Questions & Discussion on Methodology before we proceed to…….

Innovative

Applications

Objectives of SCALE project (2012-2015)

- To develop and pilot a sustainable food chain framework to help food companies optimize the financial, environmental and social costs of each unit of food delivered to the consumer.
- To develop (new) concepts and methods to overcome the lack of integrated optimization across the different decision levels on managing logistic systems.
  - Review sustainability performance indicators
  - Sustainability assessment framework
  - Food &Drink industry and LSPs
  - Optimization model combining AHP, MILP, MCA

SCALE
SUSTAINABLE FOOD CHAINS

Partners:
- Cranfield University
- DHL
- Artois University

http://www.projectscale.eu/

Results web-research: sustainability KPIs

Table 2. Overview of key sustainability indicators of food and drinks companies

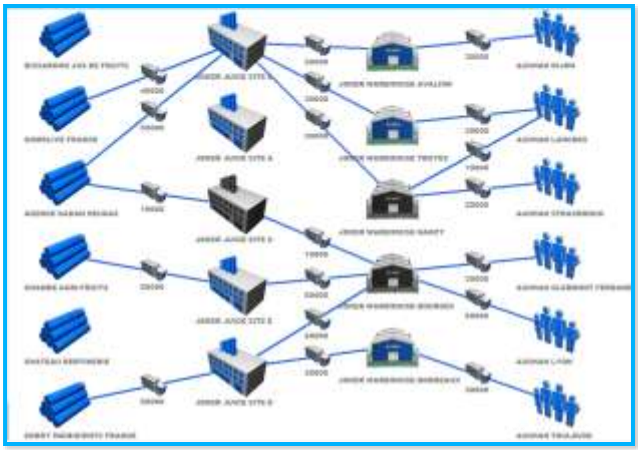
Food Industry			*Logistic Service Provider*		
Indicators	*# /17*	*3BL*	*Indicators*	*# /19*	*3BL*
Water use (m3)	11	Planet	CO2 emissions transport	5	Planet
Energy use	10	Planet	Fuel use	3	Planet
CO2 emissions (tonnes)	9	Planet	CO2 emissions facilities	3	Planet
Male-female ratio (% of total fte)	8	People	Trained employees (%)	3	People
Total waste production	7	Planet	Absenteeism (%)	3	People
Accidents (Freq. rate)	7	People	Absenteeism (total days)	3	People
Renewable energy (%)	6	Planet			
Recycling & recovery rate	6	Planet			
Absence (%)	6	People			
Trained employees (hours/fte)	5	People			

Results: sustainability improvement options

Table 3. Sustainability improvement options (*italic* = requires partner involvement)

Configuration (60%)	**Planning & Control (25%)**	**Information (10%)**	**Organisation (5%)**
Green warehouse New truck, LZV Vehicle adjustments Fuel adjustments Relocation sites New production equipment *Network redsign* *Packaging redesign* *Multi-modal network* *New supplier*	Less material use *Delivery adjustments* *Planning adjustments* *Supply adjustments* *Consolidation* *Collaboration* *Joint planning* *Client involvement*	Fleet management systems (new) TMS (new) WMS *Info sharing with clients*	Create internal awareness Change organisation structure (QSHE) *Create external awareness*

Supply Chain Network



Factors: decision variables

Water

- Location of water availability

Energy

- Mode of energy (fuel, electrical,…)

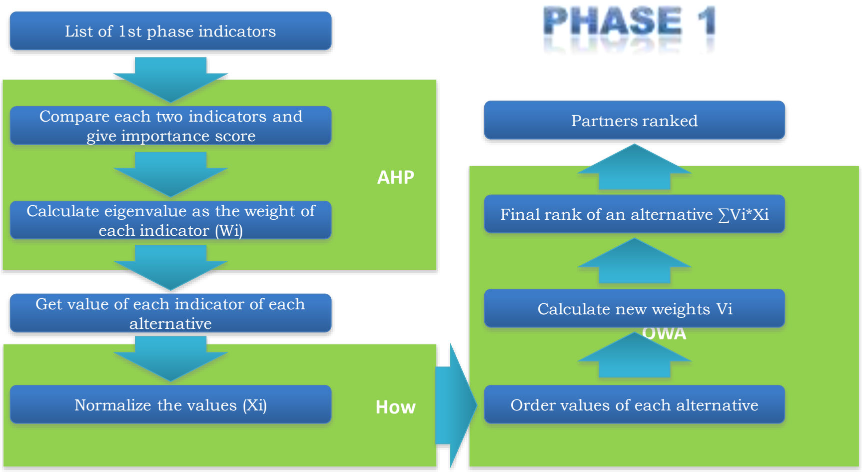
Transport

- Mode of transportation

Network

- Location of sites (warehouse, transformation)
- Suppliers selection
- Allocation

Two-phase Approach



PHASE 1

List of 1st phase indicators

Compare each two indicators and give importance score

Calculate eigenvalue as the weight of each indicator (Wi)

AHP

Get value of each indicator of each alternative

Normalize the values (Xi)

