D1.7 Project Interim S/T Report

Smart Adaptive Public Transport

Project details	**Project reference:** **Status:** Execution **Programme acronym:** ERA-NET Transport III Future Travelling **Contract type:** Collaborative project (generic)

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	Partners:	2. (TUB) Technical University of Berlin 3. (IMOB) Hasselt University 4. (KTH) Royal Institute of Technology Stockholm 5. (PUT) Poznan University of Technology 6. (SENOZON) Senozon Deutschland GmbH 7. (BUUR) Bureau Voor Urbanisme cvba

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Abstract	This deliverable describes the interim report of the project.

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1 General Introduction by the Coordinator

This report summarizes the first year of work of the SMART-PT Project Consortium. SMART-PT stands for Smart Adaptive Public Transport a project funded by the Future Travelling Flagship Call of ERA-NET Transport III. The project is comprised of 7 partners (TAU, TUB, IMOB, KTH, PUT, BUUR and SENOZON) encompassing 5 countries/regions (Israel, Flanders, Germany, Sweden, Poland). Funding has been appropriated by Israel, Flanders, Sweden, and Poland).

The first year of the project ended officially in June 2015. However actual work on the project started around September 1, 2014. This report then describes the work done from this period to the end of the reporting period. This report describes the work done by the funded partners. The non-funded partners (TUB and SENOZON) will contribute to the project in Year 2 in the development of the case studies.

The report is structured in the following manner. Each chapter is written by the different partners in respect of their role and responsibilities. The informative chapters are structured according to the work concluded with each WP. Where discrepancies appear between the Proposal and the actual work, this is thoroughly explained and justified in the text. Some partners included technical annexes according to the demands of their funding agency. The responsibility on the accuracy of the text lies on each of the partners respectively to the relevant chapter.

2 Tel Aviv University (TAU)

Tel Aviv University (TAU) is the coordinator of the project headed by Prof. Itzhak Benenson. TAU is responsible for the overall management of the project. TAU also heads WP 3 and WP5. TAU also manages the dissemination activities of the project (WP6).

The TAU team is comprised of Prof. Itzhak Benenson (Coordinator and PI), Dr. Eran Ben-Elia (Co.I) and Post Doc Dr. Andrey Shabalov. Dr. Ben-Elia transferred to a new tenure-track position at Ben-Gurion University (BGU). With the agreement of the MOT we included BGU as a subsidiary of TAU to continue his involvement in the project.

2.1 WP1 Project Management

WP1 focuses on management activities of the project.

2.1.1 Task 1.1 Financial Management

Financial management of the project is in the responsibility of each of the partners respective of their funding agencies. The project coordinator will not produce a full financial report as it is not required. Deliverable 1.4 will not be produced for the overall project.

<u>Changes to the WP:</u> Deliverable D1.4 – Cancelled.

2.1.2 Task 1.2 Administrative Management

This task includes the day-to-day running of the project, monitoring the progress of the work plan, organizing project meetings and taking action in case things need to be re-evaluated.

2.1.2.1 Consortium Agreement

The Consortium Agreement was signed and ratified in Nov. 2014. Discussions had to take place between legal advisors of the different partners because the project requires accounting for regulations and laws of 5 countries. The document is available on the EPSS.

2.1.2.2 Organized Project Meetings:

The following meetings were held:

- Kickstart meeting (milestone 1) took place in Leuven, Flanders and hosted by BUUR and IMOB in Sep. 2014
- Project meeting 2 (milestone 3) took place on OOVOO video conferencing in January 2015
- Project meeting 3 (milestone 4) took place in Stockholm and hosted by KTH (changed from Vienna) in March 2015
- Project meeting 4 (milestone 9) took place on OOVOO video conferencing June 2015

Minutes and agendas for all meetings were taken.

2.1.2.3 Project Management Plan:

The project managment plan is detailed in Deliverable D.1.5 and describes the approach of the coordinator and responsibilities of the entire consortium.

2.1.3 Task 1.3 S/T Management

S/T management aims to optimize and monitor the scientific and technological management of the project so that it meets its desired objectives. S/T management works both on a day-to-day and overview during project meetings (see above).

S/T management is based on to Deliverables: D1.3 Risk Management Plan and D1.6 S/T management plan. Both documents are available on the EPSS system.

S/T management meetings for TAU were held on a weekly basis

A common repository of all documentation including minutes, presentations and other material has been created on GoogleDocs. The repository is operated by IMOB. The repository replaces some of the specifications of the website that could not be concluded satisfactorily due to platform limitations.

2.1.4 List of Deliverables completed

Table 2.1.4: Deliverables completed (TAU/WP1)

Del. no.	Deliverable name	WP no.	Planned delivery date	Actual delivery on EPSS
D1.1	Consortium Agreement	1	M01	Oct. 2014
D1.2	Project Management Plan	1	M01	Nov. 2014
D1.3	Risk Management and Mitigation Plan	1	M01	Nov. 2014
D1.4	Financial Reports Year 1	1	M12	Cancelled
D1.6	S/T Management Plan	1	M01	July 2014
D1.7	Project Interim Report	1	M12	Sep. 2014

Delays in delivery dates of deliverables were caused by the overall delay in the actual start of the project work.

2.2 WP2 Research environment specification (SMART-PT Interface)

The Objectives of WP2 include: Establishing and specification of the data requirements; Selection of cities for the case studies; Establishing synthetic cities and FIXED-PT systems for them.

The WP is led by IMOB (see their report in the next chapter)

2.2.1 Task 2.1 Data requirements and specification

The stated objectives of this task are to map the required data for the SMART-PT flexible transit concept and set the specification for this data.

2.2.1.1 DEMAND DATA

Originally it was considered that similar data specifications would be applied by all partners but this seems now impossible. TAU has decided to remain with the original plan to make use of mobile phone call data records (CDRs). However, acquiring the data took more time than we expected. Furthermore, so far there are no agreed regulations on the transfer of this kind of data to 3rd parties from the mobile operators. We have come to a tentative agreement with one of the operators who is building a "research room" in their facilities. This room will serve for doing analysis on disaggregated anonymized call records. We will develop the necessary algorithms to process the data and run them

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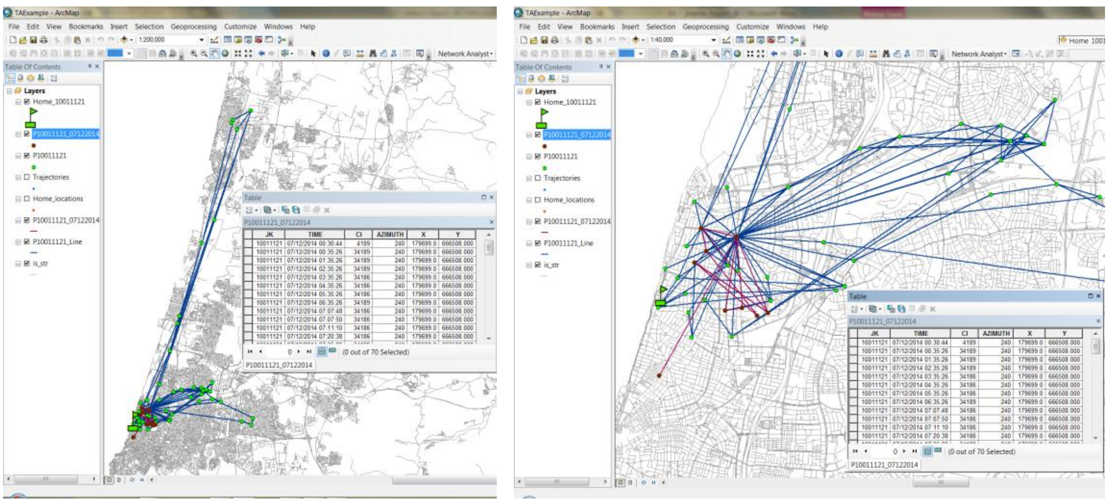
in the secure research room. Currently, the mobile operator supplied to us several exemplar datasets (on 1K-10K persons) that are used for developing and testing the algorithms. We will be able to take out the secure room processed aggregated data. It is hoped that after September (cf. High Holidays) there will be a formalized agreement on this.

The specifications of the CDR data are not trivial. We will describe the information in Deliverable D2.1 in due course. Basically the ability of the operator to track the trajectory of the person is dependent on the location of the tower, the number of antennae on the tower, the angle of transmission, the strength of the signal and the signal type. There are 3 signal types (with increasing strength):

- dormant mode: the tower sends a signal to the phone infrequently, about once an hour;
- data mode for highspeed Internet. This mode is actually the best for tracking because the operator maintains very frequent communications with the phone.
- Call mode: when the phone is in active call mode the signal strength is at maximum. The problem is that when the tower is overloaded, it may switch the phone to another tower at a distance. This means the strength of the signal becomes critical for estimating the geographical position of the phone.
- The databases used by the operator were not designed for tracking the movements of users. There is non-trivial adjustments that need to be made to the raw data in order to make it useful. Our perspective on this will be explained in further detail in Deliverable D2.1.

