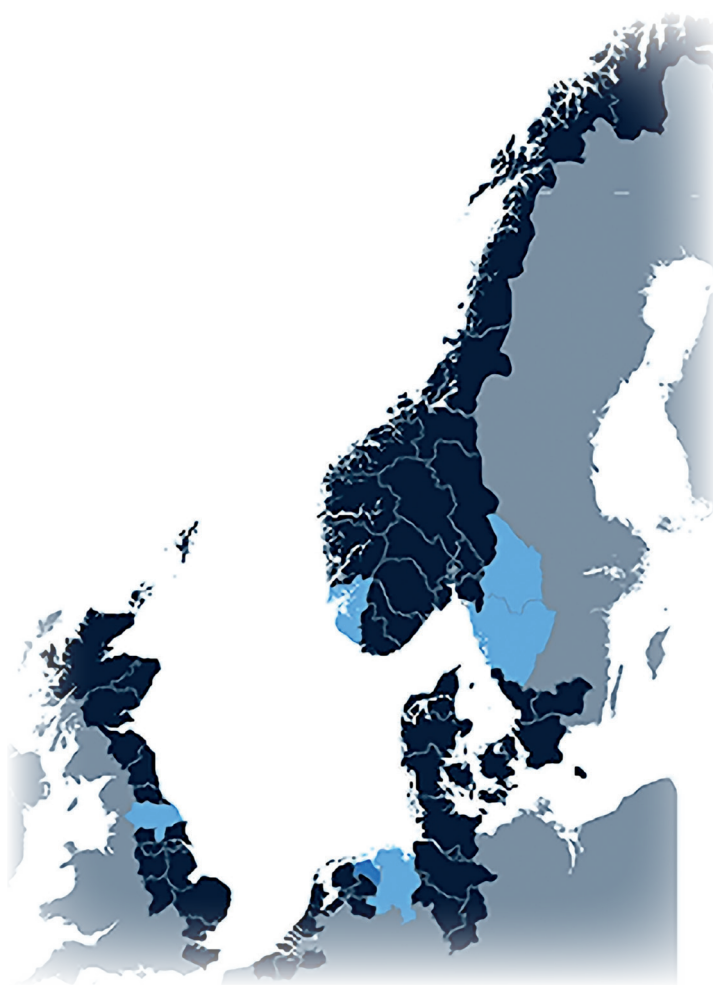


# ITRACT – Best Practice Guide

Dynamic scheduling and incentivizing  
strategies for sustainable transport



## Work Package 8



Improving Transport and  
Accessibility through new  
Communication Technologies



## Foreword

As pointed out by the United Nations Report on World Population Ageing, health care has become an imperative global issue in the twenty-first century. The health care industry is one of the world's largest and fastest growing industries. For example, the pharmaceutical sector makes a significant contribution to European and global wellbeing through the availability of safe and effective medicines, also contributing to economic growth and sustainable employment. How we continue to improve the level of health care service delivery is a key problem faced by the health care industry.

The aim of this study is to develop sustainable and cost-efficient medicine-delivery strategies for the health care industry. The study was undertaken by Prof. Kees Jan Roodbergen and Dr Stuart X. Zhu from the University of Groningen. The report is based on a 16 month study for Work Package 8 of the ITRACT project, Improving Transport and Accessibility through new Communication Technologies (extension).

Within the ITRACT project, this research serves as a case study of how transport and accessibility can be improved in rural areas by optimizing the delivery of goods.

In closing, we would like to acknowledge the assistance and cooperation offered by Gerlof Kuindersma and Jacob Mulder from the Hanze University of Applied Sciences, Andreas Kassler and Andreas Arvidsson from the University of Karlstad, Monique Kappert and Job Jehee from Alliance Healthcare Nederland, and Anna Grude from Värmland County Administrative Board.