How

Order values of each alternative

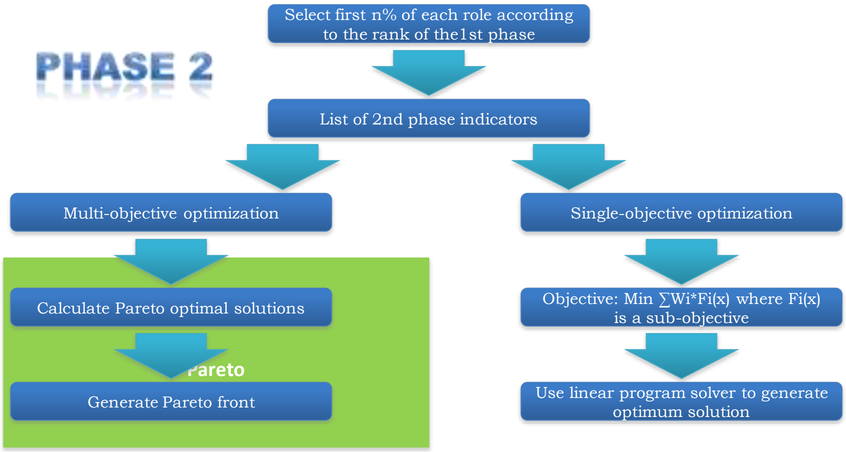
OWA

Calculate new weights Vi

Final rank of an alternative ∑Vi*Xi

Partners ranked

Two-phase Approach



PHASE 2

Select first n% of each role according to the rank of the1st phase

List of 2nd phase indicators

Multi-objective optimization

Calculate Pareto optimal solutions

Pareto

Generate Pareto front

Single-objective optimization

Objective: Min ∑Wi*Fi(x) where Fi(x) is a sub-objective

Use linear program solver to generate optimum solution

Indicator weight definition

- Three ways to define the weights of different indicators
  - ✓ **Manually Input weights.**
  - ✓ **Use a five-star system to rate the importance of each indicator.**
  - ✓ **Use AHP (Analytic Hierarchy Process) and OWA method. (First phase)**

Solution view (geographical)

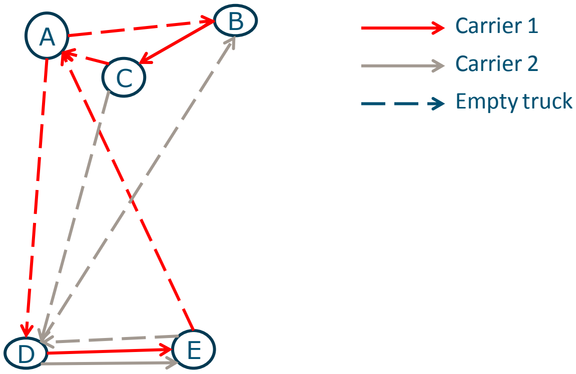
- Click each site to display the related plan.
- Click the path to display detail transportation plan between sites.

Collaborative transportation management

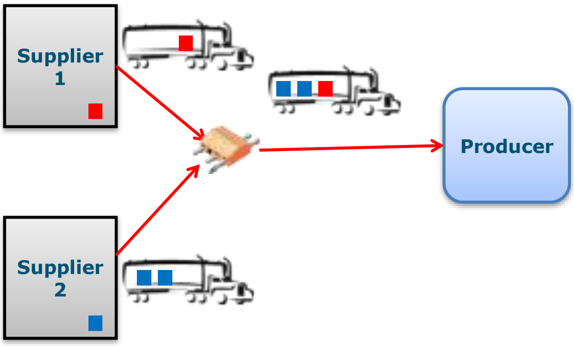
- Several points of view:
  - Collaboration between shippers: collaborate to propose bundles to a carrier.
  - Collaboration between carriers: collaborate to exchange shipments.
- Several scenarios:
  - Less than truckload: shipment of small quantity of product.
  - Full truckload: vehicles are fully loaded.

Collaborative transportation management

- **Full truckload:**



Collaborative warehouse management

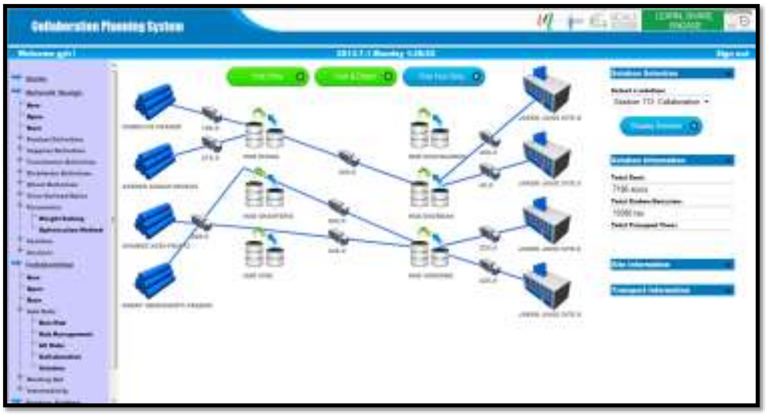


Collaboration Interface

- Three different kinds of collaboration provided:

Adding Hubs

- **Solution generated:**



SALSA Project

Knowledge-based **S**ustainable v**A**lue-added food chains: innovative too**L**s for monitoring ethical, environmental and **S**ocio-economic imp**A**cts and implementing Eu-Latin shared strategies

- **Overall objective** is to contribute to tackle Latin America countries eco-challenges (deforestation, CO2 emission, reduced biodiversity, water–air-soil pollution, reduction in food security) related to farms productions and food chains relationships between Latin America and EU and enhance the food chains value added and competitiveness.

