardenberg ziekenhuisapotheek 2	81,4	80,0	85,9	80,0	81,4	0,0	0,0	20684,0
ZGT	ZGT Almelo Ochtend	33,8	33,8	33,8	33,8	33,8	0,0	0,0	8560,5
ZGT	ZGT Almelo Middag	31,7	31,7	31,7	31,7	31,7	0,0	0,0	8010,5

Table 2-8 Kilometers per different current route

It must be noted that approximately half of the current routes by Medlon are outsourced at external courier “Kamphuis”, naturally, all Kamphuis prefixed routes are outsourced to Kamphuis couriers and are included the table above. Furthermore, MST provides the transport from other MST outpatient clinics hereby providing a service for Medlon to transport their materials as well. This is still done (for free) because of the historical relationship between the two organizations. Rides performed by MST are not included in Table 2-8.

2.6.3 Irregular rides and external parties

Apart from the regular weekly transport, there are irregular rides that are not planned.

<u>Medlon</u>

As explained in Section 2.4.1, there are external parties who perform irregular transport. Medlon has CITO samples that fail to be transported on the regular rides. No data is recorded on the number of rides provided for these transports, but an interview with the operational transportation manager and a company document estimated that

CITO transports occur around 20 times a month. The costs for such transports with the regular routes differ. CITO transports provided by own vehicles of Medlon cost [redacted] per ride, outsourced transports cost [redacted] per ride. In the current situation, all the CITO transports are outsourced to Kamphuis. This results in an estimated annual cost of [redacted]

As mentioned in Table 2-8, Kamphuis also provides regular rides for Medlon. The costs in 2016 are provided in Table 2-9. Mind you, these costs are different from the irregular rides described above.

Route name	Ride costs	Annual ride costs
Kamphuis Borne Goor Hengelo	[redacted]	[redacted]
Kamphuis Oldenzaal 1	[redacted]	[redacted]
Kamphuis Oldenzaal 2a	[redacted]	[redacted]
Kamphuis Oldenzaal 2b	[redacted]	[redacted]
Kamphuis Avondroute	[redacted]	[redacted]

Table 2-9 Medlon outsourced annual transportation costs

ZGT

As a part of the facility department of ZGT, the transportation service transports all transportation requests from ZGT staff. With the transportation service, this is known as “extra work”. In 2016 this resulted in a self-reported distance of 8947 kilometers. The extra work was performed for a total of 209 hours. Next to “extra work” the transportation service handles Alpha rides (home delivery of medication to differing pharmacy clients). In 2016 the total number of kilometers used for alpha rides was 6915 kilometers. If the transportation service has a shortage of own capacity external courier AB-Koeriers is used. In 2016 AB-Koeriers was used 31 times at a cost of [redacted].

2.6.4 Staff

This section provides information about the hours needed for transportation and the staff hired to perform transportation. Hourly rates per day of the week and organization are collected from interviews with transportation managers. The costs are calculated using the standard schedules and using 2016 as a reference year for holidays.

Staff costs per hour

Table 2-10 provides the cost rate of hiring staff for the transportation service. The costs include taxes and represent the actual costs for the organization to hire an employee.

Organization	Standard rate per hour	Saturday rate per hour	Sunday and holiday rate per hour
LabMicTA LabPON	[redacted]	[redacted]	[redacted]
Medlon	[redacted]	[redacted]	[redacted]
ZGT	[redacted]	[redacted]	[redacted]

Table 2-10 Cost of hiring staff per organization

Material transport

The hours needed for transportation are given in Table 2-11. The annual costs are calculated for the year 2016 taking the corresponding rates into account.

Organization	Route name	Scheduled start time	Scheduled end time	Workhours	Annual hours	Annual costs
LabMicTA	1	09:30:00	17:35:00	08:05:00	2045	[redacted]
LabMicTA	2	08:10:00	17:10:00	09:00:00	2277	[redacted]
LabMicTA	3	08:10:00	17:10:00	09:00:00	2277	[redacted]
LabMicTA	4	07:45:00	17:20:00	09:35:00	2425	[redacted]
LabMicTA	5	08:45:00	12:00:00	03:15:00	822	[redacted]
LabMicTA	Zaterdag auto1	08:00:00	12:00:00	04:00:00	212	[redacted]
LabMicTA	Zaterdag auto2	08:30:00	11:00:00	02:30:00	133	[redacted]
LabMicTA	Zonfeestdag auto 1	08:00:00	10:45:00	02:45:00	165	[redacted]
LabMicTA	Zonfeestdag auto 2	08:30:00	11:15:00	02:45:00	165	[redacted]
Medlon	NOW	08:15:00	09:50:00	01:35:00	401	[redacted]
Medlon	Ochtend	09:50:00	13:30:00	03:40:00	928	[redacted]
Medlon	Middag	13:30:00	17:15:00	03:45:00	949	[redacted]
Medlon	Zaterdag	12:00:00	14:00:00	02:00:00	106	[redacted]
ZGT	Taak 22 Pendel	07:45:00	16:35:00	08:50:00	2235	[redacted]
ZGT	Taak 17	11:00:00	12:00:00	01:00:00	102	[redacted]
ZGT	Taak 17 CRG Buiten Hengelo	16:00:00	19:30:00	03:30:00	886	[redacted]
ZGT	Taak 14 CRG Binnen Hengelo	16:00:00	17:45:00	01:45:00	443	[redacted]
ZGT	Taak 21 Rit Hardenberg ziekenhuisapotheek 1	09:00:00	12:00:00	03:00:00	759	[redacted]
ZGT	Taak 21 Rit Hardenberg ziekenhuisapotheek 2	13:00:00	15:30:00	02:30:00	633	[redacted]
ZGT	ZGT Almelo Ochtend	09:30:00	11:00:00	02:00:00	506	[redacted]
ZGT	ZGT Almelo Middag	12:30:00	14:00:00	02:00:00	506	[redacted]
ZGT	Alpha	12:00:00	14:00:00	02:00:00	1012	[redacted]
ZGT	Extra	-	-	-	209	[redacted]

Table 2-11 Hours of hiring staff per organization

2.6.5 Concluding costs

This section answered Sub-Research Question 1.6: "*What are the costs of the current transportation of materials by vehicles?*" When the previous cost items are combined, a grant picture of the total annual transportation costs can be created using 2016 as a reference year. This information is provided in Table 2-12.

Organization	Annual staff hours	Annual staff costs	Annual vehicle costs	Annual kilometers	Annual fuel costs	Annual outsourced costs	Total costs
LabMicTA LabPON	10500	[redacted]	[redacted]	322400	[redacted]	[redacted]	[redacted]
Medlon	2400	[redacted]	[redacted]	73500	[redacted]	[redacted]	[redacted]
ZGT	7300	[redacted]	[redacted]	162900	[redacted]	[redacted]	[redacted]
Total	20200	[redacted]	[redacted]	558800	[redacted]	[redacted]	[redacted]

Table 2-12 Annual transportation costs

2.7 CONDITIONS OF COLLABORATION

The following section describes the conditions and constraints needed for collaboration. In general, the research into the possibilities of collaboration was initiated with the different organizations desiring to work together on the condition that internal demands of logistical flows would not be altered, and transport would consider the different quality demands of each organization. These demands form the basis of this chapter. The chapter is divided into two sections, describing the hard and soft restrictions of the organizations respectively.

2.7.1 Hard collaboration restrictions

Hard collaboration restrictions are restrictions that cannot be altered. The following hard restrictions are identified:

<u>Vehicles and materials</u>

In Section 2.3, the different materials to be transported by the organizations have been described. It comes naturally that when collaborating, the vehicles of the organizations all must be equipped with the right equipment to transport all materials, i.e., having two fire extinguishers, the right ADR signs, and a bag of tools. Materials are packed such that drivers do not have to open the boxes when they contain a hazardous load. This goes similarly for the materials that are prone to be damaged such as the cooled diagnostic samples.

<u>Time restrictions</u>

Since Medlon, LabMicTA, and LabPON are laboratories, they transport diagnostic materials that have different time limits:

- For LabMicTA and LabPON to fulfill the ISO standard of transporting diagnostic materials, the rides cannot exceed a time limit of 4.25 hours.
- For Medlon the cooled transports have a temperature registration and cannot be on the road longer than 3.5 hours.
- Next to cooled materials transported by Medlon, newly collected blood samples must be centrifuged within 2.5 hours. It depends on the location whether newly collected blood samples can be collected. In this research, the general rule of thumb is that only the larger locations are equipped with a centrifuging machine.
- The ZGT transports that contain TNF-α-inhibitors are cooled and must be transported within 3.5 hours.

There are locations that have a fixed time frame in which they must be served:

- For LabMicTA and LabPON, all hospital locations and outpatient clinics must be served once before 10:30 AM.

- The daily shuttle service of ZGT between the location of Almelo and Hengelo cannot be altered.

2.7.2 Soft collaboration restrictions

The soft restrictions are restrictions that must be fulfilled but leave some space to complete them in.

Arrival streams

The arrival streams in volumes of materials play an important role as a constraint in this research. The arrival streams of materials cannot be altered too much. Daily operations of laboratories or depots depend on keeping the material stream the same. Both the usage of machines and the hiring of personnel are a value-adding component of the organizations. The internal operations of the organizations are optimized for revenue and service levels. In the optimal situation, the daily operation operates at maximum capacity, i.e., is fully utilized. The current transportation of materials per organization is fine-tuned to support the daily operation.

Customer service consecution

The order in which customers are visited throughout the day is of importance for the laboratories. The customer visit sequence directly influences the arrival streams of the laboratories and depots; not every customer has the same volume of materials to be picked up. However, while maintaining roughly the same arrival streams there are still desires concerning the sequence of visiting for the organizations.

- Medlon, LabMicTA and LabPON prefer the larger locations visited in the morning, this positively affects the arrival streams.
- General practitioners preferably would be visited in the afternoon, so they can send all the collected samples of the day at once and don't have to preserve the samples during the night.

2.7.3 Concluding conditions of collaboration

This section answered Sub-Research Question 1.7: *"What are (future) restrictions or constraints of the transport per party?".* We conclude that a model to represent the logistical operations of the organizations, as well as different interventions featured in next chapters and sections, needs to consider the hard and soft restrictions found in this chapter. For both the hard and soft restrictions, the timing of operations during the day is the main concern. Types of customers must be visited in specific time windows and arriving times of volumes of materials at the laboratories and depots must be kept within boundaries.

CHAPTER 3 THEORETICAL FRAMEWORK

This chapter gives a theoretical framework needed to model the current situation and interventions. As declared the objective of this chapter is the assessment of relevant models and methods. The first section will describe how we can define the problem best in terms of models. The second chapter focusses different ways to solve the modeled situation. Lastly, the final section focusses on the collaboration aspect of this research.

3.1 DEFINING THE PROBLEM

According to Laporte (2009), vehicle routing has been a subject of research for more than 50 years. Routing vehicles was first introduced in (1959) by Dantzig and Ramser under the title “The Truck Dispatching Problem” and since then, many variations of, and additions to, problems concerning vehicles routing have been studied. The different problems studied get a different functional name, commonly characterized by an abbreviation. Each of these vehicle routing problems can be classified as a general pickup and delivery problem, abbreviated as the GPDP; a GPDP is a problem where a set of routes has to be constructed to satisfy a number of transportation requests according to Savelsbergh and Sol (1995). Savelsbergh and Sol define the problem as follows: A fleet of vehicles is available to operate routes. Each vehicle has a given capacity, a start location, and an end location. The transportation requests specify the size of the load to be transported, the origin location, and the destination location. Loads cannot be transshipped.
Sol and Savelsbergh mention three well-known and extensively studied routing problems of the GPDP:

1. The Pickup and Delivery Problem (PDP), in which the transportation requests specify a single origin and destination and vehicles depart and return to a central depot.
2. The Dial-a-Ride Problem (DARP), in which the loads are people, literally calling a ride, with a single origin and destination. The goal in this problem is to create routes while sufficing service levels.
3. The Vehicle Routing Problem (VRP). Essentially a PDP where either all destinations or origins respond to a depot.

According to Sol and Savelsbergh, the problem in this study could be defined as either a PDP or a DARP because there are goods delivered and picked up at different locations, and there are multiple depots known in the problem. From a theoretical point of view, we could also apply literature on the DARP because people or packages of materials can be easily substituted. According to Cordeau, Laporte, Potvin, and Savelsbergh (2007), the DARP distinguishes itself from the basic PDP by its focus on controlling user inconvenience. They mention that this usually takes the form of constraints or objective functions relating to waiting time, ride time as well as deviations from desired departure and arrival times. There is no central depot for all the materials to start or end when we would combine all the transportation of the organizations, defining the problem as a VRP is therefore ruled out. Apart from defining the problem as a PDP or DARP, we have multiple other characteristic constraints that define the problem. These constraints are elaborated in the following subsections.

3.1.1 Intrinsic precedence constraint

When we consider a PDP or DARP, by definition, we have an intrinsic precedence constraint. This means that customers, goods, materials, etc. cannot be delivered before they are picked up according to Savelsbergh and Sol (1995)

3.1.2 Time constraint

According to a review by Cordeau et al. (2007), the concept of time windows is a distinguishing aspect of most transportation on demand problems. For all the vehicle transportation of the organizations in this research, we can determine customers that need to be served within a given time frame. For instance, we know that some outpatient clinics need to be serviced before 10:00 AM. Furthermore, we can determine that these materials cannot be on the road longer than, e.g., 2:30 hours. Using this information, we can determine the time frames that the customers need to be serviced in. We can conclude the problem in this research is concerned with time windows. Furthermore, we determine that the time constraints we must take into consideration are most like the time constraints used in DARPs. Like passengers, materials in this research can only be on the road for a limited amount of time.

3.1.3 Capacity constraint

For most of the materials transported, we can assume the capacity of the vehicles to be unlimited. However, there are some instances of transport by ZGT in which the capacity of vehicles cannot be assumed to be infinite because large machinery might be transported. Therefore, we use a capacity constraint in the problem.

3.1.4 Vehicles constraint

A review by Cordeau et al. (2007) addresses multiple forms of pickup and delivery problems and corresponding solutions. One distinguishable aspect of pickup and delivery problems is the number of vehicles in the problem. Problems can be stated as single- or multiple-vehicle problems. All the organizations make use of multiple vehicles, this extends when we try to establish a collaboration coalition between the organizations. We can determine that we need to define the problem as a multi-vehicle problem. In a multi-vehicle problem, a distinction can be made on a homogeneous fleet and a heterogeneous fleet. In a homogeneous fleet, all the vehicles are considered the same, in a heterogeneous fleet vehicle can have different capacities, or vehicle specific properties such as a mounted forklift or cooling capacity (Raff, 1983). In this research, we model the vehicles to be heterogeneous because they are available at different starting positions and at different times. However, according to some, only properties such as the capacity or fuel consumption can make a fleet heterogenous, varying the properties starting position or starting time does not apply to the vehicles themselves, making the fleet homogeneous. In this study, we do consider the starting position as a property of the vehicle. Lastly, we can distinguish the problems in which the fleet size is limited or unlimited. Looking at the current situation, we can determine that the problem can be best classified as a limited fleet size, since we cannot easily obtain a new vehicle, and we want to maximize the utilization of the current fleet.

3.1.5 Static vs. dynamic routing problems

According to Berbeglia et al. (2007) and Berbeglia, Cordeau and Laporte (2010) a pickup and delivery problem can be defined statically when all the input data of the problem are known before routes are constructed. In a dynamic pickup and delivery problem, some of the input data are revealed or updated during the period in which operations take place. When we look at the transportation by vehicles by the organizations we see that for most of the material transport, all the requests for transport are known in advance. The routes that are needed for all the regular transportation requests to be sufficed are fixed and do not change throughout the year. When we consider Section 2.6, most of the costs of transportation can be contributed to the regular known transports and a small part can be contributed to irregular rides that are unknown beforehand. Cordeau et al. (2007) describe different methods for static and dynamic problems that do not overlap. A study by Pillac, Gendreau, Gú, and Medaglia (2012) state that dynamic routing frequently differs in objective function and that dynamic routing problem require making decisions in an online manner, which is different from its static counterpart. Since the focus of the research is on collaboration between the organizations we want to find a model that encompasses the transportation by vehicles the most. Therefore, we consider the problem that we try to model of a static nature.