As a Plan B, should we not be able to use this data we will make use of existing Origin-Destination Matrices used by the Transport Ministry and apply the algorithms on those instead. The OD matrices are at traffic analysis zone (TAZ) level. However, we have built technological abilities that allow to break this into smaller chunks at the level of buildings or groups of buildings. This ability allows us to compute average travel times from every building to every building in the Metropolitan Area. We will make use of this alternative method should the CDR data fail to materialize. This technology was built during a project for computing accessibility at high spatial resolutions funded by the Chief Scientist Office at the Israeli Ministry of Transport.



a b

Figure 2.2.1.1.1: Example of a raw personal mobile phone data at a distant (a) and close (b) zoom. The location is given at a level of antenna.

2.2.1.2 SUPPLY DATA

We are already in possession of all the necessary supply data on public transport in the Tel-Aviv Metropolitan Area. This data arrives from the GTFS (General Transit Feed Specification) which is produced on a frequent basis by Google. The data includes GIS Shape files for lines, and tables for stops, timetables and routes. We have already tested this data and have translated it to the MATSIM (multiagent transportation mesoscopic simulation) environment where it works very well. An example is provided in Fig. 2.2.1.2.1 This example was produced by the VIA MATSIM visualization tool provided by SENOZON. It shows public transport for the Sioux Falls test network.

We are now in the process of building a similar model for the transit network of the Tel Aviv Metropolitan Area. See WP 4. The capacities built with the existing fixed transit network will allow us to establish the core algorithms in WP3.

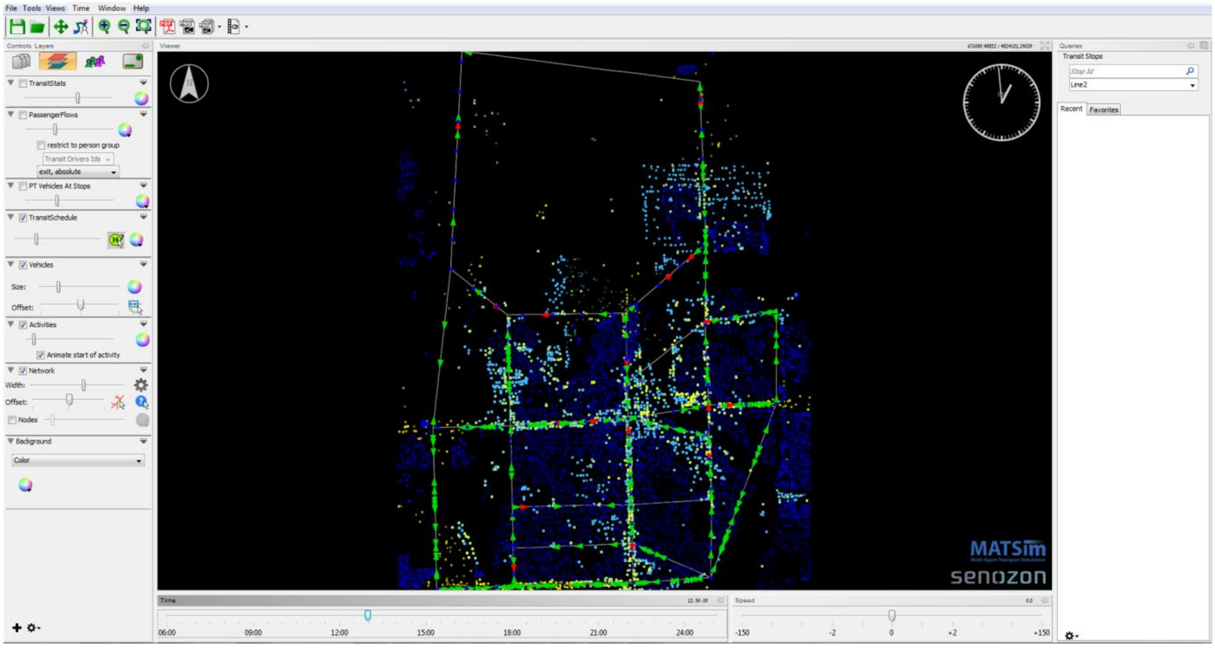


Figure 2.2.1.2.1: Example of MATSIM window for Sioux Falls.

2.2.1.3 FORMALIZATION OF PUBLIC TRANSPORT REGULATION

In agreement with all other partners we have decided to postpone this task to the 2nd year of the project and join it with the activities of WP5. We have come to the conclusion that regulations are not a pure modeling issue. Therefore we develop the capacities for flexible transit as if regulations do not apply. Once the concept is proven stable and intact we will suggest recommendations to change regulations. In particular the existing situation in Israel requires for each line, an operator wants to run, to describe a fixed timetable and locations of stops along the routes. Naturally, with flexible systems this is not something that can go on. We think changes in regulations should follow a mild to severe change as the technology ripens.

- In the first stage, flexibility will remain minimal. A set of new lines will be produced as a planning exercise based on the derived mobile phone trajectories and accessibility considerations. This new lines will replace or compliment some of the existing lines. Once in six months the system will check if distributions changed significantly and suggest line alterations or new lines be added. The system will continue to run with fixed timetables

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(which may alter every six months) and with fixed stops. This change will be the most easy for passengers and for transit service providers as the public transport operations will not change that much. This model resembles the seasonal change in Train schedules which people are accustomed to and is not too disruptive. Similar changes can apply o buses if people are given ample warning and information on expected changes to services. This occurs today when the national transit authority makes such announcement on service alterations.

- In future stages, when ICT becomes more mature we expect stops and time tables to be more flexible. However, describing the contents of such major changes is beyond what can be implemented now. This requires that passengers will be able to communicate locations and travel needs to the operators almost in real-time to be picked up. Some implementation possibilities to this kind of flexibility are possible today with demand-responsive paratransit and taxis. We are working with PUT/TUB to integrate demand responsive modes as part of the overall SMART-PT concept. The regulations for responsive transit need yet to be put in place.

2.2.2 Task 2.2 Case Study Selection and data preparation

The objectives of this task are to choose the cities where we investigate the feasibility of flexible transit and steps taken to prepare suitable data.

2.2.2.1 Case study selection

In collaboration with IMOB and KTH we agreed we will have 3 case studies:

1. Leuven (Flanders / IMOB and BUUR)
2. Stockholm (Sweden / KTH)
3. Tel Aviv (Israel / TAU)

As described for Task 2.1 the necessary data for analysis of the Tel Aviv Metropolitan area is either obtained or being obtained. (cf. mobile phone records)

2.2.2.2 Databases for demand and supply by modes

We have all the necessary databases for the Tel Aviv Case Study. This includes GIS layers for streets, buildings and land use. We also have the relevant data for public transport as described for GTFS. The necessary data is being translated to XML formats for easy use with MATSim. However the translation is not entirely automatic and some “bugs” still need to more attention. The next figure shows the auto network applied on MATSim for the Tel Aviv Metropolitan Area.

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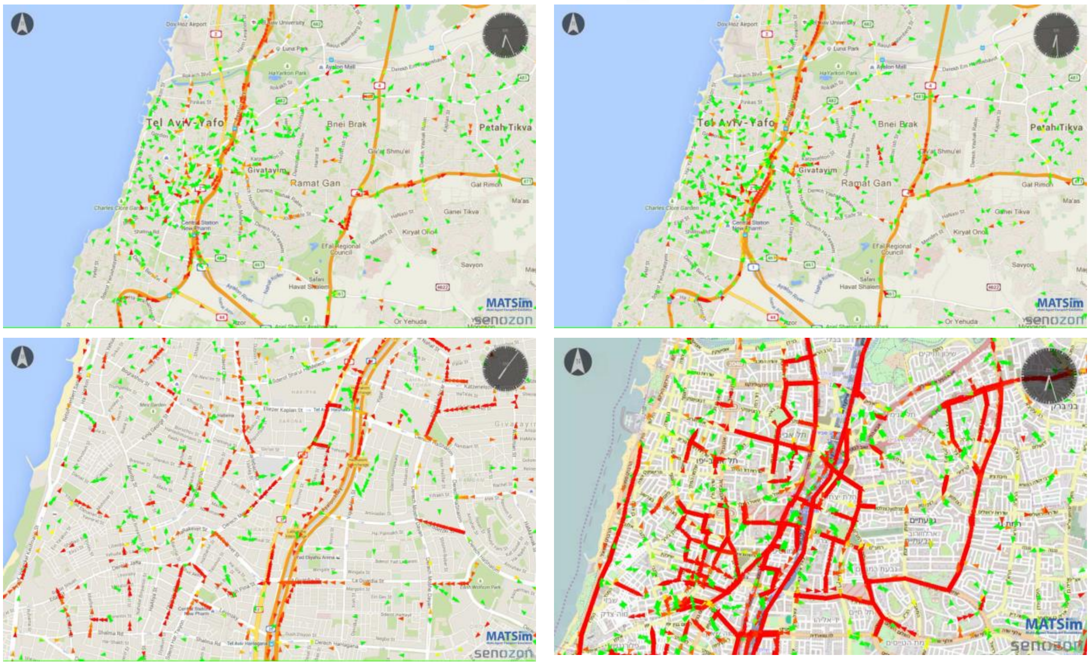

Fig 2.2.2.2.1 – MATSim Auto network for Tel Aviv

A movie clip for the auto network can be found here:

https://drive.google.com/file/d/0B_6Mit2e8Mcaam9rSHVFYkpQbGM/view?pli=1

2.2.3 Task 2.3 Establishing synthetic cities and FIXED-PT transit systems

2.2.3.1 Generation of synthetic test data on transportation demand

The original work plan was to generate a few representative examples of cities without reference to particular geography or topology. However, after discussion in the S/T meetings we decide that this approach would not give us much insight to transformation of fixed to flexible transit because the models are too simplistic. As an alternative we decided to work on the Sioux Falls test network that is commonly applied for testing algorithms in transportation studies. This network also exists for MATSim.

