LIMOS

Laboratoire d'Informatique, Modélisation et Optimisation des Systèmes

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SMART CITIES:
Old Problems/New Paradigms

Classical O.R and New Paradigms:

Innovative Urban/SubUrban Mobility

Of Smart Cities

Old Problems/New Paradigms: Innovative Mobility

Summary

I. O.R Trends, New Paradigms
II. LIMOS and Innovative Mobility
III. A reference problem: Dial/Ride
IV. Standard Methods and Benchmarking
V. Extensions toward New Contexts
    V.1. Mixing Decision Levels
    V.2. Non Standard Criteria
    V.3. Non Standard Contexts

Old Problems/New Paradigms

I. O.R Trends, New Paradigms

O.R -> born at the end of the 40's, from the needs of U.S Army;
Centralized and static point of view;
Mainframes; High human computing costs;
No web, no P.C, no mobile communication devices

⇒ Linear Programming (Von Neuman/Dantzig) -> Graph Theory (Berge), Complexity (Cook) + MIP (Gomory)
⇒ Polyhedral Theory (Edmonds).

Old Problems/New Paradigms

Year 2010 ?

Many things have changed!

Technology: web services, distributed systems, datamining, mobile communication, high performance computing
Society: democracy requirement, safety, security, environmental concerns
Economics: delocalization, outsourcing, complex supply chain, increasing weight of Finance

=>

New Problems? New way of setting old problems?
Taking into account interactions, safety requirements, economical stability.
Taking advantage from new technologies.

Old Problems/New Paradigms

=> Extensions toward New Contexts

- Mixing Decision Levels:
  - Linking Routing, Pricing and Subsidizing.
  - Linking Routing and Packing.
- Non Standard Performance Criteria:
  - Robustness and Stochastic Complexity.
  - Genericity.
  - Reliability.
- Non Standard Contexts:
  - Collaborative Planning.
  - Dynamic Scheduling.

LIMOS: Innovative Mobility

II LIMOS and Innovative Mobility

LIMOS, UMR CNRS/UBP 6158, CLERMONT-FERRAND

- **MAAD:** ***Decision Models and Algorithms***
- **SIC:** ***Information and Communication Systems***
- **SP/ROGI:** ***Production Systems, O.R for Industrial Engineering***

+

- **Transversal Actions:**
  - ***STIC-Mobility***
  - ***STIC-Environment***

- **LABEX Participations:**
  - **Clervolc: Seismic/Volcanic Monitoring**
  - **IMOB3: Innovative and Intelligent Mobility**

LIMOS: Innovative Mobility

Partnerships: **QUEBEC, HIT HARBIN, UT Compiègne, Centrale LILLE, SNCF…**

Related Projects: **Managing Decision inside New Generation Mobility Services**

Context: need for more flexibility

- Growth of oil prices
- Environnmental issues; City congestion?
- Increasingly old population.

