A mass-fow MILP formulation for energy-efficient supplying in assembly lines

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Outline

Introduction

ECO-INNOVERA Project - EASY (*Energy Aware Feeding Systems*)

- Skövde University / Volvo VCE
- Universidad de Navarra / VW Polo
- LAAS-CNRS, Toulouse

Motivations

- Develop more sustainable internal logistic practices
- Improve the energy efficiency of production systems
- Focus on the supplying system of assembly lines

Introduction

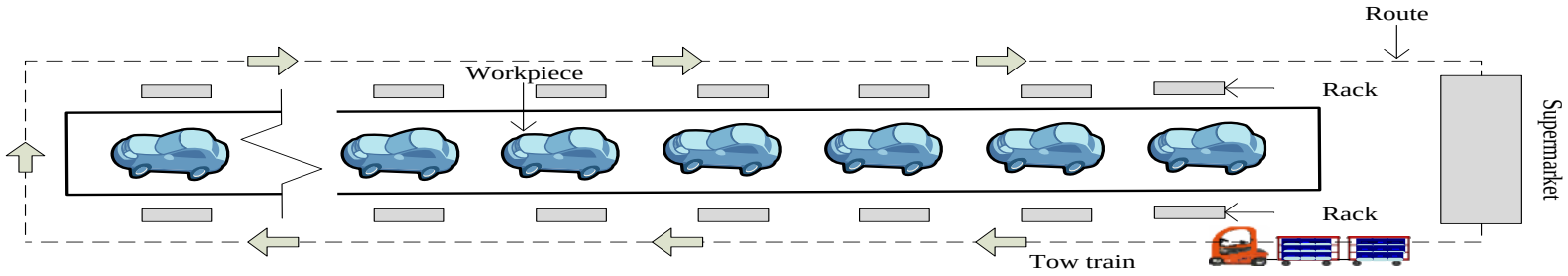
EASY's objectives

- Energy oriented analysis of supplying systems
- Determination of the most significant energy parameters
- Design new effective optimization and simulation methods
- Help decision-makers to find a good balance between energy and economical efficiency - Energy awareness

Outline

Problem description

Assembly line supplying



- Assumptions
  - Periodic supplying
  - A single vehicle / A single route
- Decision variables
  - Determine which workstations to serve at each period
  - Determine the number of components to be delivered
- Constraints:
  - Avoid component shortage / satisfy component demands along periods
  - Respect each workstation capacity / vehicle capacity

Performance objectives

Comparison

Energy minimization (vehicle) vs. Distance (Tours) minimization

Energy minimization

- Pollution Routing problem - Betkas and Laporte, Transportation Res. Part B, 2011
- Energy Minimizing VRP - Kara et al.,Verlag Berlin Heidelberg 1, 2007.
- Pollution Inventory Routing problem - Shamsi et al., Logistic Operations, 2014
- Survey of Green Vehicle Routing Problem - Lin et al. In: Expert Systems with Applications, 2014

