# Impact of the ICT on the management and performance of Intelligent Transportation Systems

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# Outline

- European Projects in the field of Intellingent Transportation Systems
  - intermodal transport chains, railway systems, maritime navigation, freight transportation
- Urban Traffic Management
  - Traffic signal control
  - A case study
- Intermodal Transportation Networks
  - Some case studies
- Conclusions

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# European Projects in the field of ITS

In recent years the European Union sponsored several projects targeting advancements of different transportation systems.

ITS topics are considered relevant and attractive research areas

ICT: primary “enabling tool” for the safe and efficient real time management of ITS.

# CESAR I & II (5th Framework Programme)

Co-operative European System for Advanced Information Redistribution in the field of Intermodal Transport Chains

Problems:

- A lot of different partners are involved in combined transport chains
- Internet based solutions can reach a wide variety of clients but are usually chaotic: every provider has different data-structure.
- CESAR-I developed and tested Internet based standards on one European corridor.

# CESAR I & II (5th Framework Programme)

- CESAR-II faces the urgent demand of European operators to open the first successful pilot system the other corridors and types of intermodal transport chains;
- proposes an Internet communication platform that aims to integrate services and data for unaccompanied traffic and the rolling motorway traffic management;
- adds new specific services for intermodal transport chains.

# CroBIT (5th Framework Programme)

- The objective of the Cross Border Information Technology is to develop, test and evaluate solutions in railways transportation :
  - for improved service reliability and data exchange;
  - for cross border freight trains;
  - using advanced IT-Technologies.

# CroBIT (5th Framework Programme)

CroBIT proposes a platform to exchange messages between Infrastructure Managers:

- on train composition,
- delays, interruptions,
- running schedule,
- rerouting
- special events

# CroBIT (5th Framework Programme)

CroBIT proposes a platform to exchange messages between Train Operating Company:

- technical characteristics of the wagon
- characteristics of the goods transported
- characteristics of running under load
- characteristics of a train or a set of wagons
- shutdown information for wagons
- information about delays.

# MarNIS (6th RTD Framework Programme)

Maritime Navigation Information Systems

- establish a maritime navigation information structure in European waters
- develop tools
  - to exchange maritime navigation information
  - to improve safety, security and efficiency of maritime traffic.

# MarNIS (6th Framework Programme)

- ***Improvement of safety and the protection of the environment;***
- using Vessel Traffic Management (VTM) in the littoral seas, continuous monitoring of high risk vessels along the European coasts

.

- ***Improvement of security;***
- The development of practical solutions to use VTM in order to monitoring of vessels and tracking of cargoes from consignor to consignee within its jurisdictional boundaries;

- ***Improvement of efficiency and reliability;***
- *Efficiency of traffic flows in ports and territorial waters* is improved by developing appropriate software for advance planning of port and terminal activities.
- *Efficiency of traffic flows in international waters* is improved by developing a co-ordinated system for the collection and presentation of dangerous goods related information to all relevant stakeholders in a port environment.
- *Efficiency of transport chains* in relation to intermodal transport and mandatory reporting to administration agencies is enhanced by developing a coherent traffic and cargo reporting system.

- ***Improvement of the economic aspects of sea transport*** by enhancing traffic management using new technologies and demonstration of Pan-European navigation and information services including the interfaces with "GALILEO" and other future navigation systems.
- ***Improvement of the legal and organizational aspects*** by improving the legal concept of European regional solutions in relation to international law and introduction of potential legal and organisational requirements as basis for an integrated European information system.

# FREIGHTWISE
# (6th Framework Programme)

- **Freight Transportation**
- **FREIGHTWISE** aims at bringing together three different sectors:

- **Transport Management** : Shippers, Forwarders. Operators and Agents;
- **Traffic and Infrastructure Management** : Rail, Road, Sea, Inland waterways;
- **Administration** : Customs, Border Crossing, Hazardous Cargo, Safety and Security

- **establishes a framework** to develop and demonstrate suitable intermodal transport solutions in a range of business cases.
- **supports the complex service integration** into integrated transport chains
- **simplifies the interaction among stakeholders** during planning, execution and completion of transport operations.

# SMARTFREIGHT (7th Framework Programme)

The main aim of **SMARTFREIGHT** is

- **to specify, implement and evaluate ICT solutions** that integrate urban traffic management systems with the management of freight and logistics in urban areas.

Motivations:

- Traffic management systems do not serve those organising freight transport in the city. It is difficult to predict the access to limited resources like loading and unloading areas.
- Freight distribution management in city centres is usually operated by several commercial companies and there is no coordination of these activities in a way that would benefit the city.

# EURIDICE (7th Framework Programme)

European Inter-Disciplinary Research on Intelligent Cargo for Efficient, Safe and Environment-friendly Logistics

**Aim:**

- Developing an advanced European logistics system around the concept of ‘intelligent cargo’.
- Networking cargo objects like packages, vehicles and containers to provide information services whenever required along the transport chain.
- Building an information service platform centred on the individual cargo item and its interaction with the surrounding environment and the user.

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# Urban Traffic Management

- Traffic congestion of urban roads undermines mobility in major cities.
- Adding more lanes and new links to the existing urban traffic networks is not a solution
- Great emphasis is nowdays placed on traffic management through the implementation of ICT solutions

# Urban Traffic Management

- Traffic signal control on surface street networks plays a central role in traffic management
- Despite the large research efforts on the topic, the problem of urban intersection connection is an open issue.

# Traffic signal control: two main classes

**Signalized area traffic control** → **Fixed semaphoric plan** → Constant cyclic sequence of traffic signals → Green times do not adapt to traffic variations

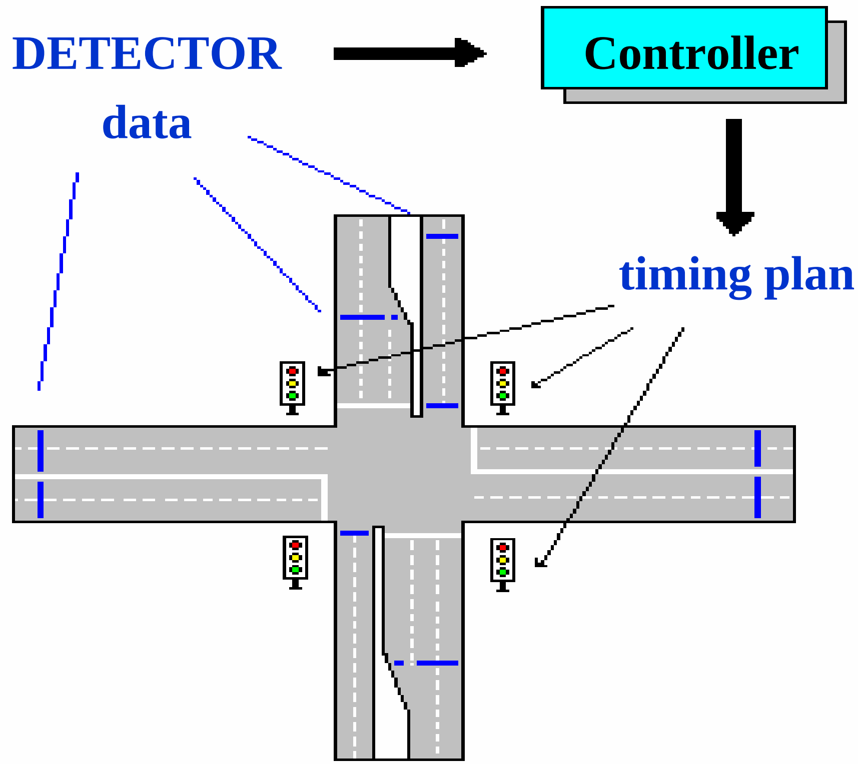
**SPILLBACK**

↓

**Traffic actuated signal control**

↓

A controller selects the semaphoric plan depending on the traffic volume measured by DETECTORS




| Off-line | On-line |
|---|---|
| Pre-calculated timing plans | Automatically adapting timing plans |

# Traffic signal control

- The main decision variables in a timing plan are

- *cycle time*= the duration of time from the centre of the red phase to the centre of the next red phase
- *green splits*= the fraction of cycle time when the light is green in a direction.
- *Offset*=the duration from the start of a green phase at one signal to the following nearest start (in time) of a green phase at the other signal.
- *Phase*= the time interval during which a given combination of traffic signals in the area is unchanged.

# Real time control strategies

- **Vehicle actuated strategies** perform an on-line optimization and synchronization of the signal timing plans and make use of real time measurements.
- **Detectors** located on the intersection feed information on the actual system state to the real time controller.
- **The real time controller** selects the duration of the phases in the signal timing plan in order to optimize an objective function.
- Although the corresponding optimal control problem may readily be formulated, its real time solution and realization in a control loop has to face **several difficulties**
  - the **size and the combinatorial nature of the optimization problem**,
  - the **measurements of traffic conditions**
  - the **presence of unpredictable disturbances**.

# Some vehicle actuated techniques

- The British SCOOT decides an incremental change of splits, offsets and cycle times based on real time measurements.
- (Lo, 2001) and (Wey, 2000) propose a formulation of the traffic signal network optimization strategy. The resulting procedures lead to **complex mixed integer linear programming problems** that are computationally intensive and the formulation for real networks requires heuristics for solutions.
- Diakaki *et al.* (2002) propose a traffic responsive urban control strategy based on a feedback approach. The strategy is simple and efficient but the **modelling approach can not directly consider the effects of offset for consecutive junctions and the time-variance of the turning rates and the saturation flows**.