Prof. Kees Jan Roodbergen  
Dr Stuart X. Zhu  
Faculty of Economics and Business  
University of Groningen  
The Netherlands  
January 2015



# Introduction

Accessibility and connectivity are essential for livability and economic growth throughout the world. Improving the accessibility of physical transport is important for achieving the social and economic inclusion of rural areas. In reality, rural areas lag behind with respect to physical accessibility and connectivity. The ambition of the ITRACT project (Improving Transport and Accessibility through new Communication Technologies) was to use ICT to create smart mobility services to improve accessibility and connectivity in rural areas.

The Digital Agenda for Europe is vital for realizing optimally accessible and connected rural regions in the North Sea Region. Moreover, collaboration between regions is essential to solve the problems of limited accessibility and connectivity in Europe. The transnational collaboration within the North Sea Region proved to be essential for realizing the mobility services within the ITRACT project, undertaken within the Interreg IVB North Sea Region Programme.

The ITRACT project started in 2012 and concluded in March 2015, developing more than 40 new ICT transport service concepts, in close interaction with users, transport organizations, transport authorities and local governments. These new smart mobility services were tested in fifteen pilots in five different rural regions in Norway, Sweden, Germany, England and the Netherlands. A novel ICT architecture was built to support the services. In a project extension awarded in 2013, new algorithms were developed to optimize the combined transportation of people and goods. These algorithms were also tested in pilots. To achieve the results, the project was divided into ten different work packages.

## Work packages of the project

The ten different work packages were led by various project partners who collaborated in multidisciplinary and cross-border exchanges to create innovative and creative service concepts which were tested in diverse environments and regions.

### General Project Activities

**WP 1** Project management (Hanze University of Applied Sciences)

**WP 2** Publicity and communication (University of Stavanger and Värmland County Administrative Board)

### Service Development, Realization, Implementation and Testing

**WP 3** Development of services and self-optimizing networks (Viktoria Swedish ICT)

**WP 4** Information architecture and exchange mechanisms (Hanze University of Applied Sciences)

**WP 5** Pilot testing on transport and accessibility (Jade University of Applied Sciences)

**WP 7** Development and implementation of improved smart algorithms (Karlstad University)

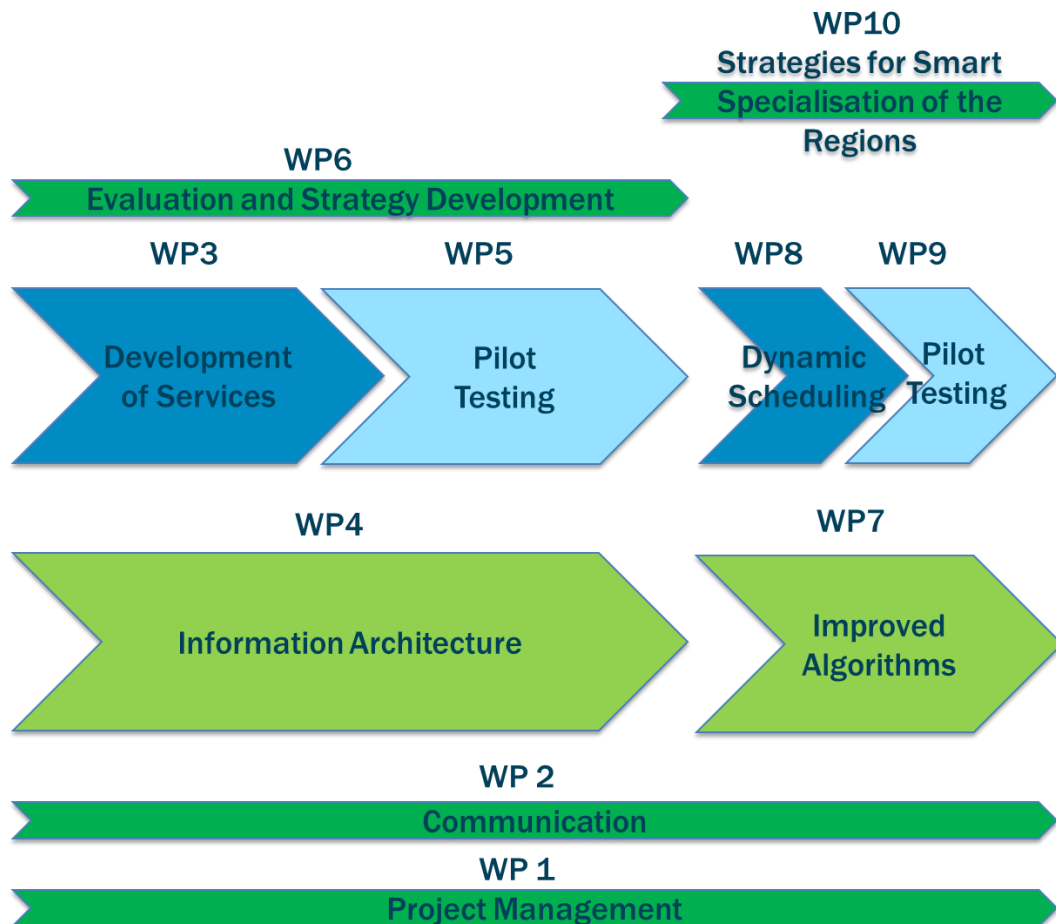
**WP 8** Dynamic scheduling and incentivizing strategies for sustainable transport (University of Groningen)