Demand: mixing reactivity with mutualization, taking into account multimodality

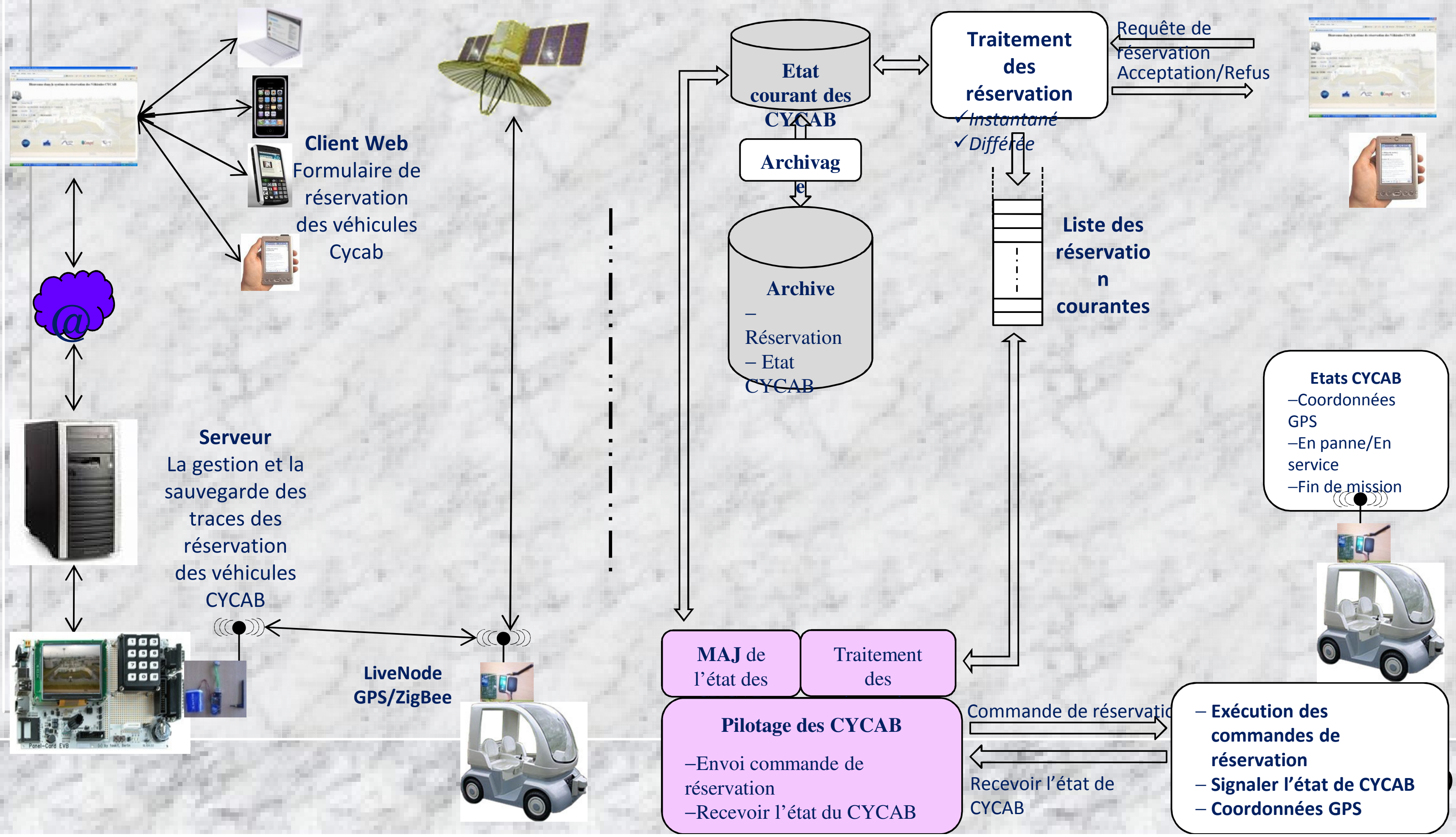
LIMOS: Innovative Mobility

New Generation Mobility Services

- **CYCAB/VIPA Real Time Dial/Ride**
- **Ad Hoc Shuttle Fleet** management
- **AUTOLIB-Vehicle Sharing** Intelligent Design and Monitoring
- **Intelligent Co-Transportation Systems**
- **Internal Logistics** Optimization

LIMOS: Innovative Mobility

1. Cycab Dial/Ride/ Cycab Autolib



Client Web
Formulaire de réservation des véhicules Cycab

Serveur
La gestion et la sauvegarde des traces des réservation des véhicules CYCAB

LiveNode GPS/ZigBee

Etat courant des CYCAB

Archivage

Archive
– Réservation
– Etat CYCAB

Traitement des réservation
✓*Instantané*
✓*Différée*

Requête de réservation

Acceptation/Refus

Liste des réservation courantes

Etats CYCAB
–Coordonnées GPS
–En panne/En service
–Fin de mission

MAJ de l'état des

Traitement des

Pilotage des CYCAB
–Envoi commande de réservation
–Recevoir l'état du CYCAB

Commande de réservatio

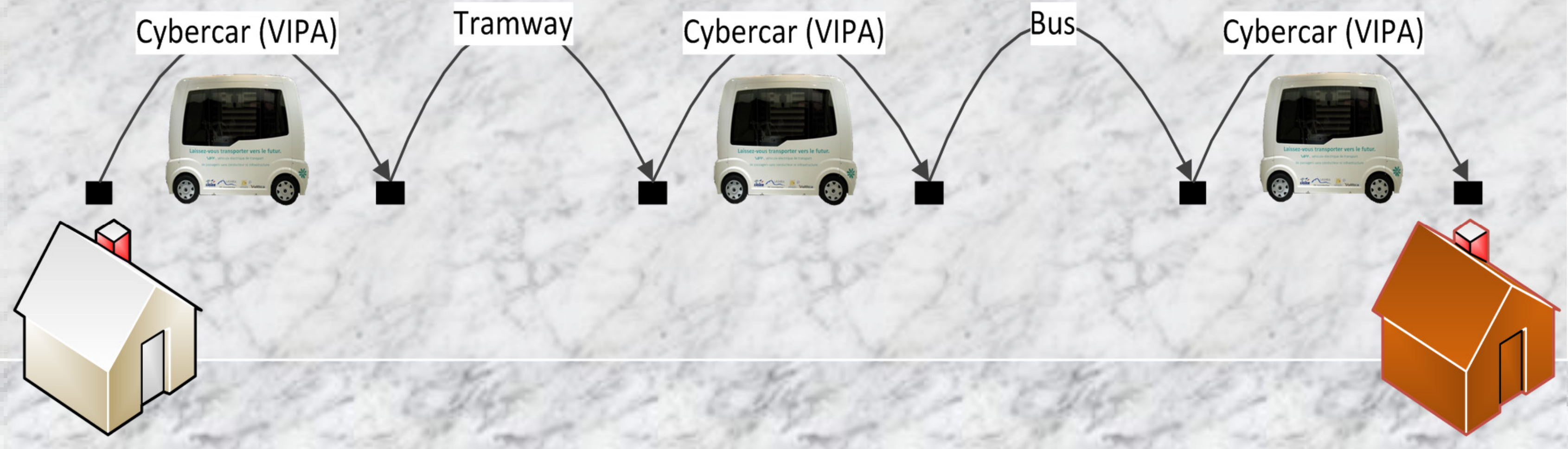
Recevoir l'état de CYCAB

- **Exécution des commandes de réservation**
- **Signaler l'état de CYCAB**
- **Coordonnées GPS**

LIMOS: Innovative Mobility

- Used on short distances
- Integration into the intermodal transport of the future

- Target
  - Large Parking Lots
  - Large Factories
  - Airports, Train Stations
  - Hospitals, Campuses
  - Business Centers



LIMOS: Innovative Mobility

- 2 Criterions
  - Economic (for the operator) :
    - Number of used vehicles and total distance,
    - VIPA Load Rate,
    - Number of accident (reliability),
  - Service (for the user) :
    - Connection speed,
    - Connection success rate (reliability).