Partners:
- UNIBO (coordinator), UGENT
- FiBL, proQ, CBHU, UFV
- EMBRAPA, RTRS, BEMEFA, UNAM, FSLA

New Research Frontiers in Sustainability: SALSA (EU FP7)

Network Configuration:

M. Soysal, J.M. Bloemhof-Ruwaard, J.G.A.J. van der Vorst (2014), Modeling food logistics networks with emission considerations: the case of an international beef supply chain, *International Journal of Production Economics 152, 57-70.*

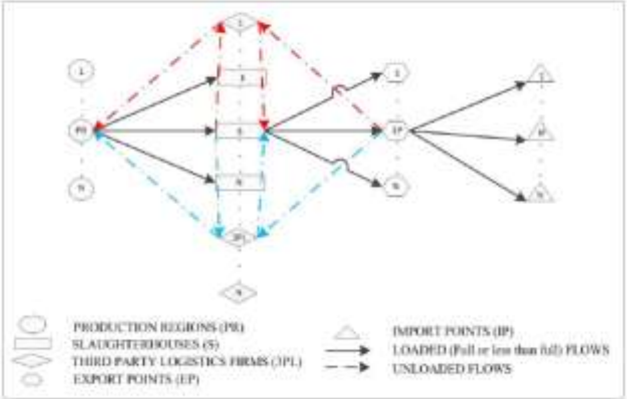
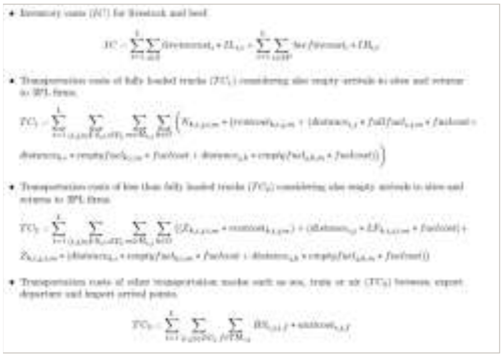


Figure 1: Representation of the generic beef logistics network

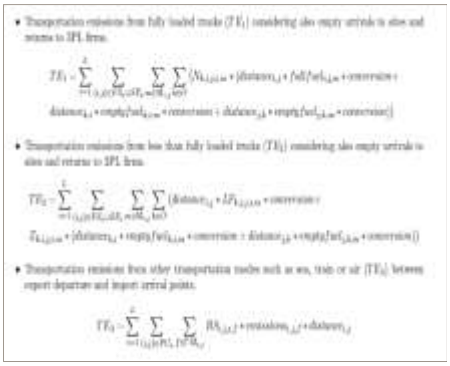
- MILP models
- Scenario studies
- Impact of new trucks
- Impact of improved road conditions
- Fuel and emission tool (carbon footprint)

Multi-Objective Multi-Period Multi-Stage MIP Model- objectives -

Minimize costs



Minimize emissions



Multi-Objective Multi period Multi-stage MIP Model - Constraints (1) -

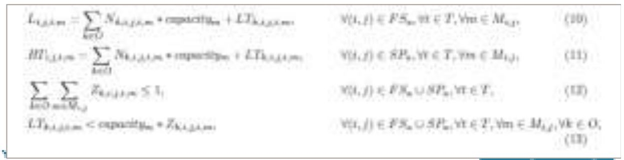
Supply & Balanced livestock inventories in slaughterhouses

Balanced beef inventories in slaughterhouses with max storage time

Demand constraint for Europe

Flow allocation to full

and LTF truckloads



Multi-Objective Multi-Period Multi-Stage IP Model - Constraints - (2)

Calculation of fuel consumption (distance & utilisation rate)

$$U_{k,i,j,t,m} = LT_{k,i,j,t,m}/capacity_m, \quad \forall (i,j) \in FS_s \cup SP_s, \forall t \in T, \forall m \in M_{i,j}, \forall k \in O, \qquad (14)$$

$$LF_{k,i,j,t,m} = (Z_{k,i,j,t,m} * emptyfuel_{i,j,m}) + ((fullfuel_{i,j,m} - emptyfuel_{i,j,m}) * U_{k,i,j,t,m}), \quad \forall (i,j) \in FS_s \cup SP_s, \forall t \in T, \forall m \in M_{i,j}, \forall k \in O, \qquad (15)$$