3.1.6 Concluding the definition of the problem

An article by Røpke and Cordeau (2009) describes the Pickup and Delivery Problem with Time Windows (PDPTW) as a generalization of the Vehicle Routing Problem with Time Windows (VRPTW), in which each customer request is associated with two locations: an origin location where a certain demand must be picked up and a destination where this demand must be delivered. Furthermore, each route must satisfy pairing and precedence constraints. The VRPTW is a special case of the PDPTW in which all requests have a common origin which corresponds to the depot. Røpke and Cordeau mention that the PDPTW has applications in various contexts such as urban courier services, less-than-truckload transportation, and door-to-door transportation for the elderly and disabled. When constraints are imposed to control the time cargo or passengers are in a vehicle, the problem is called the Dial-a-Ride-Problem (DARP). When we want to model our problem, the best suiting definition we can apply to the current situation is that of a static capacitated multi-vehicle dial-a-ride-problem with time windows and a heterogeneous vehicle fleet.

3.2 SOLVING THE DEFINED PROBLEM

Since the DARP is a generalization of the PDPTW, which on its turn is a generalization of the VRPTW, the problem is clearly NP-hard. The NP stands for "Non-deterministic Polynomial time problems". In practice, this means the problem gets too big very fast and it cannot be solved exactly within an acceptable time on a regular computer i.e. there are no known methods to solve the problem within polynomial time (Sigurjónsson, 2008).

There are several instances known where problems are solved exactly. Using a branch-and-cut approach Røpke et al. (2007) were able to solve problems with up to eight vehicles and 96 requests for transport. Looking at the current situation we can determine that exact methods are not likely to succeed. We exceed the number of requests considerably and we have two more vehicles than the maximum solved by Røpke et al. (2007). Instead, heuristics can be used to solve the problem. Heuristic algorithms approach problem solving from a practical point of view by finding a solution that approaches optimality but does not guarantee it. When finding an optimal solution is impractical or impossible, heuristics offer a satisfactory solution, often in an intended smaller time frame.

3.2.1 Heuristics

In literature, there have been a lot of studies on the VRPTW. In "A guide to Vehicle Routing Heuristics" Cordeau et al. (2002) make a distinction between classical heuristics and metaheuristics. Classical heuristics are either construction heuristics or improvement heuristics; where construction heuristics completely build new routes and improvement heuristics start with a solution and further improve them. Solomon (1987) mentions some notable construction heuristics for routing problems:

- **Nearest neighbor heuristic;** where the next customer is selected closest to the last inserted customer.

- **Insertion heuristic**; where the next customer is inserted in a route based on a criterion such as the lowest additional costs, or farthest away from the depot.
- **Sweep heuristic**; where customers are inserted clockwise or counterclockwise.

With improvement heuristics, a solution is improved by reconfiguring the customers. This can be done by searching for alternative solutions in neighborhoods. Neighborhoods are often created by switching one or more customers or segments of customers inter or intra routes. Intra route switching is switching customers within one route, while inter route switching switches customers between routes of vehicles.

Metaheuristics are heuristics that use a strategy to explore the solution space to find near-optimal solutions. Contrary to the classical heuristics of vehicle routing, metaheuristics can generally be applied to various optimization problems. A metaheuristic that is often mentioned as a good solution to routing problems by Cordeau et al. (2002) is Tabu search. Tabu search uses a neighborhood structure to find a set of neighbors. In each iteration of the search it moves to be best (but not necessarily better) solution in the current neighborhood and puts the previous solution on the Tabu list; hence the name. Meanwhile, the best solution is stored, and when a better solution is found, the best solution gets replaced. The algorithm stops when a certain stop criterion is met, such as the maximum number of iterations is reached, or a better solution has not been found for a while.

Although there is a clear structure for methods of VRPTW, for DARP this is not the case, since there are far fewer studies about DARPs. There is less literature to be found on DARP because it is a distinctive generalized problem of the VRPTW. In the work of Cordeau and Laporte (2003b) an overview of the methods available for the multivehicle static DARP is given. In this overview, thirteen articles are described to solve static multi-vehicle DARP instances. In a later work by Cordeau, Potvin, and Savelsbergh (2007) an additional six articles with methods to solve the static multi-vehicle DARP are mentioned. In a work by Cordeau and Laporte (2007) a total of eighteen articles describing methods are mentioned. Most of the methods are not all easily classified as either a classical heuristic or a metaheuristic but often consist of multiple steps.

However, one of the earliest heuristics described to solve DARP is an insertion heuristic by Jaw et al. (1986). In this heuristic, customers are first sorted in order of earliest feasible pickup time and gradually inserted into the routes of vehicles. As for most of the static multi-vehicle DARPs, the customers are appointed in a parallel fashion. The difference between parallel and series in route building heuristics for multi-vehicle problems is that in a parallel route building sequence, the routes of various vehicles are built simultaneously; appointing the customers in sequence, gradually building a route for all the vehicles. In series route building, the routes of vehicles are built in a sequence; first completing the route of vehicle one before moving to vehicle two. The insertion heuristic of Jaw et al. is described to be tested on artificial instances of 250 transportation requests but used on an instance of 2617 transportation requests.

Later work on the static multi-vehicle DARP is often characterized on the two-phase heuristic that is used. This often includes a clustering of the customers in the first step and reoptimizing the route for each vehicle such as in the works of Dumas et al. (1989) or Borndörfer et al. (1997). The second step often consists of either exact calculations or single vehicle heuristics.

In 2003a, Cordeau and Laporte introduce Tabu search for the static multi-vehicle DARP. Other works using Tabu search follow by Aldaihani and Dessouky in 2003 and Melachrinoudis et al. in 2007.

After the second millennium, we see that insertion heuristics are used again by Diana and Dessoucky (2004), Rekiek et al. (2006), Xiang et al. (2006) and Wong and Bell (2006). In the latter two studies, insertions are used as a part of a two-phase heuristic wherein the other phase the initial routes are improved by exchanges of customers.

3.2.2 Concluding solving the defined problem

Although there are not as many articles for the DARP available as for the VRPTW or PDPTW, there are multiple heuristics known to solve a static multi-vehicle DARP. In the articles found the DARP is essentially a generalized PDPTW but with quality constraints such as maximum ride duration. The heuristics fit the problem posed in the previous chapter well, the difference with the DARP in the articles and the current situation is that in the articles people are transported instead of materials. What differs is that the people transported in literature often have small time frames in which they demand to be picked up or delivered in comparison with the materials in our research problem. This might influence the calculation time of the solutions since larger time frames create a bigger solution space. The various articles describe very divergent numbers of transportation requests the corresponding heuristic can solve. In one practical implementation, the insertion procedure by Jaw et al. (1986) was able to solve an instance of one of the largest DARP problems with 2617 transportation requests. In conjunction with our research supervisor, the literature found, the explorative nature of this research, and the limited time of this research, we choose to use a construction insertion procedure using the procedures by Jaw et al. (1986) as a guideline.

3.3 HORIZONTAL COOPERATION

A literature review by Cruijssen, Dullaert, and Fleuren (2007) mentions that literature for horizontal cooperation for logistics and transport is scarce. However, they mention five different levels of integration in horizontal cooperation. The first level of cooperation between organizations is incidental, e.g., contracts for when overcapacity happens. This level is not truly a case of horizontal cooperation. The second level of horizontal cooperation is Type I Cooperation, which is a cooperation that consists of mutually recognized partners that coordinate their activities and planning with a short-term time horizon. Type II is a cooperation in which the participants coordinate and integrate part of their business planning for a long-term through the finite length of time. On this level, multiple divisions or functions are involved. Type III Cooperation is referred to in the literature as a “Strategic Alliance”. On this level of cooperation, the organizations generally agree on three years or more contract to an exchange and/or combination of some, but not all, of a firm’s resources with their partners. The last level of cooperation is defined as a merger between the organizations.

When discussing horizontal cooperation in terms of transport and logistics the model introduced by Cruijssen, Dullaert and Fleuren (2007) can be used to classify the level of cooperation. This model is depicted in Figure 3-1.

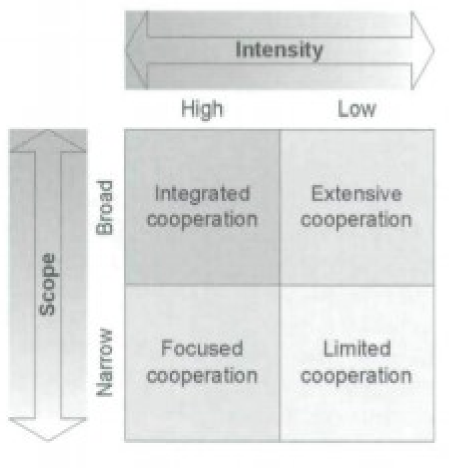


Figure 3-1 Classification based on scope and intensity

3.3.1 Literature on practical levels of collaboration

Although information above provides information and helps to classify the level of collaboration between the organizations, practical information on how to cooperate is missing. We conclude to turn to practice to find different methods of collaboration.

3.3.2 A similar practical problem

A similar problem has been explored for the Deventer hospital in a master thesis by Barneveld (2015). In this case, the clinical chemical laboratory, the microbiologic laboratory and the pathologic laboratory worked together in transporting materials. However, the current problem differs from the research by Barneveld. In the master thesis by Barneveld, the parties involved are all located in one location: The Deventer hospital. Furthermore, the laboratories considered in the study by Barneveld did not have their own transportation vehicles, dedicated to the transport of materials. Laboratories depended on mail and laboratory workers returning from service points. Organizations in this study are located over multiple locations and are not necessarily located in the same building as in the Barneveld study, e.g., Hengelo, where the Medlon office is in the ZGT building and LabMicTA and LabPON are located one street away with their own depository room. In contrast to the Barneveld study, the laboratories involved in this study are private companies with different administrative interests, financial factors, and information systems. Although the Barneveld study differs at some levels from this research, it is a good example of the potential collaboration of the organizations active in this research. The conclusion of this study was that the introduction of hubs on several locations would benefit the organizations.

3.4 CONCLUDING THEORETICAL FRAMEWORK

This chapter answered Research Question 3: *"What methods, models, and knowledge are available that can contribute to exploring collaboration between the parties involved?".* We answered this question by dividing the problem into three sub-questions that were answered in the subsections of this chapter. In the first subsection, we answered how we could model the problem of the current situation such that we can introduce interventions. We found that the best way to model the current situation is to define the problem as a static multi-vehicle dial-a-ride problem. To answer the second sub-question derived from Research Question 3, of what methods are known and which one we should use, we conclude that in this research an insertion construction algorithm is sufficient to explore the possibilities of collaboration. Lastly, to answer the third sub-question of Research Question 3, the literature described methods of how to classify different levels of collaboration but showed no practical handhold for interventions that can be implemented directly. We turn towards practice to find interventions on collaboration.

CHAPTER 4 MODELING

In this chapter, the relevant modeling is described. The modeling of the problem focuses on cooperation between the organizations on the regular rides. We assume that all transportation requests are known in advance. As described in the theoretical framework chapter, the problem in this thesis is best described as a static multi-vehicle Dial-a-Ride Problem with time windows. Section 2.7 describes the hard and soft restrictions for collaboration, these restrictions are used in modeling the problem. We set up a model to be able to construct new ways of cooperation.

4.1 SPECIFYING THE MODEL

In Chapter 3, we described various models that can be used to solve a static multi-vehicle DARP. We chose to use an insertion algorithm to rebuild the regular routes of the organizations to see the influence of various interventions. We use the feasibility procedure described by Jaw et al. (1986).

4.2 MODEL ASSUMPTIONS AND OBJECTS

In this section, the assumptions and objectives of the model are elaborated. Regardless of the heuristic that is chosen, the model needs input that is collected from the current situation. How input is collected and what function the input has in the model is elaborated. Each of the following subsections describes either an assumption or an object of the model.

4.2.1 Transportation requests

The daily operations of the transportation services of the organizations all have regular routes that are driven every day. During these rides, materials are either picked up or delivered. The routes are set up such that redistribution between the depots is performed within the routes. The routes provide specific times at which the locations are served. Section 2.7 described that arrival streams of materials at the depots or laboratories with the current material transport is fine-tuned for an optimal daily operation. For the daily operation to maintain a sufficient arriving stream of materials, arrival times at the depots or laboratories must be altered as little as possible. The current routes are therefore used to extract information about the arrival times at the depots for all customers.

The routes only provide the location of the customer that is serviced and the time or timeframe a vehicle visits the customer. Based on the organization and the route, the nature of the visit to a location can be extracted. This is either a delivery, a pickup or both. The exact exchange of materials, however, cannot be extracted. It can occur that, e.g., a regular visit of a location to pick up diagnostic material is used to deliver non-diagnostic material such as new sample collection material or mail.

Because the current routes support a complex logistic operation, switching locations in a route or between routes can result in a bottleneck for the daily operation of an organization. Furthermore, the redistribution of materials depends on a timely arrival of material at a certain location. Again, changing a route can result in a bottleneck for the redistribution. However, we can use the current routes to gather information about the locations that are visited. For each location, the following information can be collected: the nature of the visit, the origin location, the destination location, the customer located at the location, the opening hours of the location, and the desired time of service. If the customer is known, the type of customer is also known. This gives information about the number of materials that need to be handled at the location.

To ensure that the logistic operations of the organizations remain intact, the current routes are translated into a list of independent transportation requests. Each transportation request contains the information about both the origin and destination location. Using a list of transportation requests new routes can be constructed that prevent bottlenecks in daily operations or redistribution. In summary, the transportation requests serve both as the orders that must be performed and as the restrictions of the model. Lastly, the current routes are used as a baseline performance for the interventions.

4.2.2 Duration and distance matrices

Since all transportation requests are known in advance, an index of all known locations can be made. Using an index of all locations, duration and distance matrices can be created. The duration and distance matrices are used to make cost calculations and calculate times needed to visit locations. The duration and distance matrices are calculated using the Microsoft BING maps API (BING Maps, 2017). Distances are car road distances and are preferred over Euclidian distances since locations can be close but obstructed by natural obstacles such as waterways or highways. The relation between distances and durations is not necessarily linear, e.g., the speed limit on roads differs. Rush hours are not included in the model, the duration and distances are assumed to be time independent.

4.2.3 Vehicles

As discussed in Section 3.1.4, the vehicles used in the model are assumed to be heterogeneous. In the model, the vehicles have several characteristics. The vehicles have a starting position and an ending position. Furthermore, vehicles have a (different) starting and ending time. The starting and ending time of the vehicle are dependent on the starting and ending positions respectively. Depending on the settings of the model, all vehicles have an owner. Vehicles in the model are assumed to have a large capacity, but not unlimited. Most of the transportation requests can be modeled at a very low capacity that almost never causes a full capacity of a vehicle. However, there are a few exceptions for transportation requests of the ZGT where, e.g., a request takes up half the capacity of a vehicle. Breakdowns of vehicles are excluded from the model. Vehicles of parties hired externally are assumed to be homogenous.

4.2.4 Orders

The orders of the model are created from the transportation requests. In most of the experimental settings orders are directly translated from the transportation requests. However, they are not necessarily the same. This can be best described in Figure 4-1, where two orders are created from one transportation request. The transportation requests also serve as the restrictions for the model. A transportation request can be split up into multiple orders, e.g., when a location is inserted between the origin location and the destination location of a transportation request, one transportation request creates two independent orders both with a new origin location and destination location needed to be served at different times. Note that a new time x must be calculated depending on the second order.