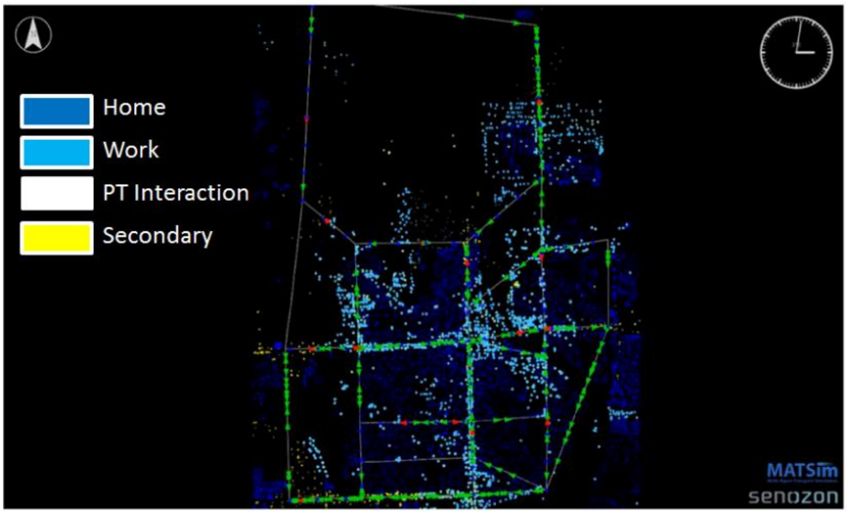

Fig 2.2.3.1.1: Visualization of Activities in Sioux Falls

2.2.3.2 Generation of fixed transit systems

As noted above, we use the Sioux Falls network, which also include road and transit networks. Some examples are shown below.

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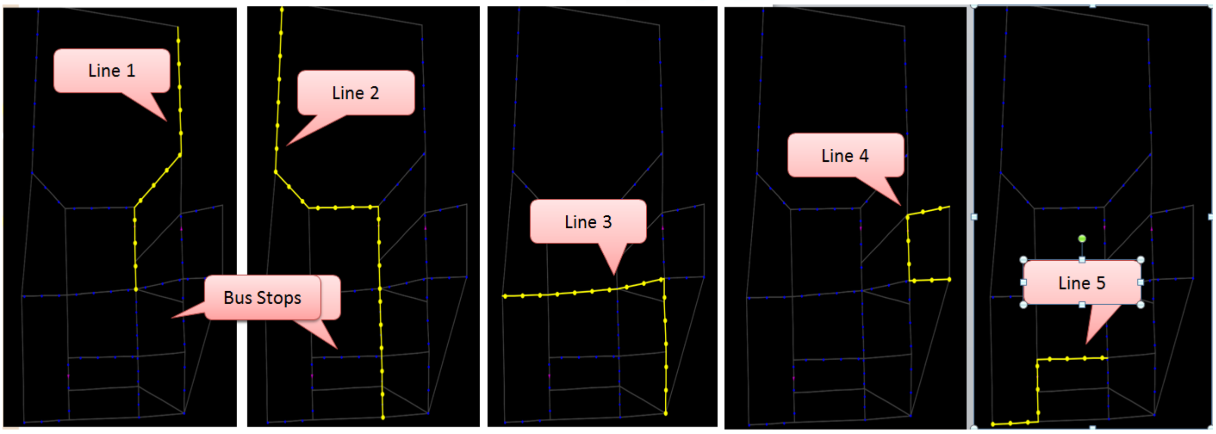

Fig 2.2.3.2.1: Examples of Bus lines and stops in Sioux Falls.

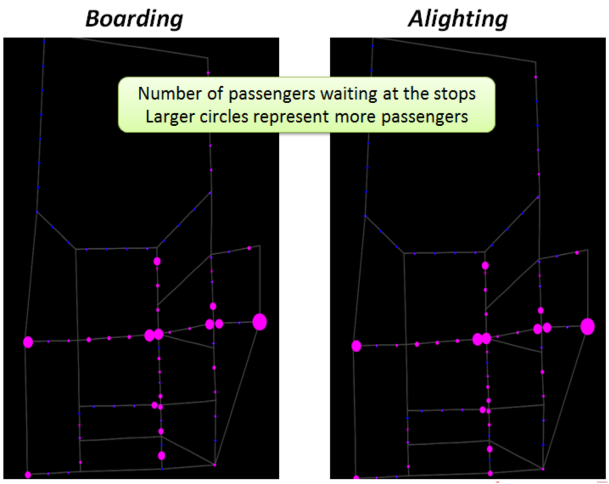

Fig 2.2.3.2.2: Boarding and alighting at stops in Sioux Falls

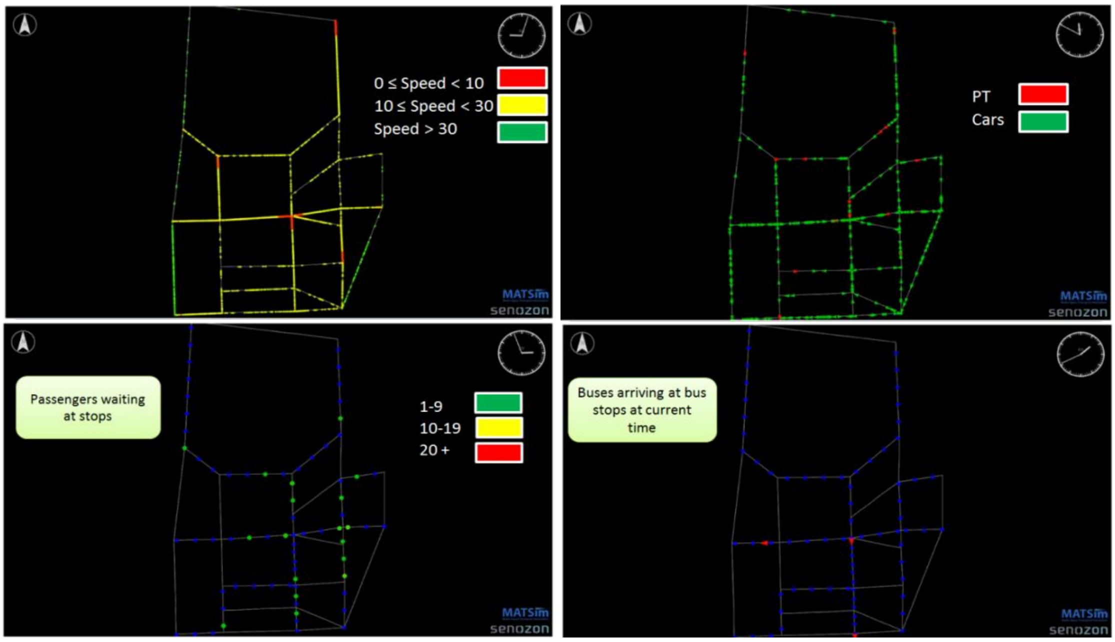

Fig 2.2.3.2.2: Visualization of public transport modes in Sioux Falls.

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2.3 WP3 Development and establishment of core-algorithms (SMART-PT Kernel)

The objectives of WP3 are: (1) Development of the Demand-Supply Analysis algorithm for clustering passengers' trajectories and estimating transit system level of service based on the individual data on travel activities. (2) Development of the Urban Dynamics algorithms for generating spatiotemporal dynamics of the travel demand in synthetic and real cities. (3) Development of the Transit Network Adaptation algorithms for establishing a multimodal SMART-PT network that adapts itself to the evolving travel demand.

These are the core algorithms which comprise the SMART-PT concept. In this report we describe progress in Objective 1. Objective 2 has been regarded as unfeasible at this stage due to large variance in the databases existing in the participating countries. Objective 3 is ongoing and will be described in the next report.

The WP is led by TAU

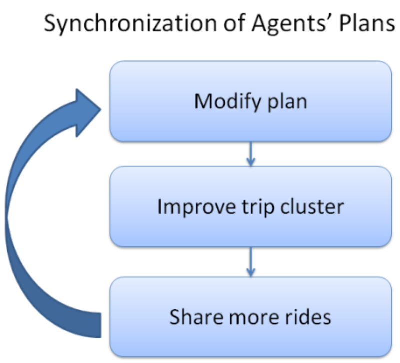
2.3.1 Task 3.1 Development of the Demand-Supply Analysis algorithm for clustering passengers' trajectories

The objective of Task 3.1 is to develop the algorithm that clusters individual spatiotemporal trajectories into meaningful clusters that can be used to rearrange the transit network.

The algorithm is in development stages and here we describe its main rationales. The coding will be described in the next report.