**WP 9** Pilot testing on transport and accessibility (Alliance Healthcare)

#### Policy Recommendations

**WP 6** Evaluation and strategy development (University of Groningen)

**WP 10** Strategies for smart specialization of the regions (Hanze University of Applied Sciences)



## **This Best Practice Guide**

This Best Practice Guide (BPG), '**Dynamic scheduling and incentivizing strategies for sustainable transport**', is the result of WP 8. It intends to present findings, results and key issues based on a case study of the distribution of medicines so that the lessons learned can be transferred to other regions with sustainable transport needs.

One of this Best Practice Guide's main aims is to encourage the use of dynamic scheduling and incentivizing strategies by regional businesses, transport companies and communities. It seeks to contribute to innovation strategies across the North Sea Region and find a balance between sustainability, user demand and the market, thereby supporting inclusion, better public services and better quality of life.

Another focus is to encourage local and regional authorities and businesses to develop incentivizing and scheduling strategies that will encourage consumers to use more sustainable and less resource-intensive transport options.

The Best Practice Guide's first objective is to provide local authorities, businesses and transport service providers, especially in remote areas, with more information about dynamic scheduling and incentivizing strategies.





## Summary

The ITRACT project intends to develop novel ICT applications to improve the transport infrastructure in the North Sea Region. In particular, this work package focuses on transport systems that integrate flows of freight and persons. In line with the European Commission strategy document, ‘A Sustainable Future for Transport – towards an integrated technology-led and user-friendly system’, this project aims to improve those capacities through innovative transport and communication concepts. The project is based on improved algorithms and dynamic scheduling and incentivizing strategies that provide far better coordination and indeed ‘smart’ interaction between those services, which will make transport more cost-effective and environmentally friendly, while enhancing connectivity in general.

Because sustainable transport options for both people and freight are key factors in economic success, Work Package 8 addresses dynamic scheduling and incentivizing strategies in close cooperation with regional businesses, transport companies and communities. Incentivizing and scheduling strategies that encourage consumers to move towards more sustainable and less resource-intensive transport options can also stimulate other users and suppliers. Such strategies are therefore an important indicator of the success of our models.

As an explorative case study in applying dynamic scheduling and incentivizing strategies was undertaken with the aim of improving the quality of a medicine-delivery service. Alliance Healthcare Nederland, a versatile company involved in the entire pharmaceutical care chain from producers to consumers, intended to explore the possibility of using medicine lockers. In practice, various types of patients may have multiple options and their own preferences with respect to medicine delivery, such as home delivery or self-pick-up at a local pharmacy. Thus, this work package planned to develop a comprehensive framework to address the issue.