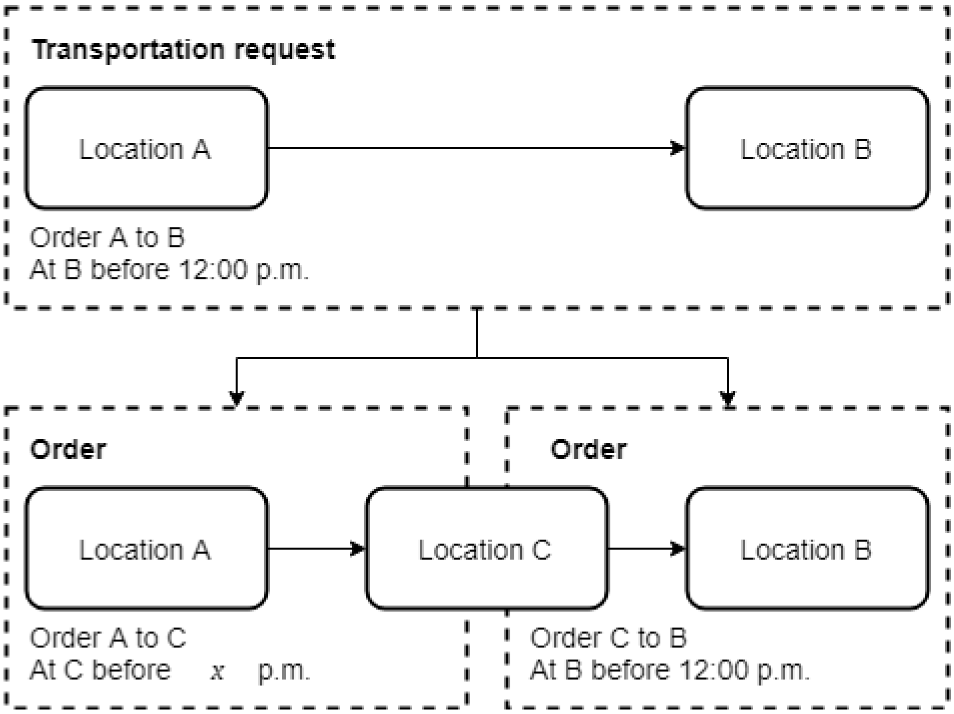


Figure 4-1 Transportation request to orders

How the orders are created from the transportation requests depend on the experimental settings; in some experimental settings, extra locations are added. Each order serves one customer and one organization. As mentioned earlier, the orders have several characteristics: an origin location, a destination location, a specification for either pickup of delivery. An order cannot be specified as both pickup and delivery, in such a situation two orders are created instead; one for pickup and one for delivery. Other characteristics of orders are the days of the week the order is performed, the name of the customer, the opening hours of the customer, and the type of customer. Based on the type of customer and the opening hours the last few characteristics are created: the desired time of pickup or delivery, the capacity space of the materials exchanged, the maximum time the order may be en-route, the maximum deviation from the desired time. All orders in the model are obligated to be met.

4.2.5 Events

Every order creates two events. Regardless whether an order is specified as pickup or delivery, an event is the actual act of picking up and delivering of material. Every event inherits all characteristics of the order it was created from. Next to these characteristics, an event in its turn creates its own characteristics from the characteristics of the order. These are the earliest time the event may occur, the actual time the event occurs, and the latest time the event can occur. The pickup event always precedes the delivery event.

4.2.6 Schedules

A schedule in this model is the collection of events performed by one vehicle on one day of the week. A schedule can consist of multiple schedule blocks. A schedule block is the consecutive performance of events by a vehicle. In a schedule block, a vehicle is either servicing an event or en-route. A schedule block ends when a vehicle needs to wait to start a new schedule block or when it is the end of the day and a vehicle returns to its depot. When the waiting period between two schedule blocks is reduced to zero, the schedule blocks merge into one schedule block. The advantage of using schedule blocks is that when trying to implement an order into a schedule, only the block with the consecutive performance of events must be adjusted and not the whole schedule. An example of a schedule with two schedule blocks is illustrated in Figure 4-2. For example, if we were to implement order 5 with pickup event +5 and delivery event -5 into the first schedule block, we would not have to check the feasibility of orders 3 and 4 if the additional time does not exceed the waiting time.

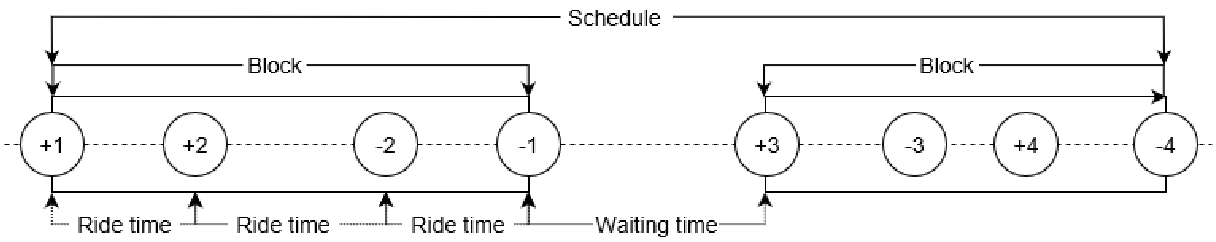


Figure 4-2 Schedule with schedule blocks

Corresponding pickup and delivery events can be scheduled into different schedule blocks keeping the order characteristics such as the maximum ride time in mind. Corresponding events cannot be placed in different schedules.

4.2.7 Employees

In the model employees hired for the transportation of materials are assumed to the be working in hours. A vehicle requires one employee to be operated. Employees are hired at their own organizations at their own cost rates.

4.2.8 Constructing new routes

As described in Section 3.4, an insertion construction heuristic is used to create new routes. For every day of the week, schedules are created.

The heuristic sorts all orders created from the transportation requests based on their earliest available pickup time for the day. We always must sort on earliest available pickup time because the algorithm builds schedules starting at the beginning of the day and new schedule blocks can only be created at the end of the schedule. Since every order consists of two events, one pickup, and one delivery, the orders are sorted only on the pickup event.

The orders are then inserted into schedules until all orders have been scheduled. Both events of the order are considered in every schedule. When no feasible insertion position is found, the order is marked as infeasible and an additional schedule is created. The creation of a new schedule means the use of an outsourced vehicle. As described in Section 3.2.1, this heuristic uses parallel route building; for every order, all schedules are considered. The schedule that increases the total duration of a schedule the least is chosen. This is contrary to the sequential route building where the schedule of one vehicle is constructed first before the next schedule is created.

4.3 FINDING FEASIBLE SOLUTIONS

The heuristic checks if an insertion is feasible by using the feasibility checking method described in a paper of Jaw et al. (1986). The paper uses four statistics calculated for each event in a schedule block to determine whether an insertion at position α in the schedule block is feasible. These statistics are the following:

$$BUP_{\alpha} = Min\left[Min_{1 \leq l \leq \alpha}(AT_l - ET_l), SKT_p\right]$$ **Equation 4-1**

$$BDOWN_{\alpha} = Min_{1 \leq l \leq \alpha}(LT_l - ET_l)$$ **Equation 4-2**

$$AUP_{\alpha} = Min_{\alpha \leq l \leq d}(AT_l - ET_l)$$ **Equation 4-3**

$$ADOWN_{\alpha} = Min\left[Min_{\alpha \leq l \leq d}(LT_l - AT_l), SKT_q\right]$$ **Equation 4-4**

Here d denotes the number of stops on the schedule block. AT, ET, and LT denote respectively the actual event time, the earliest event time and the latest event time. SKT_p and SKT_q denote the duration of the slack period immediately preceding and immediately following the schedule block in question respectively. In Figure 4-2, SKT_p of the second block is equal to the waiting time, SKT_q of the first block is also equal to the waiting time. If the schedule block is the first, the slack is calculated from the starting time of the schedule till the starting time of the schedule block. Likewise, if the schedule block is the last one, the waiting time is calculated between the last schedule block and the ending time of the schedule. BUP_{α} and $BDOWN_{\alpha}$ represent the maximum amount of time by which every stop preceding but not including stop $\alpha + 1$ can be advanced and delayed respectively. AUP_{α} and $ADOWN_{\alpha}$ respectively represent the maximum amount of time by which every stop following but not including stop $\alpha - 1$ can be advanced and delayed. Essentially, the statistics indicate by how much, at most, each segment of a schedule block can be displaced in order to accommodate (pick up, deliver, or both) an additional event (Jaw et al., 1986). In the example of Figure 4-3, if we were to implement an event +5 between +2 and -2 we would have to calculate whether an implementation is feasible. We can easily see that BUP_{α} of that implementation would be the minimum of **A (**$AT_{+1} - ET_{+1}$**)**, **B (**$AT_{+2} - ET_{+2}$**)** and **C(**SKT_p**)**, in this case **A** of event +1; we can only advance the first two events by a maximum of 1,0 on the measure scale. We could also delay the other two events by a maximum of 1,1 on the measure scale; essentially calculating $ADOWN_{\alpha}$, the minimum of **D**, **E**, and **F** for this implementation. Mind you, the schedule block consists of no waiting time. The entire block consists of direct ride time between the events in the block depicted as different colors.

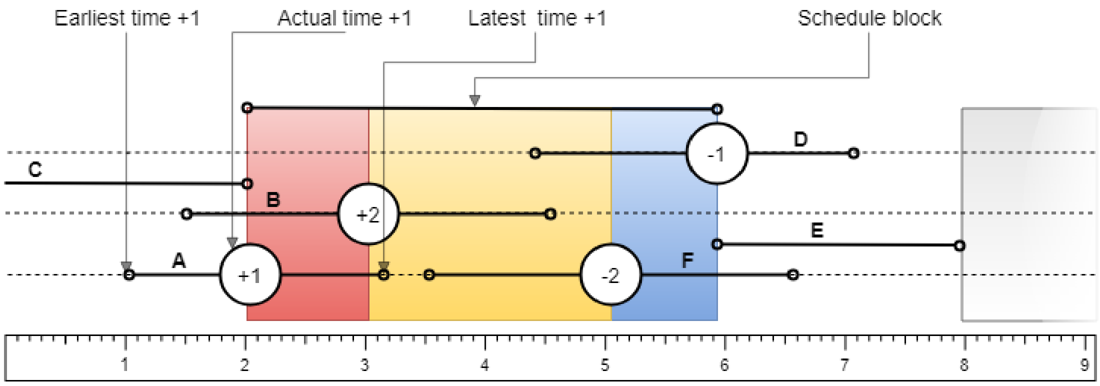


Figure 4-3 Example of schedule block

There are four possibilities for inserting an order into a schedule block:

1. Both the events of the order are placed consecutively at the end of schedule block.
2. Both the events of the order are placed consecutively somewhere between other stops in the schedule block
3. The pickup event of the order is placed somewhere between other stops of the schedule block and the delivery event is placed at the end of the schedule block.
4. Both the events are placed somewhere on the schedule block, but not consecutively.

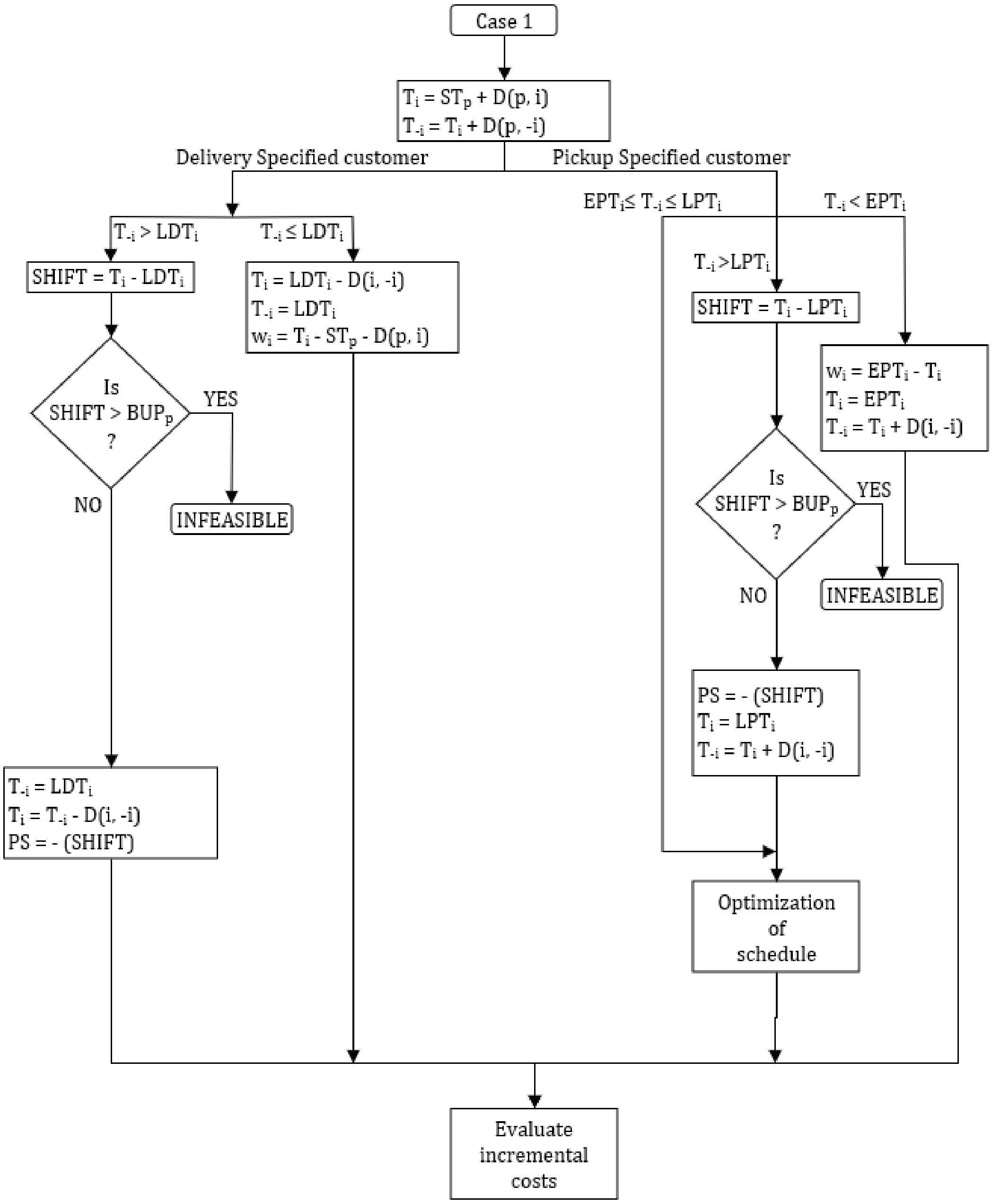
These four insertion possibilities all require a different flowchart for checking whether the insertion can be feasible, possibly altering the event times of other stops on the schedule block. There is a fifth possibility of inserting an order in a schedule. In this case, events are placed on the same schedule, but not in the same schedule block. This is not considered in this research, because the number of destinations is limited, and a short order ride time is one of the objectives. To illustrate the feasibility procedure the flowchart for the feasibility check of case 1 is given in Figure 4-4, flowcharts of feasibility checks for the other cases can be found in Appendix F, Appendix G, and Appendix H. After the insertion has been found feasible it must be checked whether none of the events on the schedule block violate their constraints such as maximum ride time or capacity of the vehicle.

To elaborate Figure 4-4 further, the most left branch of the flowchart will be walked through. Let us consider a situation where order i is inserted consecutively on the last two positions on a schedule block.

- The pickup event time is calculated adding the time of the previous position and the duration to the location of pickup. The delivery time is calculated adding the latter and duration from the pickup location to the delivery location.

- It is checked whether order i is either pickup or delivery specified, in this case, delivery specified.
- If the calculated delivery time is later than the latest possible delivery time we need to shift the whole schedule such that the calculated delivery time is exactly the latest possible delivery time. We calculate this shift in time.
- It is checked if this advancing shift is possible for the stops in the block using BUP_{α}.
- In this case the shift is feasible. We advance all the stops on the schedule block and calculate a new pickup time.
- Now that the insertion position is feasible, we can check whether this insertion is the best possible option.

The feasibility procedures also feature a box called “Optimization of schedule”. This is a small procedure that measures the total number of orders that are delivery and pickup specified in the current block. If the number of delivery specified orders is larger than the number of pickup specified orders, the times in the block are delayed the maximum amount of time possible resulting in delivery times closer to the desired times. Vice versa, if the number of pickup specified orders is larger than the number of delivery specified orders in the block, the times in the block are advanced resulting in pickup times closest to the desired times. When there is a draw, the orders are advanced to the maximum.



p, q, r, s	:	Indices denoting visit sequence in a vehicle schedule block having d stops.
T_i (T_{-i})	:	The pick-up time (delivery time) of the new customer i.
ST_j	:	Scheduled visit time of stop j in the schedule block before customer i is inserted.
w_i	:	Amount of change in vehicle waiting time due to the insertion of customer i.
SHIFT	:	The amount of time which a given time or a time schedule is being shifted.
ΔP_i (ΔD_i)	:	The extra vehicle time required to pick up (deliver) customer i.
PS (DS)	:	Shift in time schedule for all stops preceding stop +i (succeeding stop -i) after customer i is inserted.
MS	:	Shift in time schedule for all stops between stop +i and -i after customer i is inserted.
GT, ET, LT	:	Variables.
WS_i	:	The maximum acceptable deviation of the desired time (pickup or delivery) of order i.

Case 1	:	1......p +i -i
Case 2	:	1......p +i -i q......d
Case 3	:	1......p +i q......d -i
Case 4	:	1......p +i q......r -i s......d

Figure 4-4 Feasibility flowchart for case 1

4.4 OPTIMIZING THE PROBLEM

After the insertion has been found feasible, the temporal schedule is optimized. The temporal schedule is then compared to other temporal schedules. This is done such that the objective function is minimized. The objection function in this model is the amount of time the total schedule increases with the insertion of the order. In Section 3.2, this is described as the cheapest insertion method.