2. AUTOLIB-Vehicle Sharing Intelligent Design and Monitoring

VIPA Fleet for AUTOLIB System ->
Relocation through wireles convoys

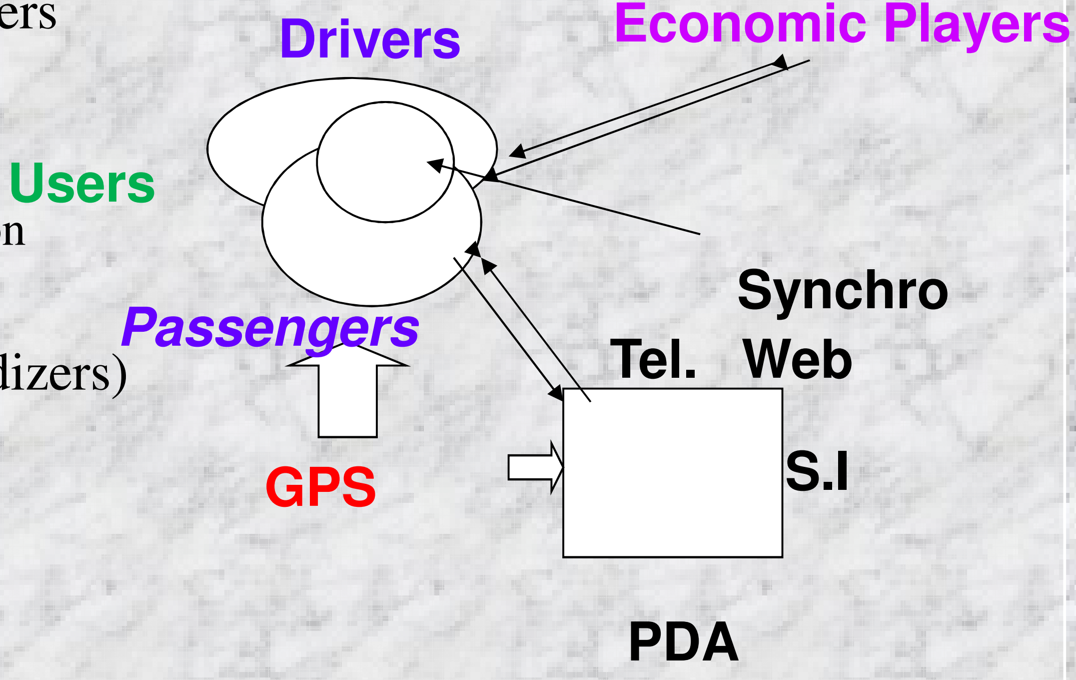
Input: Expected Demand Space-Time Distribution
Output: ***Relocation Strategy***.

- *Relocation Signal*: When? .
- *Relocation Process*: how many convoy leaders?
  Process Duration? Convoy Routing?
  Convoy Making? Inter-Convoy exchanges?

Analogy with ***Ambulance Relocation***
(Gendreau, Brotcorne, Laporte, Semet (2003, 2004)

3. Co-Transportation Systems

- Usagers: drivers and/or passengers
- Vehicles (driver owned):
  - Simple
  - Synchro (ad hoc communication
  - Traceability devices)
- Socio-economic players (subsidizers)
- Servicer: intelligent web site +
  - Geolocalization/Mobile Com.
  - Infrastructure.



A Reference Problem: DARP

III A Reference Problem: the Dial and Ride Problem (DARP).

Input.

V: Vehicle set; $v \in V$ -> C(v) = Capacity characteristics, S(v) = Speed characteristics, $\Delta(v)$ = Availability

K: Object Set; C(v) is a constraint on integer valued K-vectors

X: Demand Set; $x \in X$ -> (o(x), d(x)) = origin/destination pair, T(x) = Time Window, D(x) = Load = Integer valued K-vector

G = (N, A) = Transit Network; M = Related Shortest Path Distance Matrix

Output.

v in V -> a *timed* route $\Gamma(v)$: every node s in $\Gamma(v)$ is provided with arrive-time, leave-time: time-space, load and unload: X

A Reference Problem: DARP

Output.

v in V -> a *timed* route Γ(v): every node s in Γ(v) is provided with arrive-time, leave-time: time-space, load and unload: X

Constraint.

***Capacity constraint*: at any instant t, current load L(v, t) of vehicle v compatible with capacity constraint C(v)**

***Time windows constraint*: any instant demand x is loaded and unloaded according to T(x)**

***Availibility Constraint*: running time of vehicle v is included into Δ(v)**

***Speed constraints*: for any vehicle v, any consecutive nodes s1, s2 in Γ(v), arrive-time(v, s2) – leave-time(v, s1) is compatible with M and S(v)**

***Load/unload time constraint*: for any vehicle v, any node s in Γ(v), leave-Time(v, s) – arrive-Time(v, s) compatible with T(x) and D(x), x loaded and unloaded in s.**

A Reference Problem: DARP

Performance.

Mix (Multicriterion) = Card(Active-Vehicle), Σ_v Length(Γ(v)), Σ_x Duration(Γ, x)).

Extensions

- ***Vehicle Preemption*: a demand x may be routed from o(x) to d(x) through several vehicles.**
- ***Load Preemption*: the load D(x) may be split into several sub-loads, which are routed independently.**

Static Versus Dynamic .

- Static: all data are known in advance;
- Dynamic: data come as a dataflow; current roadmap of every vehicle is taken into account.

Remark: most often, time windows flexibility is maintained

A Reference Problem: DARP

IV. Standard Methods and Benchmarking.

***Simplified Framework**: Nodes are splitted according to the demands: any o(x), d(x) is identified with a specific node.*

A Simple MIP model (Not Practical...!).

Variables $t = (t_n, n \in N)$, rational, $z = (z^v_{nm}, n, m \in N, v \in V)$ with {0, 1} values:

$z^v_{nm} = 1$ means arc (m,n) is part of route $\Gamma(v)$

t_n = time at node n, identified with some demand load/unload, is "serviced"

p_n = load at node n, for the vehicle v which services n

Constraints:

- z represents a partition of N into circuits (*Tour Constraints*)
- $\Sigma_v z^v_{nm} = 1 \rightarrow t_m - t_n \leq M(n, m)$; (*Logical Time Constraints*)
- $\Sigma_v z^v_{nm} = 1 \rightarrow p_m - p_n = \mathrm{Load}(n)$; (*Logical Load Constraints*)
- $t_{o(x)}, t_{d(x)}, t_{d(x)} - t_{o(x)}$ inside related time windows;
- $p_{o(x)}$ compatible with capacity constraints.

Goal: Minimize $\mathrm{Cost}.z + \Sigma_x t_{d(x)} - t_{o(x)}$.