Outline

Energy analysis

A bit of physics

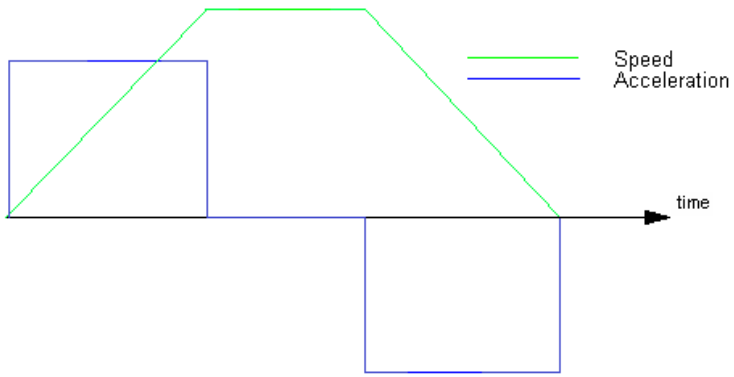
$$E = \int P * dt$$
$$P = F * v$$

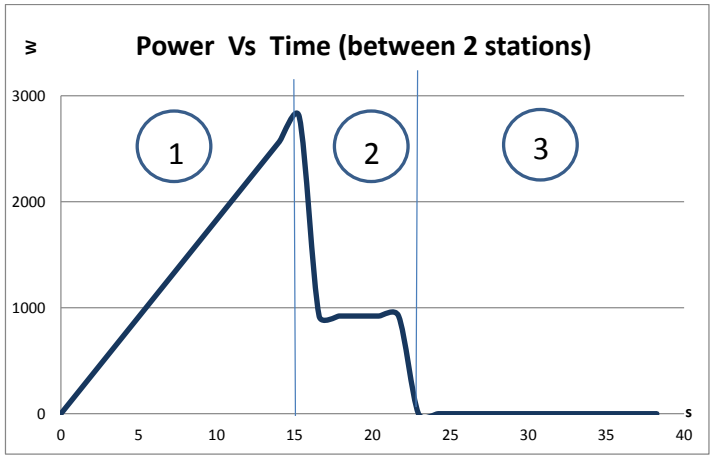
- More relevant forces:
  - Traction force (F_t) $\Rightarrow F_t = m_T a(t)$
  - Rolling resistance (F_r) $\Rightarrow F_r = m_T g C_r$
- Energy equation:

$$\boxed{E = \int m_T \times (a(t) + gC_r) \times v(t)dt}$$

Energy consumption profile

Assumption on the acceleration profile





Properties

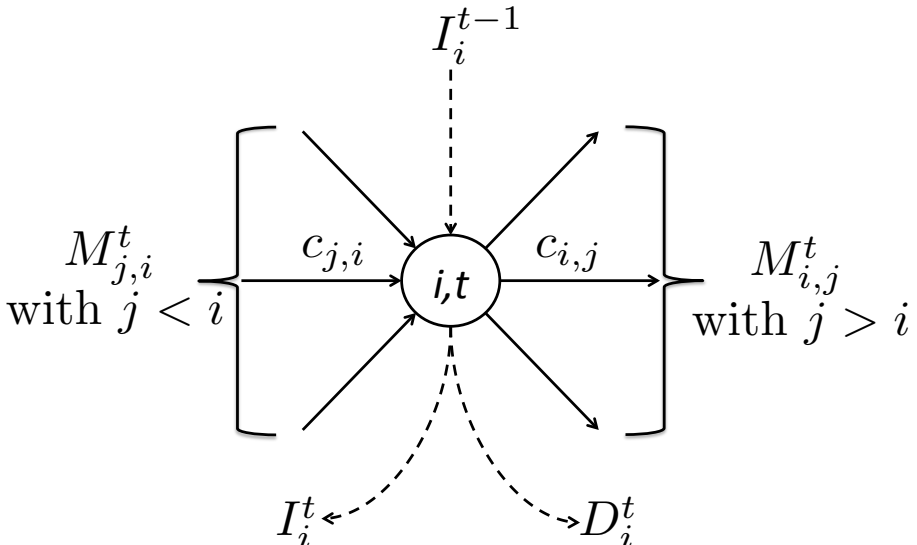
- Any vehicle stop produces a pic of energy consumption.
- The consumed energy is proportional to the carried mass.