# An urban traffic actuated control strategy (Dotoli, Fanti, Meloni 2006)

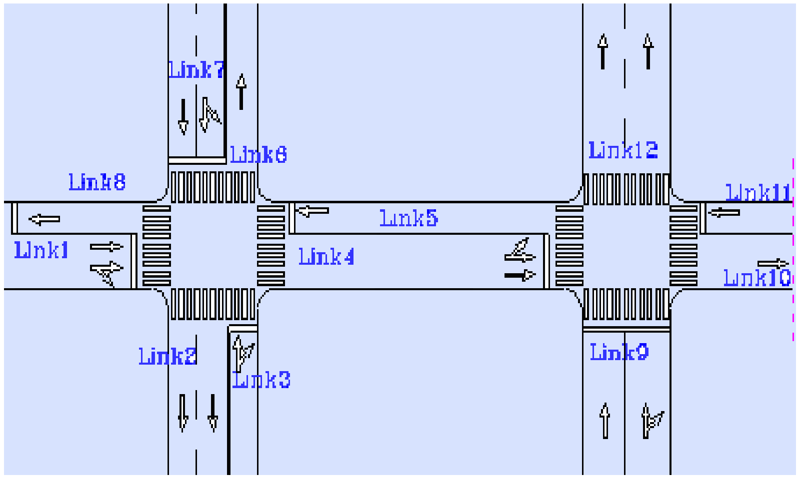
A real time optimization model is proposed taking into account:

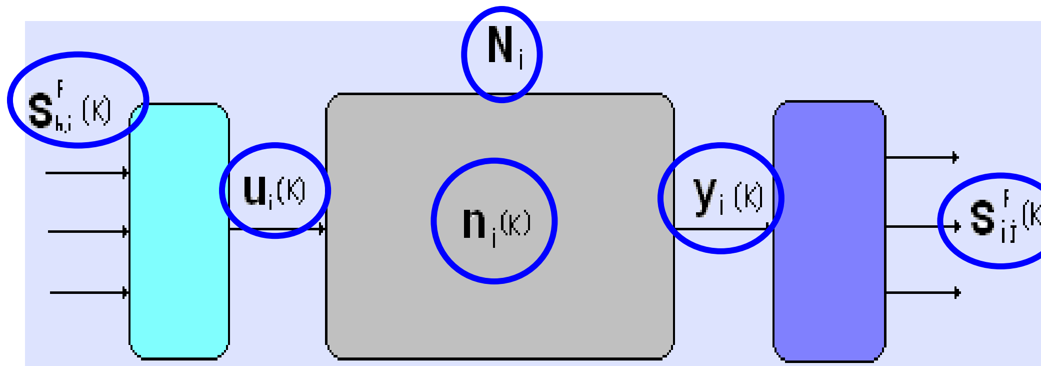
- Topology of the signalized area
- Different types of vehicles in the area
- Pedestrian crossings
- Different congestion scenarios

# An urban Traffic actuated control strategy

Macroscopic model for real time optimization of traffic in an urban area

Link: space available between two subsequent traffic lights (may include several lanes)




$n_i(k)$ number of vehicles in link *Li* at the beginning of the *k*-th semaphoric cycle

$N_i$ capacity of link *Li*

$u_i(k)$ number of vehicles entering *Li* within the *k*-th cycle

$y_i(k)$ number of vehicles leaving *Li* within the k-th cycle

$S^f_{h,i}(k)$ $S^f_{i,j}(k)$ number of vehicles traveling from link *Lh* to *Li* and from *Li* to *Lj* in the *f*-th phase of the *k*-th cycle

# Real time optimization method

Real time optimization → Minimization of vehicle number in the system in the optimization horizon → $\min_{t^f(k)} \frac{1}{N}\left[\sum_{k=1}^{N}\sum_{i\in L\setminus L_{out}} n_i(k)\right]$

**We optimize the values of the green times subject to:**

$$\sum_{f=1}^{F} t^f(k) = C$$

The cycle length is fixed

$$(1-\delta)\cdot \hat{t}^f \le t^f(k) \le (1+\delta)\cdot \hat{t}^f$$

δ is the maximal percentage variation of the nominal value

# The constraints

$$u_i(k) = \sum_{f=1}^{F} u_i^f(k) \qquad \left( y_i(k) = \sum_{f=1}^{F} y_i^f(k) \right)$$

$$u_i^f(k) = \sum_{h \in L_{in}^i} S_{h,i}^f(k) \qquad \left( y_i^f(k) = \sum_{j \in L_{out}^i} S_{i,j}^f(k) \right)$$

$$n_i(k+1) = n_i(k) + u_i(k) - y_i(k)$$

the vehicle balance equation

$$u_{go\,i}^f(k) = \begin{cases} u_i^f(k) \cdot \dfrac{t^f - \tau_i}{t^f} & se\ \tau_i \le t^f \\ 0 & se\ \tau_i > t^f \end{cases}$$

$$u_{stop\,i}^f(k) = u_i^f(k) - u_{go\,i}^f(k)$$

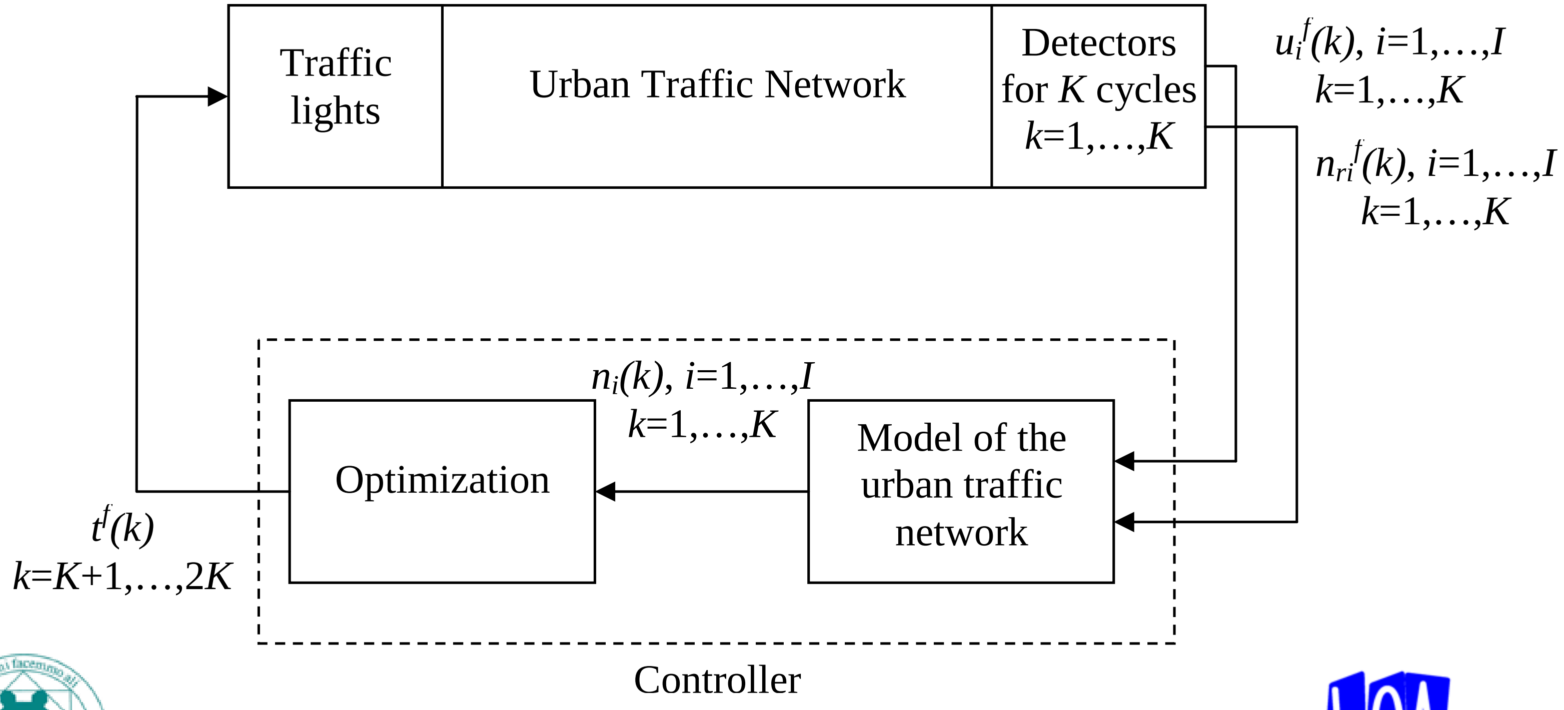
Number of vehicle leaving from $L_i$ to $L_j$

$$t_{eff\ i,j}^f = t^f - \left[ \sum_{(h,z) \in P_{i,j}} S_{h,z}^f(k) \cdot \frac{x_{h,z}}{v_{h,z}} \right] \qquad Q_{i,j} = \phi_{i,j} \cdot t_{eff\ i,j}^f$$

$$S_{i,j}^f(k) = \min\left\{ \beta_{i,j} \cdot n_i^f(k),\ \beta_{i,j} \cdot ps_i^f \cdot Q_{i,j},\ N_j - n_j^f(k) + u_{go\,j}^f(k) - \sum_{(h,j) \in P_{i,j}} S_{h,j}^f(k) + y_j^f(k) \right\}$$

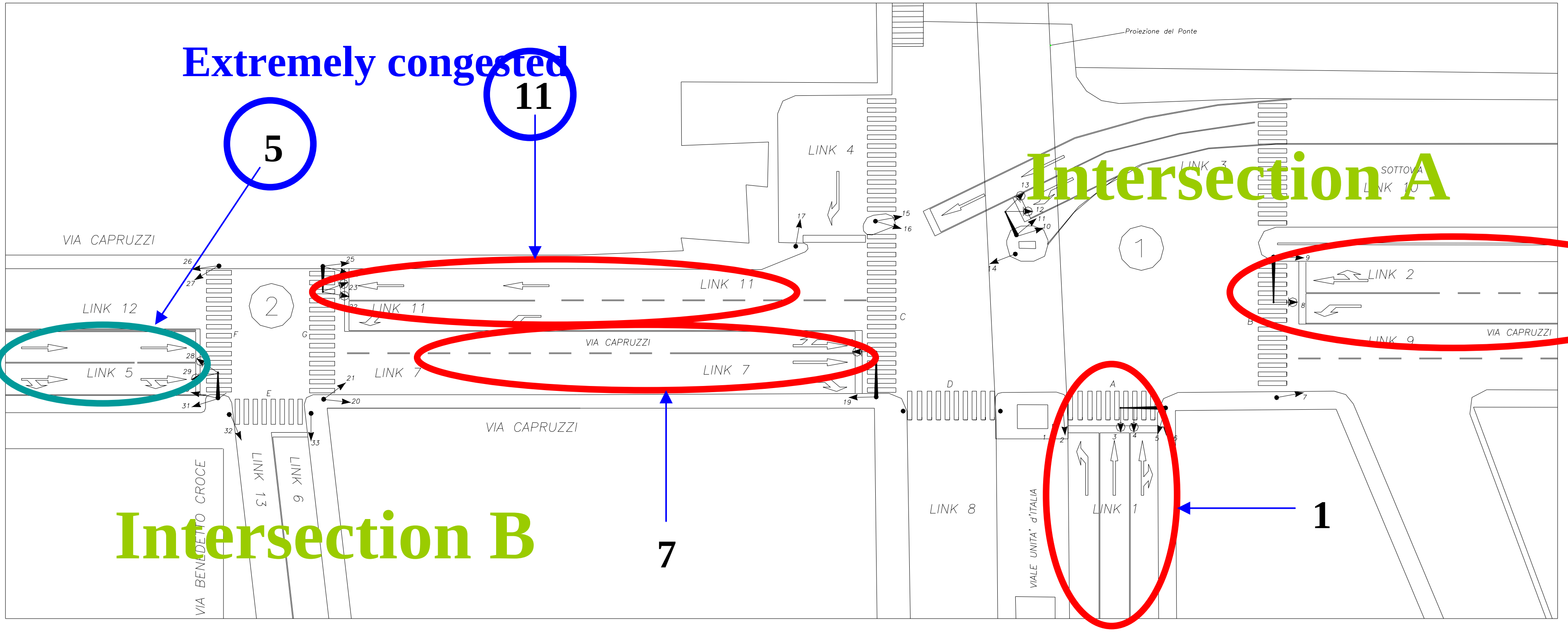
# The urban traffic actuated control strategy

- **Controller inputs:** the previous phase durations, the number of vehicles entering the input links and the number of rows of pedestrians crossing each link.
- The **model** evaluates the UTN state.
- A **mathematical programming problem** minimizes every *K cycles* the objective function subject to the defined constraints
- **Controller outputs:** the optimized green phase durations *tf(k)* to be used for the next *K* cycles.