4.5 MODEL OUTPUTS

The main output of the model is the weekly schedules created to satisfy all the orders. This includes the use of outsourced vehicles. In Section 2.5, the performance indicators for the current means of transportation were described. Continuing the argumentation of this section, the model gives these performance indicators for the weekly schedules of the selected orders for each organization and the organizations combined.

4.6 VALIDATION AND VERIFICATION

Validation of the model was done by presenting the problem and model to our mentor at the University of Twente by evaluating how we could best model the real situation with the data available. More validation of the model was done by comparing the newly constructed routes to the current situation on a small scale. Similar results were found for the current situation and the modeled situation. The verification of the model was done while building the model. With each newly implemented part, the model was checked on whether the constraints were not violated, and the results were logical. For example, in building new routes we checked whether the duration of one location to another would not exceed the time it would take in the route and whether all events did not violate their feasible time windows.

CHAPTER 5 EXPERIMENTAL DESIGN

This chapter describes the different strategic interventions to explore the different possibilities for collaboration between the organizations, the different experimental settings of the model and the validation and verification of the experiments.

5.1 VARIOUS STRATEGIC INTERVENTIONS

This section describes the different strategic interventions proposed for collaboration between the organizations.

5.1.1 Intervention 0.1: Current routes

To provide a baseline performance, the first intervention is a non-collaboration intervention. The current routes are used to gather the baseline values of the performance indicators described in section 2.5.

5.1.2 Intervention 0.2: Optimized routes

This intervention setting is used to translate the current routes into transportation requests and using these requests directly as orders. The goal of this intervention is to create insights into the performance of the model itself. An improved performance will indicate that it is possible to improve the current situation only by changing the routes, not the current compositions of the organizations.

5.1.3 Intervention 1: Various model interventions

This intervention focusses on using different methods in the model. The sorting method, used to sort the orders before they are appointed sequentially, is one of the methods that we can alter. In the model described in section 4.4, orders are only sorted on the earliest available pickup time of the first event. We must sort on earliest available pickup time because we can only add new schedule blocks at the end of a schedule. Sorting on the earliest available pickup time of the first event must therefore always be performed last for the model to work accordingly. However, before we sort on earliest available pickup time we can also sort on other criteria. Since a lot of orders are available at the same time there can be varied between the following characteristics of orders.

- Type of customer (small, medium, large)
- Maximum ride time of the order
- Desired completion time

Using these characteristics, we can define the following variations on the sorting method of the model found in Table 5-1.

Alternative	Sorting method(s)
Default	Earliest pickup time
Alternative 1	Type of customer (small to large) Earliest pickup time
Alternative 2	Type of customer (large to small) Earliest pickup time
Alternative 3	Maximum ride time of the order (smallest first) Earliest pickup time
Alternative 4	Maximum ride time of the order (largest first) Earliest pickup time
Alternative 5	Desired time (smallest first) Earliest pickup time
Alternative 6	Desired time (largest first) Earliest pickup time

Table 5-1 Sorting alternatives for the model

Next to the alternation in the sorting method, different objective functions can be used. In the current model, the duration of the order is used as an objective function. Other objective functions that can be minimized in the model given in Table 5-2.

Alternative	Objective function
Default	Total duration of schedule
Alternative 1	Total number of kilometers of schedule
Alternative 2	Total deviation of schedule
Alternative 3	Earliest possible time of order

Table 5-2 Objective functions for the model

5.1.4 Intervention 2: Collaboration on types of customers

This intervention is focused on the distinction between the different types of customers. Collaboration can be explored when only different types of customers, e.g., general practitioners or only hospitals are shared among organizations. The types that can be varied are small, medium, large, and shared customers. Classification of different types of customers is can be found in Table 5-3.

Type	Customer
Large customers	hospitals, laboratories, outpatient clinics, front offices
Medium customers	health centers, clinics, care homes, locations housing four or more general practitioners
Small customers	general practitioners, remaining customers
Shared customers	common customers among the organizations

Table 5-3 Type of customers

Again, this setting is performed by selectively choosing which vehicle schedules are available for the order to be inserted in. The possible combinations that can be made for the different types of customers are given in Table 5-4.

Options	Collaboration types
Option 1	Shared customers
Option 2	Small customers
Option 3	Medium customers
Option 4	Large customers
Option 5	Small and medium customers
Option 6	Medium and large customers
Option 7	All customers
Option 8	No customers

Table 5-4 Type based collaborations

5.1.5 Intervention 3: Hubs

This intervention focusses on the creation of cross-docking locations known as hubs. In conjunction with the transportation managers, we choose three logical locations that could be used as hubs. These locations are the front offices in Enschede and in Almelo of Medlon and LabMicTA-LabPON and in the Hengelo ZGT building. These are already shared locations and are opened in regular office hours and looking at the service area of the organizations prove to be geographically centered. For the hubs to support the transportation process fixed times must be chosen for when the hubs should be visited, because when materials are exchanged between vehicles there needs to be an agreement on when materials should be delivered at the hub location and when they are available for pickup. It can be calculated for each transportation request what hub is closest by depending on the location of the origin location in case of a pickup order or a destination location in case of a delivery location. Furthermore, it can be calculated for each transportation request what time would be feasible to for the transportation request to insert a hub location between the origin location and the destination location. Multiple orders are created for the same transition request considering that time windows must be calculated to ensure feasibility. There are many possibilities for choosing fixed times during the day when hub locations can be visited. Most of the routes have two moments during a given day when depots are visited: One could say that in general, vehicles are on the road between 08:30-12:30 and 12:30-17:00. Therefore, we test a maximum number of two hub times simultaneously. We test the hub locations for multiple times.

Option	Hub locations
1	Hengelo, Almelo, Enschede
2	Hengelo, Almelo
3	Hengelo
4	Almelo, Enschede
5	Almelo
6	Hengelo, Enschede
7	Enschede

Table 5-5 Variations for hub locations

5.1.6 Intervention 4: Combined organization orders

The next intervention addresses the possibilities of combining the orders of different organizations. Collaboration between three organizations can result in a total of three settings of collaboration. These settings are all organizations work together or two out of three organizations work together. This setting is performed by selectively choosing which organization's vehicles are collaborating and therefore available for the current order in the experimental settings.

5.1.7 Intervention 5: External parties

Medlon uses external courier Kamphuis in some of their regular routes because they determined that the costs of outsourcing were comparable with the costs of own personnel and vehicles. This implies that the costs of outsourcing are like the costs of performing transportation by an organization itself. If collaboration is introduced, there are more orders to combine and outsourced vehicles could lead to fewer costs. This intervention, therefore, focusses on substituting own vehicles with externally hired vehicles.

5.2 ADAPTED PROBLEM SIZE

During testing of the model, we encountered that the problem is too large to solve within an acceptable time due to a large number of possible combinations of orders. Ideally, performing the algorithm for all the orders combined in a single run would give better results since the solution space would be the largest. Furthermore, performing the algorithm with all the orders combined in a single run would instantly give new possible routes with a calculated base score using the performance indicators and give the organizations a handhold in new collaborations. We estimated that calculation time for the worst intervention settings would take up to two weeks for all the transportation requests for the different organizations combined for a single run. The nature of this research is that it is to be completed within an acceptable time. In practice, this means an experiment must be reproducible in a short period of time in case of faulty experiments or adjustments. It is therefore not possible to test the different interventions on all the orders of the organizations at once within an acceptable time. Lastly, the goal of this research is not to come with a direct possible solution for a possible collaboration but to evaluate the possible outcomes of the different interventions to evaluate future decisions of the organizations. The research, therefore, limits itself to a maximum of ~50% of the total number of transportation requests in a single experiment.

5.3 EXPERIMENTAL SETTINGS

This section will give a description of the settings of the different experiments.

5.3.1 Experiment groups

Since all orders combined will not be evaluated in this research, a selection of orders will be compared to each other. As mentioned before, by running the algorithm on a selection of orders instead of the total number of orders, the solution space will be smaller. However, one can argue that although we do not get the exact optimum, we try to find a solution close to the optimum and this solution should also show if there is a reasonable advantage to collaboration. This is because the implementation in practice usually goes hand in hand with the simplest solution. To provide a good comparison with the current means of transportation, the current routes will, therefore, serve as the groupings of orders - i.e., all the transportation requests collected from one route will be translated into one set of orders. To decrease the total number of experiments, the researcher in conjunction with the project initiators chose the most promising routes to be combined in the experiments. Mind you, the groups were chosen such that all transportation requests are considered.

The most promising routes were chosen by selecting the routes of different organizations that have the most customers in the same geographical area in the same time frames. The selected routes to be combined are given in Table 5-6.

Group	Organization	Route name
Group 1	LabMicTA-LabPON Medlon ZGT	Route 1; Route 2; Route 5; NOW; Ochtend; Middag; Kamphuis Borne, Goor, Hengelo; Kamphuis Oldenzaal; Kamphuis Avondroute; Taak 22 Pendel; Taak 21; Taak 17; Taak 14; Almelo Ochtend; Almelo Middag
Group 2	LabMicTA-LabPON Medlon ZGT	Route 3; Route 4; Route 5; NOW; Ochtend; Middag; Kamphuis Borne, Goor, Hengelo; Kamphuis Oldenzaal; Kamphuis Avondroute; Taak 22 Pendel; Taak 21; Taak 17; Taak 14; Almelo Ochtend; Almelo Middag
Group 3	LabMicTA-LabPON Medlon ZGT	Route 1 Ochtend; Route 2 Ochtend; Route 3 Ochtend; Route 4 Ochtend; Route 5; NOW; Ochtend; Kamphuis Borne, Goor, Hengelo; Kamphuis Oldenzaal Ochtend; Taak 22 Pendel Ochtend; Taak 21 Ochtend; Taak 17 Ochtend; Almelo Ochtend
Group 4	LabMicTA-LabPON Medlon ZGT	Route 1 Middag; Route 2 Middag; Route 3 Middag; Route 4 Middag; Middag; Kamphuis Borne, Goor, Hengelo; Kamphuis Oldenzaal Middag; Kamphuis Avondroute; Taak 22 Pendel Middag; Taak 21 Middag; Taak 17 Middag; Taak 14 Middag; Almelo Middag
Group 5	LabMicTA-LabPON Medlon	Zaterdag auto1 Zaterdag auto2 Zaterdag

Table 5-6 Experiment groups

5.3.2 Experiments

In section 5.1 we described multiple interventions to be tested, and we constructed 5 groups. Table 5-7 lists all the possible variations of these interventions.

Intervention or setting	Variations
Groups	5
Sorting method + current situation	8
Objective function + current situation	5
Collaboration type + current situation	9
Hubs + current situation	7+
Leave out parties + current situation	5
Use of external parties + current situation	3

Table 5-7 Number of experiment variations

If we would test all the different settings for all the groups, we would do at least $5 \times 8 \times 5 \times 9 \times 7 \times 5 \times 3 = 189{,}000$ experiments. To decrease the total number of experiments, the experiments will be carried out in different stages. In each stage, we vary with one intervention setting and choose the best possible setting for the rest of the experiments. The first two stages are executed first to calibrate the model for later stages. The sequence of the rest of the stages is not chosen with any intent. The sequence of the stages is chosen arbitrarily because the researchers could not think of a reason for a particular sequence for the rest of the stages. An arbitrarily chosen sequence does influence the outcomes, but not more than any other sequence of stages. The stages are set out in the section below.

Stage I

In the first stage, we do experiments to find the best sorting method for the algorithm. We keep all the experiment settings on default. We keep the setting for collaboration on "No collaboration" to mimic the situation of the daily operations so that we can make a good comparison. Since the research focusses on the effects of collaboration, we also check for different outcomes if we change the setting of no collaboration to full collaboration. This is done to avoid an outcome that is optimized for no collaboration.

Stage II

After we determined the best sorting method, we use the found settings to determine the best objective function. Again, we keep the other interventions settings on default and use two different settings for collaboration: "No collaboration" and "Full collaboration".

Stage III

We use the outcomes of Stage I and Stage II to evaluate the best ways of collaborating for all the groups. We vary the degree of collaboration by allowing collaboration between different types of customers.

Stage IV

With the most promising settings of the stages so far, we evaluate the effect of inserting hub locations into the orders. In the intervention description, we argued that hub locations could be best inserted in two-time frames of the day. We therefore test this intervention using groups 3 and 4. These groups contain all the transportation requests in the morning and the afternoon during the week respectively. We test the influence of adding geographically centered hubs on existing locations of the organizations on various times with different types of collaboration.

Stage V

We use the settings found in the stages so far to test the effect of leaving out one party from the collaboration coalition. We do this for the most promising settings found in the previous stages.

Stage VI

On a selection of promising collaboration groups, we test the influence of using external vehicles only.

CHAPTER 6 ANALYSIS OF RESULTS

This chapter describes the results found from the experiments proposed in Chapter 5. In sections 6.1 - 6.4, the clearest performance indicators are used to illustrate the outcomes of the experiments. The researcher can be contacted for the full disclosure of other performance indicators.

6.1 STAGE I – CHOOSING A SORTING METHOD

In Stage I, we first determine the best sorting method for the algorithm. In Section 2.5, we found multiple performance indicators to evaluate the results on. The performance indicator that illustrates the results produced by the experiments the best are the total costs. An overview of the outcomes on total costs can be found in Table 6-1.

	Current	Default - EPT	Alt. 1 - Type S to L, EPT	Alt. 2 - Type L to S, EPT	Alt. 3 - MRT Small First, EPT	Alt. 4 - MRT Large First, EPT	Alt. 5 - Desired time S First, EPT	Alt. 6 - Desired time L First, EPT
Group 1	100,00%	100,90%	106,28%	107,22%	102,88%	101,26%	103,67%	98,39%
Group 2	100,00%	122,65%	125,78%	123,32%	118,50%	126,63%	119,73%	123,06%
Group 3	100,00%	99,04%	106,40%	104,22%	101,12%	98,59%	104,38%	98,07%
Group 4	100,00%	102,16%	106,04%	105,74%	102,82%	102,22%	104,35%	106,52%
Group 5	100,00%	67,09%	72,61%	67,08%	70,95%	67,09%	95,86%	67,09%
Average	100,00%	98,37%	103,42%	101,52%	99,26%	99,16%	105,60%	98,63%

Table 6-1 Total costs comparison of sorting methods with no collaboration

It can be shown in Table 6-1, that with the "No collaboration" setting, the algorithm for some settings outperforms the current situation. We get the best results from the settings Default, Alternative 4, and Alternative 6. When we look at the results from the same experiments but with "Full collaboration", we see similar results in the total costs. An overview of the total costs is found in Table 6-2. We can see the results are similar for group 5 in Table 6-1 and Table 6-2. We conclude that for group 5 there is room for improvement, no matter the sorting method. Furthermore, we can see for group 5 that when collaboration is allowed, it does not commence, because no better results are found.

	Current	Default - EPT	Alt. 1 - Type S to L, EPT	Alt. 2 - Type L to S, EPT	Alt. 3 - MRT Small First, EPT	Alt. 4 - MRT Large First, EPT	Alt. 5 - Desired time S First, EPT	Alt. 6 - Desired time L First, EPT
Group 1	100,00%	89,36%	91,92%	93,08%	95,29%	86,26%	90,21%	87,87%
Group 2	100,00%	104,87%	117,14%	108,66%	101,24%	105,24%	116,08%	103,59%
Group 3	100,00%	91,84%	110,55%	99,46%	101,38%	92,78%	98,29%	91,98%
Group 4	100,00%	95,10%	98,43%	94,25%	93,93%	97,43%	97,75%	97,32%
Group 5	100,00%	67,09%	72,61%	67,08%	70,95%	67,09%	95,86%	67,09%
Average	100,00%	89,65%	98,13%	92,51%	92,56%	89,76%	99,64%	89,57%

Table 6-2 Total costs comparison of sorting method with full collaboration

We see the best improvements for the same alternatives as before. Looking at the other performance indicators we see no distinctive differences between these three alternatives except when looking at the external hours used for the setting of “Full collaboration”. This difference is shown in Table 6-3, where the default setting, on average, scores the lowest result of 55,56%. Looking at the use of external hours, we can see that for groups 1 and 4 there is room for improvement compared to the current situation, no matter the sorting method. In group 5, only for alternative 1, we need external hours to satisfy all requests, which is relatively 100% more than the current situation. In groups 2 and 3, we see that no matter the alternative - except for alternative 3 for group 2 - we need more external hours compared to the current situation.