Outline

Model basis

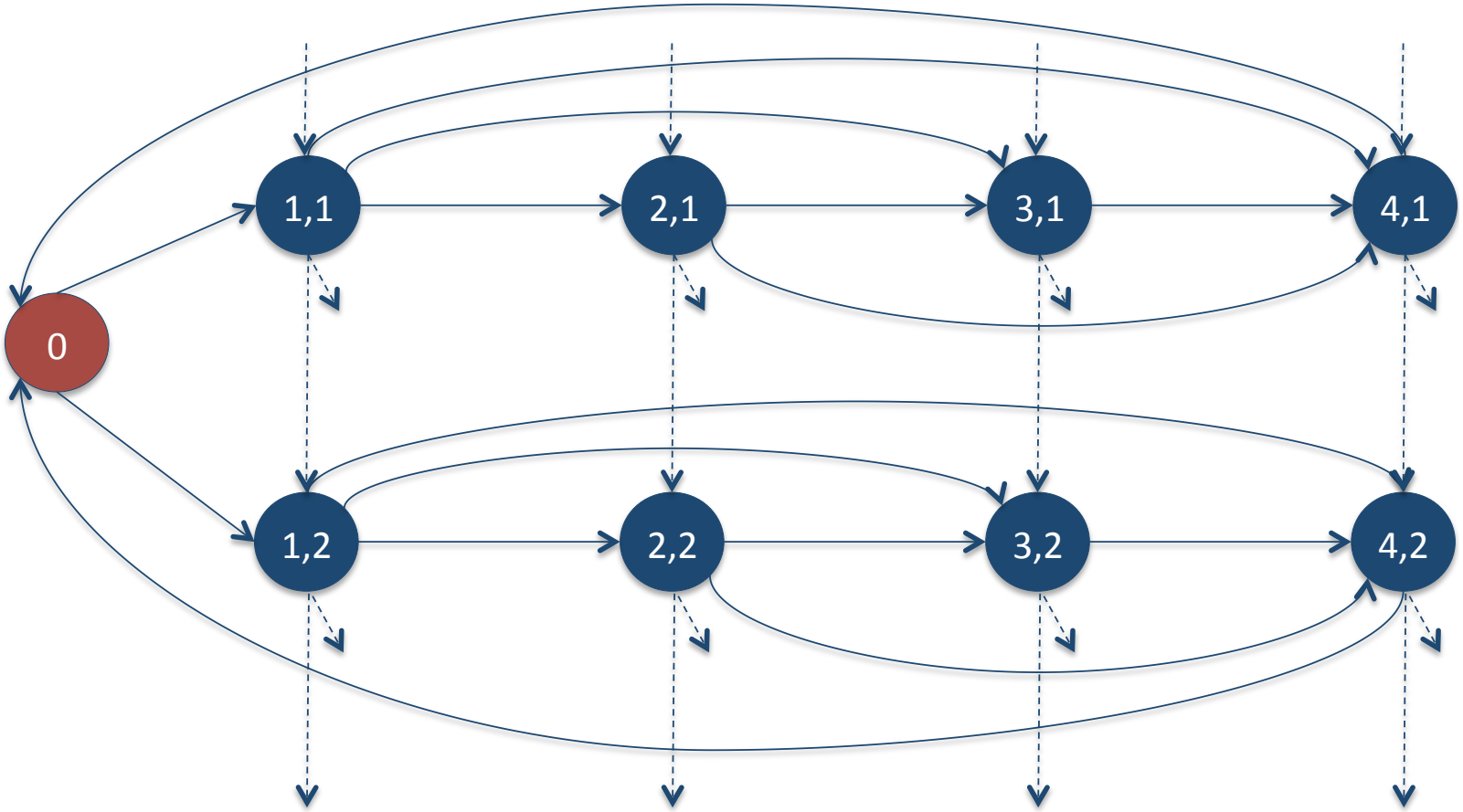
A transportation network

- A node (i, t) in the network = a workstation i at period t
- A mass flow circulates from the depot along the network at each period t (plain arcs)
- A energy cost $c_{i,j}$ is associated to each arc
- A component flow circulates from workstation i at period t to workstation i ar period $t + 1$ (dotted arcs)



Model basis

A 2-periods / 4-workstations network



A MILP formulation

Decision variables

- M_{ij}^t : mass going from i to j during period t
- Z_i^t : components delivered to workstation i at period t
- IL_i^t : inventory level of workstation i at period t
- ϕ_{ij}^t = 1 whether the vehicle is going from i to j at period t

Constraints

- Mass, component, vehicle flows conservation
- Vehicle / stock capacity
- Demand satisfaction