# The case study

## An area including two congested interesections in downtown Bari, Italy




**2 intersections**
**13 links**

**6 input links**
**2 intermediate links**
**5 output links**

**Both cycles of intersections equal**
**C = 105 s**

# Initial signal timing plan

## Intersection A


## Offset = 8 s

**(heuristically determined)**

## Intersection B

22 phases with 13 fixed-length amber phases and 3 all-red phases. Hence, 6 phases are optimized, for each time slot.

# Optimization results (I)

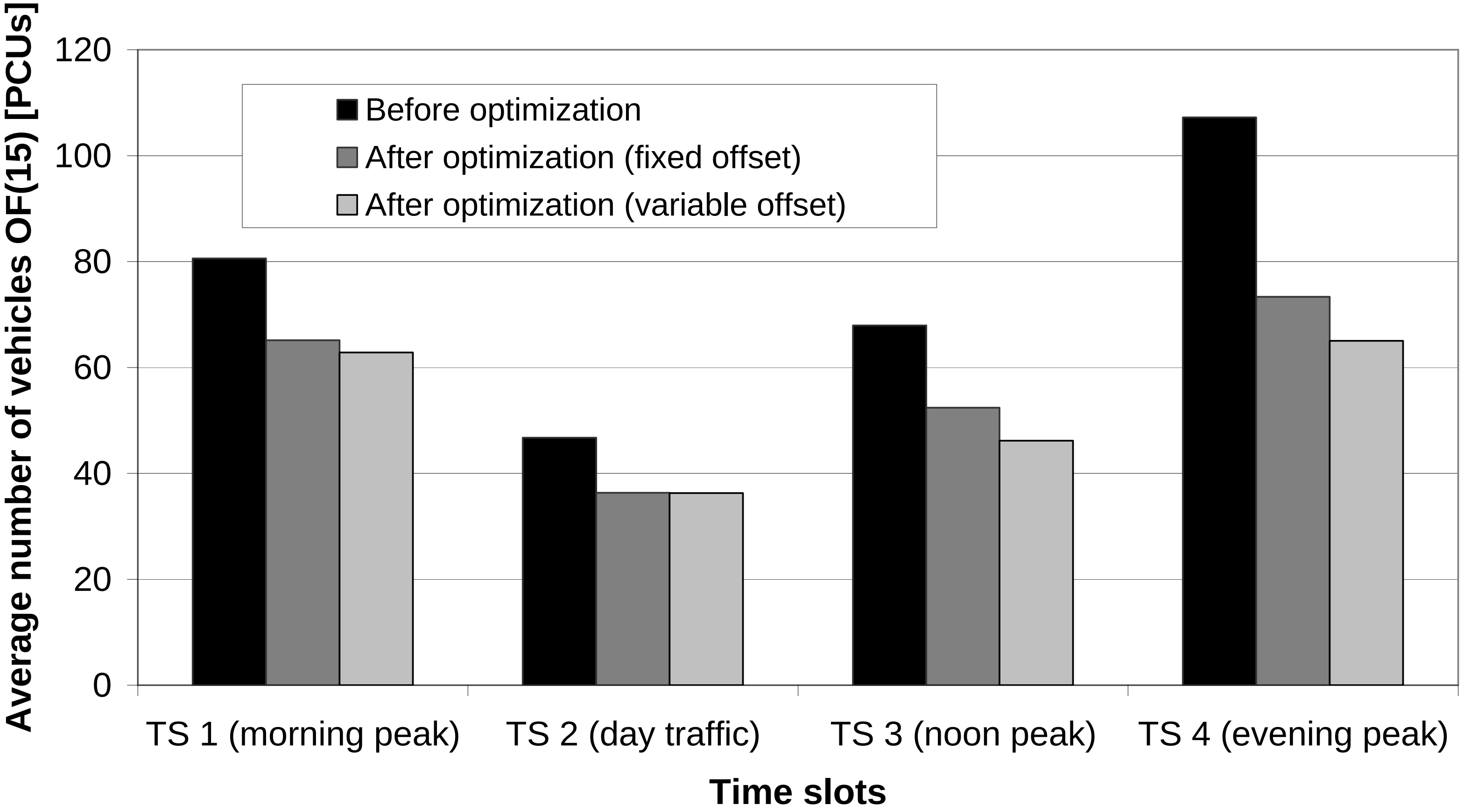
Noon Peak (TS 3) Results

| Performance indices [PCU] | Before optimization | After optimization (fixed offset) | After optimization (variable offset) | Percentage variation |
|---|---|---|---|---|
| *OF(15)* | 67.95 | 52.42 | 46.16 | -32.1% |
| $OF_1(15)$ | 18.25 | 19.14 | 19.41 | 6.4% |
| $OF_2(15)$ | 5.53 | 7.36 | 8.03 | 45.2% |
| $OF_3(15)$ | 6.25 | 7.02 | 5.11 | -18.2% |
| $OF_4(15)$ | 0.07 | 0.07 | 0.07 | 0.0% |
| $OF_5(15)$ | 12.06 | 6.27 | 2.5 | -79.3% |
| $OF_6(15)$ | 7.27 | 5.07 | 3.69 | -49.2% |
| $OF_7(15)$ | 11.49 | 5.52 | 5.08 | -55.8% |
| $P_7(15)$ | 52.2% | 25.1% | 23.1% | -55.8% |
| $OF_{11}(15)$ | 7.02 | 1.96 | 2.27 | -67.7% |
| $P_{11}(15)$ | 31.9% | 8.9% | 10.3% | -67.7% |

Evening Peak (TS 4) Results

| Performance indices [PCU] | Before optimization | After optimization (fixed offset) | After optimization (variable offset) | Percentage variation |
|---|---|---|---|---|
| *OF(15)* | 107.22 | 73.35 | 65.02 | -39.4% |
| $OF_1(15)$ | 21.60 | 22.80 | 22.64 | 4.8% |
| $OF_2(15)$ | 5.55 | 7.47 | 8.3 | 49.5% |
| $OF_3(15)$ | 10.76 | 11.11 | 8.24 | -23.4% |
| $OF_4(15)$ | 0.07 | 0.07 | 0.07 | 0.0% |
| $OF_5(15)$ | 38.58 | 18.42 | 12.64 | -67.2% |
| $OF_6(15)$ | 9.21 | 4.63 | 3.96 | -57.0% |
| $OF_7(15)$ | 12.08 | 5.83 | 5.07 | -58.0% |
| $P_7(15)$ | 54.9% | 26.5% | 23.0% | -58.0% |
| $OF_{11}(15)$ | 9.37 | 3.01 | 4.1 | -56.2% |
| $P_{11}(15)$ | 42.6% | 13.7% | 18.6% | -56.2% |

# Optimization results (II)



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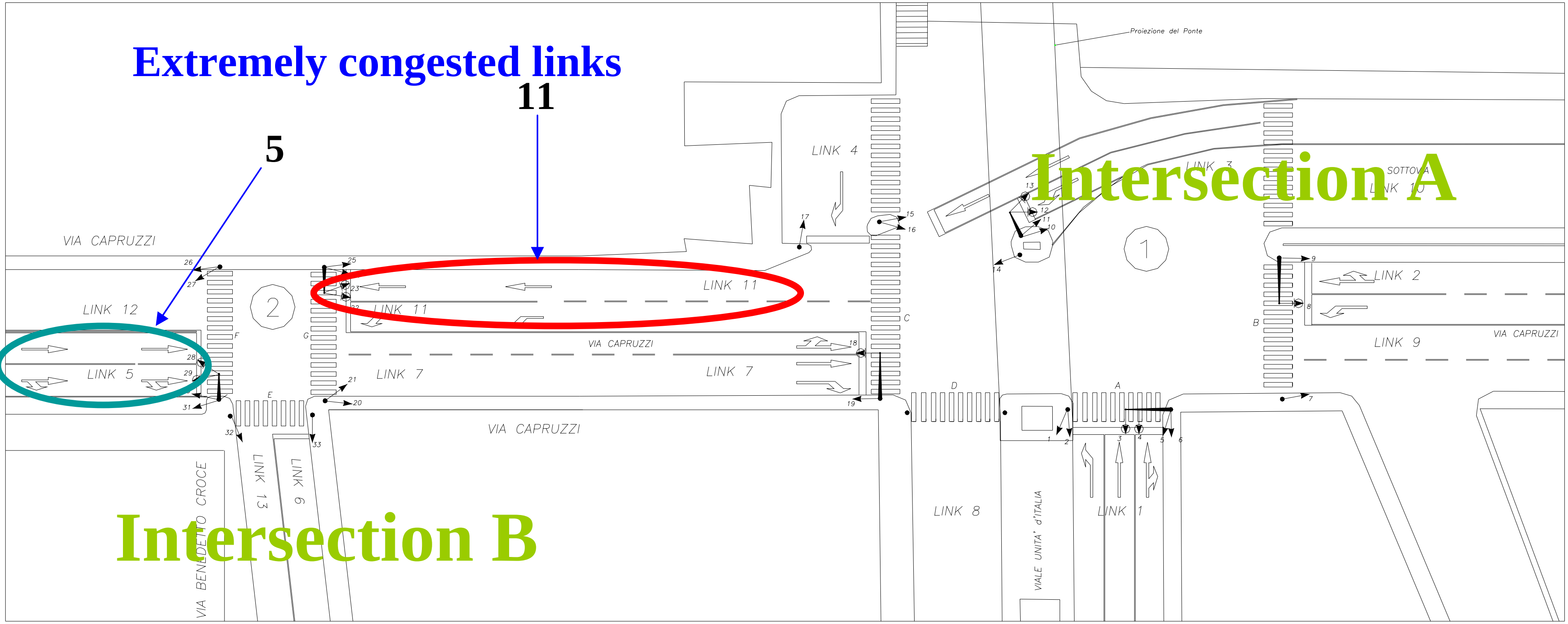
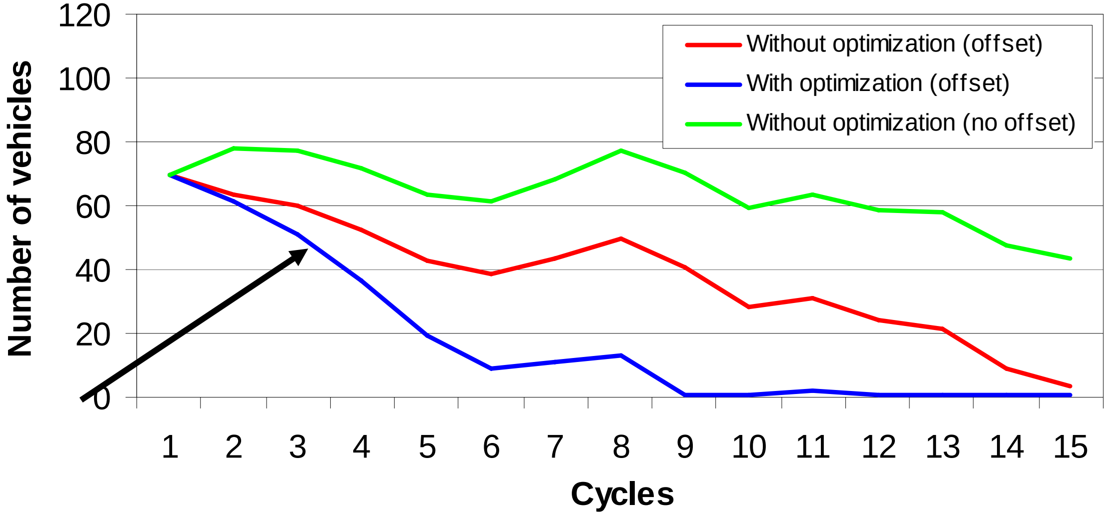