Capacity constraints livestock and beef transportation, slaughtering, stocking at slaughterhouses and ports

$$\sum_{t=1}^{L} C_{i,t} \leq slaughtercap_i, \quad \forall i \in S, \qquad (16)$$

$$\sum_{t=1}^{L} IL_{i,t} \leq liveinvcap_i, \quad \forall i \in S, \qquad (17)$$

$$\sum_{t=1}^{L} IB_{i,t} \leq beefinvcap_i, \quad \forall i \in SP, \qquad (18)$$

$$\sum_{t=1}^{L} \sum_{j \in S} \sum_{m \in M_{i,j}} BT_{j,i,t,m} \leq transcap_i, \quad \forall i \in P, \qquad (19)$$

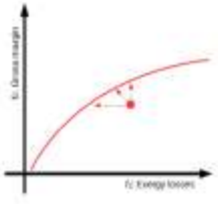
Solve by Epsilon-Constraint method

Min OF1
S.t. Constraints (3) to (26)
OF2 <= OF2_max – eps
0 <= eps <= OF2_max – OF2_min

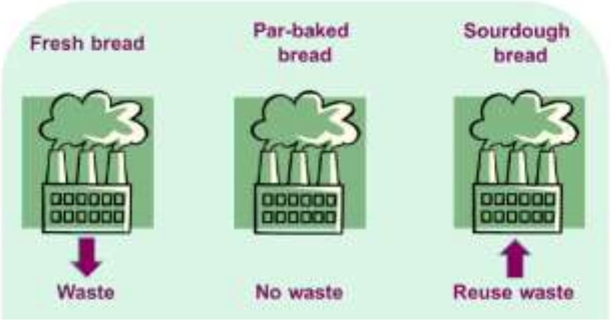
Project Valorization of ByProducts

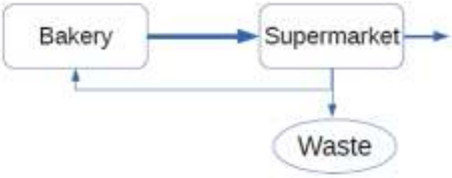
- 2012-2016
- Exergy-based method to quantify the sustainability of food processes and entire food chains, including waste streams.
- A multi-criteria decision-support system will be developed to evaluate alternative processing methods, logistics, reuse of waste streams or alternative designs of entire food chains, with respect to sustainability and other factors such as costs.
- Mushroom case & Bread case
- After 2014: Dairy case & Biorefinery case

Objectives:
- Quantify environmental performance at chain level
- Optimize production planning decisions
- Eliminate inefficiencies
- Evaluate opportunities for re-cycling and valorization