Input: Population of travelers, each has its own plan of daily activities

Goal: Synchronization of travelers' activities to ensure ridesharing



Example: home-work trips only

Agent 1: Leave **home** located at (x_1^1, y_1^1) at t_1^1 and travel to **work** located at (x_2^1, y_2^1) to be there at t_2^1

Agent 2: Leave **home** located at (x_1^2, y_1^2) at t_1^2 and travel to **work** located at (x_2^2, y_2^2) to be there at t_2^2

Individual taxi is costly. Agents may want to share a ride. To share, agents have to **synchronize** their plans. Synchronization is, in fact, an evolutionary process: agents modify their plans in respect to each other, to minimize personal travel cost

Implementation of the algorithm:

Partition and Group clustering framework as the bases algorithm:

1. Partitioning phase: Each "trajectory" is partitioned into a set of line segments. These line segments are provided to the next phase.
2. Grouping phase: Similar line segments are grouped into a line cluster (density based clustering method).

A graphical representation is shown below

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Pseudocode I: Approximate Trajectory Clustering

Input: A trajectory $TR_i = p_1 p_2 p_3 \dots p_j \dots p_{len_i}$
Output: A set CP_i of characteristic points
Add p_1 into the set CP_i; *// the starting point*
$startIndex = 1, length = 1;$
while $(startIndex + length \leq len_i)$ **do**
    $currIndex = startIndex + length;$
    $cost_{par} = MDL_{par}(p_{startIndex}, p_{currIndex});$
    $cost_{nopar} = MDL_{nopar}(p_{startIndex}, p_{currIndex})$
/ check if partitioning at the current point makes the MDL cost larger than not partitioning */*
    if $(cost_{par} > cost_{par})$ **then**
        // partition at the previous point
        Add $p_{currIndex-1}$ into the set CP_i;
        $startIndex = currIndex - 1, length = 1;$
    else
        $length = length + 1;$
Add p_{len_i} into the set CP_i;

Pseudocode II: Line Segment Clustering

Input: A set of line segments $D = \{L_1, \dots, L_{num_{ln}}\}$
    Two parameters ε and $MinLns$
Output: A set of clusters $O = \{C_1, \dots, C_{num_{clus}}\}$
Set $clusterId$ to 0; *// an initial id*
Mark all the line segments in D as *unclassified*
for each $(L \in D)$ **do**
    if (L is unclassified) **then**
    Compute $N_\varepsilon(L)$;
    if $(|N_\varepsilon| \geq MinLns)$ **then**
        Assign $clusterId$ to $\forall X \in N_\varepsilon(L)$;
        Insert $N_\varepsilon(L) - \{L\}$ into the queue Q;
        ExpandCluster$(Q,\ clusterId, \varepsilon,\ MinLns)$;
        Increase $clusterId$ by 1; *// a new id*
    else
        Mark L as a *noise*;
Allocate $\forall L \in D$ to its cluster $C_{clusterId}$;
// check the trajectory cardinality
for each $(C \in O)$ **do**
    if $(|PTR(C)| < MinLns)$ **then**
        Remove C from the set O of clusters;

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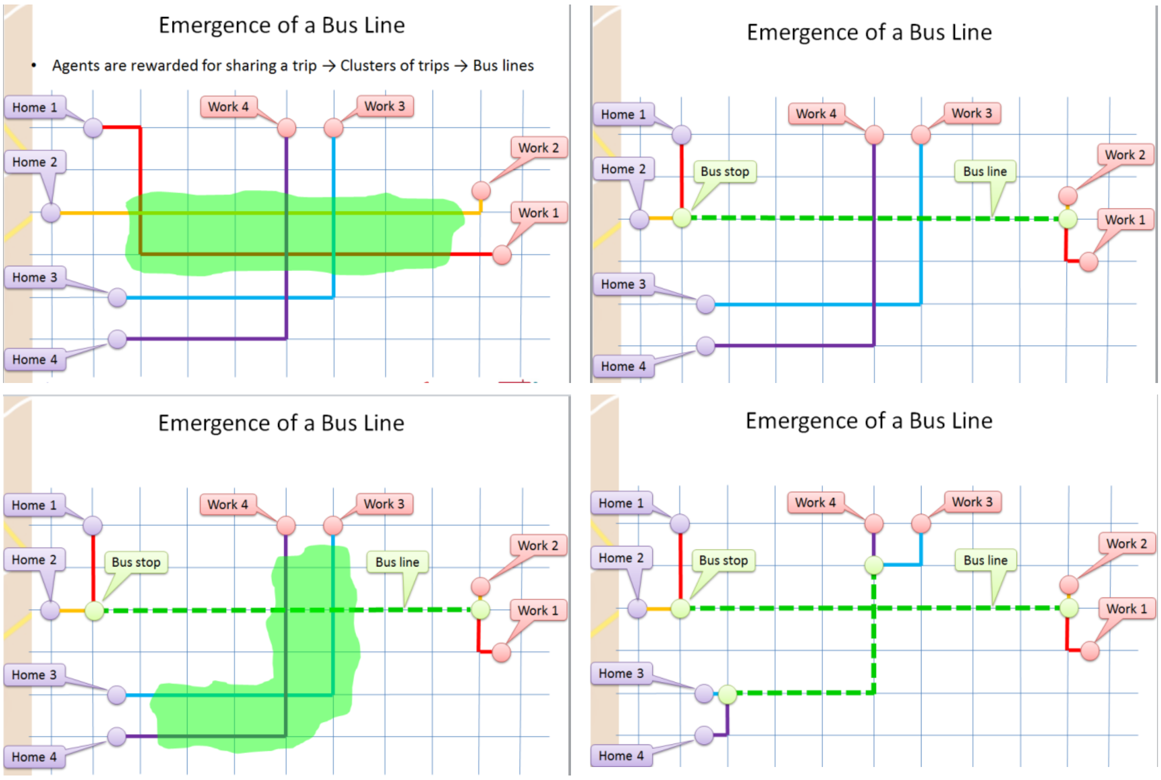

Figure 2.3.1.1.1: Graphical representation of trip clustering and ridesharing

Example of Implementation – Tel Aviv synthetic data

Figure 2.3.1.1.1: Graphical representation of synthetic individual trajectories and resulting clusters

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2.3.2 Task 3.2 Development of the Urban Dynamics algorithms for generating spatiotemporal dynamics of the travel demand

The objective of this task is to develop urban spatial histories to test the SMART-PT system in various changes of the travel demand dynamics.

This task has been delayed to the second reporting period. The delay reason is that there is lack of suitable data at the needed resolutions at this point in time to make critical decisions on how to make the changes in demand. We will reinvestigate this point in the next year. One option would be to use existing OD matrices for years 2020, 2030, 2040 to disaggregate them to the level of buildings as discussed in section 2.2.1.1 (Plan B). The possibilities will be investigated with our steering committee.

2.3.3 Task 3.3 Development of the Transit Network Adaptation algorithms for the multimodal SMART-PT system

This task has been delayed due to much work given to the 1st algorithm. We expect to make more progress during Year 2.

2.3.4 List of Deliverables completed

Table 2.1.4: Deliverables completed (TAU/WP1)

Del. no.	Deliverable name	WP no.	Planned delivery date	Actual delivery on EPSS
D3.1	Summary WP report on development and establishment of core algorithms	3	M12	Delayed to M18

We expect to to have this task completed by M18 (March 2016)

2.4 WP4 Simulation of SMART-PT functioning (SMART-PT Sim)

The objectives of WP4 include: (1) Implementation of the SMART-PT algorithms in the agent-based simulation environment MATSim; (2) Validation by simulation of the SMART-PT approach based on synthetic data; (3) Investigation of transit adaptation pathways from FIXED-PT to SMART-PT in Leuven, Tel Aviv and Stockholm case-studies.

The WP is led by KTH

2.4.1 Task 4.1 Implementation and validation of SMART-PT algorithms in MATSim's agent-based simulation environment

This task will take place in Year 2

2.4.2 Enhancement and validation by simulation of the SMART-PT concept, based on synthetic data

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As discussed in WP4 the algorithms developed in WP3 will be tested in a small-scale network. We consider the Sioux Falls test network to be suitable for this purpose.

2.4.3 Task 4.3 Application of the SMART-PT concept in real case studies (Leuven, Tel Aviv, Stockholm)

This task will implement the core algorithm on the Tel Aviv Metropolitan Area Network built in MATSim. It is scheduled for Year 2.

2.4.3.1 Consequences of SMART-PT implementation in Tel Aviv's Bus Reform and Future LRT

Following the request of the MOT we will also look into the impacts of the current changes to the road and bus network due to the construction works of the 1st LRT line (The Red Line). This depends on availability of data from the Tel Aviv Transport Modeling group.

Work on this task will begin in Year 2.

2.5 WP5 Consequences of SMART-PT implementation in Tel Aviv's Bus Reform and Future LRT

Work on WP5 will begin during Year 2

2.6 WP6 Dissemination and Exploitation Plans

The objectives of this WP include: (1) To ensure that the project has an effective and well-articulated Dissemination Action Plan (DAP). (2) To ensure the project has an effective and well-articulated Exploitation Action Plan (EAP).