**2 intersections**
**13 links**

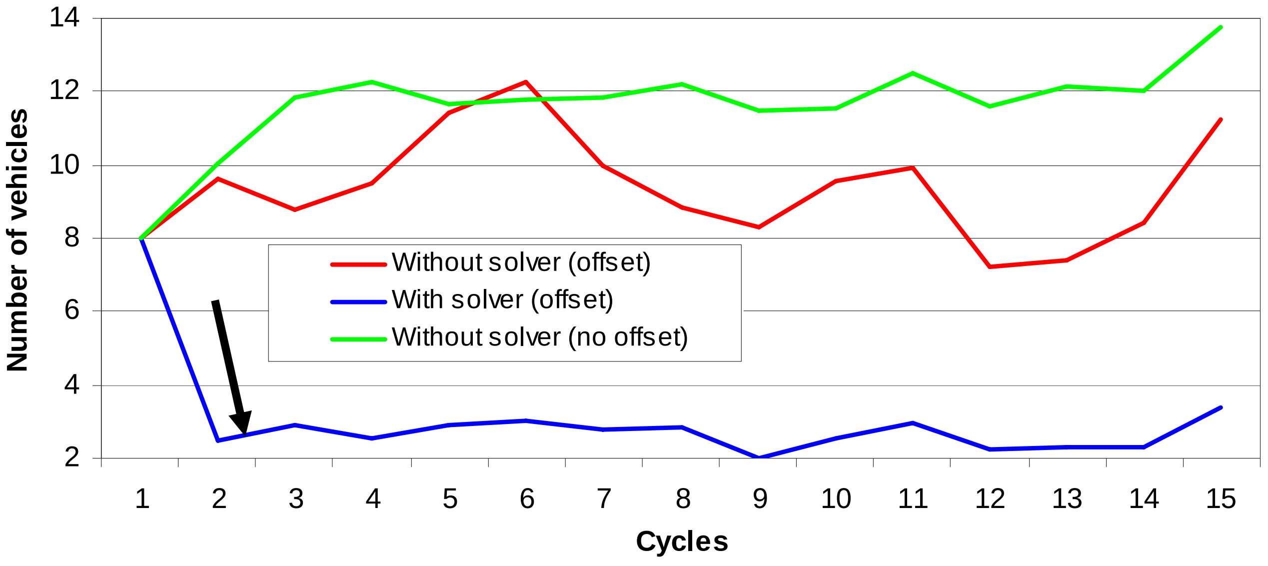
**6 input links**
**2 intermediate links**
**5 output links**

# Optimization results (III)

## Number of vehicles in L5 at the beginning of each semaforic cycle (TS=4)




## Number of vehicles in L11 at the beginning of each semaforic cycle (TS=4)



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# Intermodal Transportation Networks

**Intermodal Transportation Network (ITN)** is a logistically linked system integrating different transportation modes to move freight/people from origin to destination in a timely manner and using intermodal transportation

- renewed focus on ITN in 21st century:
  - » moving ever growing quantities of goods;
  - » technological evolution.
- ICT: primary "enabling tool" for the safe and efficient real time management and operation of ITN.

- ITN are dynamical and large scale systems
- ITN decision making is a very complex process

# A case study in a PRIN Italian project

(a **National Interest** Research Project

of the Ministry of Education, University and Research)

Decision models for design and management of **logistic networks** characterized by high interoperability and **information** integration

Scientific coordinator: Prof. Riccardo Minciardi, University of Genoa

Project period: 24 months

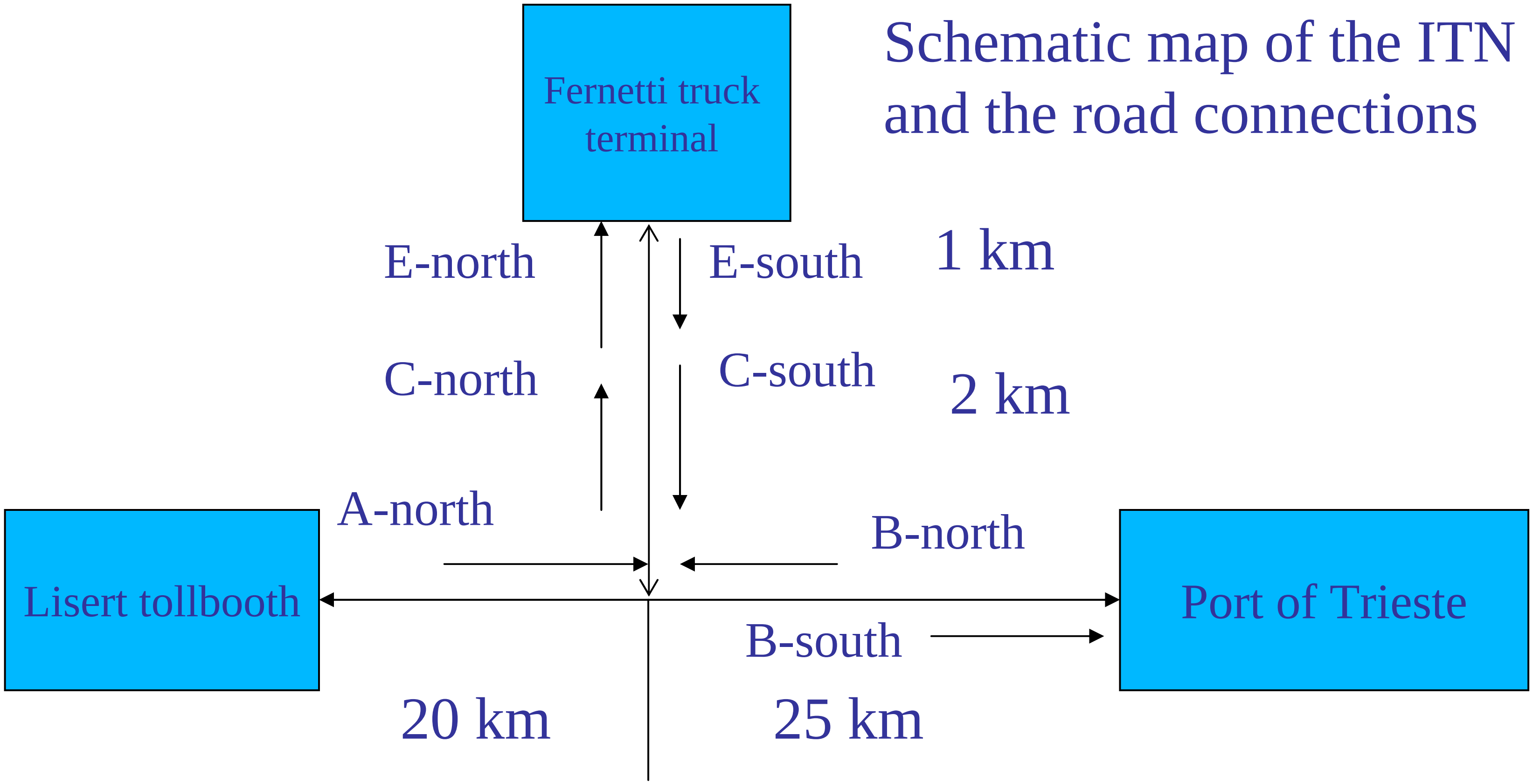
# Quantitative analysis of a case study: the Port of Trieste and the Fernetti terminal

- Management of the **truck traffic** referred to the Port of Trieste, in particular the ferry service between Trieste and Turkey

- The system is modeled and simulated in **different conditions** characterized by a different **level of information** that is shared between infrastructures and transport operators

# Quantitative analysis of a case study: the Port of Trieste and the Fernetti terminal

Schematic map of the ITN and the road connections



# Analysis approach: the modelling and simulation of the ITS

The system structure and dynamics are reproduced by discrete event system models and discrete event simulation.

Simulation objectives:

- Reproducing the real logistic system behavior
- Suggesting some strategic modifications and evaluating the relationship between costs and benefits
- Studying and foreseeing the impact of the proposed strategies on the real system.