Bread case

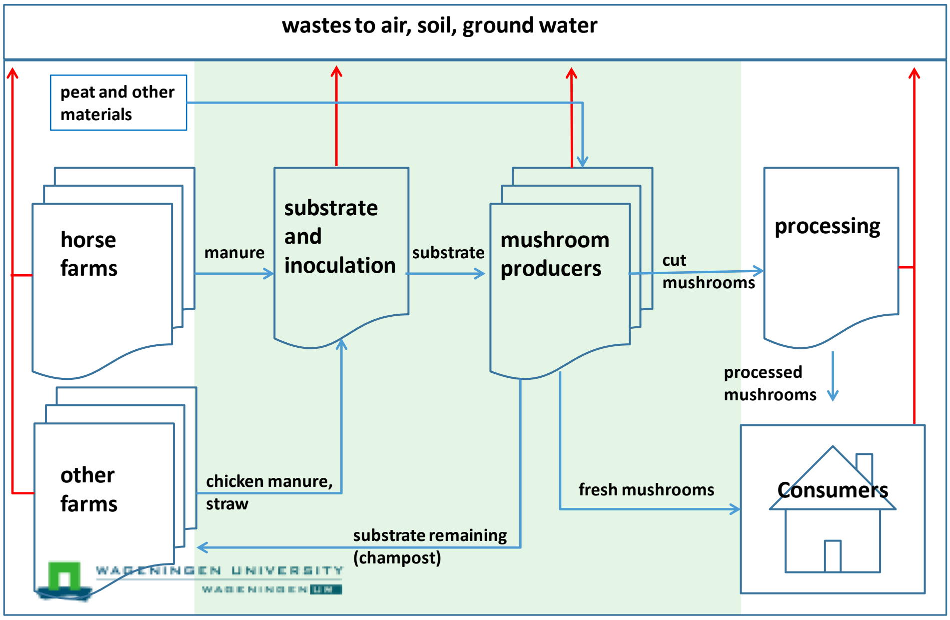



Bakery

Supermarket

Waste

The mushroom chain in the NL


wastes to air, soil, ground water

peat and other materials

horse farms

manure

substrate and inoculation

substrate

mushroom producers

cut mushrooms

processing

processed mushrooms

other farms

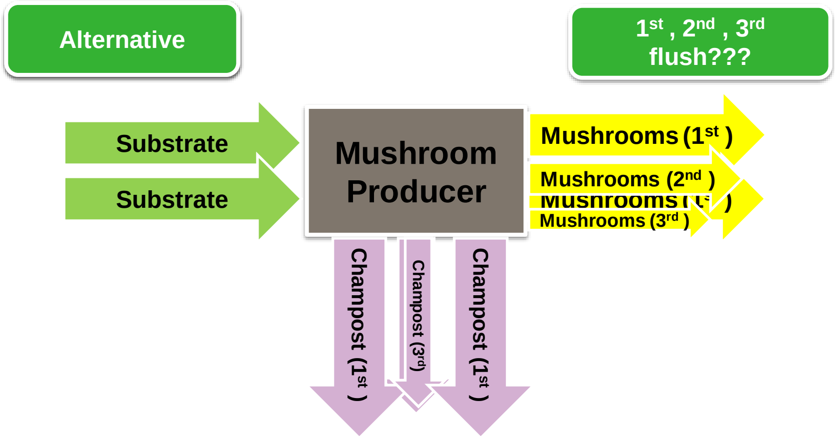
chicken manure, straw

fresh mushrooms

Consumers

substrate remaining (champost)

Terminating production (flushes)



Alternative

1st , 2nd , 3rd flush???

Substrate

Substrate

Mushroom Producer

Mushrooms (1st)

Mushrooms (2nd)

Mushrooms (

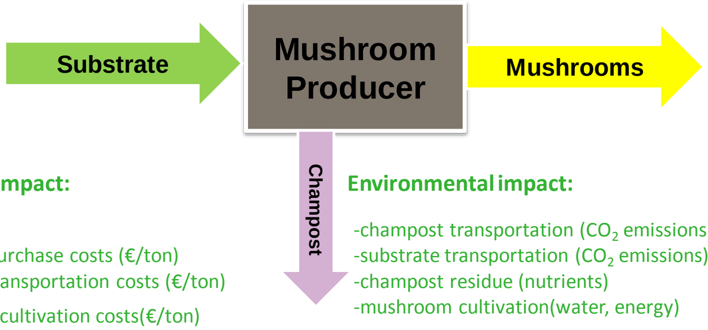
Mushrooms (3rd)

Champost (1st)

Champost (3rd)

Champost (1st)

Resource use efficiency



Substrate

Mushroom Producer

Mushrooms

Champost

Economic impact:

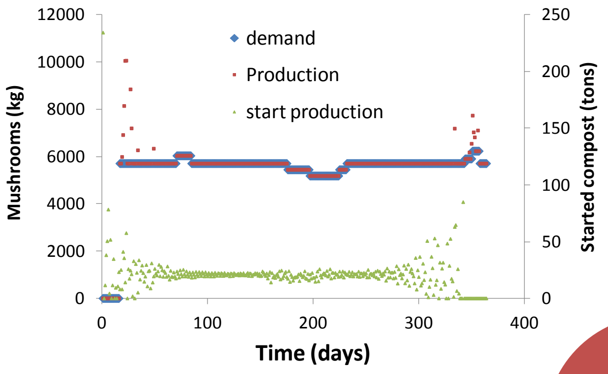
Costs:
-substrate purchase costs (€/ton)
-substrate transportation costs (€/ton)
-mushroom cultivation costs(€/ton)
-champost transportation costs(€/ton)
-(diseases in 3rd flush)

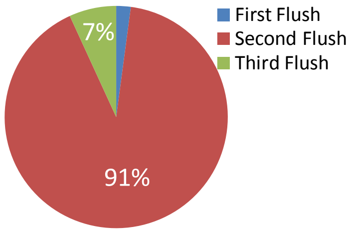
Revenues:
-selling mushrooms (€/ton)

Environmental impact:

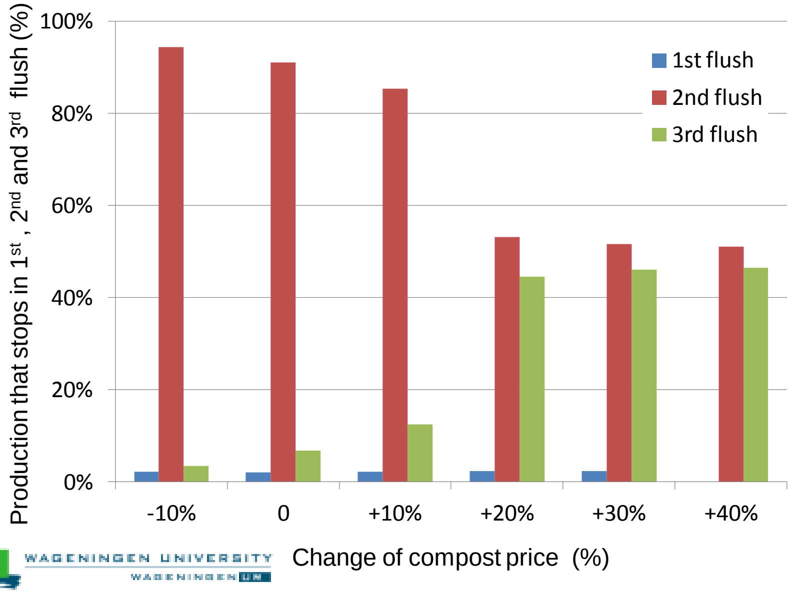
-champost transportation (CO_2 emissions)
-substrate transportation (CO_2 emissions)
-champost residue (nutrients)
-mushroom cultivation(water, energy)

