CHALMERS
UNIVERSITY OF TECHNOLOGY

WP-4

TRANSPORT EFFICIENCY: INTEGRATION OF MINIBUS & DELIVERY ROBOT

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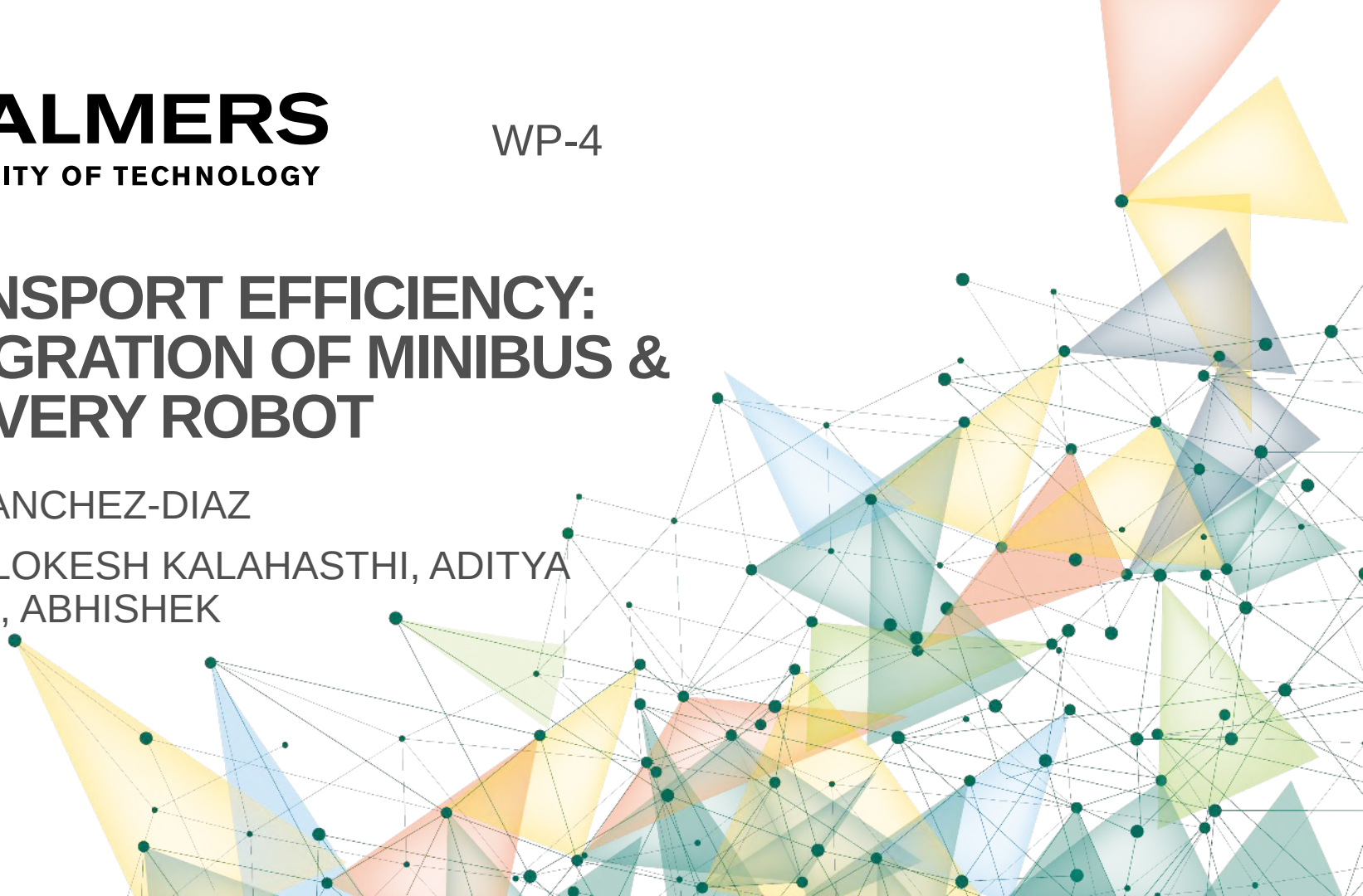