# Evaluated solutions

**The main task:**

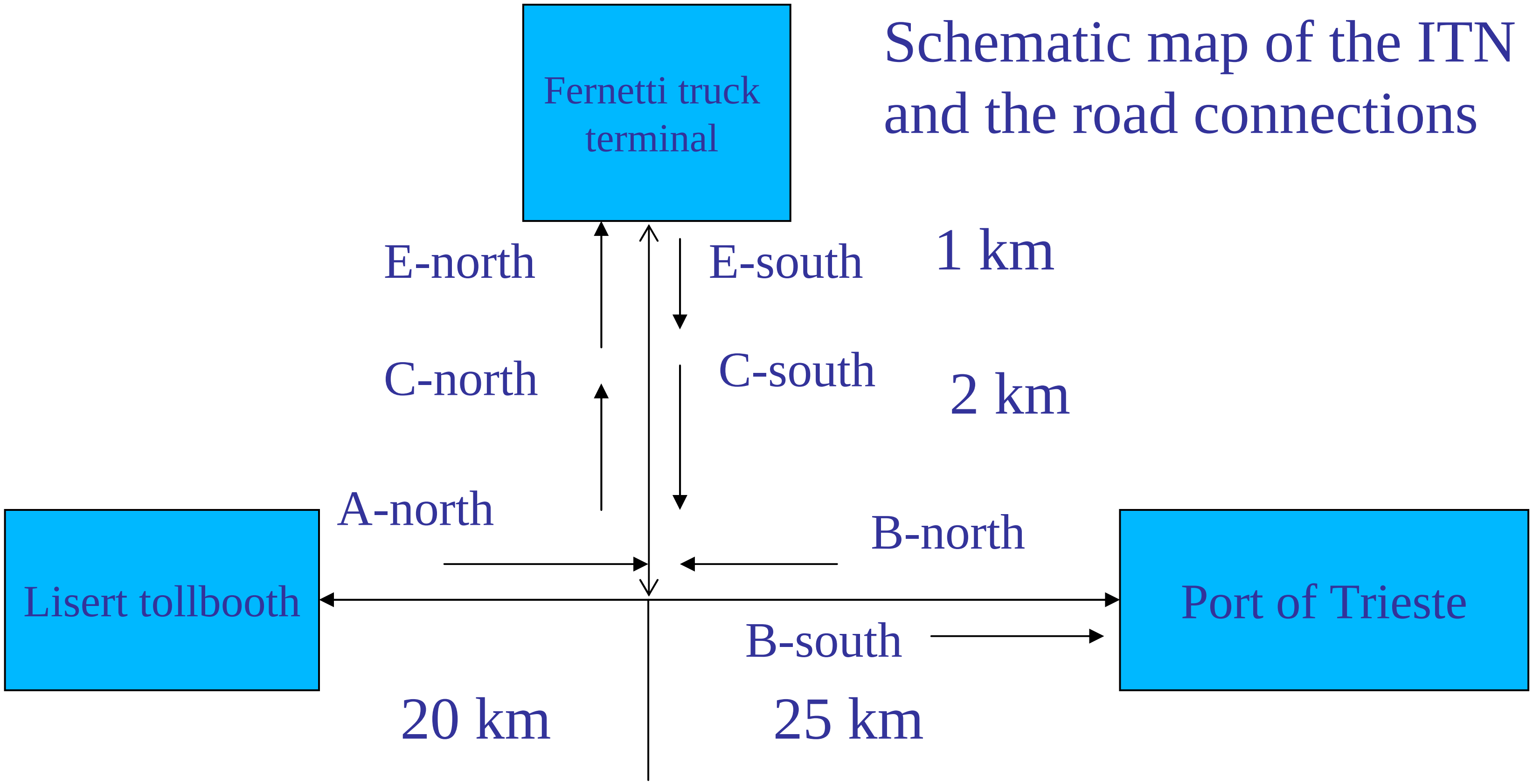
- **Decreasing** the truck traffic in the port area in order to:
  - Limit pollution
  - Decrease travel costs
  - Increase road safety
- **Evaluated solutions**
  - Increasing the **parking areas** of the port and of the Fernetti Terminal
  - Increasing the **ICT integration** and information among the logistics actors.

# The port area is analyzed in two operative conditions

- <u>The actual management of the port logistics:</u>
- The waiting port area has a capacity of 40 complete trucks and 450 trailer trucks.
- If a trailer truck has to be embarked, the truck coming from the Lisert tollbooth can go directly to the port parking area to wait for its turn.
- If the port area is full or closed the truck is re-directed to the Fernetti terminal.
- If a complete truck has to be embarked, the truck has to go to the Fernetti truck terminal to wait for its turn.

# Quantitative analysis of a case study: the Port of Trieste and the Fernetti terminal

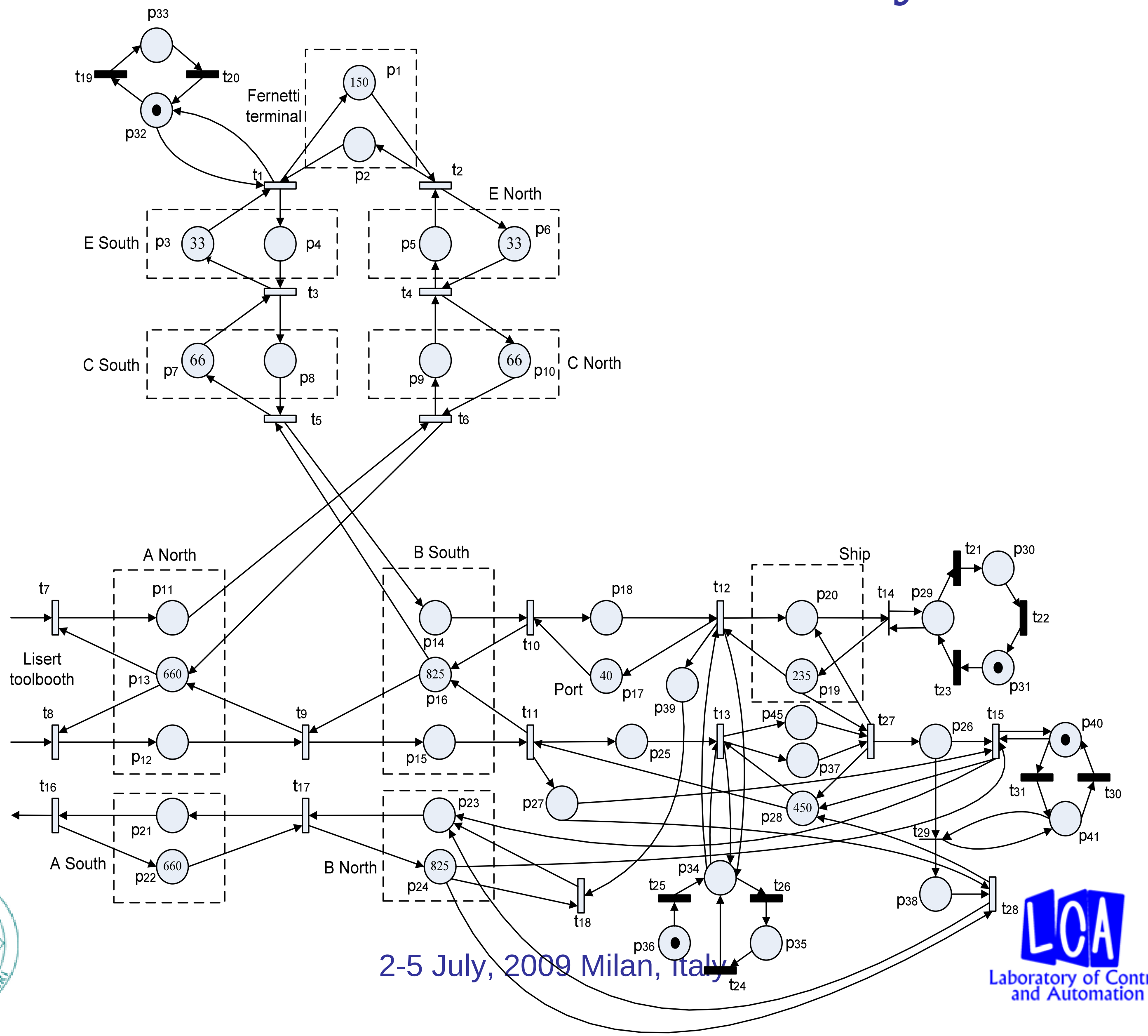
Schematic map of the ITN and the road connections



# The port area is analyzed in two operative conditions

- Modifying the logistics management by an ICT integration: The complete trucks entering the ITS from the Lisert tollbooth receive the information about the availability of the port parking and the ship.
- In such a case, the complete trucks can go directly to the port without reaching the Fernetti terminal,
- The port parking is considered available when the overall number of complete trucks in the port and in the C-South and B-South roads does not overcome 40 units.