A Reference Problem: DARP

Greedy Insertion Scheme:

JAW (86), Xiang, Xu, Chen (2006), Toussaint/Quilliot (2010)
Demands are randomly ordered, and inserted according to this order into current partial routes $\Gamma(v)$, v in V
(filtering process through constraint propagation)

Local Search and Metaheuristics scheme (Tabu, Simulated Annealing…)

- Ropke, Cordeau, Laporte (2006): Tabu Heuristics
- Calvo, Colorni (2006): Heuristics Insertion/Assignment
- Psafaratis, Sexton, Bodin (80, 79, 85, 95)

Local operators:

- *Exchange*: 2 demands are exchanged between 2 tours
- *Shift*: 1 demand is shifted from one tour to another one;
- *Internal-Shift*: 1 demand is relocated inside a given tour

A Reference Problem: DARP

Branch/Bound, Branch and Cut:

Ropke, Cordeau, Laporte (2001, 2003);
Exact results up to 25 demands
Branching Process: on the variables z^{v}_{nm} of the PLNE representation
Bounding process: using the PLNE representation + ad hoc cuts

Toussaint/A.Q (2010)
Greedy Insertion + Branch/Bound
Branching Process + Constraint Propagation:
    Demand x in tour v?
    Efficient if sharp time window constraints.

A Reference Problem: DARP

Dynamic Flow (Flow over Time):

Recall: Flows/Multicommodity Flows

Network G = (Z, E)

Flow z = E (arc) indexed vector such that for every node x, $\Sigma_{e \text{ enter } x}\, z_e = \Sigma_{e \text{ out } x}\, z_e$, (**Kirshoff Law**)

Kirshoff *Law may be adaptated in order to make z express the routing of a given quantity from one node to another*

Multicommodity Flow*: collection of flow vectors, whose values identify distinct class of objects*

Dynamic Flow **Framework**: nodes are (pair (n, t), n in N, t in the time space)

-> *Explicit* or *implicit* representations

DARP: Vehicle Flow + Multicommodity Demand Flow, tied with coupling capcity constraints (Master/Slave scheme) -> Local operators related to the flow/multicommodity-flow machinery -> Cancelling circuits/cycles (Bauman (2007), Skutella (2006), Fleischer (2000, 2001), Ford/Fulkerson (1962), Martens, Salazar(2007))

A Reference Problem: DARP

Clustering and Column Generation: Ropke, Laporte (2001, 2003), Desrosiers, Soumis, Dumas (89), Vigo, Toth (96), BERLIN-TELEBUS, Bjorndorfer 97: Clustering.

Column Generation: main vector indexed on the set of all the possible tours ->induced subproblem: Generating efficient tours.

Clustering: **master vector** index on the set of X subsets, i.e: which demands are handled by the same vehicles; **slave object**: the tour related to some subset A of X, which is part of the cluster. **Column generation** -> generating the ad hoc subsets A.

A Reference Problem: DARP

Dynamic Context: *(few studies)*

- BERLIN-TELEBUS, Bjorndorfer 97: Extraction of Seed Trajectories
- Madsen, Rygaerd, Ravn (Copenhagen TAD System, 1995): Adaptation of Jaw Insertion Techniques
- Todorovic, Radijonovic (2000): Application of Fuzzy Logic Rules
- Colorni, Righini (2001): Real Time Clustering through Local Transformation
- Coslovitch, Pesenti, Ukovitch (2006), Fabri (2007): insertion rules + 2-opt like reoptimization heuristics

A Reference Problem: DARP

Remarks about usual dynamic models.

Models: dataflows, algorithms take into account current roadmaps of the vehicles;
Demands: n = 25 to 900, no focus on the real time constraints induced by communication and supervision;
What about taking into account stochastic demand distribution?
Soft management of real contraints: time windows remain open all throughout the process, until the user is serviced.
What about system/user communication
and « rendez-vous »mechanism?
Dynamic most often means « perturbation handling »: what about failure (vehicle delay, user give up…)?

A Reference Problem: DARP

Static/Dynamic DARP: Benchmarking.

TSP LIB, Laporte Cordeau Instances, ... -> Toy Problem -> many academic test beds

A few word about instances generation:

Fagin Theorem: The theoretical values of randomly generated instance with non null density {0, 1} of a problem expressed according to the 2 order monadic logic formalism converge almost surely (either to 1 or to 0).

Courcelle Theorem: 2 order monadic logic problems with bounded clique width are time-polynomial

A Reference Problem: DARP

In most cases, testbed instances => generated according to the 2 order monadic logic formalism.

=> They are strongly biased.

Experiments -> Testing ad hoc Indicators on common testbeds:

- ⇒ *parallelism rate*: number of demands which may be simultaneously handled;
- ⇒ *Dispersion rate* : variance of o(x), d(x) distribution....

We remark: very concentrated distribution.

⇒ Generating meaningfull testbeds is a difficult game.

Example: Cordeau/Laporte instances -> very strong temporal constraints -> getting initial solution is difficult -> advantage to constraint propagation + “repairment” heuristics.

Dynamic Case: what about dataflow generation, and lauching of the recomputation process? What has to be measured?

DARP: New Paradigms

V. DARP: New Contexts mean New Paradigms.

- **Mixing Decision Level** **(routing/packing, economical management)**
- **Non Standard Criterion** **(reliability, robustness…)**
- **Non Standard Contexts** **(collaborative, reactive…)**

DARP: New Paradigms

V.1. Mixing Decision Levels.