The WP is led by TAU

2.6.1 Dissemination Action Plan

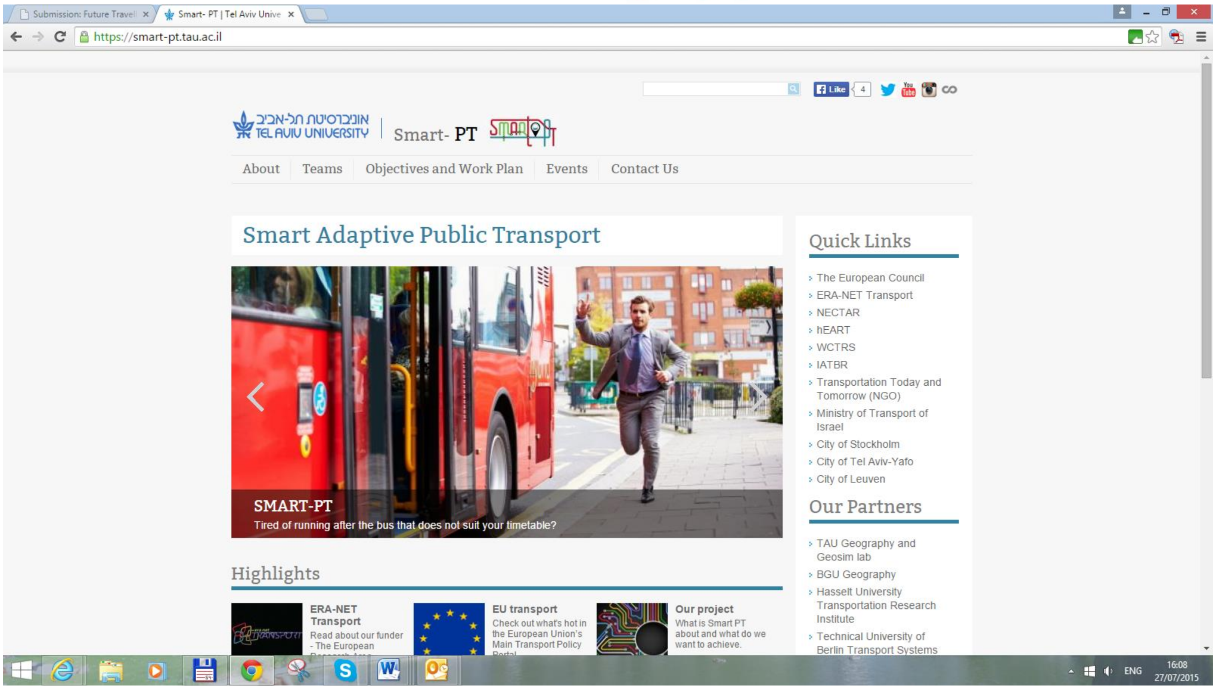
The DAP Plan was submitted on the EPSS (see deliverable D6.1)

2.6.1.1 Project website and social media

The project website came online in May 2015. The website is built on a common platform used by Tel Aviv University. The website can be found at: http://smart-pt.tau.ac.il

The website includes information on the project and its objectives, the team members, activities and events, and contact information. The website respects all the accessibility requirements that are posed by the University regulations and allows people with disabilities to reach the content using standard translation devices.

For security issues we could not find a way for the website to be used also as a communication portal for the partners. Instead we make use of an effective sharepoint built on Google Docs hosted by Hasselt University (IMOB).



The project also has a FaceBook page which can be found at:
https://www.facebook.com/smartpt.ent3

A link to the page can be found in the website as well.

SMART-PT also appears at the 1st page of Google search engine

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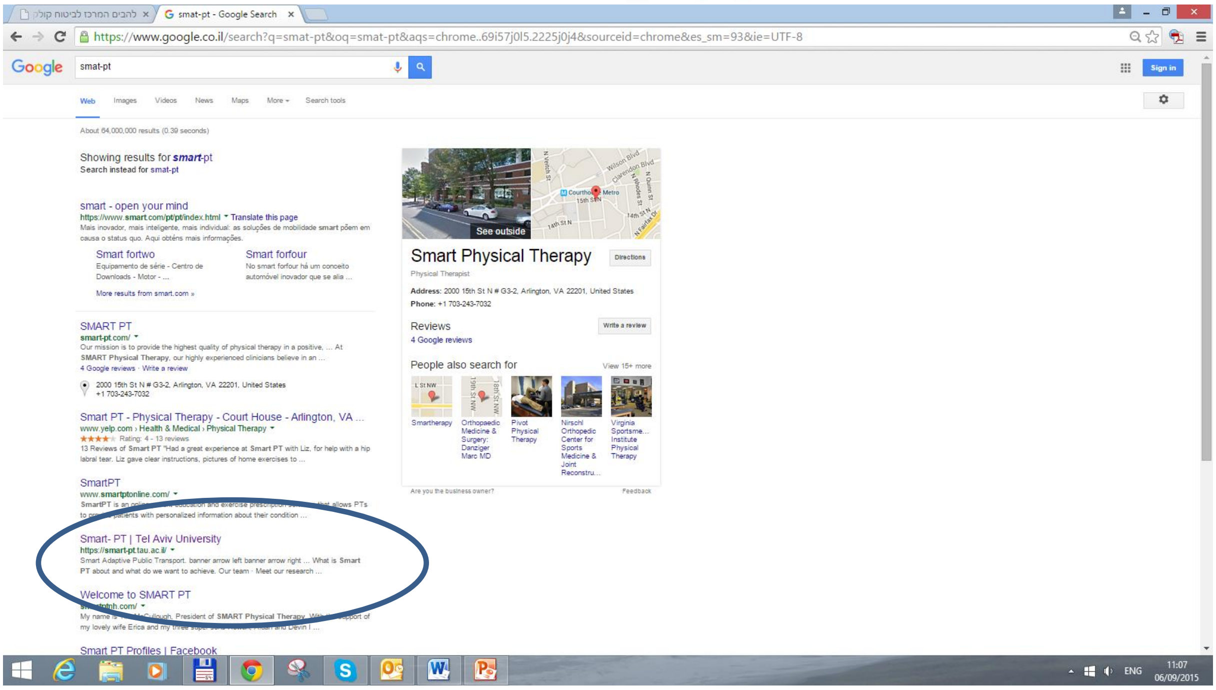

2.6.1.2 Project Branding

The project was issued its own logo and the logo is visible on any official document issued by the partners including docs and presentations. The logo is also used on the website and FaceBook page. The logo will also be used for the e-newsletter.

2.6.1.3 Project E-Newsletter

We decided that a project e-newsletter will appear once a year. The first e-newsletter will be scheduled for the end of September or late October. The e-newsletter will summarize the main activities of the project to date.

2.6.1.4 Workshops

Two workshops were planned at the end of Year 1 and Year 2.

The 1st workshop (see to the right) will take place in Copenhagen as a special session during the hEART symposium (http://www.heart2015.transport.dtu.dk/). The decision was made to shift the 1st workshop from Poznan Poland to Copenhagen to increase the visibility of the project and to attract highly esteemed researchers to attend. The workshop is organized by PUT. 6 presentations of 30 minutes each are planned by each of the academic partners and the workshop will span 3 hours.

Discussions on the 2nd workshop will take place later in Year 2.

	Session B from 13.30 - 16.30 is funded by ERA-NET Transport. SMART-PT: Smart Adaptive Public Transport
113	Opening words – I. Benenson, Tel Aviv University. Andrey Shabalov, Eran Ben-Elia and Itzhak Benenson. Adaptive Public Transit Network Design
	M. Saleem. Development of a public transport model with self-optimizing capabilities for Stockholm
88	Daniel Hosse and Andreas Neumann. Modelling of operational variants for the use of Personal Rapid Transit in public transit
30	Michal Maciejewski. Effcient real-time taxi dispatching by solving the assignment problem
42	Antonin Danalet and Michel Bierlaire. An activity-based approach for transport hubs
97	Jan Vuurstaek, Glenn Cich, Luk Knapen, Ansar-Ul-Haque Yasar, Tom Bellemans and Geert Wets. Integrating OSM and GTFS to create MATSim plans using PT

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2.6.1.5 CONFERENCES AND PRESENTATIONS

We disseminated SMART-PT in the following events

- International Summer School « Spatial structures & Dynamics », Florence 13-16 July 2014
- AESOP 13th Planning and Complexity Thematic Group Meeting Tampere 15th-16th January 2015
- Symposium on Geography and Digital Technologies – BGU Beer Sheva, May 2015.
- Tel Aviv Metropolitan Transport Modeling Forum, Tel Aviv, May 2015
- NECTAR International Conference, Ann Arbor Michigan, June, 2015
- Workshop hosted by the National "Fuel Choice" Initiative – Tel Aviv, July 2015
- Frontiers in Transportation Workshop, Windsor, UK, July 2015
- ERSA Congress 2015, August 23 - 28, Lisbon

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3 Hasselt University (IMOB)

3.1 Introduction

This document serves as the fi annual report for the Smart-PT project: Smart Adaptive Public Transport (ERA-NET Transport III Flagship Call 2013 "Future Traveling"). This document describes IMOB's approach to fulfill the project's requirements.

The technical report is included as an appendix.

3.2 Project Changes

Urban history data are not available. The corresponding tasks have been replaced by tasks involving *thin flows simulation* (see appendix A). The *thin flows problem* currently receives a lot of attention in Flanders. One of the government objectives is to replace the current PT-on-demand *BelBus* concept by a concept that allows to make better use of available vehicles and drivers. Special attention has to be paid to facilities for mobility impaired people and to the optimal use of special vehicles by deploying those to serve demand by regular travelers too.