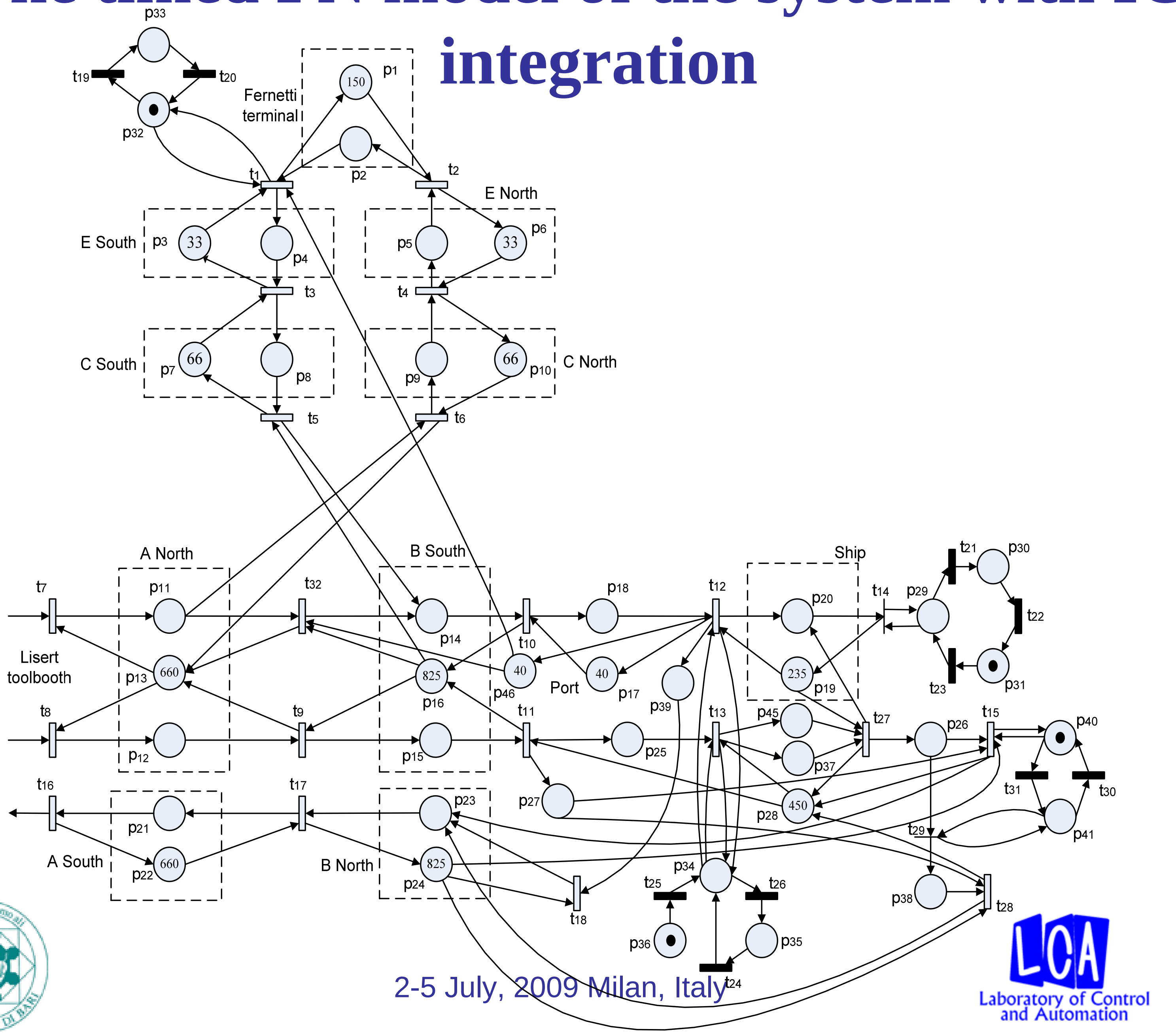
# The timed PN model of the system






Laboratory of Control and Automation

# The timed PN model of the system with ICT integration






Laboratory of Control and Automation

| Transition | Mean waiting time |
|---|---|
| T1 | 0.0650 |
| T2 | 0.0300 |
| T3 | 0.0167 |
| T4 | 0.0667 |
| T5 | 0.0333 |
| T6 | 0.6667 |
| T7 | 0.3000 |
| T8 | 0.1550 |
| T9 | 0.6667 |
| T10 | 0.3000 |
| T11 | 0.3000 |
| T12 | 0.0600 |
| T13 | 0.0100 |
| T14 | - |
| T15 | 0.6400 |
| T16 | 0.6667 |
| T17 | 0.6000 |
| T18 | 0.0710 |
| T19 | 6.0000 |
| T20 | 18.0000 |
| T21 | 0.5000 |
| T22 | 17.0000 |
| T23 | 6.5000 |
| T24 | 18.5000 |
| T25 | 1.0000 |
| T26 | 5.5000 |
| T27 | 0.2200 |
| T28 | 0.2000 |
| T29 | - |
| T30 | 0.5000 |
| T31 | 23.5000 |

# The port timing and capacities

235 trucks daily arrive: 155 trucks leave the trailers, 80 trucks depart complete

Fernetti terminal opens at 11.00 a.m.

The embarkation starts at 12.00 a.m.

Fernetti terminal closes at 5.00 p.m.

The embarkation closes at 5.30 p.m.

The ship sails at 6.00 p.m.

Capacity of the ports for truck trailers: 450

Capacity of the ports for complete trucks: 40

Capacity of the ship: 235

Capacity of the Fernetti Terminal for Turkish trucks: 150

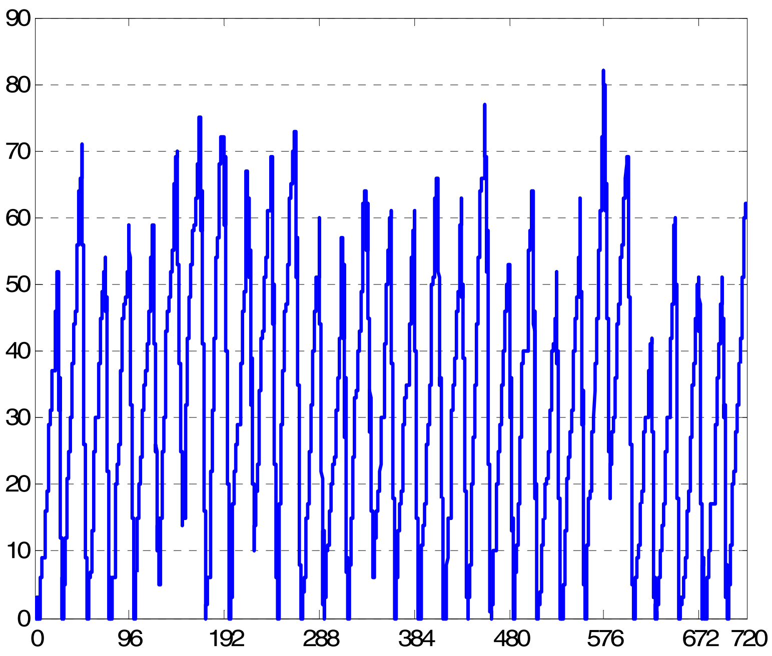
# The simulation results

- The performed simulation run is of one year.
- We show the utilization of the port, the Fernetti terminal, the B-south route in two ways:
  - the daily utilization during one month showing the variations,
  - the average utilization obtained in one year

# Simulation results

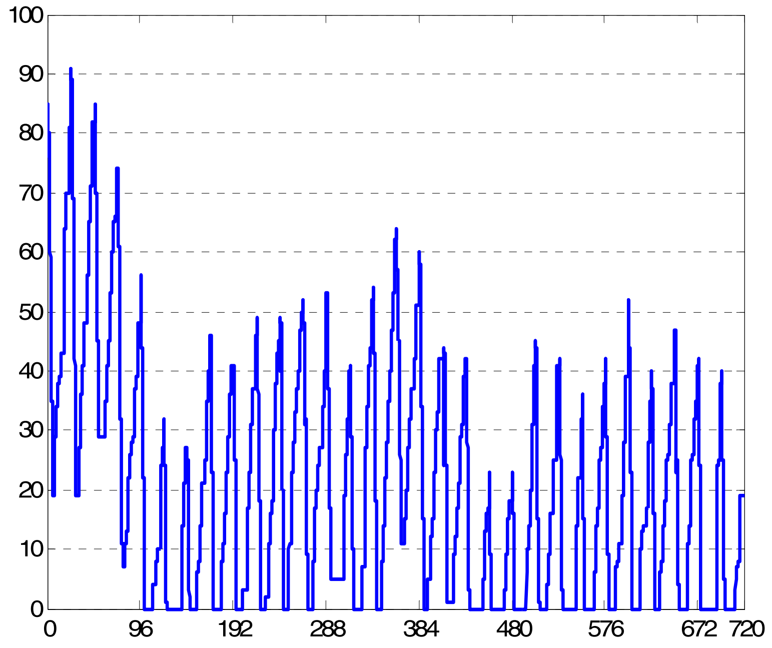
## The ICT integration does not affect the Fernetti terminal utilization

**Actual situation**




**Average utilization: 31.35**

**With ICT integration**

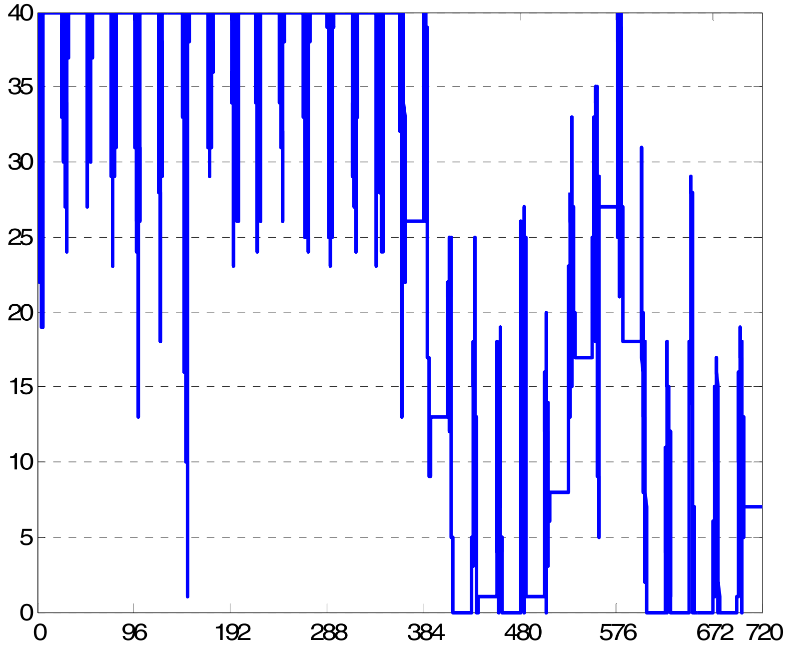



**Average utilization: 32.78**

# Simulation results

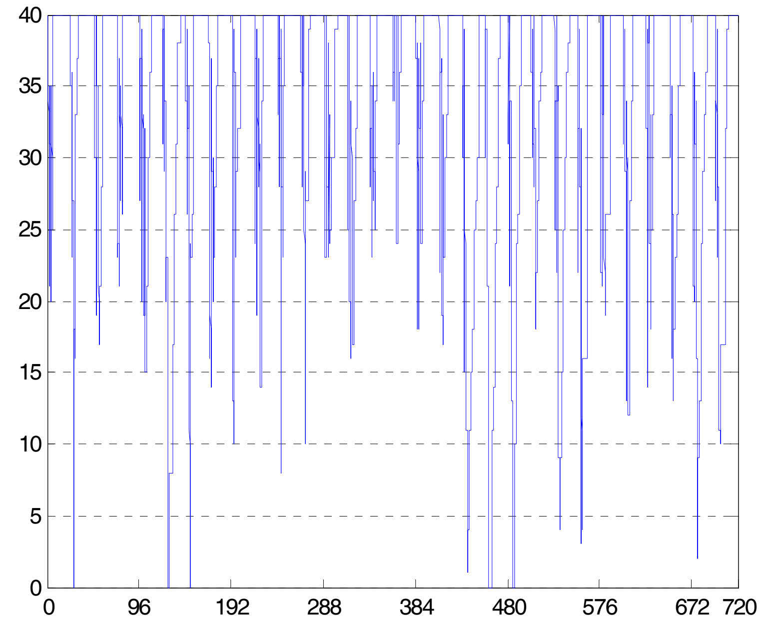
**The port utilization by the complete trucks increases with ICT integration**