ASSESSING TRANSPORT EFFICIENCY: A PROSPECTIVE VIEW

We studied current goods and people movements at Chalmers, and modeled a full implementation of an integrated system

Objectives:

- Quantify demand for goods and people movements within Chalmers' campus
- Develop mathematical models to plan routing for minibus & robot
- Assess energy consumption savings for different scenarios of integrated autonomous systems within Chalmers

Analyses: 1- Robots vs. e-vans; 2- Automated minibus, 3- Integrated robots & minibus

1- Assessing the efficiency of goods deliveries by robots

- How to pack robots?
- What route should the robots take?
- How many robots are required?
- Are robots' energy efficient compared to e-vans?

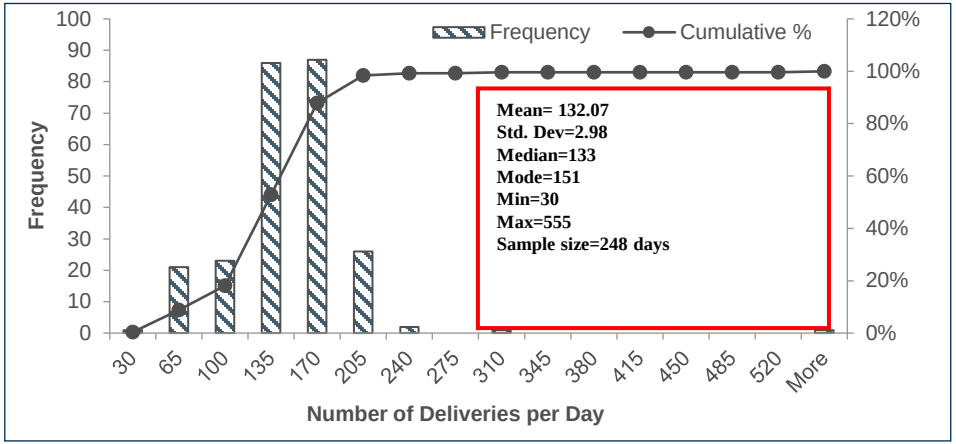
Letters

Packages

Pallets

1-Goods deliveries & robot energy consumption

Freight Data from Transport Central



Robot Pilot tests (7 days)

Date	Duration	Distance (Km)	Avg. Speeds (Kmph)	Wh/Km
05-10-2020	1:02:17	1.14	1.10	3.83
06-10-2020	2:22:48	2.53	1.06	2.48
07-10-2020	2:01:12	2.47	1.22	2.98
08-10-2020	1:47:21	2.37	1.32	3.34
09-10-2020	2:01:52	2.89	1.42	1.92
02-12-2020	1:26:32	1.85	1.28	3.54
03-02-2021	0:51:59	0.52	0.60	7.73
11-10-2022	1:20:00	3.40	2.55	16.23
13-10-2022	0:44:00	3.05	4.16	12.49

- Six package types:
  - Ordinary Packages (PKG) ~ 79%
  - Express letters from UPS, DHL, FedEx (EXP) ~ 14.5%
- 22 buildings including transport central
  - Kemi, SB3, Fysik, Maskin account for 75% of deliveries.
- Demand varies significantly across days

The average power consumption depends on the speed and weather. 3 scenarios tested

1. ~**12.5 WH per KM** if Avg. speed is ~4 Kmph
2. ~**16.2 WH per KM** if Avg. speed is ~2.5 Kmph
3. ~**20 WH per KM** if Avg. speed is 2.5 Kmph+Winter

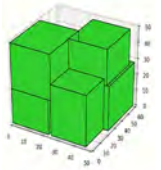
1- Robot delivery plan

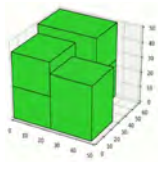
Objective: Minimize the total energy consumption