Mathematical models were first formulated to characterize the operations of medicine delivery. Optimization software was then used to obtain the optimal solution and perform a sensitivity analysis to examine the robustness of the solution under different scenarios. The real-life data from Alliance Healthcare Netherlands was then applied to validate our model. The findings revealed that our solution was consistent with the operational practice of the company. Finally, three methods were developed to estimate the cost of home delivery of medicine prescriptions.

In short, the findings can be used to develop a decision-making tool that can provide guidelines for determining the locations of medicine lockers and a delivery route schedule for the medicine.



Improving Transport and  
Accessibility through new  
Communication Technologies



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# 1 Introduction

Accessibility and connectivity are key issues for areas located at the periphery of the North Sea Region. Being at a distance from economic agglomerations, these remote areas usually lag behind in terms of socioeconomic development.

The ITRACT project intended to develop novel ICT applications to improve the transport infrastructure in the North Sea Region, with particular focus on transport systems to integrate flows of freight and persons. In line with the European Commission strategy document, ‘A Sustainable Future for Transport – towards an integrated technology-led and user-friendly system’, this project aimed to improve these capacities through innovative transport and communication concepts. This specific project is based on improved algorithms and dynamic scheduling and incentivizing strategies to provide far better coordination and indeed ‘smart’ interaction between those services, which will make transport more cost-effective and environmentally friendly, while enhancing connectivity in general.

Because sustainable transport options for both people and freight are key factors in economic success, Work Package 8 addresses dynamic scheduling and incentivizing strategies in close cooperation with regional businesses, transport companies and communities. Incentivizing and scheduling strategies that encourage consumers to use more sustainable and less resource-intensive transport options may also stimulate other users and suppliers. Such strategies are therefore an important indicator of the success of our models.

As an explorative case study applying dynamic scheduling and incentivizing strategies, this project focused on the problem of the delivery of medicines. This was the issue faced by Alliance Healthcare Nederland (AHN), which wholesales, distributes and retails pharmaceutical, surgical, medical and health care products throughout the Netherlands. Health care organizations worldwide are under increasing pressure to deliver greater value and increased efficiency, while guaranteeing an ever higher quality of care. At the same time, patients’ needs are becoming more complex, advances in technology are enabling and forcing delivery-model reform, expectations of service excellence are increasing, and payers are continuing to demand greater cost controls. To improve its service quality, AHN wanted to evaluate the benefit of the use of medicine lockers. The major advantage of providing medicine lockers is that patients can access them 24/7. AHN had to determine where to locate the lockers, how many lockers should be placed at each location, and the routing for home delivery that would minimize total operation costs. The goal of AHN was to reduce the total cost (preparation and distribution) per prescription by 50 percent.

To achieve the goal, the research question was defined as follows: *What is the most cost-efficient way of distributing medication to patients within the catchment area of the local pharmacy?*

To address the question, mathematical models were first formulated to characterize the operations of medicine delivery. Optimization software was then used to obtain the optimal solution and perform a sensitivity analysis to examine the robustness of the solution under different scenarios. Real-life data from Alliance Healthcare Netherlands were then applied to validate our model. The findings showed that the solution was consistent with the operational practice of the company. Finally, three methods were developed to estimate the home-delivery costs of medicine prescriptions.

The remainder of the report is organized as follows. Sections 2 and 3 focus on the formulation and solution analysis of a benchmark model. Section 4 extends the benchmark model by including home delivery. Section 5 addresses the issue of delivery-cost estimation. Section 6 concludes the report and highlights valuable lessons learned.