**Actual situation**




**Average value: 24.61**

**With ICT integration**

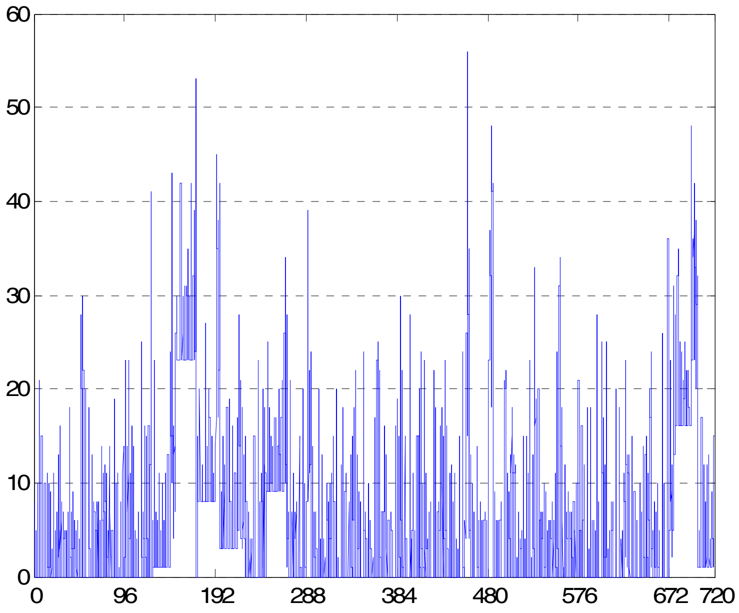



**Average value: 33.80**

# Simulation results

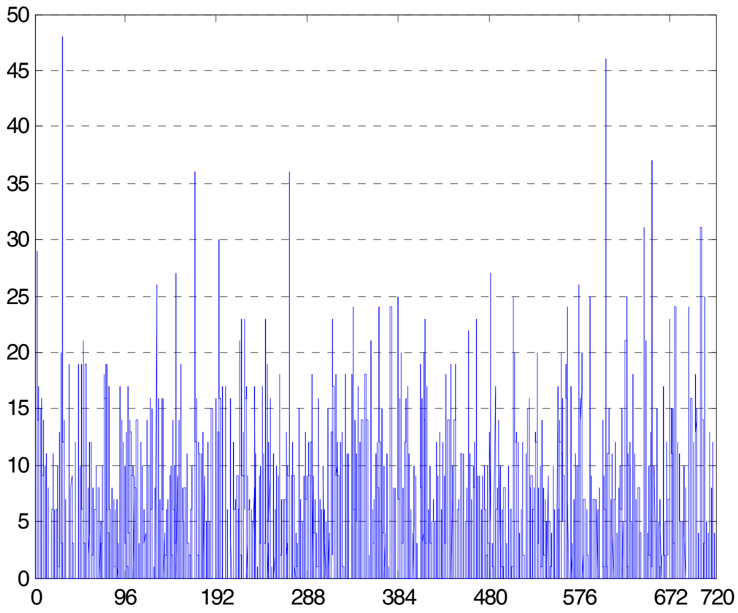
**However the B-south route utilization decreases (all trucks)**

**Actual situation**




**Average value: 16.99**

**With ICT integration**




**Average value: 2.96**

# The traffic performance index

We consider the subsets of transitions modeling the paths of the trucks $T_H$

We associate with each transition $t_i \in T_H$ the length $L(t_i)$ of the corresponding highway.

The average traffic cost $C$ is:

$$C = \sum_{t_i \in T_H} TR(t_i) \cdot L(t_i) \cdot A \cdot S \ [€/\text{year}]$$

where $TR(t_i)$ is the average throughput of transition $t_i$, $A$=8760 h/year is the number of hours in one year, while $S$ is the cost in €/km associated to one truck.

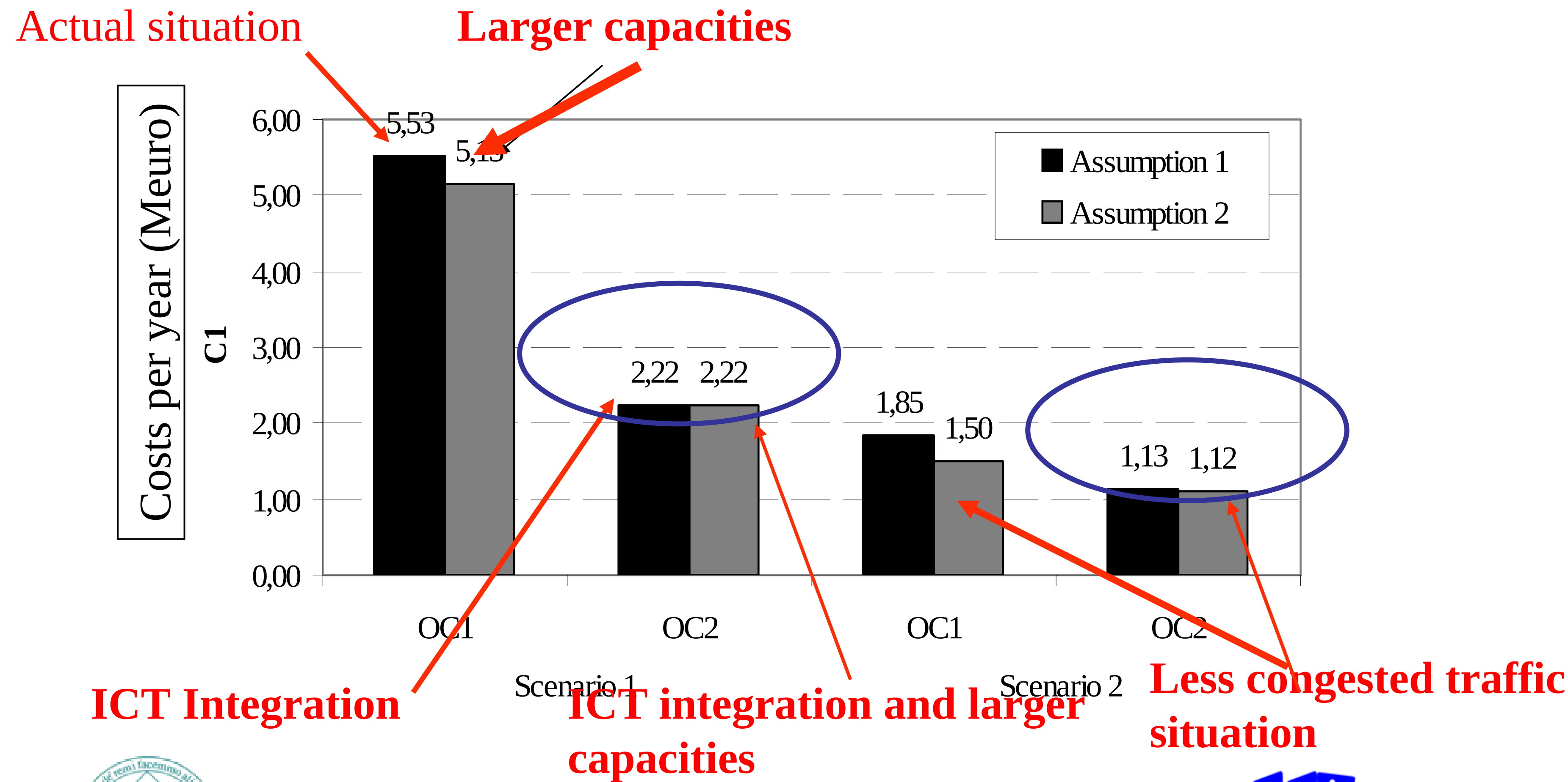
# Simulation results

| | Present situation | With ICT integration | % difference |
|---|---|---|---|
| Average traffic cost per year: (Cumulative cost for all trucks) | 1.192.761,6 | 1.133.894,4 | -4,94% |
| Lead time: (Average waiting time of complete trucks) | 14,6 hours | 10,9 hours | -25,34% |

**Using a simplified model, the system is analyzed in four operative conditions**

- The actual management of the port logistics (the actual capacities of the port and of Fernetti terminal, no information about the port and ship occupation).
- Larger capacities of the port and Fernetti terminal (no information about the port and ship occupation)
- ICT integration (the actual capacities of the port and of Fernetti terminal).
- Larger capacities of the port and Fernetti terminal with ICT integration

# Simulation results



# Using Information and Communication Technologies in Intermodal Freight Transportation: a Case Study

- The case study (analyzed in the frame of the EURIDICE Project) shows the benefits of ICT in typical interactions of cargo with authorities and infrastructure operators