Linking Routing and Packing: loads are 2D or 3D-objects, with geometrical characteristics -> Non trivial testing of capacity constraints, time consuming loading and unloading operations

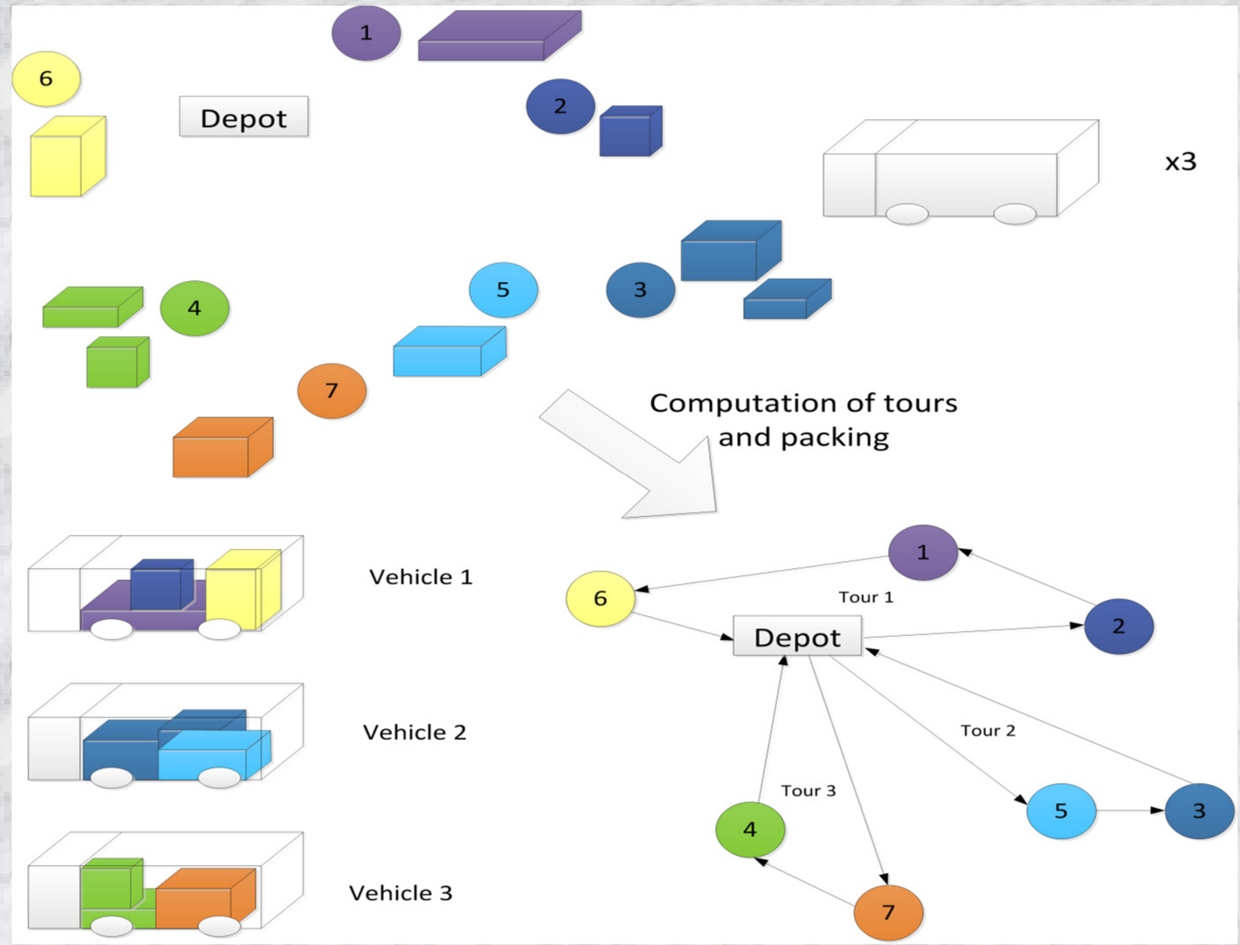
-> 3L-CVRPV (Duhamel, Lacomme, Quilliot, Toussaint)

An approach: introducing learning devices (SVM, Neural Network..) in order to deal with the *weak* and *strong* feasibility of 2D and 3D-packing

At stake:

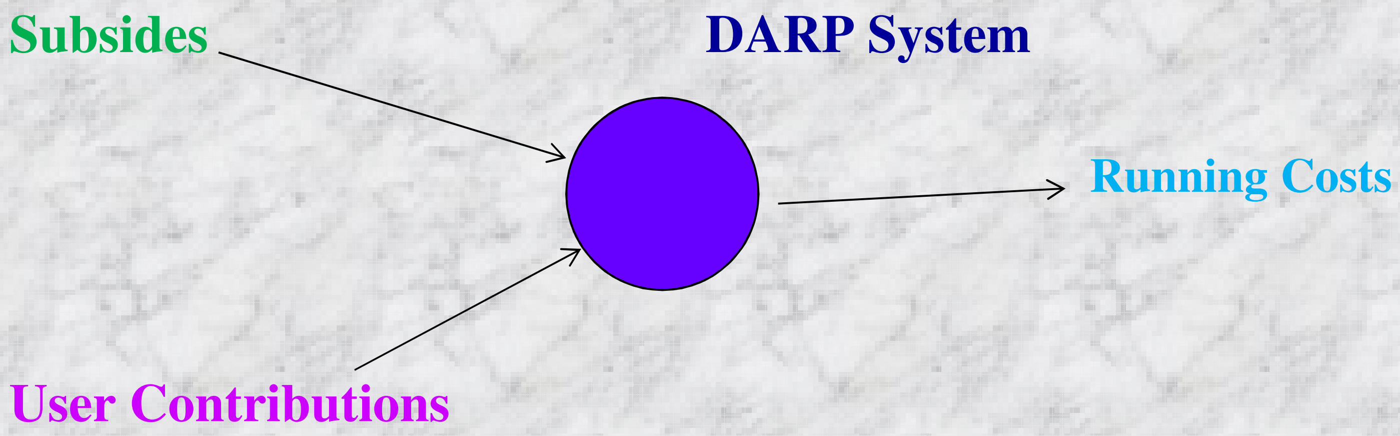
- **Simultaneously dealing with distinct granularity levels;**
- **-> Getting fast approximation results for complex problems**
- **Ensuring consistency of linked models -> Getting fast approximation results for complex problems**

DARP: New Paradigms



DARP: New Paradigms

Linking Routing/Pricing/Subsidizing.



Subsides

DARP System

Running Costs

User Contributions

Routing policy + Expected Demand -> Expected Costs

Prices + Routing Policy -> QoS -> Expected Demand

DARP: New Paradigms

Question: which prices, which subsides?