Results: optimal production plan





Results: Sensitivity on compost costs



Stochastic applications

- Modelling a stochastic inventory routing problem for perishable products with environmental considerations (Soysal, Bloemhof, Haijema, van der Vorst)
- M. Soysal, J.M. Bloemhof-Ruwaard, T. Bektas, The time-dependent two-echelon capacitated vehicle routing problem with environmental considerations, *under review with the International Journal of Production Economics, SI on Carbon-efficient Production, Supply Chains and Logistics*

Inventory Routing Problem (IRP)

Coordination of inventory management and vehicle routing

1. When to deliver to each customer,
2. How much to deliver to each customer each time it is served,
3. How to combine customers into vehicle routes

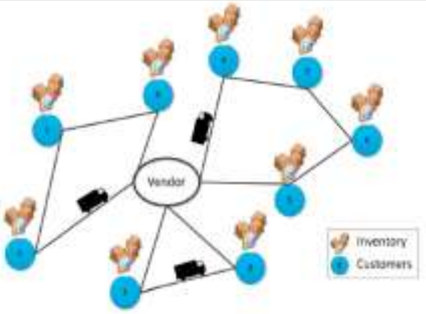


Figure 1: A generic representation of the Inventory Routing Problem

* Traditional assumptions for the IRP

Problem description

- Single vendor, multiple customers
- Homogeneous vehicles at the vendor
- Routes start and end at the vendor's location
- Demand of a customer two or more vehicles
- Demand ~ $N(\mu_{it},\sigma_{it})$
- Inventory at the customers (Fixed shelf life of $m \geq 2$ periods)
- The demand should be met with a probability of at least α
- The routes and quantity of shipments in each period such that the total cost comprising routing, inventory and waste costs is minimized

---

Stochastic chance-constrained programming model (M_{PF})

Minimise Expected inventory cost + Expected waste cost + Fuel cost from transportation operations + Driver cost

$$Minimise \sum_{i\in V'} \sum_{t\in T} I^{+}_{i,t} h_i \tag{1.i}$$

$$+ \sum_{i\in V'} \sum_{t\in \{T|t\geq m\}} E[W_{i,t}]p \tag{1.ii}$$

$$+ \sum_{(i,j)\in A} \sum_{k\in K} \sum_{t\in T} \lambda\Big(y(a_{ij}/f) X_{i,j,k,t} + \gamma\beta a_{ij} f^2 X_{i,j,k,t} + \gamma s(\mu X_{i,j,k,t} + F_{i,j,k,t}) a_{ij} \Big) l \tag{1.iii}$$

$$+ \sum_{(i,j)\in A} \sum_{k\in K} \sum_{t\in T} (a_{ij}/f) X_{i,j,k,t} r. \tag{1.iv}$$

Stochastic chance-constrained programming model (M_{PF})

Inventory decisions:

- Inventory balance
- Waste calculation
- Service level

$$E[I_{i,t}] = \sum_{t'=1}^{t}\sum_{k\in K} Q_{i,k,t'} - \sum_{t'=1}^{t}(E[d_{i,t'}] + E[W_{i,t'}]), \qquad \forall i \in V', t \in T \qquad (2)$$

$$I^{+}_{i,t} \geq E[I_{i,t}], \qquad \forall i \in V', t \in T \qquad (3)$$

$$E[W_{i,t}] \geq E[I_{i,t-m+1}] - \sum_{t'=t-m+2}^{t} E[d_{i,t'}] - \sum_{t'=t-m+2}^{t-1} E[W_{i,t'}], \qquad \forall i \in V', t \in \{T|t \geq m\} \qquad (4)$$

$$E[W_{i,t}] = 0, \qquad \forall i \in V', t \in \{T|t < m\} \qquad (5)$$

$$Pr\left(I_{i,t} \geq 0\right) \geq \alpha, \qquad \forall i \in V', t \in T \qquad (6)$$

Routing decisions:

- Flow conservation
- Each vehicle at most 1 route per period
- Vehicle capacities
- Eliminate subtours

$$\sum_{i\in V, i\neq j} X_{i,j,k,t} = \sum_{i\in V, i\neq j} X_{j,i,k,t}, \qquad \forall j \in V', k \in K, t \in T \qquad (7)$$

$$\sum_{j\in V, i\neq j} X_{i,j,k,t} \leq 1, \qquad \forall i \in V, k \in K, t \in T \qquad (8)$$

$$\sum_{j\in V, i\neq j} F_{i,j,k,t} = \sum_{j\in V, i\neq j} F_{j,i,k,t} - Q_{i,k,t}, \qquad \forall i \in V', k \in K, t \in T \qquad (9)$$

$$F_{i,j,k,t} \leq c X_{i,j,k,t}, \qquad \forall (i,j) \in A, k \in K, t \in T \qquad (10)$$