	Current	Default - EPT	Alt. 1 - Type S to L, EPT	Alt. 2 - Type L to S, EPT	Alt. 3 - MRT Small First, EPT	Alt. 4 - MRT Large First, EPT	Alt. 5 - Desired time S First, EPT	Alt. 6 - Desired time L First, EPT
Group 1	100,00%	55,56%	63,83%	79,57%	74,49%	42,64%	71,87%	67,48%
Group 2	100,00%	115,49%	181,10%	137,76%	88,96%	123,47%	139,69%	122,65%
Group 3	100,00%	106,78%	207,27%	189,19%	151,08%	118,80%	152,57%	168,01%
Group 4	100,00%	0,00%	16,86%	14,03%	12,45%	14,56%	27,64%	16,84%
Group 5	0,00%	0,00%	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%
Average	80,00%	55,56%	113,81%	84,11%	65,39%	59,89%	78,35%	75,00%

Table 6-3 External hours used comparison for different sorting methods on full collaboration

In Stage I, we choose the default setting of sorting on earliest pickup time as our winner to continue with, in further stages.

6.2 STAGE II – CHOOSING AN OBJECTIVE FUNCTION

In Stage II, we examine the effect of using different objective functions, using the best sorting method found in Stage I, keeping the other interventions settings on default, and varying on the collaboration setting between “No collaboration” and “Full collaboration”.

The clearest results can be shown by looking at the impact on total costs. We can see that we get the best results when we optimize either on increase in duration or increase in the total number of kilometers. Looking at the total costs for alternative 3 and 4, we see a considerable increase and thus do not consider them as viable options.

No collaboration	Current	Default - Duration of order	Alt. 1 - Number of kilometers	Alt. 2 - Dev. of desired time	Alt. 3 - Earliest time of order complete
Group 1	100,00%	100,90%	100,93%	115,71%	136,91%
Group 2	100,00%	122,65%	120,91%	131,80%	155,84%
Group 3	100,00%	99,04%	106,98%	122,22%	165,84%
Group 4	100,00%	102,16%	100,25%	123,15%	160,74%
Group 5	100,00%	67,09%	67,12%	96,31%	99,30%
Average	100,00%	98,37%	99,24%	117,84%	143,73%
Full collaboration	Current	Default - Duration of order	Alt. 1 - Number of kilometers	Alt. 2 - Dev. of desired time	Alt. 3 - Earliest time of order complete
Group 1	100,00%	89,36%	85,67%	114,38%	121,10%
Group 2	100,00%	104,87%	102,64%	124,51%	149,76%
Group 3	100,00%	91,84%	98,34%	116,73%	155,82%
Group 4	100,00%	95,10%	93,34%	115,61%	152,71%
Group 5	100,00%	67,09%	67,12%	96,31%	99,30%
Average	100,00%	89,65%	89,42%	113,51%	135,74%

Table 6-4 Total costs comparison of different objective functions for both no and full collaboration

One would expect that if we optimize on increase in duration, we would get the lowest score in total duration and if we optimize on increase in kilometers we would get the lowest score in total kilometers. When we look at Table 6-5, we see that on average, this is indeed the case for Default and Alternative 1 for both no collaboration and full collaboration. However, when we look at Table 6-6, we see that the column of total number of kilometers is not necessarily lower for the objective function of the increase in total kilometers for no collaboration and on average virtually equal for full collaboration. These scores come very close. Furthermore, when we look at the quality performance indicators we see an equal number of vehicles and more subsequent visits to customers for the objective of kilometers. Therefore, we choose the increase in duration as the winner of Stage II.

No collaboration	Current	Default - Duration of order	Alt. 1 - Number of kilometers	Alt. 2 - Dev. of desired time	Alt. 3 - Earliest time of order complete
Group 1	100,00%	110,42%	117,14%	138,09%	65,41%
Group 2	100,00%	79,79%	78,96%	115,13%	67,36%
Group 3	100,00%	92,73%	95,37%	137,36%	70,93%
Group 4	100,00%	77,69%	104,55%	128,14%	77,38%
Group 5	100,00%	109,74%	107,67%	140,86%	100,45%
Average	100,00%	94,07%	100,74%	131,92%	76,31%
Full collaboration	Current	Default - Duration of order	Alt. 1 - Number of kilometers	Alt. 2 - Dev. of desired time	Alt. 3 - Earliest time of order complete
Group 1	100,00%	83,97%	102,26%	118,53%	61,78%
Group 2	100,00%	80,34%	77,97%	116,93%	66,41%
Group 3	100,00%	79,02%	78,38%	129,93%	68,28%
Group 4	100,00%	92,47%	112,72%	129,80%	69,06%
Group 5	100,00%	109,74%	107,67%	140,86%	100,45%
Average	100,00%	89,11%	95,80%	127,21%	73,20%

Table 6-5 Total duration for different objective functions for both no and full collaboration

No collaboration	Current	Default - Duration of order	Alt. 1 - Number of kilometers	Alt. 2 - Dev. of desired time	Alt. 3 - Earliest time of order complete
Group 1	100,00%	94,89%	94,42%	119,31%	155,34%
Group 2	100,00%	104,80%	112,12%	133,90%	172,47%
Group 3	100,00%	100,88%	116,61%	141,82%	189,26%
Group 4	100,00%	97,68%	96,65%	143,84%	197,08%
Group 5	100,00%	95,05%	94,99%	100,44%	98,95%
Average	100,00%	98,66%	102,96%	127,86%	162,62%
Full collaboration	Current	Default - Duration of order	Alt. 1 - Number of kilometers	Alt. 2 - Dev. of desired time	Alt. 3 - Earliest time of order complete
Group 1	100,00%	100,75%	93,89%	134,70%	160,22%
Group 2	100,00%	115,11%	111,86%	148,66%	178,74%
Group 3	100,00%	106,37%	116,35%	145,96%	200,11%
Group 4	100,00%	101,37%	95,75%	139,19%	197,62%
Group 5	100,00%	95,05%	94,99%	100,44%	98,95%
Average	100,00%	103,73%	102,57%	133,79%	167,12%

Table 6-6 Total kilometers for different objective functions for both no and full collaboration

One other effect that is visible from Table 6-6, is that compared to the current situation we get a result that performs less on the total number of kilometers when we change the setting from no collaboration to full collaboration. It can be shown that there is room for a slight decrease in the total number of kilometers for the organizations, however, this value does not decrease when we allow more possible combinations. We can conclude that for the number of kilometers, collaboration is not beneficial.

6.3 STAGE III – EVALUATING THE DIFFERENT SETTINGS FOR COLLABORATION

In this stage, we evaluate the influence on the performance indicators varying on the collaboration setting and using the settings found in the previous stages. The performance indicator that gives a good overview of the effects of collaboration is the total costs, this is given in Table 6-7.

	Current	Option 1 - Shared customers	Option 2 - Small customers	Option 3 - Medium customers	Option 4 - Large customers	Option 5 - Small and medium customers	Option 6 - Medium and large customers	Option 7 - All customers	Option 8 - No customers
G1	100,00%	89,89%	101,51%	97,75%	87,58%	99,47%	89,00%	89,36%	100,90%
G2	100,00%	118,44%	114,25%	126,80%	112,46%	118,86%	120,87%	104,87%	122,65%
G3	100,00%	96,21%	103,94%	102,64%	88,92%	108,17%	97,89%	91,84%	99,04%
G4	100,00%	98,03%	104,20%	99,82%	96,94%	104,26%	97,30%	95,10%	102,16%
G5	100,00%	67,09%	67,09%	67,09%	67,09%	67,09%	67,09%	67,09%	67,09%
Av.	100,00%	93,93%	98,20%	98,82%	90,60%	99,57%	94,43%	89,65%	98,37%

Table 6-7 Total costs comparison on different levels of collaboration

For groups 1, 3 and 4, we see an improvement in total costs if we allow collaboration on "Large customers". Furthermore, the shared customers are often also the large customers, we see similar results here. If small or medium customers are included in the collaboration we see an equal or worse score compared to the current situation. In group 2 we see no improvement in total costs. For group 5, the weekend group we always see an improvement in the total costs. Looking more closely at group 5, we see that LabMicTA-LabPON's own customers have been redistributed to a single vehicle instead of two. For groups 1 to 4, we see a large resemblance for the total costs in the use of extra vehicles hired to suffice all transportation requests. This is shown in Table 6-8.

	Current situation	Option 1 - Shared customers	Option 2 - Small customers	Option 3 - Medium customers	Option 4 - Large customers	Option 5 - Small and medium customers	Option 6 - Medium and large customers	Option 7 - All customers	Option 8 - No customers
G1	2	1,8	2	2	1,8	2	1,8	1	2
G2	2	3	3,6	4	3	4,2	3,6	2	3,6
G3	1	1,2	1,4	2	1	2,6	1,2	1	1,2
G4	2	1	1,8	1,6	1	2	1	0	1,4
Av.	1,75	1,75	2,2	2,4	1,7	2,7	1,9	1	2,05

Table 6-8 Extra vehicles needed for different levels of collaboration

If we look at the other performance indicators, we see for the total number of kilometers in Table 6-9, we get mixed results, with the emphasis on a lesser performance compared to the current situation. This effect is not what one would assume but can be explained that if the organizations work together they must visit extra depots compared to the current situation.

	Current	Option 1 - Shared customers	Option 2 - Small customers	Option 3 - Medium customers	Option 4 - Large customers	Option 5 - Small and medium customers	Option 6 - Medium and large customers	Option 7 - All customers	Option 8 - No customers
G1	100%	97%	101%	97%	94%	102%	100%	101%	95%
G2	100%	122%	110%	118%	114%	117%	124%	115%	105%
G3	100%	111%	115%	124%	107%	107%	121%	106%	101%
G4	100%	106%	104%	101%	104%	102%	104%	101%	98%
G5	100%	95%	95%	95%	95%	95%	95%	95%	95%
Av.	100%	106%	105%	107%	103%	105%	109%	104%	99%

Table 6-9 Total number of kilometers for different levels of collaboration

The total duration of orders, as shown in Table 6-10, shows that the overall emphasis is a decreased order duration compared to the current situation. However, if we look at the types of collaboration that performed best on total costs, we see a negative correlation with the total duration. Here collaboration on Shared customers, Large customers, Medium and large get the worst results and collaboration on, e.g., small customers show one of the best scores. The increase in total duration is an undesirable effect, but since we set the maximum ride time beforehand, we can never exceed the duration limit violating quality constraints.

	Current	Option 1 - Shared customers	Option 2 - Small customers	Option 3 - Medium customers	Option 4 - Large customers	Option 5 - Small and medium customers	Option 6 - Medium and large customers	Option 7 - All customers	Option 8 - No customers
G1	100%	104%	87%	92%	113%	86%	97%	84%	110%
G2	100%	86%	82%	77%	82%	78%	83%	80%	80%
G3	100%	89%	78%	93%	97%	83%	93%	79%	93%
G4	100%	94%	75%	77%	98%	75%	95%	92%	78%
G5	100%	110%	110%	110%	110%	110%	110%	110%	110%
Av.	100%	97%	86%	90%	100%	86%	96%	89%	94%

Table 6-10 Total duration of orders for different levels of collaboration

We choose the best performing collaboration levels to continue with, to be the following types: Option 1 – Shared customers, Option 3 – Large customers, All customers. Furthermore, we continue with the collaboration type Option 8 – No customers, to see the effect on one of the worst performing types in further stages.

6.4 STAGE IV – EVALUATING THE INFLUENCE OF HUBS

We see that for most of the groups, the introduction of hubs on fixed times gives a worse performance than the current situation. We tested the introduction of several fixed times (09:30, 10:00, 10:30, 11:00) for group 3 on locations Hengelo, Almelo, and Enschede and several fixed times for group 4 (14:30, 15:30, 16:00, 16:30) on locations Hengelo, Almelo, and Enschede, but in every experiment the usage of extra vehicles increased considerably. Other than the quality performance indicators, such as the duration of orders, all the performance indicators performed worse compared to the current performance. This can be seen by looking at the outcomes of one of the experiments on the total costs for group 3 found in Table 6-11. Overall the time of a hub did not really matter, performance always looks similar. Ranging from No customer collaboration to All customer collaboration, we get a decreasing score on vehicle usage and total costs respectively, although any of these options perform less compared to the current situation. Furthermore, we see that the introduction of fewer hubs always increased the performance on total costs or vehicle usage.

		Current	Option 8 - No customers	Option 1 - Shared customers	Option 4 - Large customers	Option7 - All customers
Group 3 11:00	Hengelo, Almelo, Enschede	100%	130%	123%	113%	112%
Group 3 10:30	Hengelo, Almelo, Enschede	100%	124%	114%	111%	115%
Group 3 10:00	Hengelo, Almelo, Enschede	100%	114%	113%	108%	108%
Group 3 09:30	Hengelo, Almelo, Enschede	100%	122%	118%	114%	112%
Group 3 09:00	Hengelo, Almelo, Enschede	100%	134%	126%	121%	114%
Average		100%	125%	119%	113%	112%

Table 6-11 Total costs for introduction of hubs in group 3 at various times for different types of collaboration

		Current	Option 8 - No customers	Option 1 - Shared customers	Option 4 - Large customers	Option7 - All customers
Group 3 11:00	Almelo	100%	126%	118%	111%	112%
Group 3 10:30	Almelo	100%	121%	111%	109%	114%
Group 3 10:00	Almelo	100%	110%	110%	108%	107%
Group 3 09:30	Almelo	100%	121%	110%	112%	111%
Group 3 09:00	Almelo	100%	126%	120%	117%	113%
Average		100%	121%	114%	112%	111%

Table 6-12 Total costs for introduction of hubs in group 3 at various times for different types of collaboration

The intervention of hubs was thought of as an alternative way of collaboration, taking away the extra time needed to visit collaborating organizations' depots. One would expect that if the vehicles did not have to visit the depots they could focus on other orders to transport, thereby increasing overall performance. However, because we use an insertion algorithm in the model of this research, we must create the orders beforehand from the transportation requests. Creating the orders before executing the algorithm requires us to know the times at which hubs should be visited. Therefore, we must agree upon fixed when hubs can be visited to assure collaboration. In the model, this translates to less large time windows for the same transportation requests to be sufficed resulting in the usage of extra vehicles to suffice all orders. By introducing hubs to the transportation requests, we only create a smaller solutions space. Hubs as an intervention for transportation are in itself not necessarily a bad idea, although not in the model used in this research. We do not continue with the use of hubs in further stages.

6.5 STAGE V – VARYING ON THE COLLABORATION COALITION

In this stage, we examine the effect of leaving out one organization in the collaboration coalition. When we look at the total costs performance indicator, we get three different tables. It can be shown from Table 6-13 that if we leave LabMicTA-LabPON out of the collaboration coalition, we see a decrease in performance for groups 1 to 4 for the other two organizations compared to the current situation. We can conclude that the combined costs for Medlon and ZGT will only increase when LabMicTA is involved in the coalition. For a collaboration on Large customers, we often still get an increased performance compared to the current situation.

	Current	No collaboration	Shared customers		Large customers		All customers	
			Leave out none	Leave out LabMicTA-LabPON	Leave out none	Leave out LabMicTA-LabPON	Leave out none	Leave out LabMicTA-LabPON
G1	100%	101%	90%	95%	88%	91%	89%	94%
G2	100%	123%	118%	117%	112%	109%	105%	116%
G3	100%	99%	96%	102%	89%	92%	92%	99%
G4	100%	102%	98%	103%	97%	102%	95%	103%
G5	100%	67%	67%	67%	67%	67%	67%	67%
Av.	100%	98%	94%	97%	91%	92%	90%	96%

Table 6-13 Total costs on different levels of collaboration leaving out LabMicTA-LabPON

When we look for an explanation for the decrease in score on total costs when we leave out LabMicTA-LabPON from the collaboration coalition, we see that the use of external hours needed to suffice all transportation increases compared to the current situation.

	Current	No collaboration	Shared customers		Large customers		All customers	
			Leave out none	Leave out LabMicTA-LabPON	Leave out none	Leave out LabMicTA-LabPON	Leave out none	Leave out LabMicTA-LabPON
G1	100%	124%	99%	113%	104%	115%	56%	109%
G2	100%	245%	266%	226%	237%	225%	115%	220%
G3	100%	212%	220%	216%	205%	227%	107%	205%
G4	100%	85%	41%	70%	50%	61%	0%	77%
G5	0%	0%	0%	0%	0%	0%	0%	0%
Av.	80%	133%	125%	125%	119%	126%	56%	122%

Table 6-14 External hours needed on different levels of collaboration leaving out LabMicTA-LabPON

From Table 6-15, we see that leaving out Medlon of the collaboration coalition further increases the combined performance of LabMicTA-LabPON and ZGT for most of the collaboration settings. When we set the collaboration type on Large customers, we get a decreased performance for group 3; all the transportation requests before noon.