Approach:

(1). **Cooperative Game Framework** (*Network cooperative Games*: Granot, Maschler 1998, Tamir 1993) *Cooperative Games with Elastic Demands*: Bendali, Quilliot 2005 => Avoiding a user subgroup to set its own TAD service

(2). **Master Slave (bilevel) Decomposition Scheme**:

- Main Problem -> Prices
- Slave Problem -> Designing a routing policy for a user subgroup
- **Technological Gap: *Evaluating Price/QoS Elasticity of Demand***

DARP: New Paradigms

V.2. Non Standard Criteria.

Robustness/Stochastic Complexity.

At stake: Adaptability of the solution when it comes to implementation .

Example: DARP (dynamic/Static) => Current Schedule σ: which ability to take into account future demands, unexpected delays and "rendez-vous" failure?

Difficult problem: Currently suffering from a deficit of formal approach.

DARP: New Paradigms

The basic point: the problem cannot be handled according to its current representation

- **Input data**: must involve a formal and quantified representation of the events: ad hoc language;
- **Output Object**: must take the form of:
  - *A set of constraints and decision rules;*
  - *A strategy (decision tree) on those constraints*

Example: Simple DARP

Schedule: a set Λ of additional constraints: (Un)Load(x) precede (Un)Load(y) on vehicle v + implicit priority rule.

Schedule Strategy (mixed schedule): set of decision rules.

Rule: Instant t, State S contain pattern E

Finished tasks A, Currently running task B |= Modify Λ

A problem: part the schedule language semantics must be shared by the users.

DARP: New Paradigms

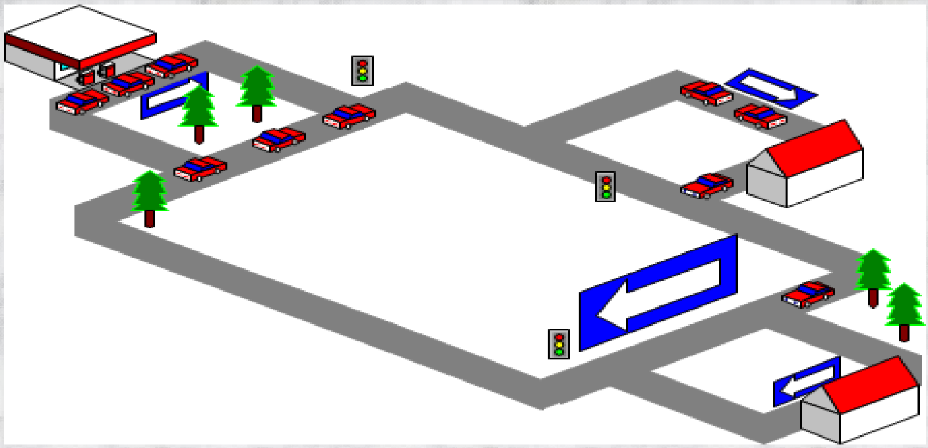
Reliability.

VIPA DARP: Avoiding “hazardeous” manoeuvring: overtaking..., avoiding schedule modifications

=> Making passenger of a given vehicle share same loading and unloading nodes.

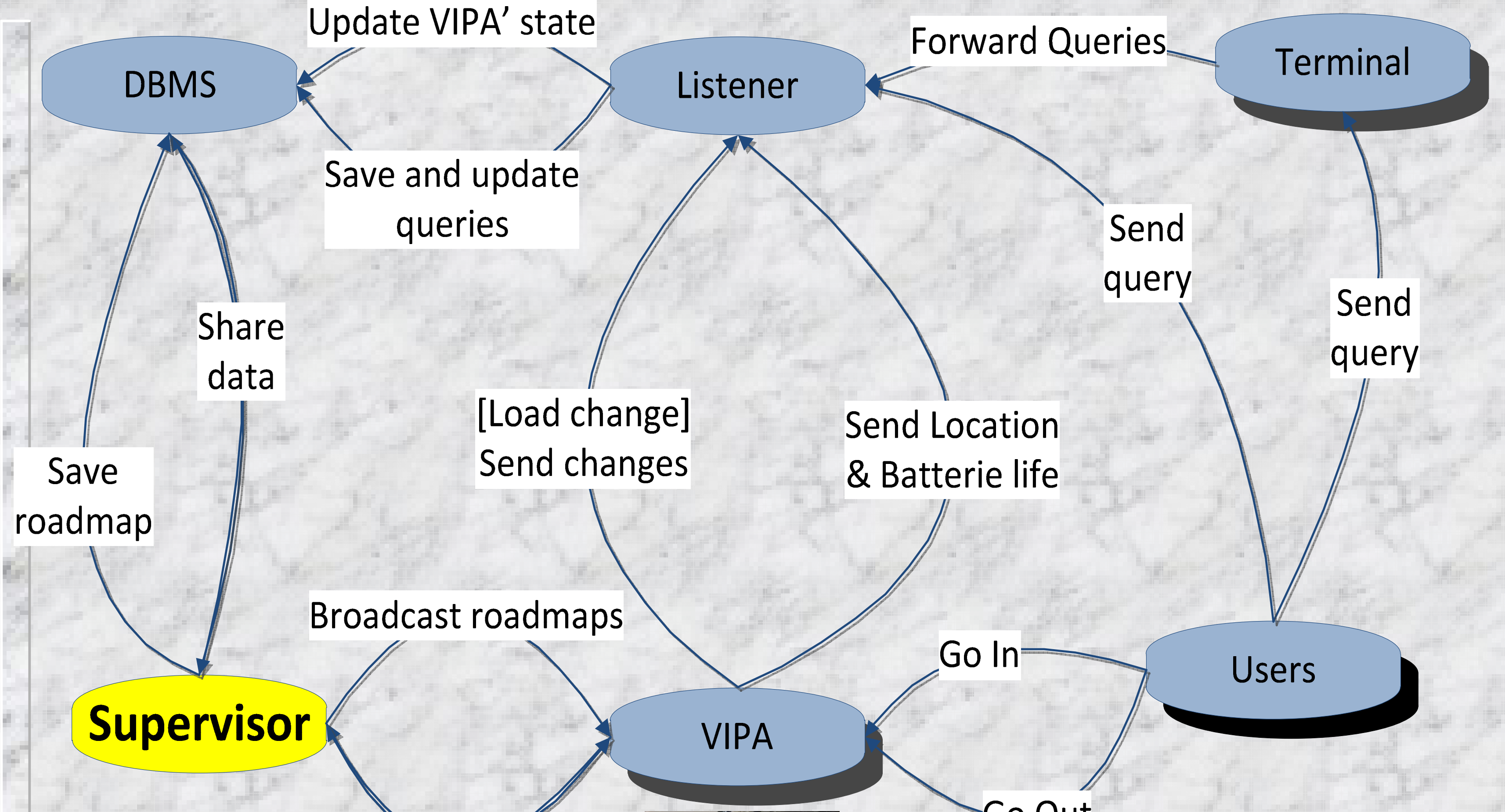
At stake: conveniently modelling reliability in a given monitoring context, and casting it into the decisional framework .