Factors: Number of packages, dimension, destination

- ***Optimal packing minimizes number of robots*** *but not necessarily best solution for energy consumption (↗ distance)*
- ***Optimal routing minimizes distance*** *but not necessarily best solution for energy consumption (↗ # robots → more total energy)*

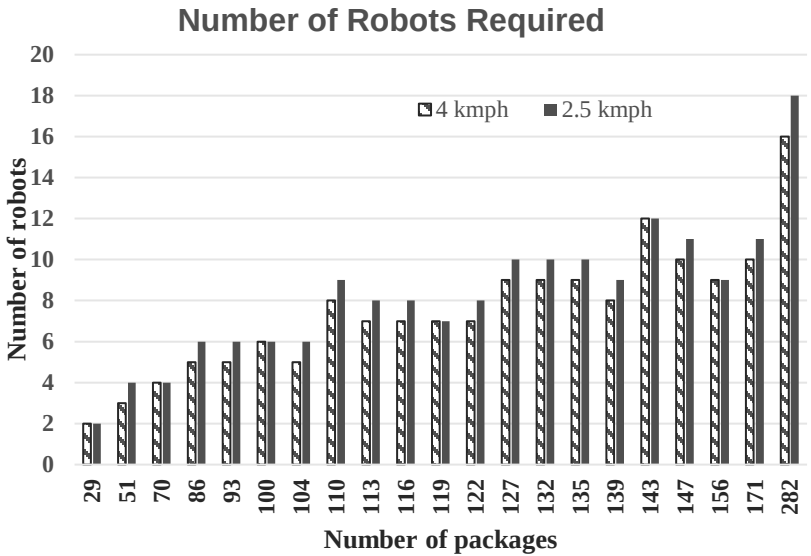
Robot 1 Robot 2



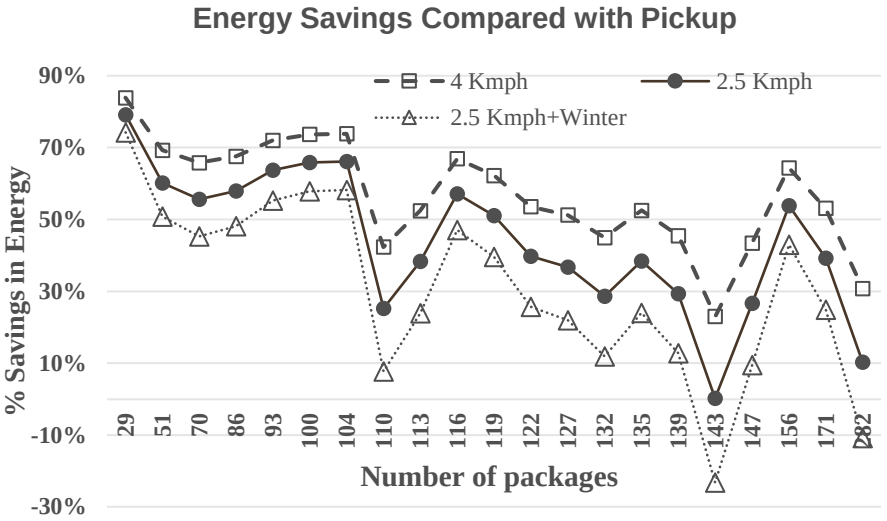


We developed a new algorithm that combines packing & routing to find optimal plan for energy consumption. This leads to **energy savings of 4,3%** on average (up to 13%)