	Current	No collaboration	Shared customers		Large customers		All customers	
			Leave out none	Leave out Medlon	Leave out none	Leave out Medlon	Leave out none	Leave out Medlon
G1	100%	101%	90%	93%	88%	93%	89%	98%
G2	100%	123%	118%	113%	112%	113%	105%	105%
G3	100%	99%	96%	96%	89%	94%	92%	97%
G4	100%	102%	98%	94%	97%	97%	95%	94%
G5	100%	67%	67%	67%	67%	67%	67%	67%
Av.	100%	98%	94%	93%	91%	93%	90%	92%

Table 6-15 Total costs on different levels of collaboration leaving out Medlon

From Table 6-16, we see that if we leave out ZGT from the collaboration coalition we almost always get a decreased or almost equal performance compared to the current situation. We conclude that for groups 1 to 4 it is not beneficial to collaborate for LabMicTA-LabPON and Medlon only. When we look at the collaboration setting No collaboration, we see that these outcomes score better or equal to the other collaboration settings, e.g., all customers and leaving out ZGT. This means that concerning the total costs, the organizations without ZGT are better off restructuring their own transportation rather than collaborating on any level.

	Current	No collaboration	Shared customers		Large customers		All customers	
			Leave out none	Leave out ZGT	Leave out none	Leave out ZGT	Leave out none	Leave out ZGT
G1	100%	101%	90%	102%	88%	103%	89%	101%
G2	100%	123%	118%	133%	112%	133%	105%	123%
G3	100%	99%	96%	101%	89%	100%	92%	100%
G4	100%	102%	98%	103%	97%	103%	95%	104%
G5	100%	67%	67%	67%	67%	67%	67%	67%
Av.	100%	98%	94%	101%	91%	101%	90%	99%

Table 6-16 Total costs on different levels of collaboration leaving out ZGT

We conclude that the involvement of LabMicTA-LabPON and ZGT benefit the coalition and although involvement of Medlon improves results, we find better results when only LabMicTA-LabPON and ZGT are involved.

6.6 STAGE VI – USE OF ONLY EXTERNAL PARTIES

In the last stage of experiments, we examine the effect of only hiring external parties. Looking at the total costs we can see that if we were to completely replace the transportation by vehicles for the organizations and allow full collaboration we get a worse performance in Table 6-17.

	Current	External parties
Group 1	100%	130%
Group 2	100%	144%
Group 3	100%	120%
Group 4	100%	108%
Group 5	100%	60%
Average	100%	112%

Table 6-17 Total costs comparison for full collaboration by external parties compared to current situation

When we further examine the performance indicators on quality, we find that quality is not improved considerably. We find no improvement on subsequent visits to individual customers, and when there is an improvement on the duration of orders, we find extremely high costs.

	Duration of order		Subsequent visits to customers	
	Current	External parties	Current	External parties
Group 1	100%	95%	100%	105%
Group 2	100%	82%	100%	108%
Group 3	100%	89%	100%	101%
Group 4	100%	136%	100%	102%
Group 5	100%	110%	100%	76%
Average	100%	102%	100%	98%

Table 6-18 Quality performance indicators of external parties compared to current situation

We already found that there is room for improvement in the weekend group in previous stages. However, looking at the results, we find that compared to the current situation, we get one of the best results on total costs comparisons in the weekend with the use of external parties. It must be noted though, that in the costs calculation, usage of a vehicle is taken per year. In group 5 we assume vehicles are only used in the weekend, but we know that during the rest of the week the vehicles are also used. The annual costs of vehicles should, therefore, be adjusted for the other activities, which in this table is not.

6.7 CONCLUDING ANALYSIS OF RESULTS

Going through the different stages, we conclude that there is room for improvement in the modeled current situation. In Stage I, we found that the best results are found sorting the orders only on earliest pickup time. In Stage II we found the best results by minimizing the objective value on the increase in duration and increase in total kilometers. We favored minimizing on total duration because it decreased the total kilometers more than the kilometers influenced the effect on total duration. In Stage III we found the best results if we collaborate on shared customers, large customers, or all customers. In stage IV we found that introducing fixed hub locations and times decreases the overall performance because we further limit the solution space. In stage V we found that we get the best improvements if we use the collaboration coalition {LabMicTA-LabPON, ZGT}, however, we also get improved results if we use the coalitions {LabMicTA-LabPON, ZGT, Medlon} or {Medlon, ZGT}. The collaboration coalition {LabMicTA-LabPON, Medlon} is not beneficial. In the final stage, we found that if we were only to use external parties the total costs would increase considerably.

6.8 ELABORATION OF RESULTS

We combine the results found to create various scenarios. By aggregating the groups determined earlier, we examine the effect of the intervention settings that have a positive influence on several scenarios for collaboration on regular transport. These scenarios offer the possibility for improvement relative to the current situation.

6.8.1 Scenario 1: Collaboration coalition between three organizations

In the first scenario, we involve all organizations in the collaboration coalition. When we examine the effect on total costs for regular transport, we find the best improvement when we allow collaboration for all locations on the routes.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 10 - Regular total transportation costs for different types of collaboration

In the experiments, we find the best results when we minimize the increase in ride duration. This is reflected in the total time that vehicles are on the road. Independent of the type of collaboration, we can see a profit in total duration for all the organizations. With the setting of no collaboration, the profit on total duration is virtually the same as full collaboration.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	100,0%	91,9%	97,7%	86,1%	86,0%

Table 11 - Regular transportation duration for different types of collaboration

For the number of kilometers, we see a trend that when we allow collaboration, the number of kilometers increases. We conclude this is possible because we minimize on total duration, not total kilometers.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	100,0%	107,7%	105,1%	103,5%	99,1%

Table 12 - Regular transportation distances for different types of collaboration

6.8.2 Scenario 2: Collaboration coalition between LabMicTA-LabPON and ZGT

In the second scenario, we involve only ZGT and LabMicTA-LabPON in the collaboration coalition. In this scenario, we see the strongest decrease in total costs.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 13 - Regular transportation costs for different types of collaboration

For the total duration of regular transport, we see that there is room for improvement for the regular transport.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	100,0%	94,8%	98,1%	85,6%	84,7%

Table 14 - Regular transportation duration for different types of collaboration

In contrast to Scenario 1, we see that in this scenario the total number of kilometers does not increase when we collaborate but stays virtually the same.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	100,0%	100,7%	102,0%	98,4%	99,6%

Table 15 - Regular transportation distances for different types of collaboration

6.8.3 Scenario 3: Collaboration coalition between Medlon and ZGT

Section 6.5 showed that a collaboration coalition between Medlon and ZGT has a positive influence on the total costs. When we regard these findings in the grand total picture, we see that there is no room for improvement in a coalition of only Medlon and ZGT. In parallel with the previous scenarios, we see that there is room for improvement looking at the total duration of transportation. In this scenario, we see a worsening of the total number of kilometers driven.

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 16 - Regular transportation costs for different types of collaboration

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	100,0%	94,6%	99,2%	89,0%	91,0%

Table 17 - Regular transportation duration for different types of collaboration

	Current situation	Shared locations	Large locations	All locations	No collaboration
Group 3, 4 and 5 combined	100,0%	128,9%	127,1%	125,8%	101,0%

Table 18 - Regular transportation distances for different types of collaboration

6.8.4 Scenario 4: Route optimization within the own organization

Despite Table 1 showing no improvement on total costs, there is room for improvement within the organizations themselves. The redistribution of small groups of transportation requests or redistributing the transportation requests that in the current situation are appointed to a single vehicle show no improvement on average. However, the practical implementation of newly constructed routes offers the possibility to only selectively redistribute transportation requests within the own organization. An example of such a situation is the transport on Saturday, for both LabMicTA-LabPON and Medlon there is room for improvement without collaboration. In this case, the requests of Saturday can be reorganized and combined with the current routes for the rest of the week. Many small groups of transportation requests can be reorganized by the model and combined with the rest of the current routes or transportation requests. Which selections to be combined with the current situation is a variable problem that is to be examined in conjunction with the transportation managers.

CHAPTER 7 CONCLUSIONS AND DISCUSSIONS

This chapter summarizes and discusses the findings of this research to conclude this thesis. In Section 7.1, we give answers and conclusions in multiple subsections keeping the structure of the research questions. Section 7.2 discusses the limitations of this research and its assumptions. In addition to the discussions in Section 7.2, recommendations and advice for future research regarding the organizations are given subsequently after each discussion point.

7.1 CONCLUSIONS

The objective of this research was to gain insights into the transportation processes of the organizations and to identify possible ways to collaborate with the organizations. To reach this objective, the following research goal was constructed:

To analyze the current transportation processes of materials and identify and prospectively assess ways to establish collaboration between ZGT, LabMicTA, LabPON, and Medlon to lower costs and provide a higher level of service.

To answer the research goal properly and in a structured approach, five research questions were derived from the main research goal. The questions that were derived from the research goal were the following:

RQ1. How is material transport currently organized at all parties/companies and what is their performance?
RQ2. What methods, models and knowledge are available that can contribute to exploring collaboration between the parties involved?
RQ3. How can the current logistical planning and collaboration suggestions be modeled?
RQ4. What are interventions for collaboration relevant to test using applicable models?
RQ5. What results do the various collaboration scenarios give and how can they be interpreted

The chapters in this report subsequently answered each of the research questions. The findings of the research questions are summarized below.

The first research question, which was answered to gain insights into the current workings of the transportation of materials by the organizations, is the most elaborated chapter of this research. For the organizational structure, we found that comprehending the structure of the organizations into a larger picture is complex, but that all the locations of the organizations can be collected and classified accordingly. Analyzing the materials to be transported, and the flow and volumes of these materials, further increased the complexity to comprehend the grand picture of the organizations. For the materials to be transported, a clear distinction can be made to whether the cargo is diagnostic or non-diagnostic. The different materials hold different properties that need to be considered, such as the limited time materials can be on the road or the certification needed to transport the materials. Information on the volumes of the organizations was not complete for all the types of materials but showed that fluctuations during the year could be contained in a fixed weekly planning for all the organizations. By extracting information from the fixed weekly planning, we could rebuild the transportation by vehicles. Analyzing the flow of the organizations showed that there was no clear direction of the materials overall. The flow of materials is often location specific and is not easy to generalize based on, e.g., type of location. We eventually modeled the flow as an extensive combined list of separate pickup and delivery transportation requests to guarantee the flow of materials remains intact when reorganizing the transportation operation. We collected various performance indicators derived from the pillars that were deemed important by the organizations and used these indicators to evaluate the outcomes of the different interventions. By creating a grand picture of the total costs of the transportation operation, we gave the organizations an overview of their unknown own and combined costs and collected parameters needed to calculate costs of a reorganized transportation operation. By collecting the restrictions and constraints of transportation by each organization, which mainly concerned the aspect of time, all the limitations to model the transportation operation were collected.

In the theoretical framework chapter, we found that a static multi-vehicle Dial-a-Ride Problem seems to be the best to model the transportation operation of the organizations. The expansion of the pickup and delivery problem with quality constraints made the problem a DARP, although the people in this problem are replaced with materials. Although DARP and PDPTW do not differ much, the models used to solve a DARP suit the problem in this study better than PDPTW, e.g., a maximum ride time or capacity constraint is not always included in the models to solve a PDPTW, while this is the case for DARP. Originally, when talking about a DARP, we talk about a dynamic problem; because people calling rides is a stochastic process. However, there is a distinction in literature between static and dynamic DARPs. In this research, we specifically refer to the problem as static, but in future works, when irregular rides of the organizations are included, the modeling of the problem as DARP might be more applicable, since including irregular rides makes the problem dynamic. An insertion heuristic was chosen to explore the possibilities of reconstructing the regular transport of the organizations.

In the modeling chapter, we introduced multiple collaboration and model interventions. Groups and stages were used to decrease the total number of experiments. For the first intervention, where we used several approaches to rebuild routes, we found that time plays an important part in rebuilding the routes. The best results were found when we sorted the locations on the earliest available time of pickup and we assigned the requests to vehicles minimizing the total increase in driving time.

For the second intervention, where we tested the influence of a collaboration structure based on different types of customers, we see an improvement for the total costs when we allow collaboration between the organization for the following types of customers: all customers, large customers, e.g., outpatient clinics and hospitals, and shared locations. With the remaining types of collaboration e.g., only collaborate for the small customers, such as general practitioners, we see a deterioration of performance compared to the current situation.

For the third intervention, where we test the influence of the use of hubs, we find no improvements compared to the current situation using a construction-insertion heuristic and front office locations as hubs on fixed times. We conclude that inserting hubs into the routes is not a good intervention when we use a construction-insertion heuristic.

As a fourth intervention, where we test the influence of leaving out one of the organizations, we see that ZGT is key to get improvements in performance. When we include ZGT in the collaboration collective, we get an improvement in total costs. This improvement holds for the coalitions {ZGT, Medlon, LabMicTA-LabPON}, {ZGT, LabMicTA-LabPON}, and {ZGT, Medlon}. When we allow collaboration between Medlon and LabMicTA-LabPON we see, despite the strong resemblance in motivation for transport using vehicles, only scores that are either equal or worse compared to the current situation.

As the last intervention, we see that outsourcing the transportation operation to an external party increases the total costs considerable compared to the current situation. We do see an improvement when we look at the performance indicators for quality of service, but the increase in quality does not justify the increase in extra costs.

When we combined the results found, we were able to create four scenarios on different levels of collaboration for the organizations to consider. In the first scenario, where all the organizations are involved, we find a saving of [redacted]. In the second scenario where only LabMicTA and ZGT are involved, we find a saving of [redacted]. Although we found improvements for the coalition Medlon and ZGT in the fourth intervention, we see no improvements in a grand total picture in scenario three. As a fourth scenario, it is possible for the transportation managers to improve the current situation without collaboration on small parts of the regular transport. It is up to the management of the organizations to decide if they continue with a scenario, and which scenario this should be.

7.2 DISCUSSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

In this section, we discuss the limitations of the research and the assumptions made in this research in different subsections. Recommendations and advice for future research regarding the organizations are given subsequently after the discussion points.

7.2.1 Limited number of experiments

The total number of transportation requests and the various interventions to be tested resulted in a total number of experiments that would have been too large to complete within acceptable time. Because we used groups instead of all the transportation requests, we could only make calculated guesses which intervention settings would improve the current situation in scenarios for all the transportation requests at once. Different results might have been found in single experiments if we used all the transportation requests instead of groups. There are two limits that are contributed to the stages that we used to decrease the number of experiments. The first limit of the stages is the sequence that the stages were performed in. A different sequence might have given a different outcome. Although the first two stages were deliberately chosen to be the first ones - so we could calibrate the model - the other stages were not. The second limit that can be contributed to the use of stages is that we skip some parts of the solution space and do not know whether we missed some of the better outcomes.

7.2.2 Use of external parties in solutions

In the model, usage of external parties is assumed to be unlimited at a fixed hourly cost. However, when using the newly constructed routes in practice, these external parties must be contracted. Sometimes external parties are only hired for small groups of transportation requests where own vehicle capacity comes short. In practice, this could mean a lot of contracts have to be made with external couriers. Furthermore, to assume on the costs of external couriers, we used the costs of Kamphuis couriers from a costs calculation by Medlon. Other external parties might have different prices for transportation services. By offering external parties a large quantity of work, discounts might be applicable.

7.2.3 Staff side activities and vehicles

In the model, we assumed each vehicle to have one staff member. Furthermore, we did not consider any skill, knowledge, or permanent labor agreements of the employees. In practice, the know-how of employees to handle materials or customers influences the times and quality that is needed to service a customer. Furthermore, if we find that we can decrease the hours that are needed in vehicle transport, additional activities that are also performed by transportation service might prevent this from implementing. Next to additional activities of the transportation service, labor agreements with the employees might also prevent a decrease in hours. The same principle can be applied to the number of vehicles needed for transportation. If we find that we can run the transportation of materials with one vehicle less, we might still be stuck with the vehicle because it is depreciated over multiple years. Lastly, all the employees and vehicles are assumed to be equal in the model. In practice, every employee has a unique contract. And each vehicle has its own parameters.

7.2.4 Service times

In the model, we assumed service times to be zero. We assumed the service times to be zero because this would only be a few minutes per location to visit and when reconstructing the current routes, we found that the duration from one location to another was a few minutes larger than in reality. This canceled each other out. However, this does not hold if a location is returning to a depot and all the cargo of the vehicle must be unloaded. Furthermore, we used a feasibility procedure in which a service time was not integrated. If one were to implement service times into the model, we would need two service times: one for picking up, one for delivery. Furthermore, we would need to either introduce a correction to the duration between locations, e.g., a factor, or another database. Lastly, the model must be adapted to introduce the service times.