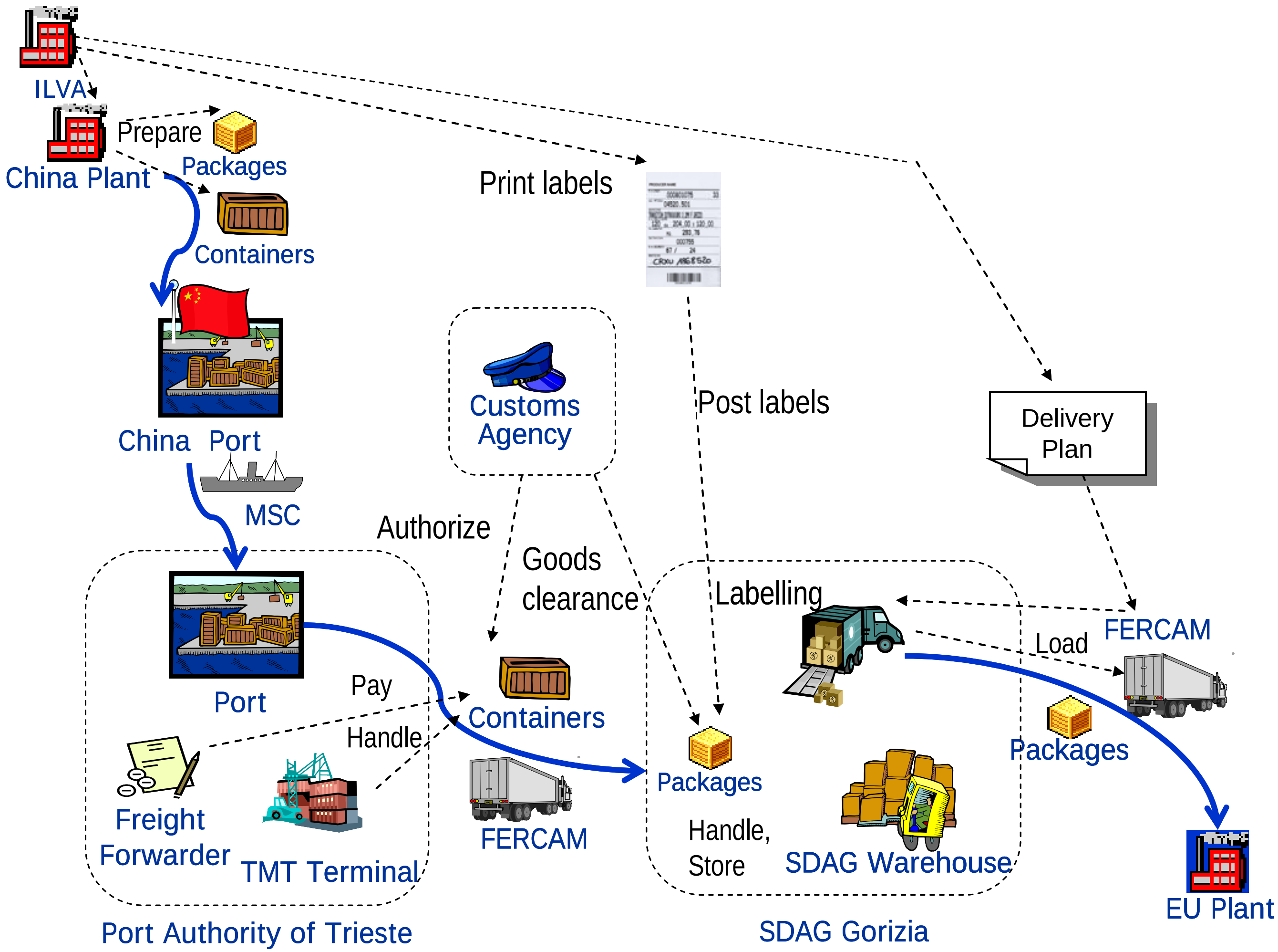
- transport of glass sheets coming from China and arriving to the Port of Trieste (Italy) and the intermodal terminal SDAG in Gorizia (Italy).

- **Intelligent cargo** connects itself to logistics service providers, industrial users and authorities to exchange transport-related information and to perform specific functions.

# Using Information and Communication Technologies in Intermodal Freight Transportation: a Case Study

- The system is simulated by a discrete-event simulation in Arena environment.
- the simulations compare the interactions among cargo, authorities and infrastructure operators in two cases.
- The first case (**As is**) reproduces the current organization in which the flows of material and information are completely disconnected.
- The second case (**to be**) describes a new proposed solution: efficient utilization of infrastructures, both singularly and across territorial networks (e.g., port terminals synchronization with rail and road connections) and to contain the impact of logistic infrastructures on the local communities, reducing congestion and pollution caused by the associated freight movements.

# A case study


ILVA
China Plant
Prepare
Packages
Containers
Print labels
China Port
MSC
Customs
Agency
Post labels
Delivery
Plan
Authorize
Goods
clearance
Labelling
Load
FERCAM
Port
Pay
Containers
Handle
Packages
Freight
Forwarder
TMT Terminal
FERCAM
Handle,
Store
SDAG Warehouse
EU Plant
Port Authority of Trieste
SDAG Gorizia

# First case: “as is”

- 1*a*) **Production phase**
- 2*a*) **Shipping phase**: the load is shipped by the shipping company. During this phase, a set of documents is transferred to Customs and contains information about all the goods in the ship.
- 3*a*) **Unloading phase** in the port.
- 4*a*) **Payment phase**: the freight forwarder receives the information regarding units and packages inside them and shipping tariffs are paid in relation to the quality and quantity of the goods.
- 5*a*) **Authorization phase**: the freight forwarder and the customs authority prepare the transportation documents to authorize the exit of the containers from the port area.
- 6*a*) **Transportation phase**: after executing the payment and authorizing phases, the goods are loaded on trucks and transported by the carrier to the truck terminal of Gorizia.
- 7*a*) **Unloading phase in SDAG**.
- 8*a*) **Customs clearance phase:** depending on the quality and quantity of the goods, customs tariffs are paid. Customs clearance operations are quite slow to execute and they are carried out by the freight forwarder that prepares the customs duties bill.
- 9*a*) **Warehousing phase:** goods are managed by SDAG. Current information flow requires that SDAG personnel stick labels on packages. Now labels are produced and posted from Verona before the goods arrival.
- 10*a*) **Loading phase in SDAG:** the freight forwarder communicates to SDAG by phone or by e-mail the delivery plan and SDAG loads the goods on trucks depending on the packing list.

# Second case "To be"

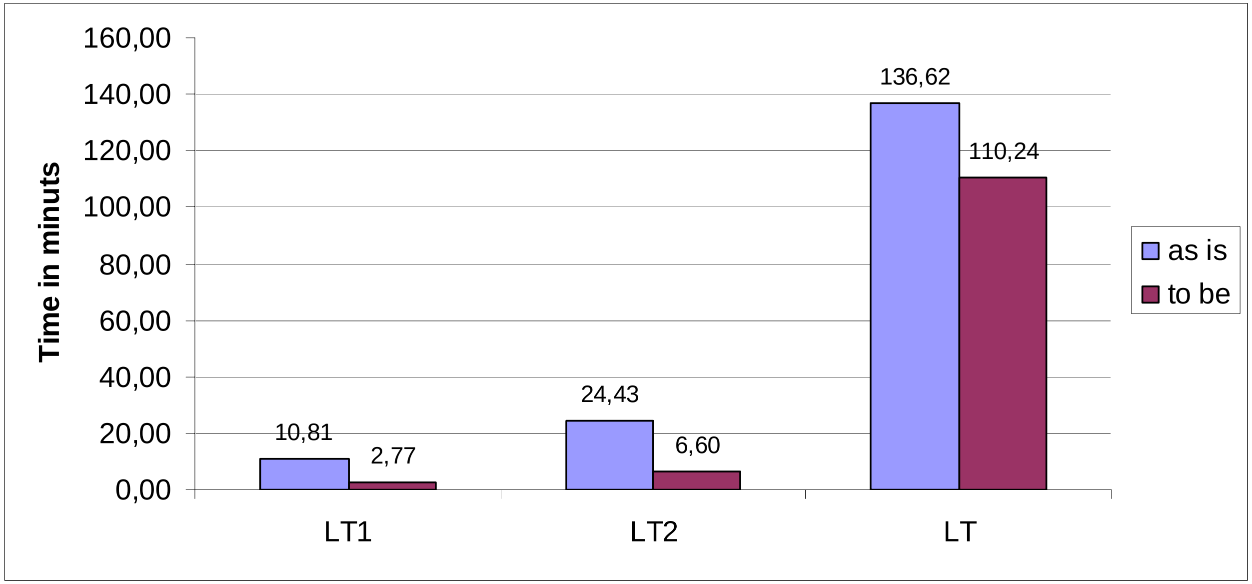
- 1*b*) **Production phase**: Smart tags are created for containers and packages and they are directly linked to objects in the platform. In this way the hierarchy among IC items is automatically created.
- 2*b*) **Shipping phase:** information that are collected in the picking list for loading, the "manifest", is requested in order to allow the unloading of goods in the Port of Trieste. This document is generated directly via cargo-ship interaction, possibly using satellite communications.
- 3*b*) **Unloading phase in the port.**
- 4*b*) **Payment phase:** shipping tariffs are automatically paid by the direct interaction on the hosted service platform with the bank system.
- 5*b*) **Authorization phase:** thanks to the cargo intelligence and the hosted services all the data for creating the authorization documents are in the platform and the process is automatically done.
- 6*b*) **Transportation phase**.
- 7*b*) **Unloading phase in SDAG**: once arrived in SDAG, containers do not wait for the authorization to enter in SDAG because their status is already known and updated.
- 8*b*) **Customs clearance phase**: goods are automatically cleared communicating with the platform and with the custom authority system.
- 9*b*) **Warehousing phase**: containers are opened by SDAG personnel and packages are managed in the warehouse. Packages are already labeled and a hierarchy between packages has been created, so it is possible to trace all the information about goods from the beginning of the flow.
- 10*b*) **Loading phase in SDAG**: the delivery plan is present in the platform and so it is available to all the involved actors in this phase and finally goods are transported to destination.

# Performance indices

- **average lead time *LT1*:** average time interval elapsed from the unloading phases in the port (3*a* and 3*b*) till the authorization phases (5*a* and 5*b*);
- **average lead time *LT2*:** average time interval elapsed from the unloading phases in SDAG (7*a* and 7*b*) till the warehousing phases (9*a* and 9*b*);
- **total average lead time *LT*:** the time spent by the goods from the unloading phases in the port (3*a* and 3*b*) till the warehousing phases (9*a* and 9*b*).

# Simulation results

- The system is modelled as a Discrete Event model that is implemented in the Arena environment.
- Index evaluation performed by a long simulation run of 15.768.800 t.u. (transient period of 43.200 t.u.)
- 50 independent replications with a 95% confidence interval
- the half width of the confidence interval, being about 1.5% in the worst case, confirms the sufficient accuracy of the performance indices estimation.




The average lead times in the two cases: “as is” and “to be”

# Conclusions

- Applications of Information and Communication Technology (ICT) tools to Urban Traffic  Control, Intermodal Freight Transportations, Itermodal Transportation Networks.
- In any case integrating ICT into the system leads to a more efficient system management
- The ITS is modeled in discrete event system frameworks
- Some simulation studies allows us to evaluate performance indices that show the benefits obtained integrating ICT into the systems (in terms of system resources utilization and overall cost index).

# Conclusions

- **Urban Traffic control:** the controller selects on line the duration of the phases in the signal timing plan in order to optimize an objective function. The number of vehicles in the links at the beginning of the semaphoric cycle is drastically reduced

- **Intermodal transportation network of the Port of Trieste and the Fernetti Intermodal terminal:** An integrated ICT-based system is applied.
  - The traffic congestion and the connected costs are reduced.
  - A more efficient system management in terms of system resources utilization and overall cost index is obtained
  - The alternative solution of increasing the system resources are non effective.

- **Intermodal Freight Transportation**: application of the ICT tools to the transport of sheets coming from China and arriving to the Port of Trieste and the intermodal terminal of Gorizia
  - A more efficient system management is obtained
  - the system lead times are drastically reduced.

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# Impact of the ICT on the management and performance of Intelligent Transportation Systems

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