1- Robot delivery efficiency



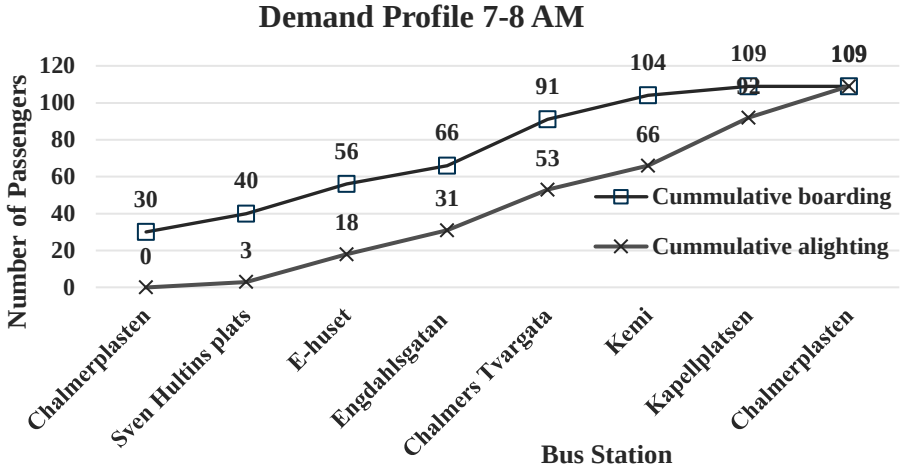
- **7-8 robots sufficient for 50% of cases**
- **2-18 robots required depending on demand**
- **6 tours/ robot**
- Depends on demand, robot speed and time window



- **Savings of -23% to 84% in energy compared to pickup**
- **Average savings of 27% is possible**
- Beneficial unless during winters, and at lower speeds
- Depends on freight demand, typology, and dimensions

2- Minibus schedule & energy consumption

Passenger Demand Data



Pilot tests (7 days)

	Pilot Test 1	Pilot Test 2	
Shuttle	P95	P94	P95
Date	12-20 Jan23	27 Feb- 25April 2023	
Time	7 Days	31 Days	19 Days
Distance	155 Km	797 Km	462 Km
AVG Speed (kmph)	4.08 kph	4.8 kph	4.72 kph
Laps	42	483	483
Passengers	48	422	125

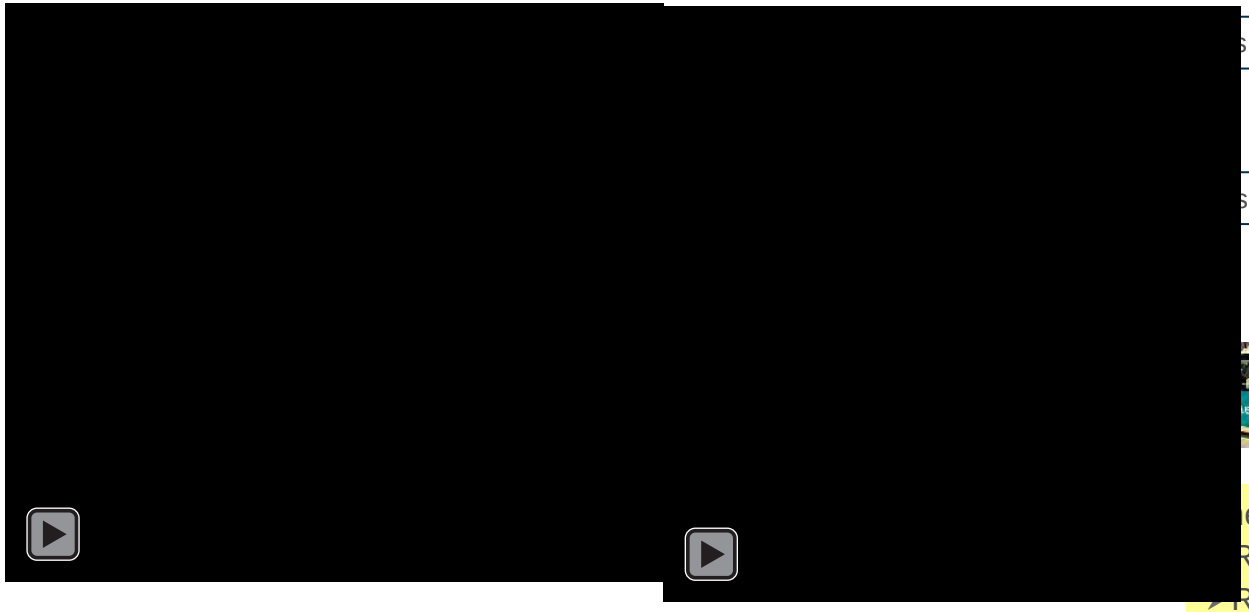
- 7 bus stops
- Bus schedule (6-18)
  - ~3 bus routes between 6-7 and 8-9 (15-16 and 17-18)
  - ~6 bus routes between 7-8 (and 16-17)
  - ~2 bus routes between 9-15
- In a day: no of trips 37, energy consumption is 41.85 KWH