7.2.5 Cargo load sequence

In the model, we did not consider the sequence in which cargo was loaded. For the organizations Medlon and LabMicTA-LabPON this is of no importance. However, this is of importance for ZGT which transports various materials including larger medical equipment and came up as a point of discussion during meetings with the transportation managers of ZGT.

7.2.6 Managing collaboration

In this research, the possibilities of collaboration between the organizations are examined, keeping the focus on the limits of reorganization of only the transportation services. The issue of managing the implementation of a newly formed collaboration coalition is not included in this research. Managing collaboration is of importance to find consensus on, among others, making agreements on responsibility, the division of costs, the supply of personnel and assets, etc. One can assume that there is a different level of complexity in managing the transportation operation when a setting for collaboration for all customers is chosen in contrast to only collaborating on large customers. It is up to the management of the organizations to estimate whether the intended profit offsets the additional management costs that come with the level of collaboration. We recommend the organizations to explore the implementation impact of the various scenarios and determine if and which scenario they would like to continue with. Further research by the organizations themselves if therefore needed.

7.2.7 Implementation

In this research, we use a model to evaluate the possible outcomes of collaboration. The principle of a model is that it is an approach to reality, but it can never fully comprehend reality. As mentioned in the discussions section 7.2, there are limitations to the model that could pose a problem in reality. For a practical implementation, it is of importance to evaluate the - by the model constructed routes - in conjunction with the transportation managers. In practice, matters like irregular transport, supporting facilitating duties of the transportation services, exceptional customers with specific demands, assumptions about the equality of vehicle specifications and professional knowledge of employees, etc. are additional or different than in a modeled situation. Further research is needed for the practical refutation.

7.2.8 Insertion algorithm

The model chosen in this research is an insertion algorithm. We collected all the conditions that were needed for collaboration and used these conditions to rebuild the transportation situation by vehicles to gain insights for future collaboration plans. We used an insertion algorithm because it was a good alternative to radically change the operations of the vehicle transport. However, as mentioned in Section 3.2.1, there are other heuristics available that can be used on either the current situation or on the routes found by the model. The transportation requests collected could be still be used as an input for such an algorithm. This would benefit an intervention such as the introduction of hubs to the current routes.

7.2.9 Dynamic problem

In this research, we only considered the regular rides of the organizations. In future research, the irregular routes could also be introduced into the problem using a dynamic approach to the multi-vehicle DARP. Because of the explorative nature and limited time of this research, we did not include the irregular rides into the problem. By choosing a static approach to the problem, we covered far more of the problem than if we would have chosen vice versa. An advantage of the static variant of the model is that we can use the routes constructed as a starting solution for the dynamic problem. Dynamic multi-vehicle DARPs also incorporate events such as vehicle breakdowns and therefore are a viable topic of future research.

7.2.10 Input of the problem

When we started this research, we agreed in conjunction with the organizations that there are hard time restrictions for the laboratories. However, in later stages of the research when the topic resurfaced, organizations changed their statements about the hardness of these restrictions. Due to the limited time of this research, we did not reconsider the hardness of these constraints. Results of this research showed that without adjustments to the arrival stream of materials, collaboration is not beneficial to the laboratory organizations Medlon and LabMicTA-LabPON. A redefinition of the predetermined demands can lead to different results in future research.

7.2.11 Transportation of materials by phlebotomists

In this research, the transportation operations of the phlebotomists in service of Medlon have not been considered. The reason phlebotomists were not included in the research is that the operations of the phlebotomists are not similar to the other transportation processes of the other organizations. Furthermore, the phlebotomists drive back to the depots when all the customers are serviced, this is not a fixed time. However, the transportation by phlebotomists is a large part of the total transportation by Medlon and should be considered a valid topic of research.

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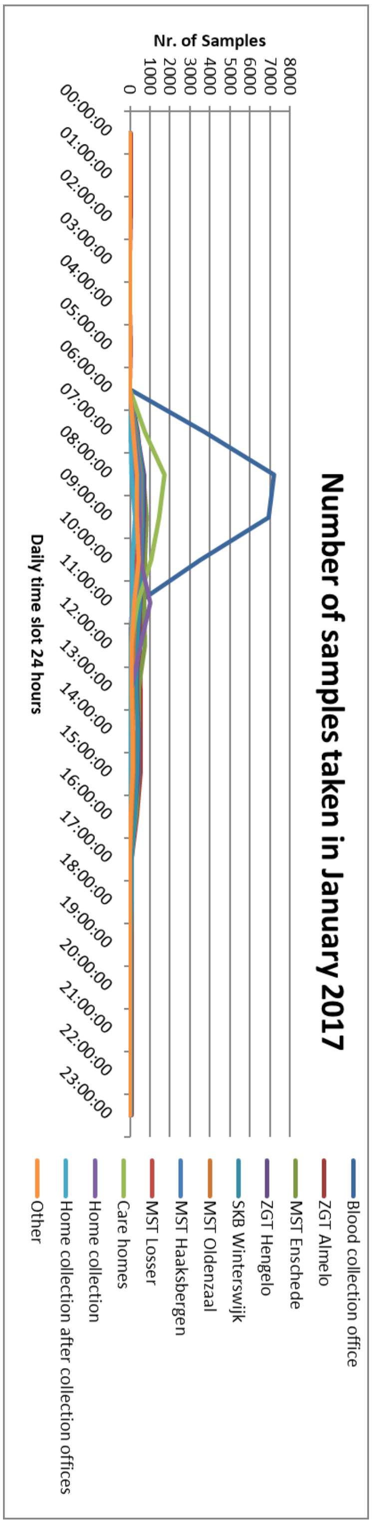
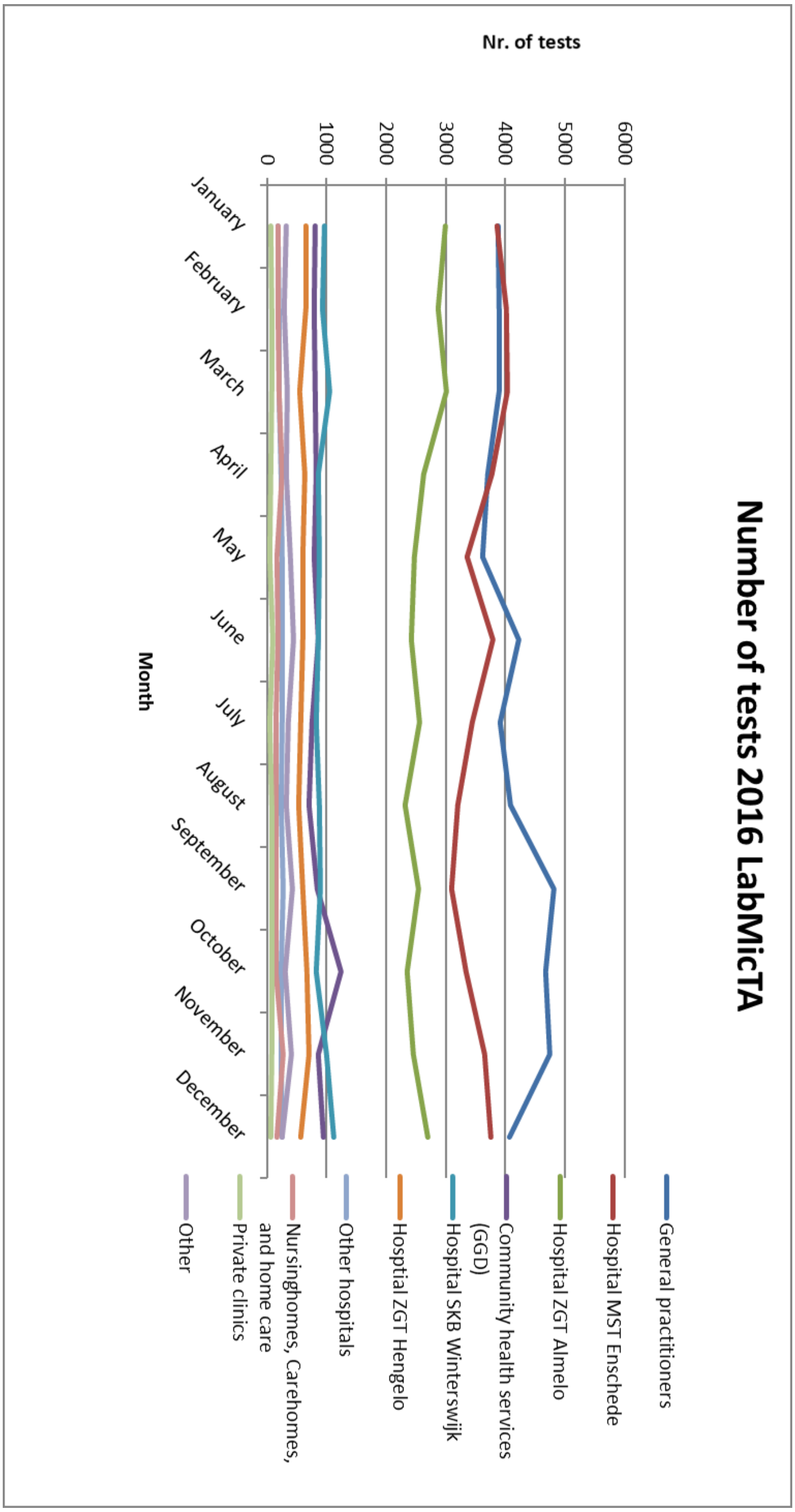
APPENDICES

This section shows all the referenced appendices of the research paper.

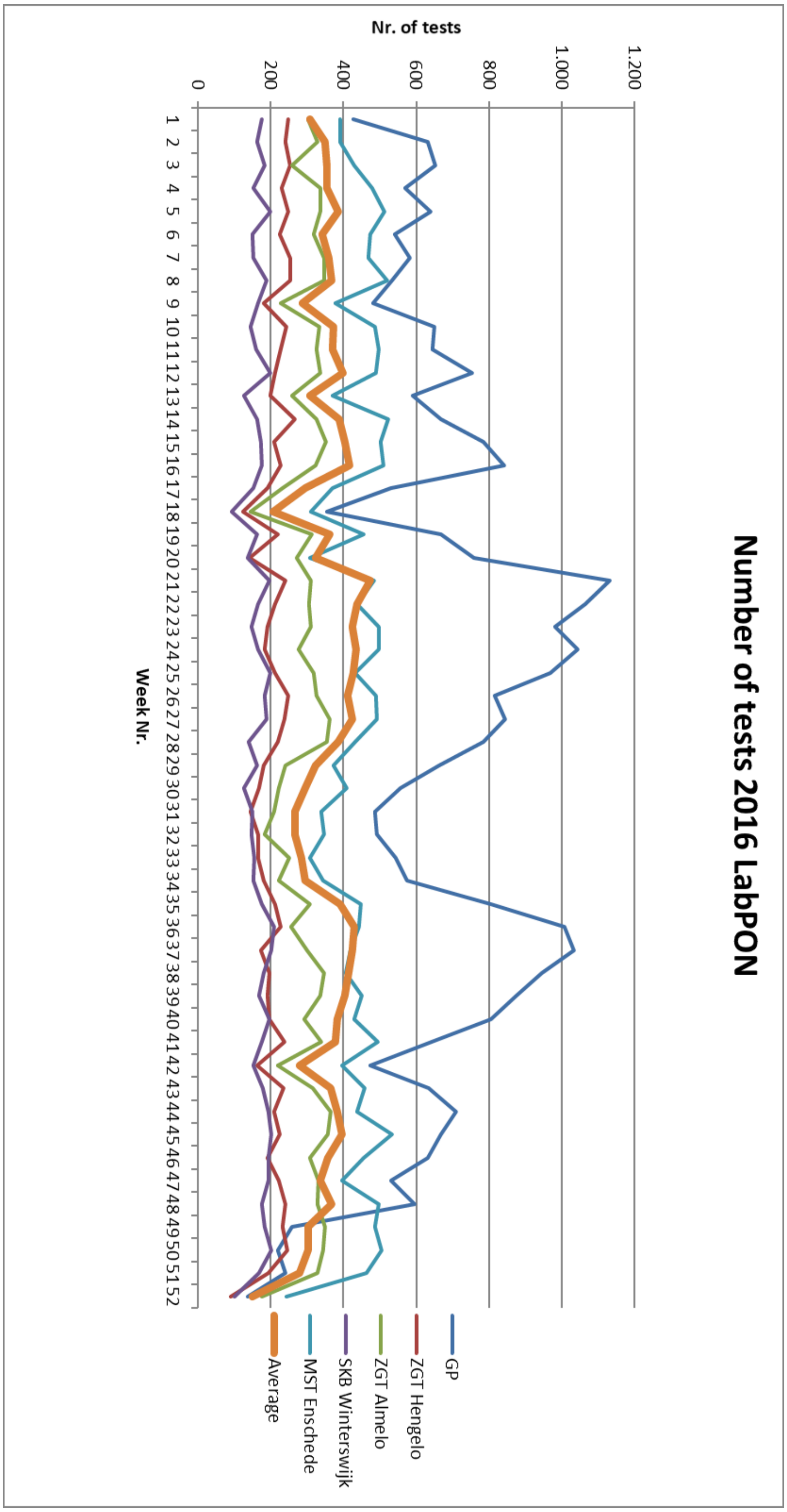
APPENDIX A - DAILY TREND MEDLON IN JANUARY 2017



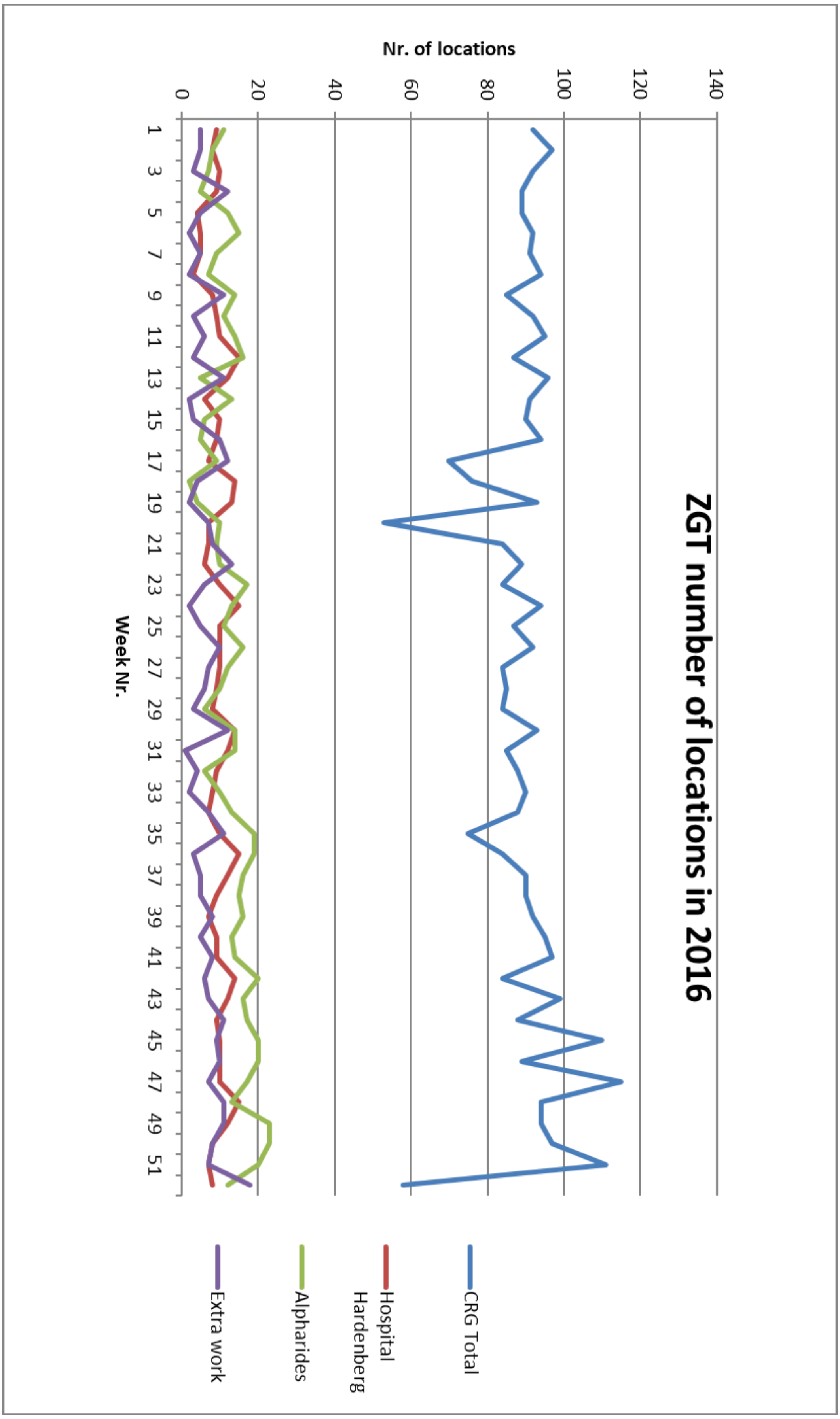
APPENDIX B - ANNUAL TOTALS PER MONTH LABMICTA IN 2016