3.3 Work packages

Work Package	Description
WP 1 WP 1	Report to local funding agency IWT was submitted before the deadline. S/T Management : weekly technical meeting for sci- entific project members (Glenn Cich, Jan Vuurstaek, Luk Knapen).
WP 2	Organized and attended meeting at De Lijn, Mechelen to explain Smart-PT project and ask for input data. We required and will obtain the history of transactions for *BelBus* requests. The *BelBus* concept is a Flemish form of dial-a-ride-like *PT-on-demand*, operated by the public transportation provider using mini-buses. It will be abandoned to be replaced in the near future.
WP 3 WP 3	Specification for hospital visitors model: completed. Specification for behavioral model for brokers and their interactions (see section A.2) : to be completed by 2015-sep-30.
WP 4	Effort to integrate OSM and GTFS for De Lijn: on-going.
WP 5	Reoriented part of the research objectives to accom-modate *thin flows simulation*.
WP 6	Organized and attended RegioNet workshop at De Lijn Leuven (together with BUUR) to explain project concepts and research and ask for feedback.
WP 6	Attended BIVEC conference in Eindhoven 2015-may-28/29 and presented paper [2]

Work Package	Description
WP 6	Attended MTS Summerschool in Diepenbeek 2015-jul-13/16 and presented Smart-PT research progress in graduate symposium. Glenn Cich presented the current software design ideas about the broker con- cept. Jan Vuurstaek presented the software to convert GTFS and OSM to MATSim PT schedules.

3.3.1 Milestones

Milestone	Description
2	Reached
8	Ongoing (FEATHERS results, OSM, GTFS)
10	Ongoing
11	Ongoing
13	Dropped (see section 2.1)
17	Ongoing
20	Ongoing

Please the Annex to this document for further reporting.

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4 KTH Stockholm (KTH)

4.1 Stockholm model system

We are completing the Stockholm model system (**Task 2.2**). This comprises the following items:

1. Road network. After first tests with an automatically generated Openstreetmap network, we have developed a network transformation routine that creates a MATSim road network from an available and continuously refined Transmodeler network. The resulting MATSim network file is standalone available.
2. Public transport network. We have been given access to the full public transport data base of the Greater Stockholm region. The tables of this database had to be manually downloaded from a web interface. The resulting files were transformed into the MATSim XML format. The sole data item yet to be extracted is a mapping of public transport lines on links in the road network; several tools are currently investigated for that purpose.
3. Zonal and building geometries. This information is available as shape files, for which MATSim provides in- and output facilities. Since the building geometries are proprietary information, we have developed a procedure to sample x/y activity locations without explicitly feeding the building information into the MATSim simulation.
4. Travel demand. We are relying on the existing tour-based travel demand model Regent, for which a MATSim import routine has been developed. Regent creates a synthetic population and attaches to each individual a home zone, possibly a work zone, and possibly a zone in which “other” activities are performed. The import routine uses the available zonal and building geometries to create a population file in the MATSim xml format.

Our current efforts focus on running and testing the simulation. Since MATSim is open source, not all of its subtleties are fully documented and need to be revealed either experimentally or by personal inquiry with the respective developer. Some imprecisions in the travel demand model Regent also need further investigation.

We realistically expect to have running system by M12 of the project. This is 3 months later than the planned end time of WP2; the reason for this delay is that it took us almost half a year until we succeeded in hiring a postdoc who now is building the model system.

4.2 Public transport optimization algorithm

We have worked intensively on a new algorithm to optimize simulation trajectories by adjustment of complex simulation parameters such as public transport schedules, lines, etc. (**Task 3.3**). Our current work focusses on finalizing and testing the algorithm with synthetic and abstract test cases. The algorithm is already largely integrated with MATSim (**Task 4.1**); the most important remaining task is to refine the currently high-level interfaces to a concrete public transport context.

A (by now somewhat outdated) description of the high-level algorithm has been accepted for presentation of the 2015 hEART symposium in Copenhagen; the corresponding full article is currently being completed. The high-level MATSim interfaces can be found in the “gunnar” playground in the MATSim repository; they are, however, subject to ongoing changes. These interfaces are comprehensively documented in the Javadoc format.

We realistically expect the algorithmic development and high-level MATSim integration to be completed and tested by M12 of the project. This work is hence overall on schedule, with some aspects of Task 3.3 being delayed in favor of the earlier completion of other aspects of Task 4.1.

4.3 Dissemination activities

4.4 Workshops

We organized a one-day workshop on the "Alignment of ongoing and coming R&D activities with MATSim" at KTH on March 19. 24 persons from national, regional, local agencies (Trafikverket, Trafikförvaltningen, Trafikkontoret), from consultancies (Sweco, th-inc/senozon, WPS) and from academia (KTH, Tel-Aviv University, TU Berlin) participated in this event. The scope of this workshop was defined as follows:

MATSim is a state-of-the-art multi-agent transport simulation that has gained increasing popularity in the last decade. Several current research efforts aim at the development of a MATSim-based model system for Stockholm. These include the European project SMART-PT and a follow-up to Trafikverket's IHOP project. An early coordination of these works is clearly desirable. This workshop aims at the identification of possible synergies and the definition of concrete measures to exploit them. This comprises data provision and the integration of legacy and emerging model systems.

4.5 Presentations

The following presentations address, to various degrees, aspects of the SMART-PT project:

1. Optimization subject to transport micro-simulation constraints. National Transport Research Conference, Karlstad, Sweden, forthcoming in October 2015.
2. Development of a public transport model with self-optimizing capabilities for Stockholm. 4rd International Symposium on Quantitative Methods in Transportation Systems, Copenhagen, Denmark, forthcoming in September 2015.
3. Optimization subject to transport micro-simulation constraints. 4rd International Symposium on Quantitative Methods in Transportation Systems, Copenhagen, Denmark, forthcoming September 2015.
4. Flexible coupling of disaggregate travel demand models and network simulation packages. Transmodeler workshop, Stockholm, April 30, 2015.
5. Relatively efficient optimization subject to multi-agent simulation constraints. Agent-based modeling workshop, Singapore, March 26, 2015.
6. Alignment of ongoing and coming R&D activities with MATSim. MATSim workshop, Stockholm, Sweden, March 19, 2015.
7. Inserting MATSim into a strategic transport model system for Stockholm. Transportforum, Linköping, Sweden, January 9, 2015.
8. SPSA in the loop -- optimization during simulation convergence. KTH Transportation Seminar Series, Stockholm, Sweden, November 14, 2014.

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5 Poznan University of Technology (PUT)

This document describes work done by PUT in each work package during the first year of the project.

5.1 WP1 Management

Continuous cooperation with TAU and other partners in order to ensure the project is in line with the objectives, and all the specified deadlines and milestones are met.

Hosting Dr. Andrey Shabalov (TAU) at Division of Transport Systems, Faculty of Machines and Transport between 30/11 and 12/12/2014.

Hosting Joschka Bischoff (TUB) at Division of Transport Systems, Faculty of Machines and Transport between 27/01 and 26/02/2015.

5.2 WP2 Research environment specification

PUT does not participate in WP2.

5.3 WP3 Development and establishment of core-algorithms

PUT's main focus is on extending the proposed long-term transit network adaptation approach with short-term adaptation capabilities by adding on-demand (dynamic) transport services, such as minibuses or shared taxis which are routed/scheduled based on continuously incoming real-time information. Dynamic transport services are simulated in MATSim as one component of the overall transport system by means of the DVRP extension that is being developed by PUT. The optimizer plugged into the DVRP contribution reacts to selected events generated during simulation, which could be: request submissions, vehicle departures or arrivals, etc. Additionally, it can monitor the movement of individual vehicles, as well as query other sources of online information, e.g. current traffic conditions. In response to changes in the system, the optimizer may update drivers' schedules, either by applying smaller modifications or re-optimizing them from scratch. Drivers are notified about changes in their schedules and adjust to them as soon as possible, including immediate diversion from their current destinations. For passenger transport, such as taxi or demand-responsive transport services, interactions between drivers, passengers and the dispatcher are simulated in detail, including calling a ride or picking up and dropping off passengers.

To address the problem of the short-term adaptation by inclusion of on-demand transport services, the following tasks were performed during the first year of the project:

- VRP model was extended in order support so-called Rich Vehicle Routing Problems. The major enhancement was addition of many-to-many topologies (prior to that only one-to-many was supported).
- Improved trip pre-booking for more realistic simulation of interactions between drivers, passengers and the dispatcher
- Handling of time-invariant networks; this feature is important for massive testing of dynamic optimization algorithms for on-demand vehicles without taking into account the regular traffic (time-dependent travel times on links are used instead)

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- Improved vehicle on-line tracking; on-line tracking is necessary to continuously monitor the state of vehicles (including their geolocation); this allows for inclusion of the most up-to-date information into the planning/optimization process
- Vehicle diversion was added to enable the dispatcher to immediately change routes of busses; prior to that routes could be changed only when vehicles were stopped (e.g. waiting for new customers).
- DijkstraTree search (with additional caching functionality) in order to speed up least-cost path search, which is extensively used in DVRP during route/schedule optimization; easy switching between Dijkstra and DijkstraTree was also added
- Standalone taxi-mode added to MATSim to offer SmartPT partners (and other MATSim users) an out-of-box taxi functionality (beta version)
- Improved spatiotemporal vehicle generation based on selected statistical data (e.g. active vehicles over time, distribution of requests, etc.)