DARP: New Paradigms



- Stops for users and maintenance
- A one-way loop with outputs for stations
- Homogeneous fleet of autonomous vehicles (VIPA)
- Users ask for a vehicle via mobile phone or a terminal

DARP: New Paradigms



DBMS

Listener

Terminal

Supervisor

VIPA

Users

Update VIPA’ state

Save and update queries

Forward Queries

Send query

Send query

Share data

Save roadmap

[Load change]
Send changes

Send Location
& Batterie life

Broadcast roadmaps

Share data

Go In

Go Out

DARP: New Paradigms

Genericity.

DARP Contexts: Highly Evolutive, Continuum Dynamic/Static

At stake: Development cost, adaptability to model evolution .

Generic Framework?

- *Dynamic Flow/Time Over flow*
- *Ruled Based Systems*
- *Insertion Algorithms...*

DARP: New Paradigms

V.3. Non Standard Contexts.

Taking into account technological, organizational, societal context!

Collaborative Planning

The principle: even if you are the "boss", negociation is at the heart of any decision process

DARP? The ruler of a DARP service may not be in direct control of all the vehicles involved in the system: mix of AUTOLIB shared vehicle fleet, ad hoc shuttle fleet, "co-transportation" devoted individual cars -> Dependence on the will of other players (subcontractors), which have their own agenda and criteria.

DARP: New Paradigms

An illustration of Collaborative Planning: The Doodle.

A "master", and its partners => May be viewed as a collaborative RCPSP.

Main task: the meeting; Auxiliary tasks: the moves of the partners

Partners are at the same time resources and tasks.

Decision oriented computing devices (and related models):

- A master device $\mathcal{M}$: consider the constraints provided by the partners and schedule the meeting;
- Partners devices $\mathcal{P}_i$, i = 1..N: schedule partner i, compute constraints and transmits them to $\mathcal{M}$;

Process Main Loop:

$\mathcal{P}_i$, i = 1..N ←-----------→ $\mathcal{M}$: -> succeed or fail in computing

accept or reject the proposal

The master $\mathcal{M}$: if failure, ask some of the $\mathcal{P}_i$, to relax their constraints Else send the proposal to the partners

DARP: New Paradigms

The partners: $\mathcal{P}_i$, i = 1..N:

- If they reject the proposal, send new constraints to $\mathcal{M}$ Else: OK.

Requirements: Design a common constraint language: syntax/semantics

- Design $\mathcal{P}_i$, in such a way they compute constraints (cf Robustness)
- Handling hidden part…! It is like playing a game. Not everybody want the same thing. Ex: partner j may want the meeting without partner k.

A theoretical framework: Pricing:

- Master M, schedule σ -> Value V(σ) resulting from model $\mathcal{M}$;
- Partner i, schedule σ, Value $V_i(\sigma)$, resulting from model $\mathcal{P}_i$;

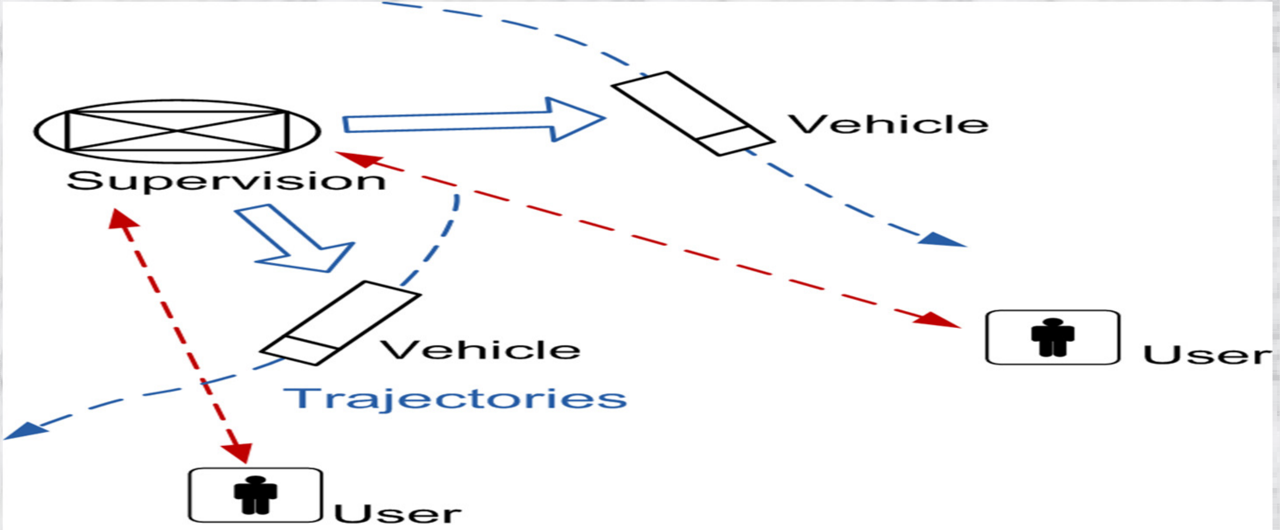
Questions:

- Which payments between M and its partners in order to make possible reaching a convenient schedule?
    - Cooperative Game Framework (Shapley, Core notion…)
    - Concurrential (non cooperative) framework? (Nash…)

DARP: New Paradigms

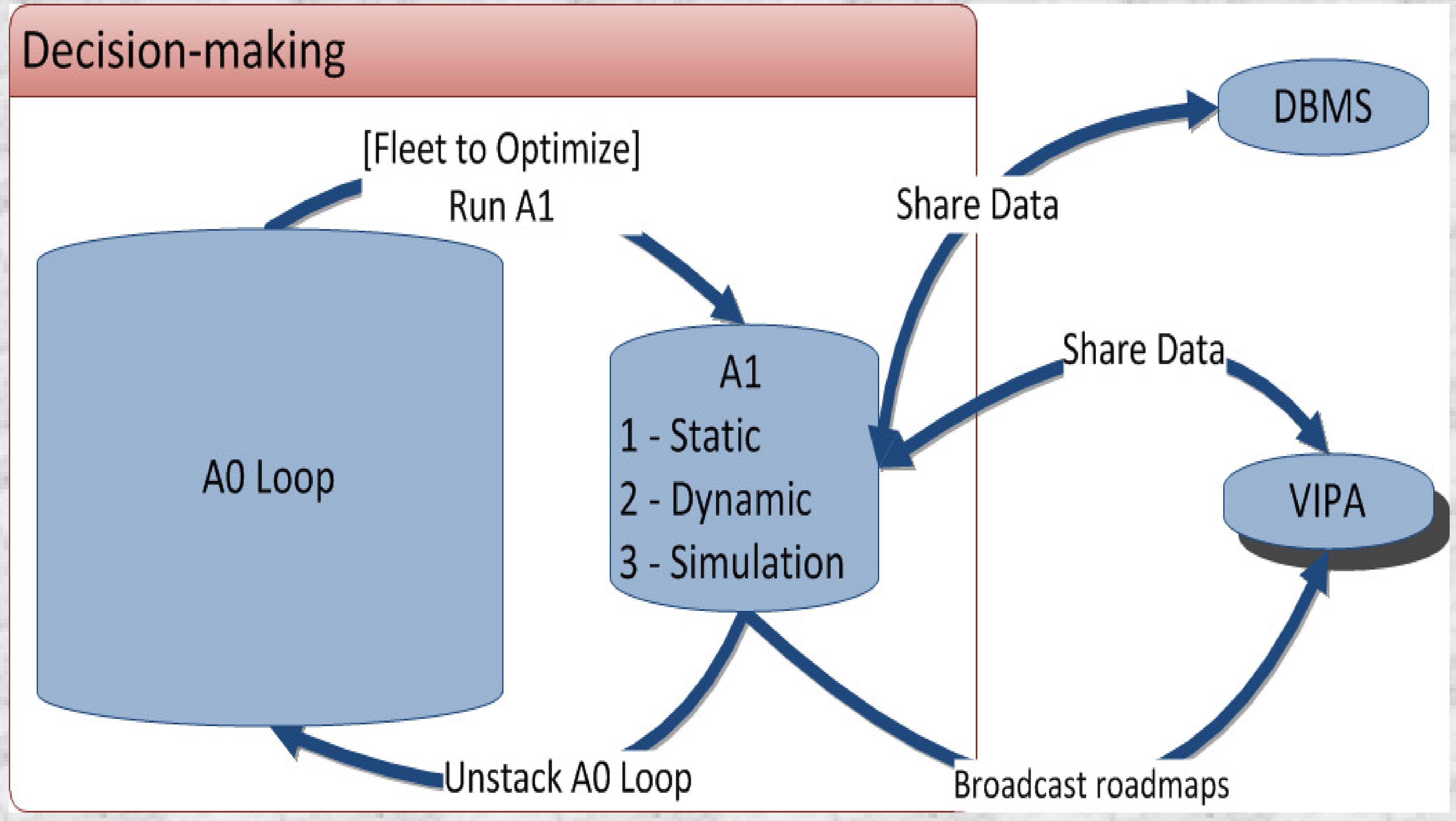
Dynamic Scheduling.

- **Real Time DARP**



Customer x (tasks) asks for service from origin node o(x) to destination node d(x), while imposing temporal constraints

Innovative Mobility



DARP: New Paradigms

Process:

Between instant t_{n-1} and instant $t = t_n$, customers ask (the supervisor or some of the vehicles: centralized/decentralized) for service;

Instant [t, t+α]: some activation process $\mathcal{A}$ decide to launch the replanification process $\mathcal{P}$;

Instant [t+α, t + α + β]: $\mathcal{P}$ compute a new planning for the vehicles, send answers to the customers: meeting proposal or rejection of the demand,

and send orders to the vehicles;

Instant [t+α+β, t_{n+1}]: vehicles and customers run their way, new demands are registers, as well as failed meetings or rejected proposals.

Requirements:

- Design algorithmic processes A and B; Models: which meaning to "*replanification*" , acceptable for users and communication system
- Adquire and conveniently model input data;
- Evaluate.

DARP: New Paradigms

The basic points:

- The stochastic dimension of the problem cannot be ignored;
- A priori evaluation must be performed while considering that the input is a stochastic process;
- A posteriori evaluation (test) must be performed through **simulation**;
- The underlying decisional model (module $\mathcal{P}$) must take into account:
    - *QoS criterion related to the meetings (waiting times…)*
    - *Safety concerns related to communication process between the systems, the vehicles and the customers (ensuring the reliability of the meetings).*

Consequence: the decisional model becomes very different from the static one, and not only a “on line” adaptation of this static model

DARP: New Paradigms

VI. Conclusion.

O.R: a risk of getting old…

New Trends: arise from societal and technological change

But: Tackling new issues requires more than inserting additional constraints and applying old processes.

Smart cities: a very rich play-ground