## 2 Description of Benchmark Model

This work package first considered a deterministic model, consisting of two types of patients and two types of medicine lockers. The two types of patients were ‘plannable’ and ‘non-plannable’. Plannable patients require repeat medications while non-plannable patients were those who require medication for the first time. The two types of lockers are a regular medicine locker (Type-1 locker) and an advanced drug dispenser (Type-2 locker). The regular locker can only serve the plannable patients while the advanced drug dispenser can serve both non-plannable and plannable patients. In addition, there were two delivery options: home delivery or self-pick-up.

Plannable patients can thus pick up their medicines from the counter of a local pharmacy, from a regular locker (Type-1 locker) or from an advanced dispenser (Type-2 locker), while non-plannable patients can only pick up their medication at the counter of a local pharmacy or from an advanced dispenser (Type-2 locker). The reason why non-plannable patients must pick up medicines in this manner is that they need individual instruction about their use.

In addition to these parameters, all of the corresponding information is assumed to be known, including types of patients, medicine requirements of patients and cost parameters. The list of variables is presented in Table 1.

Table 1: List of variables for notation

Decision Variables	Definition
$u_k^i$	The number of type-i lockers at location k
$v_k^i$	Indicator about whether Location k is chosen for type-i locker
$x_n^{k,i}$	Indicator about whether patient n picks up the medicines from type-i locker at Location k
Parameters	Definition
$K$	The number of potential locations for locker placement
$N$	The number of patients
$c_k^i$	Variable operational cost of type-i at location k
$f_k^i$	Fixed operational cost of type-i at location k
$s_n^{k,i}$	The cost if patient n picks up the medicine from type-i locker at Location k
$o_k^i$	Capacity of type-i locker at location k
$p_n$	The number of prescription lines required to prepare medicines for patient n

The benchmark model only considers the option of self-pick-up from either a local pharmacy or a locker. It is assumed that there are  $K$  potential locations for locker placement, such as supermarkets or petrol stations. In particular,  $K = 0$  represents the location of the local pharmacy. The decisions faced by AHN concern the locations of lockers, the capacity of lockers at each location and the delivery options for patients. The objective is to minimize the total cost, including the fixed and variable costs for operating lockers and the costs for patients picking up their medicines, such as travel costs and waiting costs.

The model can be formulated as a mixed-integer linear programming problem given by:

$$\min \sum_{k=0}^K \sum_{i=1}^2 (f_k^i v_k^i + c_k^i u_k^i) + \sum_{k=0}^K \sum_{n=1}^N \sum_{i=1}^2 s_n^{k,i} x_n^{k,i}$$

subject to

$$u_k^i \leq M v_k^i, \quad \forall i, k \quad (1)$$

$$\sum_{n=1}^N x_n^{k,i} \leq M v_k^i, \quad \forall i, k \quad (2)$$

$$\sum_{k=0}^K \sum_{i=1}^2 x_n^{k,i} = 1, \quad \forall n \quad (3)$$

$$\sum_{n=1}^N p_n x_n^{k,i} \leq o_k^i u_k^i, \quad \forall i, k \quad (4)$$

$$u_k^i \in \mathbb{N}, v_k^i = \{0,1\}, x_n^{k,i} = \{0,1\}, \forall i, k, n.$$

Note that  $M$  is a very big positive real number (e.g. one million). For the above model, constraint (1) means that only if location  $k$  is chosen for type- $i$  lockers, is it possible to place type- $i$  lockers there. Constraint (2) means that only if location  $k$  is chosen for type- $i$  lockers, are patients allowed to pick up medicines there. Constraint (3) means that a patient can only pick up his/her medicines at one locker. Constraint (4) means that the total demand for medicines for type- $i$  lockers at location  $k$  cannot exceed the capacity available.



### 3 Solution Development and Analysis

Based on discussion with other work package members, this project decided to first implement the benchmark model for a city in the Netherlands, Beilen. According to Alliance Healthcare, in the current situation, there is one pharmacy located in the town centre. To provide a better service, the company intended to investigate whether it was beneficial to place some lockers in the region of Beilen. Alliance Healthcare suggested several potential locations for locker placement, such as supermarkets, pharmacies and petrol stations, for patients' convenience.