Objective

- Energy minimization : $\sum_{i,j}^{n} \sum_{t}^{NT} c_{ij} M_{ij}^t$

NP-hard in the strong sense ...

$$\text{Min} \quad z = \sum_{i,j} \sum_{t}^{NT} c_{ij} M_{ij}^{t} + \sum_{i,j} \sum_{t}^{NT} c_{ij} m_v \phi_{ij}^{t} \tag{1}$$

st:

$$Z_i^t + IL_i^{t-1} - d_i^t = IL_i^t \qquad \forall \ (i,t) \tag{2}$$

$$Z_i^t - \frac{1}{m_i}\left(\sum_{j<i} M_{ji}^t - \sum_{j>i} M_{ij}^t\right) = 0 \qquad \forall \ (i,t) \tag{3}$$

$$Z_i^t + IL_i^{t-1} \leq c_i \qquad \forall \ (i,t) \tag{4}$$

$$\sum_{j>i} \phi_{ij}^t = \sum_{j<i} \phi_{ji}^t \qquad \forall \ (i,t) \tag{5}$$

$$M_{ij}^t \leq m_{\max} \phi_{ij}^t \qquad \forall \ (i,j,t) \tag{6}$$

$$IL_i^t \geq 0 \qquad \forall \ (i,t) \tag{7}$$

$$M_{ij}^t \geq 0 \qquad \forall \ (i,j,t) \tag{8}$$

$$Z_i^t \in \mathbb{N} \qquad \forall \ (i,t) \tag{9}$$

$$\phi_{ij}^t \in \{0,1\} \qquad \forall \ (i,t) \tag{10}$$

Outline

Experimentation

Problem instances

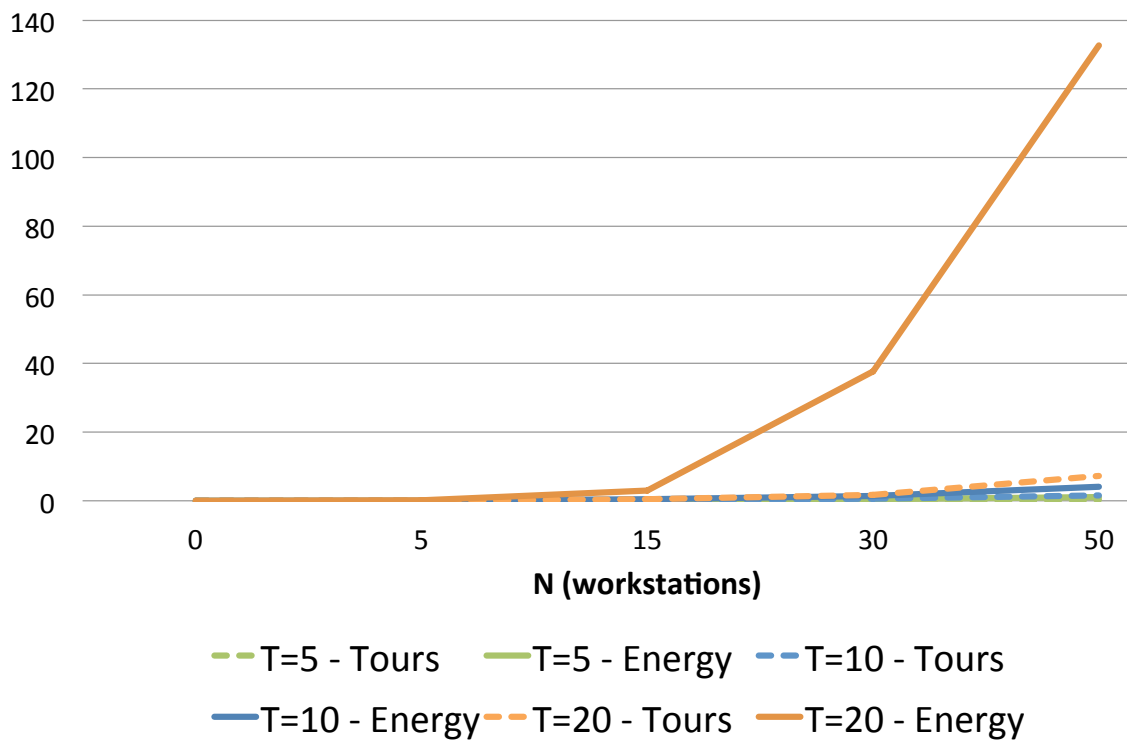
- Instances adapted from those (IRP) of C. Archetti et al., Transportation Science (2007).
- Each workstation demand is periodic and assumed constant
- One single route among the customers is imposed
- New added parameters: energy cost, vehicle mass, component mass, maximum vehicle load
- 9 instances for each $NT = \{5, 10, 20\}$ and $N = \{5, 15, 30, 50\}$ values were created $\Rightarrow$ 108 instances