Based this extended functionality of the DVRP module, it was possible to model and simulate on-demand services. PUT collaborated with University of Melbourne in order to design and simulate demand-responsive transport for Yarrawonga and Mulwala, Australina twin towns. Recently PUT has started to collaborate with TUB (VSP) in building a model and creating algorithms for taxibusses in Wolfsburg. DVRP was also used by TUB (VSP) in research on PRT in Berlin.

5.4 WP4 Simulation of SMART-PT functioning

WP4 is scheduled for the second year (M13 – M24).

5.5 WP5 Assessments of SMART-PT Impacts and implementation policies

According to the schedule, PUT did not performed any task in WP5 in the first year.

5.6 WP6 Dissemination and Exploitation Plans

PUT is the organiser of the 1st Smart PT Workshop that closes up the first year of the project. In order to increase the rank of the workshop TAU and PUT decided to organise it as a session of the hEART'15 conference, allowing to reach a broader spectrum of transport researchers and practitioners with the current project results.

Papers and presentation in the first year:

- Maciejewski M.: A Microscopic Simulation Platform for Rich Dynamic Vehicle Routing Problems. VeRoLog 2015, 4th Meeting of the EURO Working Group on Vehicle Routing and Logistics Optimization, Vienna, 8-10 June, 2015.
- Maciejewski M., Bischoff J.: Large-scale microscopic simulation of taxi services. Procedia Computer Science, 52, 2015, pp. 258–364.
- Maciejewski M.: DVRP - advance requests – modelling, simulation and optimization in MATSim. MATSim Conceptual Meeting 2014, Wiepersdorf, 29-31 August, 2014.
- Maciejewski M.: Online taxi dispatching via exact offline optimization. Logistyka, 3/2014, pp. 2133–2142.

- Maciejewski M.: Simulation and optimization of dynamic transport services. Matsim User Meeting 2015, Singapore, 27-28 March, 2015.
- Maciejewski M.: Benchmarking minimum passenger waiting time in online taxi dispatching with exact offline optimization methods. Archives of Transport, 30(2), 2014, s. 67–75.
- Maciejewski M.: Dynamic Transport Services. In: Horni A., Nagel K., Axhausen K.W (eds.): The Multi-Agent Transport Simulation MATSim. 2015 (forthcoming).

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6 Bureau voor Urbanism (BUUR): Case Study Leuven-Hageland

6.1 Context

The case study research for the Leuven region was started with a thorough analysis of the present situation in the region. The existing PT network of De Lijn is underperforming and too expensive, on top of that the region faces serious mobility challenges. At the same time the Flemish government is demanding budget cuts from De Lijn and is developing a new approach towards PT performance. The present network in Flanders is based on the legal concept of 'basic mobility' that demands that each person living in a residential area has a PT stop with a minimum service within a certain distance of his doorstep. The new concept that is under development, is called 'basic accessibility' and will include more flexible demands that are more suited for flexible, smart collective transport. BUUR has been involved in this debate with a presentation in the Flemish Mobility Commission on May 7th 2015, where we presented the Leuven Regionet case (see below).

The combination of the failing current network, the general mobility challenges in the region and the political momentum makes that there is a big need for transition in the Flemish public transport. In previous research projects, BUUR has developed a new PT network for the region of Leuven, called Regionet Leuven. This network includes new fast light rail and bus lines between the main cities in the region, a better operation system and, most innovating, a close connection between PT development and spatial planning along new lines to create development potential and a higher support for the PT services themselves. Until now, Regionet Leuven has been focusing mainly on the main lines that serve the denser areas in the region. Within our contribution for SMART-PT, we want to focus on the rural area in-between those lines (the 'Hageland') and develop a smart, demand-based feeder system that guarantees the accessibility of these areas and also here can become a catalyst for punctual, sustainable spatial development. The first results of this case study research were presented to De Lijn and the Province of Vlaams-Brabant (where Leuven is located) on June 26th.

6.2 Methodology

We started the research by defining the objectives for a smart PT, that can be elaborated into an evaluation framework for different options. We also collected information about the different modes of smart collective transport, also including bike and car sharing or demand-responsive private transport. For a rural area a combination of modes will be necessary. The main focus of the research however was demand-responsive collective transport (DRT). After agreeing on a broad definition, we characterized the design elements to develop a DRT network. Within four fields a range of options was defined that allow more or less flexibility within the DRT system: the organization of the network (centralized or decentralized), the operation system (and the choices it offers towards passengers, drivers and the operator), the time schedule (from fixed to flexible) and the network design (from fixed routes and stops to door-to-door service). For the network design, we also created a categorization of options and analysed international case studies in a small benchmark.

6.3 Application

With the knowledge from this analysis, we moved to the Hageland case study region. With the main lines of Regionet Leuven as a basis, we developed three scenarios for feeder networks. The first scenario foresees only DRT in the Hageland, using fixed stops and flexible routes in-between them. In the second scenario we designed a couple of semi-fixed feeder routes (with possible deviations) and a door-to-door system in the areas that these routes didn't serve. The third scenario is the most extensive network, with fixed feeder lines, semi-fixed routes with deviations that serve the feeder lines, and a very local, small-scale door-to-door service for the remaining areas. For each scenario a first design was made.

6.4 Further research steps

In the current step, we are further investigating the performance of these three scenarios (focusing mainly on the first and the second). A more detailed network design is being made, including time schedules and a concrete operation and service system. Using statistical information about the displacements in the region, we will estimate the travelers potential of each system. Also the combination of each DRT scenario with other, supportive modes of smart PT (like bike or car sharing,…) will be investigated.

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Appendices

A The Approach

Due to budget constraints it becomes more difficult to serve *thin flows* using public transport services. Thin flows occur in rural areas having a low population density as well as from specialized demand from elderly and from people requiring special support during travel (because of visual impairment, wheelchair use etc). In Flanders (Belgium) the main bus based public transportation provider (De Lijn) investigates how regular time-table based *fixed public* transportation on one hand and *demand responsive collective* transportation on the other hand can cooperate in order to cut costs. The second category of services is provided by both employed workers and volunteers and covers both regular transport as well as transport requiring special support. Furthermore, some of the providers in the second category are subsidized by the government and their services are accessible at low cost for specific categories of customers only.

A.1 Problem Statement and Research Questions

The problem to be solved requires cooperation (or at least alignment) between several providers of several kinds, using different business models, subject to different rules and targeting specific markets. The main research question is whether or not it is possible to cut costs and enhance the service level by cooperating in such a way that *thin flows* are serviced by excess capacity available from particular collective transport providers during specific periods of the day. In order to find out which business models are suitable to solve the problem, the research questions involve (i) modeling of *thin flows* i.e. low demand, (ii) modeling customer perception of available services, (iii) the provider's market perception, (iv) multi-modality and (v) matching special requirements and provisions.

Modeling thin flows raises special challenges to the micro-simulation methods used in classical activity-based travel demand predictors. Those models allow to produce results segmented by several variables (space, time-of-day, socio-demo characteristics) and in most cases results are aggregated values even if a single day is simulated. We anticipate that in the *thin flows* context temporal aggregation will be required because of high variability of the small demand as a function of time. It is expected that the simulated period shall be extended to one or more years in order to assess the *viability of collective transport providers* that serve dozens instead of hundreds of customers each day. Travel demand prediction for thick flows is possible for a single since the required results follow from spatial aggregation. This is essentially what is done in 4-step models and classic activity-based models. For thin flows this no longer makes sense and temporal aggregation of micro-simulated results is required.

Demand estimation is expected to be more cumbersome than for regular activity-based models since (i) each member of the synthetic population in our model needs a plan (agenda) extending over multiple days and (ii) individuals can have special mobility impairment related requirements.

A.2 Concept

Thick flows will be modeled since multi-modality is to be evaluated. A customer may use the *thin* flow as feeder to a flow serviced by the regular public transportation provider. However, we will assume that the behavioral choices made by the customers we simulate, will have negligible effect on the thick flows. As a consequence, we will operate the simulation in two stages: (i) calculation of network loading by thick flows in order to establish an near equilibrium state and (ii) simulation of the collective transport services under time dependent demand for a multi-day period. The main characteristics of the required simulations are:

1. Trips will be multi-modal, except for the shortest ones. This is because of applicable legal and business rules. Customers will be required to compose their trips using as much as possible existing thick flow services.

2. Customers who need special support shall cooperate (i.e. align their schedules): e.g. a visually impaired customer might require support to board/alight a train.

3. People will have several mode choice options and the cost for the options may mutually differ. For every category of customers, a model for travel decision behavior is to be build; this includes models for perception and evaluation of experienced service while traveling.

4. Estimation of time dependent demand is expected to be difficult and the variability in time is expected to have large effects on the optimization results of small scale service providers (e.g. a Vehicle Routing Problem (VRP) needs to be solved for every simulated day and for every thin flow provider. The resulting tours are expected to show large variability).