The following three steps were executed to obtain the optimal solution.

Step 1. By cooperating with Work Package 9 (Pilot tests on transport and accessibility), data were acquired, including patients' postcodes, the required number of medicines per patient and the related cost parameters.

Step 2. Through cooperation with Work Package 7 (Development and implementation of improved smart algorithms), a computer program was developed to obtain the cost for a patient to pick up medicines from a specific location based on its distance from their home. The program used the postcodes of patients as input and employed the trip planner designed by Work Package 7 to generate the costs for each patient.

Step 3. The formulation of the benchmark model and the information on parameters were put into AIMMS, an optimization software program, which would find the optimal solution to the model.

Based on the data provided by Work Package 9, the optimal solution was found to be to open the counter and place one regular locker at the local pharmacy. All of the plannable patients should pick up their medicines from the locker, while all the non-plannable patients should pick up their medicines at the counter of the local pharmacy. Since AHN had decided to place a locker at the pharmacy in Beilen in March 2014, the optimal solution was consistent with current practice. Thus, our model was validated.

Sensitivity analysis was also performed with respect to 'Patient cost (travel time + waiting time) not at home per minute', from EUR 0.045 to EUR 0.45. This cost means that if a patient chooses self-pick-up, it costs them such an amount of money per minute. This cost includes the travel cost and the waiting cost for picking up the medicines. The results are shown in Table 2.

Table 2. Sensitivity Analysis

Patients cost per minute	Optimal Solution
0.045	Open the counter and place one locker at the local pharmacy
0.09	Open the counter and place one locker at the local pharmacy
0.135	Open the counter and place one locker at the local pharmacy
0.18	Open the counter and place one locker at the local pharmacy
0.225	Open the counter and place one locker at the local pharmacy
0.27	Open the counter and place one locker at the local pharmacy
0.315	Open the counter and place one locker at the local pharmacy
0.36	Open the counter and place one locker at the local pharmacy
0.405	Open the counter at the local pharmacy and place one locker at Kruidvat
0.45	Open the counter at the local pharmacy and place one locker at Kruidvat

NB: The postcode of the local pharmacy is 9411 AP and the postcode of Kruidvat is 9411NB.  
(Kruidvat is one possible location for the locker suggested by Alliance Healthcare).

Table 2 shows that for a wide range of patient costs, from EUR 0.045 to EUR 0.36, it is optimal to place one locker at the local pharmacy, which supports the robustness of the current business practice of AHN.

## 4 Extension with Home Delivery

Here, the benchmark model was extended to include the option of home delivery. This required the consideration of a location-routing problem. It was assumed that there was one local pharmacy and that home delivery would only occur from the local pharmacy to patients. A vehicle with sufficient capacity for medicine delivery was also required.

First, some notation needs to be introduced. Let  $\mathcal{R}$  be the index set of all routes passing through the local pharmacy. Let  $R_i \subseteq \mathcal{R}$  be the subset of routes of the pharmacy passing through customer  $i$ . Let  $R_l$  be the subset of customers visited by route  $l \in \mathcal{R}$ . With each route  $l \in \mathcal{R}$  there is an associated load  $w_l = \sum_{i \in R_l} p_i$  and a routing cost  $t_l = \sum_{\{i,j\} \in E(R_l)} d_{ij}$ ,

where  $E(R_l)$  represents the edges forming the route  $l$  and  $d_{ij}$  represents the cost of the edge.  $W$  denotes the medicine stock available at the local pharmacy. More decision variables should also be added, i.e.,  $z_l$ . Let  $z_l$  be a (0, 1) binary variable equal to 1 if route  $l \in \mathcal{R}$  is in the solution, 0 otherwise. The location-routing problem can thus be written:

$$\min \sum_{l \in \mathcal{R}} t_l z_l + \sum_{k=0}^K \sum_{i=1}^2 (f_k^i v_k^i + c_k^i u_k^i) + \sum_{k=0}^K \sum_{n=1}^N \sum_{i=1}^2 s_n^{k,i} x_n^{k,i}$$