$$X_{i,j,k,t} \in \{0,1\}, \qquad \forall (i,j) \in A, k \in K, t \in T \qquad (11)$$

$$F_{i,j,k,t} \geq 0, \qquad \forall (i,j) \in A, k \in K, t \in T \qquad (12)$$

$$-\infty < I_{i,t} < +\infty, \qquad \forall i \in V', t \in T \qquad (13)$$

$$I^{+}_{i,t}, W_{i,t} \geq 0, \qquad \forall i \in V', t \in T \qquad (14)$$

$$Q_{i,k,t} \geq 0, \qquad \forall i \in V', k \in K, t \in T \qquad (15)$$

Deterministic approximation M_{PF} and variations

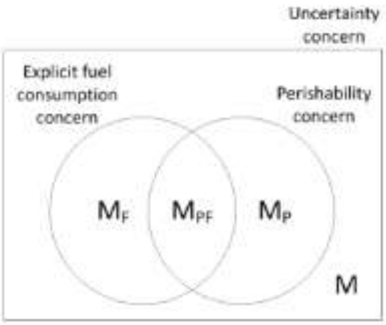


Figure 2: Considered aspects in the model variations

* Simulation model

$$\sum_{t'=1}^{t}\sum_{k\in K} Q_{i,k,t'} - \sum_{t'=1}^{t-1} E[W_{i,t'}] \geq \sum_{t'=1}^{t} \mu_{i,t'} + \sqrt{\left(\sum_{t'=1}^{t}(\sigma_{i,t'})^{2}\right)} Z_{\alpha}, \qquad \forall i \in V', t \in T$$

Benefits of including perishability and explicit fuel consumption considerations in the model

Base case solution

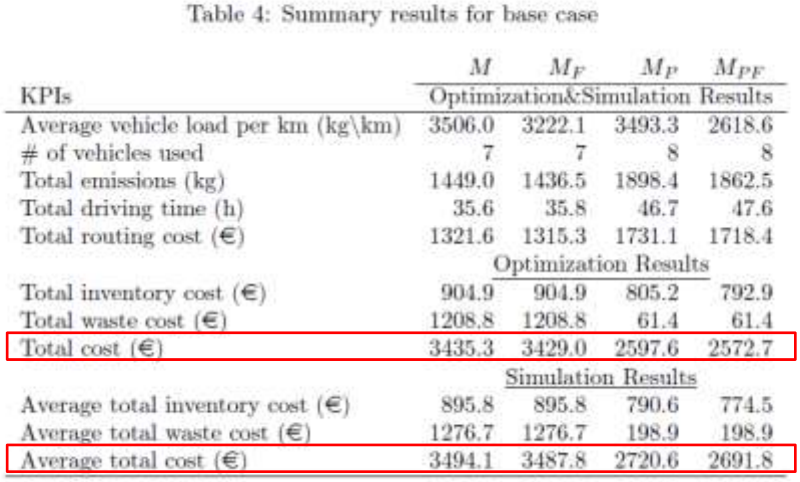


Table 4: Summary results for base case

	M	M_F	M_P	M_{PF}
KPIs	Optimization&Simulation Results			
Average vehicle load per km (kg\km)	3506.0	3222.1	3493.3	2618.6
# of vehicles used	7	7	8	8
Total emissions (kg)	1449.0	1436.5	1898.4	1862.5
Total driving time (h)	35.6	35.8	46.7	47.6
Total routing cost (€)	1321.6	1315.3	1731.1	1718.4
	Optimization Results			
Total inventory cost (€)	904.9	904.9	805.2	792.9
Total waste cost (€)	1208.8	1208.8	61.4	61.4
Total cost (€)	3435.3	3429.0	2597.6	2572.7
	Simulation Results			
Average total inventory cost (€)	895.8	895.8	790.6	774.5
Average total waste cost (€)	1276.7	1276.7	198.9	198.9
Average total cost (€)	3494.1	3487.8	2720.6	2691.8

Two-echelon distribution systems

- Large trucks → transport freight over long-distances to intermediate depots (satellites) where consolidation takes place,
- Small and environmentally-friendly vehicles → the products are transferred to destination points.

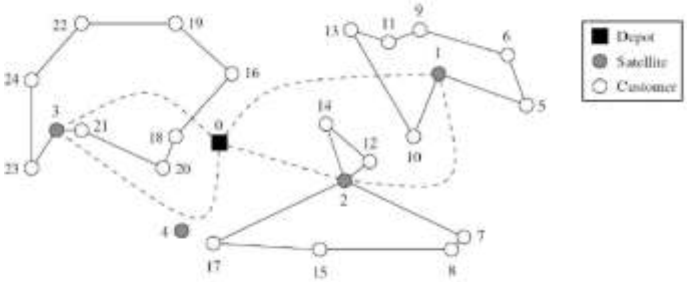


Figure 1: A solution to the 2E-CVRP (Source: Baldacci et al. (2013))