5. Each special request will be identified by a label. Customers may carry a set of such labels and providers may provide support for specific labels during specific periods of the day. While booking a tour consisting of multi-modal trips, a set of constraints (established by label matching requirements) shall be fulfilled.

6. The viability of a service provider depends on the demand it can attract, on the rules it is subject to, on the payment model (income from fares, subsidized) and on the provided labeled services.

7. A large part of the thin flow services are demand based with coordination between customers and providers. Each provider has its own objectives: providers may compete.

8. Brokers providing services to book door-to-door multi-modal trips will be integrated. They model real world actors such as manned services as well as route advisor websites. A broker can be part of a provider or be stand-alone. Brokers will coordinate among them, with providers and with customers.

A.3 Research Focus

Focus is on

1. defining business models [1, 3] and evaluating their viability

2. modeling behavioral choice for everyone (including mobility impaired customers) with respect to flexible collective transportation

3. modeling thin flows (requiring multi-day periods)

4. modeling cooperation among actors

5. choice models for multi-modal tours in *labeled networks*

B Data Preparation

Activity-based transport micro-simulations are commonly used to determine travel demand in space and time in order to determine network loads. When these simulations are capable of simulating public transport, they can be used to determine the capacity utilization of public transport. This is necessary when we want to simulate cities at a fine grained scale. However, in order to enable the simulation, detailed knowledge of the services is required.

The aim is to automatically build a consistent dataset describing both the network and the public transportation services. When open data are used, rebuilding is required because the input data evolve. Hence the requirement to build an automated process which turns out not to be a trivial task.

B.1 Problem Statement

Aligning GTFS data with OSM shall be automated since for Flanders about 20k bus stops are in use and since both OSM and GTFS datasets are frequently updated. Automatic alignment however is not a trivial task since the $\langle lon, lat\rangle$ pairs for the bus stops clearly have the same accuracy as points recorded using a smartphone. Hence, many stops cannot be unambiguously associated with a network link or with the correct side of the street. If a bus is assigned to the wrong side of the street, bus routes are heavily affected which in turn might lead to severe errors in simulation results.

B.2 Solution Method

The solution we are implementing consists of following steps.

B.2.1 Step 1: Non-ambiguous cases

In the first step, only street names and bus stop $\langle lon, lat\rangle$ tuples given in `GTFS` are used. Those are called *gtfsStop*s.

1. A distance threshold δ which is a function of the GPS accuracy, is used. For each bus stop, the links for which the shortest distance to the bus stop is not larger than δ, are selected. This is illustrated in Figure 1. If more than one link is selected, we try to narrow the selection set by using street names: thereby we do *not* assume that all names in all databases are correctly spelled. This can result in zero or more selected links for each bus stop. Projecting the given coordinate pair $\langle lon, lat\rangle$ to a selected link generates a *projectedStop*.

2. Practical solutions for cases where no link is selected by a $\langle lon, lat\rangle$ using δ still have to be devised. The remainder of this document only covers bus lines for which each *gtfsStop* has a non-empty set of *projectedStop*s. The other cases are the subject of ongoing research.

3. The sequence of stops for each line is specified in GTFS. Each such *gtfsStop* is associated with a non-empty set of *projectedStop*s. We assume that the shortest path between stops is used. Hence, for every

pair of consecutive *gtfsStop*s, we consider every pair of corresponding candidate *projectedStop*s and select the pair resulting in the smallest distance. If and only if the sequence of *projectedStop*s selected in this way, constitutes a path in the graph representing the road network, it is assumed that the bus stops are found. Indeed, fulfilling the condition implies that for each set of *gtfsStop*s exactly one *projectedStop* was unambiguously chosen.

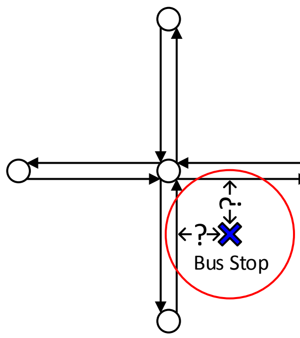

Figure 1: Finding links within the distance threshold δ. The cross labeled *bus stop* is a *gtfsStop*. It has two associated *projectedStop*s.

B.2.2 Step 2: Ambiguous cases with non-shared stops

In the second step, all bus lines for which no solution was found and that do not share stops with any other line, are reconsidered. The sets of *projectedStop*s found in step 1 for each *gtfsStop* are reused.

1. For each pair of consecutive *gtfsStops* s_G^a and s_G^b the connection is evaluated as follows. Each of both considered *gtfsStop*s has a set of *projectedStop*s denoted by S_P^a and S_P^b respectively. All possible pairs of *projectedStops* $s_P^{a,i} \in S_P^a$ and $s_P^{b,j} \in S_P^b$ are candidates to constitute a connection from s_G^a to s_G^b. Each such connection gets an evaluation score which is a function of the travel distance between the *projectedStop*s and of the distance between *projectedStop* and its associated *gtfsStop*. Those scores are penalty scores (the lower, the better).

2. The *projectedStop*s together with the $\langle s_P^{a,i}, s_P^{b,j} \rangle$ pairs, constitute a graph having weighted edges.

3. Finally, a lowest weight path between $s_P^{0,i}$ and $s_P^{N,j}$ is determined; $s_P^{0,i}$ is any *projectedStop* for the first *gtfsStop* s_G^0 and $s_P^{N,j}$ is any *projectedStop*

for the last *gtfsStop* s_G^N. The *projectedStops* on this minimum weight path are the bus stops for the considered line.

B.2.3 Step 3: Ambiguous cases with shared stops

This is the general but most resource consuming case; hence, the simpler cases are filtered in the first two steps. In Figure 2 the *gtfsStop* in the red

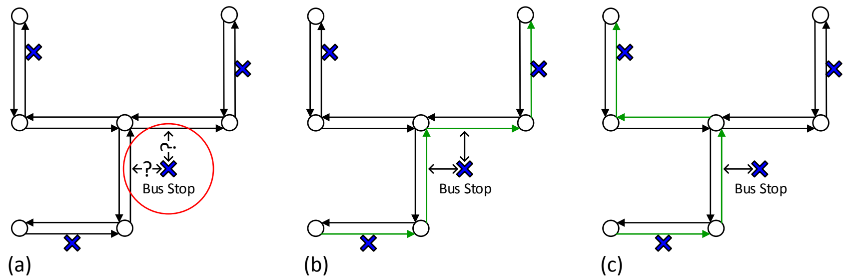

Figure 2: Using bus lines to determine the correct link for a bus stop.

circle has two *projectedStops*. Buses are driving from bottom to top. The *projectedStop* on the vertical link is optimal for the line serving the *gtfsStop* at the upper left and feasible but sub-optimal for the *gtfsStop* at the upper right. The *projectedStop* on the horizontal link is optimal for the line serving the *gtfsStop* at the upper right and nearly infeasible (because it induces a long detour) for the *gtfsStop* at the upper left. In the end, one of both shall be chosen because there is only one physical bus stop.

1. The weights calculated in step 2 are used.

2. From each *gtfsStop* exactly one *projectedStop* is to be chosen such that (i) for each bus line, a path in the graph is reconstituted and (ii) the sum of the path weights is minimal

B.3 Previous Attempts

In the past, several attempts[1] have been made to link bus stops to the correct side of the street. The problem with these attempts is that they do not take shape characteristics of the roads into account but use smallest distance to select a link. Figure 3 illustrates this problem. In the real-world the bus stop is connected to the green street, however when the shape information is lost, the bus stop will be connected to the incorrect red street.

[1] e.g. `http://matsim.org/docs/extensions/gtfs2transitschedule`

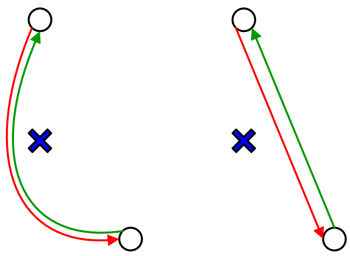

Figure 3: Conversion problem when shape information is lost.

In http://www.matsim.org/node/681 an interactive GUI-based solution is provided but this is not feasible for our purpose because of the large open datasets which evolve over time.

C Progress

We are currently working on the software specification of the simulation model, described in Section A. It is important that this is conducted on a very fine grained level in order to avoid unexpected/unwanted situations during the implementation and testing of the software. Our deadline for this software specification is by the end of August.

In the meantime, we are already working on the data preparation as described in Section B. Most of the preparatory work has already been completed. There are only a few parts of the core algorithm that needs to be implemented. Our goal is to finish the data preparation software before the 15^{th} of July.

References

[1] Andreas Neumann, *A Paratransit-Inspired Evolutionary Process For Public Transit Network Design*, Phd thesis, Technischen Universitaet Berlin, 2014, p. 267.

[2] Jan Vuurstaek, Luk Knapen, Bruno Kochan, Tom Bellemans, Davy Janssens, and Geert Wets, *Modelling hospital visitors for the city of Leuven as input for a FEATHERS-MATSim simulation*, BIVEC/GIBET Transport Research Day 2015 (Eindhoven), May 2015.

[3] Konstantinos G. Zografos, Konstantinos N. Androutsopoulos, and Teemu Sihvola, *A methodological approach for developing and assessing business models for flexible transport systems*, Transportation **35** (2008), 777–795.