Optimization strategy

- First, distance (tours) minimization (GUROBI)
- Then energy minimization (GUROBI, Time Limit = 300sec)
- Comparison of the energy consumed by both solutions

Results

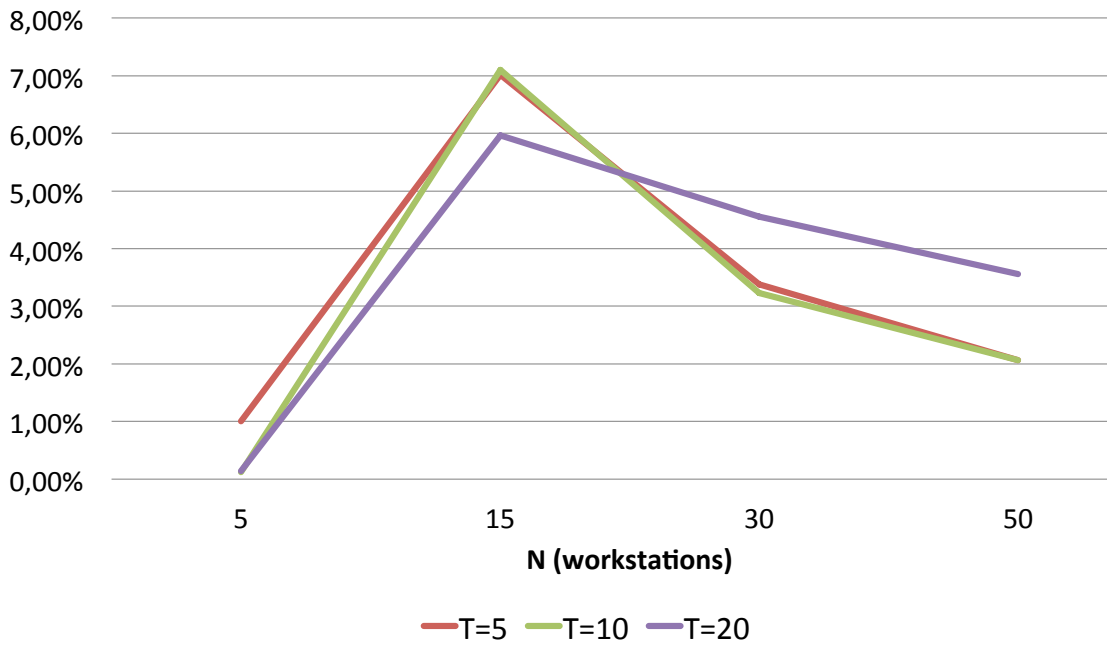
Time performance (sec)



For $NT = 20$ and $N = 50$, 2 instances were not solved to optimality ($GAP < 1\%$)

Results

Energy savings (%)



For every instance, the optimal number of tour remains unchanged when energy is minimized.

Outline

Conclusion and perspectives

Conclusion

- Significant energy parameters : distances, masses, number of stops.
- An “effective” MILP model for energy minimization
- Energy optimization does not cause the increase of the number of tours

Perspectives

- Improvement of the problem instances
- Need of more advanced optimization techniques
- Generalization to the Inventory Routing Problem