Problem description

- Graph G={V, A}, V={V_0,V_S,V_C}
- Two echelons:
  - First-echelon
  - Second-echelon
    - Congested arcs: in multiple time zones (no limit on #)
    - Non-congested arcs: free flow
- The total freight assigned to each satellite can be split into two or more vehicles,
- Each customer is visited exactly once by a second-echelon route,
- Known nonnegative demand,
- Minimize the total cost of travel and handling,
  - Total cost of travel
    - Driver cost
    - Fuel consumption cost (speed, load and distance)→ Emissions

MILP model for the 2E-CVRP - I

Minimise fuel cost for the first-echelon

+ driver cost for the first-echelon

+ handling fee in the satellites

+ fuel cost for the non congested arcs in the second-echelon

+ fuel cost for the congested arcs in the second-echelon if departure and arrival times are in the *same* time zone

+ fuel cost for the congested arcs in the second-echelon, if departure and arrival times are in *different* time zones

+ driver cost for the second-echelon.

MILP model for the 2E-CVRP - II

Constraints, e.g.,

- Flow conservation for each vehicle at each satellite,
- Vehicle visits a satellite at most once,
- Link the delivery from all first-echelon vehicles with the total demand delivered from each satellite,
- Traffic elimination between the satellites,
- Total demand is equal to total amount delivered from all satellites,
- Compute the time zone while departure and arrival,
- Compute the travel time for the congested second-echelon arcs.
- …

Application

- One depot (outside the city), two satellites (boundary of the city) and 16 supermarket branches (customers at the city center),
- Two types of vehicles: large (20 tonnes) and small (10 tonnes),
- Congested arcs based on the traffic data provided by the Google Maps,
- Two-time zones: rush-free flow,
- Three types of speed: outside city (80km/h), rush hour speed (20km/h), free-flow speed (40km/h),
- Random demand,

➢The ILOG-OPL development studio and CPLEX 12.2 optimization package,

➢A computer of Pentium(R) i5 2.4GHz CPU with 3GB memory.

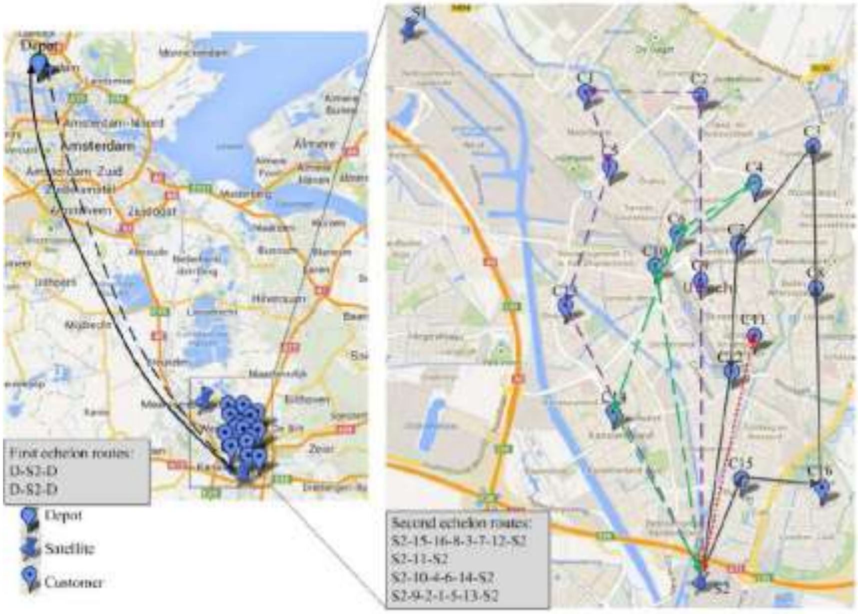


Figure 7: Cost minimizing solution

Comparison of the single-echelon and two-echelon distribution systems

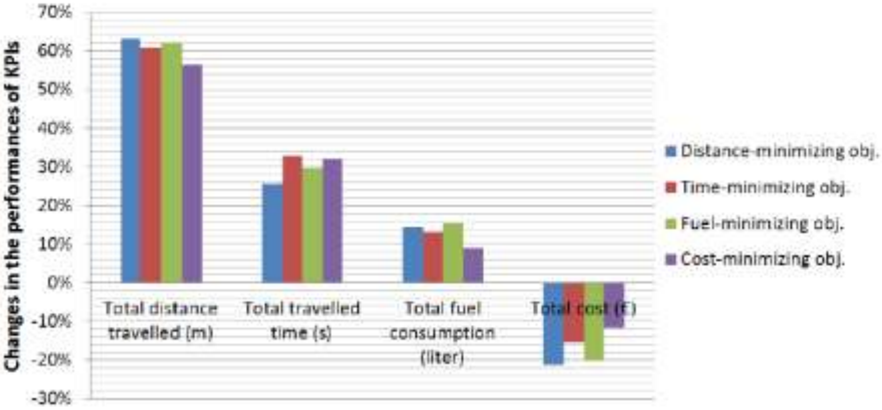


Figure 9: The performance of the single-echelon case compared to the base (two-echelon) case

Questions & Discussion

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