APPENDIX C - ANNUAL TOTALS PER WEEK LABPON IN 2016



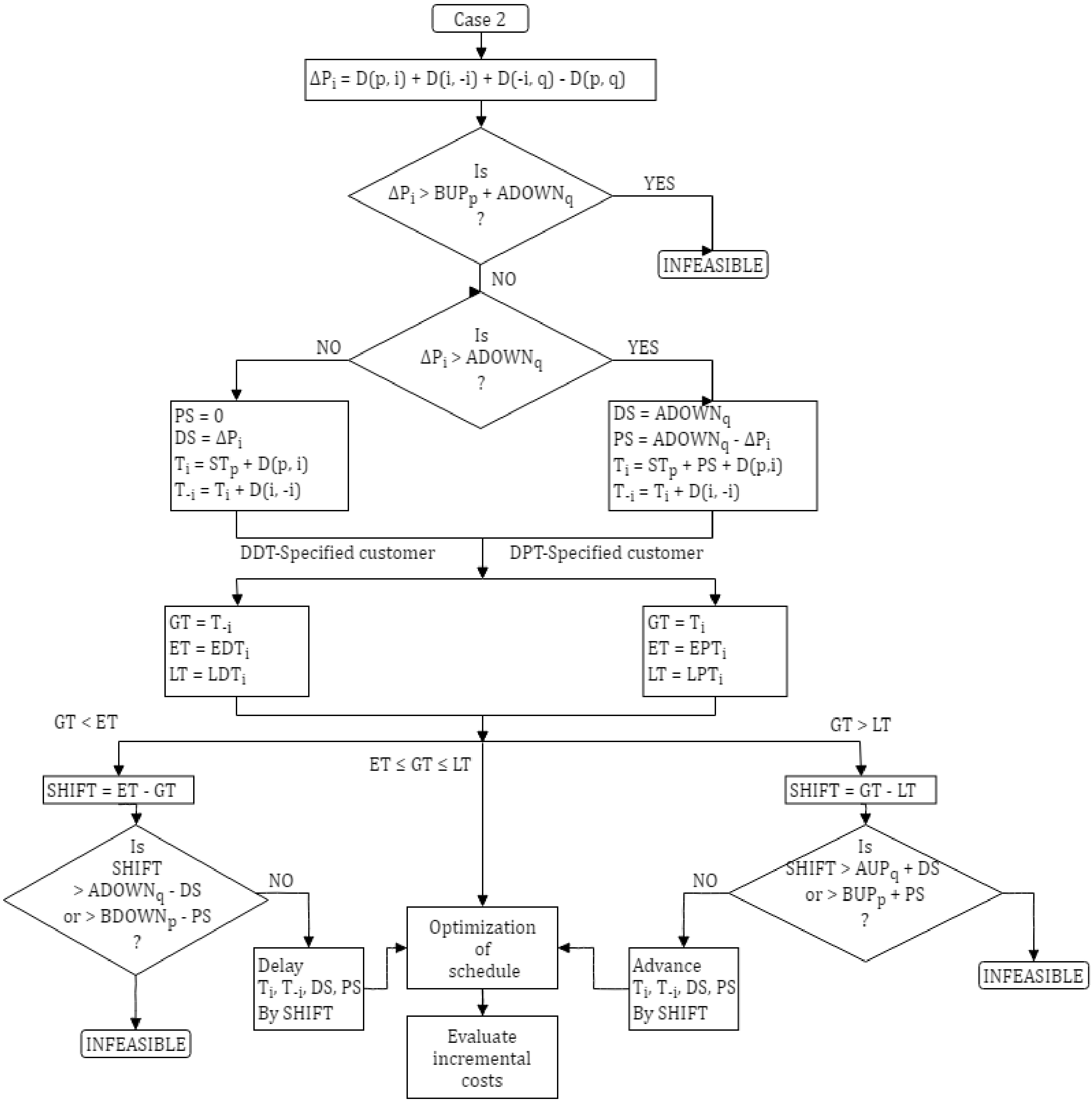
APPENDIX D - ZGT TOTALS PER WEEK IN 2016



APPENDIX E - VEHICLE INFORMATION OF THE ORGANIZATIONS

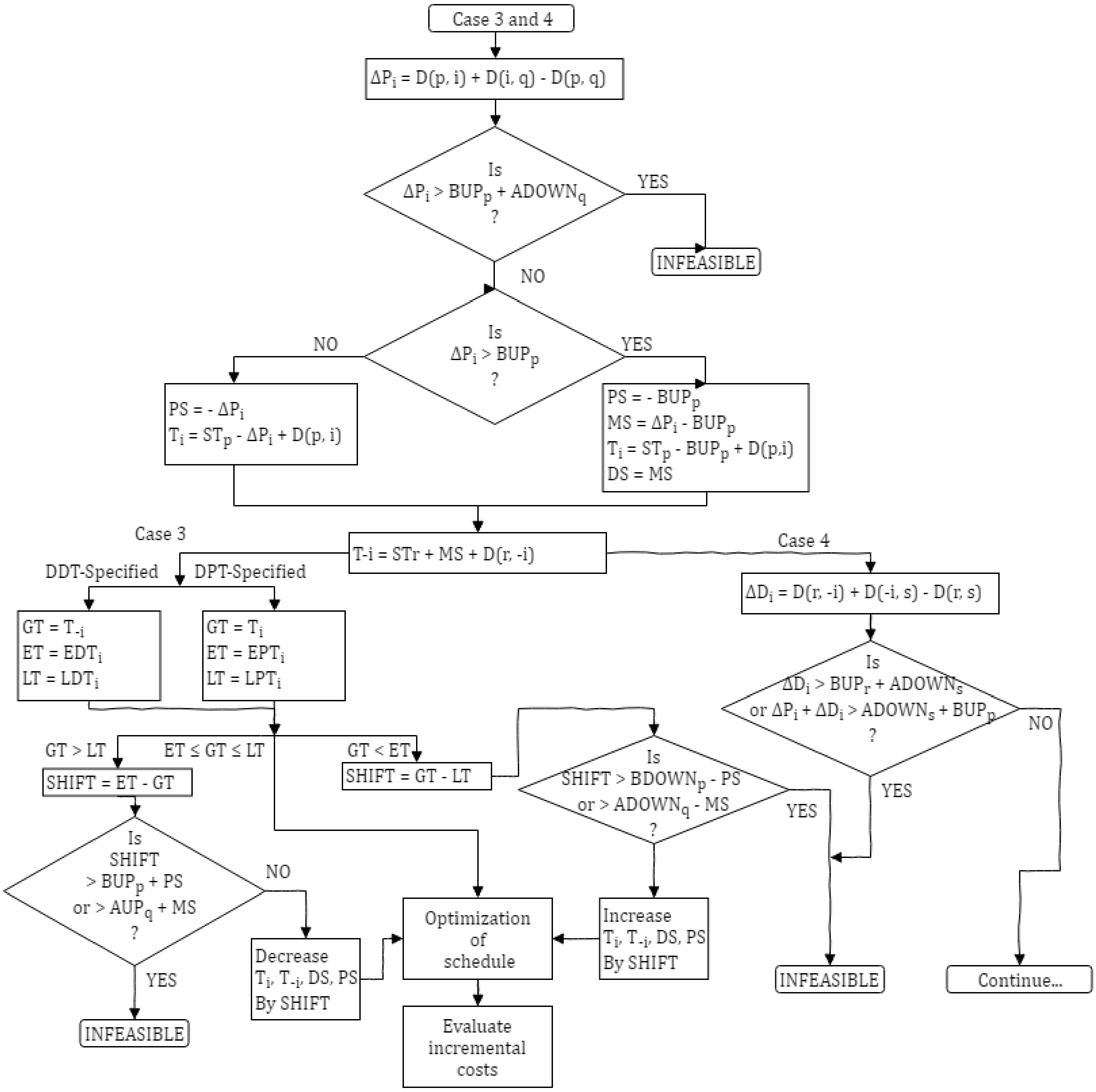
Organization	Type Car	Fuel	Fuel consumption (Kilometers per liter)	Cargo space (Liters)	Price new (€)	BPM (€)	Reduced Price (€)	Price Excl. BTW Tax (21%)	KIA Investment deduction (28%)	Residual value after three years (€)	Amortization over three years (€)	Road taxes for business (€)	Insurance and service costs Ex BTW Tax (€)	Total vehicle costs (€)
LabMicTA LabPON	Peugeot Partner EBHY	Diesel	23,8	1076	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LabMicTA LabPON	Peugeot Partner EBHY	Diesel	23,8	1076	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LabMicTA LabPON	Peugeot Partner EBHY	Diesel	23,8	1076	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LabMicTA LabPON	Peugeot Partner E9HF	Diesel	18,2	1228	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
LabMicTA LabPON	Peugeot Partner E9HF	Diesel	20,0	1228	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Medlon	Peugeot Partner E9HF	Diesel	20,0	3700	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ZGT	Citroën Jumpy S9HM	Diesel	14,9	5000	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ZGT	Citroën Jumpy S9HM	Diesel	14,9	5000	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ZGT	Citroën Jumpy S9HM	Diesel	14,9	5000	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ZGT	Mercedes Sprinter 906 KA 35 SPRINTER 310CDI	Diesel	10,5	10500	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

APPENDIX F - FEASIBILITY PROCEDURE CASE 2



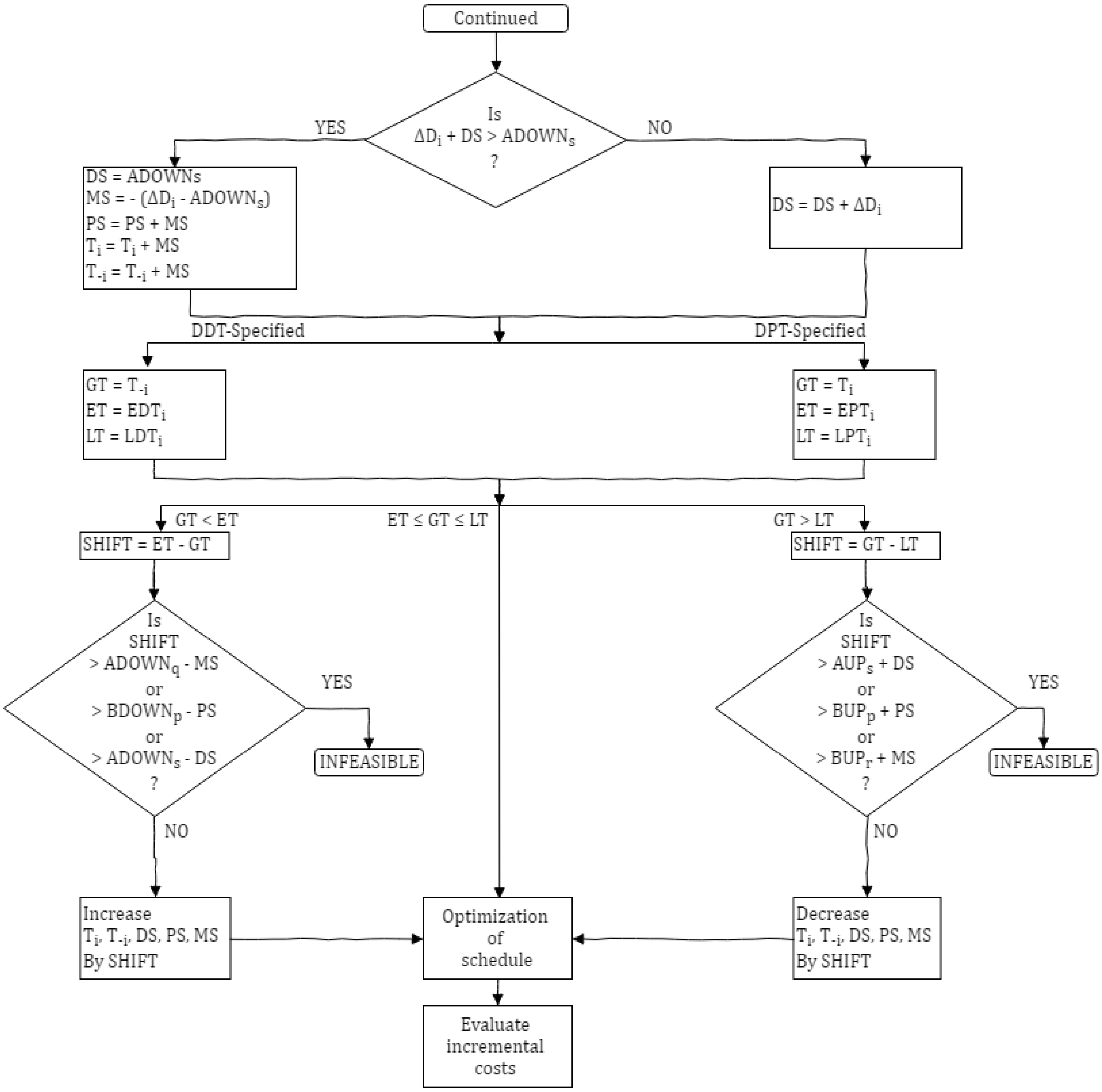
p, q, r, s	:	Indices denoting visit sequence in a vehicle schedule block having d stops.
T_i (T_{-i})	:	The pick-up time (delivery time) of the new customer i.
ST_j	:	Scheduled visit time of stop j in the schedule block before customer i is inserted.
w_i	:	Amount of change in vehicle waiting time due to the insertion of customer i.
SHIFT	:	The amount of time which a given time or a time schedule is being shifted.
ΔP_i (ΔD_i)	:	The extra vehicle time required to pick up (deliver) customer i.
PS (DS)	:	Shift in time schedule for all stops preceding stop +i (succeeding stop -i) after customer i is inserted.
MS	:	Shift in time schedule for all stops between stop +i and -i after customer i is inserted.
GT, ET, LT	:	Variables.
WS_i	:	The maximum acceptable deviation of the desired time (pickup or delivery) of order i.

APPENDIX G - FEASIBILITY PROCEDURE CASE 3 AND 4



p, q, r, s	:	Indices denoting visit sequence in a vehicle schedule block having d stops.
T_i (T_{-i})	:	The pick-up time (delivery time) of the new customer i.
ST_j	:	Scheduled visit time of stop j in the schedule block before customer i is inserted.
w_i	:	Amount of change in vehicle waiting time due to the insertion of customer i.
SHIFT	:	The amount of time which a given time or a time schedule is being shifted.
ΔP_i (ΔD_i)	:	The extra vehicle time required to pick up (deliver) customer i.
PS (DS)	:	Shift in time schedule for all stops preceding stop +i (succeeding stop -i) after customer i is inserted.
MS	:	Shift in time schedule for all stops between stop +i and -i after customer i is inserted.
GT, ET, LT	:	Variables.
WS_i	:	The maximum acceptable deviation of the desired time (pickup or delivery) of order i.

APPENDIX H - FEASIBILITY PROCEDURE CASE 4 CONTINUED



p, q, r, s	:	Indices denoting visit sequence in a vehicle schedule block having d stops.
T_i (T_{-i})	:	The pick-up time (delivery time) of the new customer i.
ST_j	:	Scheduled visit time of stop j in the schedule block before customer i is inserted.
w_i	:	Amount of change in vehicle waiting time due to the insertion of customer i.
SHIFT	:	The amount of time which a given time or a time schedule is being shifted.
ΔP_i (ΔD_i)	:	The extra vehicle time required to pick up (deliver) customer i.
PS (DS)	:	Shift in time schedule for all stops preceding stop +i (succeeding stop -i) after customer i is inserted.
MS	:	Shift in time schedule for all stops between stop +i and -i after customer i is inserted.
GT, ET, LT	:	Variables.
WS_i	:	The maximum acceptable deviation of the desired time (pickup or delivery) of order i.