subject to

$$\begin{aligned} u_k^i &\leq M v_k^i, & \forall i, k \\ \sum_{n=1}^N x_n^{k,i} &\leq M v_k^i, & \forall i, k \\ \sum_{k=0}^K \sum_{i=1}^2 x_n^{k,i} &= 1, & \forall n \\ \sum_{n=1}^N p_n x_n^{k,i} &\leq o_k^i u_k^i, & \forall i, k \\ \sum_{l \in R_i} z_l &\leq 1, & \forall i \quad (5) \\ \sum_{l \in \mathcal{R}} w_l z_l &\leq W, & \quad (6) \\ u_k^i &\in \mathbb{N}, v_k^i = \{0,1\}, x_n^{k,i} = \{0,1\}, & \forall i, k, n \\ z_l &= \{0,1\}, & \forall l \in \mathcal{R} \end{aligned}$$

Compared with the formulation of the benchmark model, the differences are as follows. Firstly, in the objective function, the cost of home delivery is given by the first term. Secondly, two more constraints, (5) and (6), were added. Constraint (5) means that each customer cannot be visited more than once by exactly one route. Constraint (6) means that there is sufficient stock available at the pharmacy to fulfil patient demand.

To find the optimal solution for the location-routing problem, it is necessary to first obtain information about routing costs between any two locations of a patient and the local pharmacy. To obtain the optimal solution, AIMMS can be used to develop an algorithm (based on Baldacci et al., 2011).

Under the supervision of Dr Zhu, Lucas Vogels, a Bachelor of Science student in the Econometrics and Operations Research programme at the University of Groningen, wrote his Bachelor's thesis on the design of a heuristic for this extended model (The thesis is available on the website: [www.itract-project.eu](http://www.itract-project.eu); deliverables for WP/WP8).

## 5 Delivery Cost Estimation

The complexities of scheduling deliveries from a number of storage points to locations with demand were investigated. The study was inspired by a problem faced by Alliance Healthcare, an ITRACT project partner. Their products (in this case, medicines) were available at one or more distribution centres, but were in need of delivery to individual consumers (patients). There were a number of options to choose from to resolve this issue, known as multi-channelling. For example, products might be shipped from a distribution centre to a shop (pharmacy), where the consumer comes to pick up the product, or products might be home delivered to consumers from either the distribution centre or from a nearby shop. Alliance Healthcare was also interested in investigating options for self-service, unmanned lockers, where patients could pick up their medicines at any time.

Numerous arguments played a role in selecting the right channel for product delivery. Firstly, costs are an important factor, especially for commercial companies. However, other factors may be equally or more important, depending on the application. For example, if transportation is required for people rather than products, then factors such as timing and comfort (e.g. fewer stops) would also be vital. The sustainability of the operation is also of crucial concern. Sustainable transport options for both people and freight are key factors in economic success. Part of the ITRACT project aimed at developing incentivizing and scheduling strategies to influence consumer demand for more sustainable and less resource-intensive transport options. This can in turn stimulate further users as well as suppliers. Such strategies are thus important indicator of the success of our models. This is especially true for sparsely populated areas in the North Sea Region. In this context, understanding the price of offering certain services, such as delayed pick-up and/or arrival, is key to the dynamic pricing of transport features. It is in this area that this paper makes a contribution, by creating models that can be used to determine the effects of pricing trade-offs.

In more technical terms, this project considered a number of locations with inventories of products (e.g. libraries with books, or pharmacies with medicines) and customers with a known demand for these products. A number of vehicles, with given, diverse home bases, were available for transporting the products. While vehicle capacity did not impose limits in practice, there was a maximum travel time per vehicle. The objective was to minimize transportation costs, under the condition that as much demand must be fulfilled as possible. That is, if total supply suffices for total demand, then all demand will be met. This model will thus include home delivery in the most economical way in the scheduling of daily operations. Three models were created, programmed and tested for the situation described.