- Capacity 8 passengers per bus
- Power consumption depends on demand, headway, distance, speed
  - ~390 WH per KM if Avg. speed is ~4 Kmph

3- Integrated freight & passenger: Robot & Minibus

Robot Alone

Robot + Minibus



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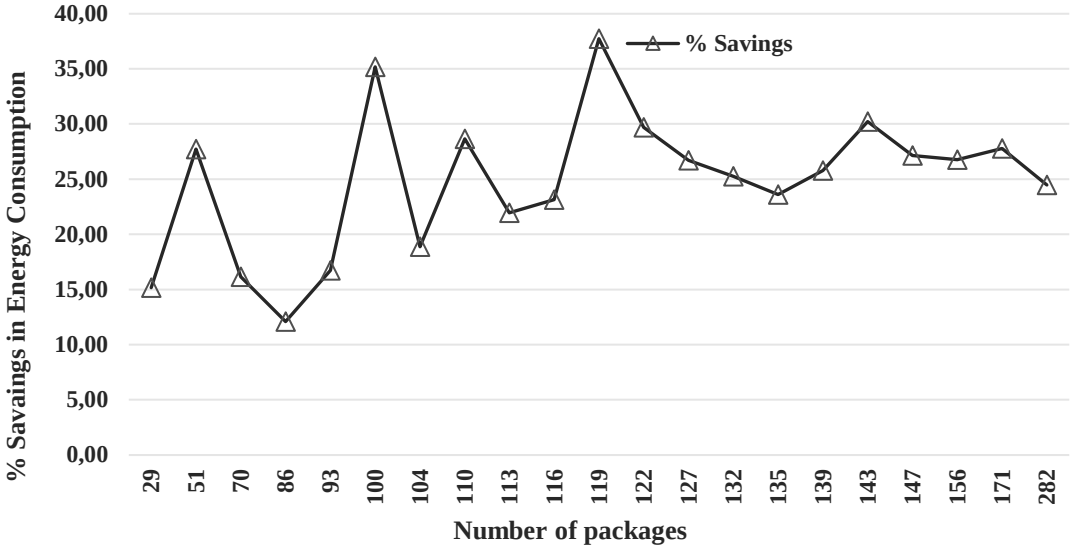
s to bus

ergy consumption:
- Robot alone: 230-370 WH based on speed
- Robot & Minibus: 160-260 WH
- Savings ~ 30% for this example

3- Integrated freight & passenger: Robot & Minibus



Integration can save 16-35% energy depending:

- Freight demand, destinations, typology, dimensions
- Passenger demand, peak/non-peak hours
- Bus stops

Conclusions

For Chalmers case:

- **7-8 robots required** to fulfill a typical freight demand
- Automated robots can save **27% of energy compared to e-vans**
- An integrate autonomous system for freight & people can save **25% of energy compared to isolated freight robot**

Overall:

- Demand for goods and people movements determine # of vehicles, capacity required, # and location of bus stops, distance and energy efficiency
- Higher speed leads to lower energy consumption (sensors)
- Algorithms that determine allocation and routes are required for automation
- Identifying deliveries outliers (in # of packages and size) can lead to less robots required and lower energy consumption