These models may assist other ITRACT work packages in determining additional cost parameters, and provide insights into the logistics costs of sustainability or service choices. Please refer to the report 'Routing vehicles with inventory constraints', prepared by Roodbergen et al. (2014) for detailed information (The report is available on the website: [www.itract-project.eu](http://www.itract-project.eu); deliverables for WP/WP 8).



## 6 Conclusions and Lessons Learned

By considering flexible delivery options, the study provides a sustainable solution for medicine transport in rural areas, including self-pick-up and home delivery. To improve accessibility, medicine lockers are placed in rural areas so that patients can pick up medicines from a medicine locker during 24 hours/7 days.

By close cooperation with other work packages, the project successfully developed realistic models that reflected the current business practice of Alliance Healthcare Nederland. Furthermore, this project provided a corresponding solution and demonstrated how to implement the models with real-life data. Moreover, three methods were developed for the cost-estimation of the home delivery of medicines.

After the proof-of-concept was confirmed by Alliance Healthcare, the models might now be applied to all pharmacies in the Netherlands. According to the representatives of Alliance Healthcare, the franchisees of the company in the United Kingdom and Germany face a similar problem. We expect that our model can be implemented there with slight adjustments. The formulas/models developed by this project can be used as a basis for the further development of a decision-making tool that can provide guidelines to determine the location of medicine lockers and delivery route schedules for the medicine.

In addition to the results mentioned above, four international peer-reviewed journal articles related to the project have been published: Zhu (2015a), Zhu (2015b), Riezebos and Zhu (2015), and Wu, Zhu, Teutner (2014).

In our opinion, the following two directions deserve further research. Firstly, the current models are based on a single pharmacy. The project can be extended to a study of multiple pharmacies. Secondly, this project could relax the assumption of deterministic requirements of patients and examine the impact of uncertainty requirements.

### Lessons Learned

During the project, some valuable lessons were learned.

Firstly, to make the model realistic, the assumptions should be thoroughly discussed with the relevant stakeholders at an early stage of the project. To adapt the model to another situation, the assumptions should thus be carefully re-examined. Based on the modified assumptions, the model should be adjusted correspondingly.

Secondly, the key assumption of the current model is that each patient will follow the optimal delivery option indicated by the model so that the total cost can be minimized. However, in reality, each patient has their own preference for the delivery option. Therefore, an incentive mechanism needs to be designed (e.g. attractive price or high-quality service) to motivate patients to follow the optimal delivery option indicated by the model.



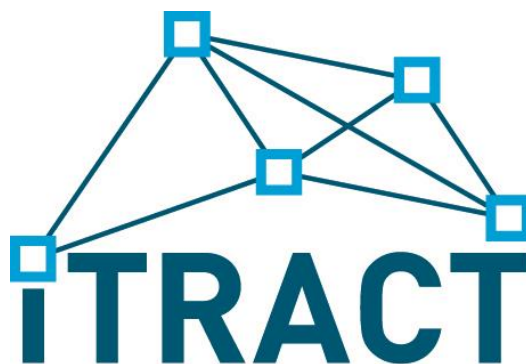


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## Contact

University of Groningen  
Prof. Kees Jan Roodbergen  
Phone: +31 50 363 2360  
E-mail: [k.j.roodbergen@rug.nl](mailto:k.j.roodbergen@rug.nl)

Dr Stuart X. Zhu  
Phone: +31 50 363 8960  
E-mail: [x.zhu@rug.nl](mailto:x.zhu@rug.nl)

Lead Beneficiary  
Hanze University of Applied Sciences  
[www.hanze.nl](http://www.hanze.nl)

Drs. Theo Miljoen  
Phone: +31 683 099 791  
E-mail: [t.a.miljoen@pl.hanze.nl](mailto:t.a.miljoen@pl.hanze.nl)