Applications of Lot Sizing

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Presentation Structure

1. Brief Overview of Lot Sizing (LS)
   - Some Reviews
   - Variety of models and their features
2. Main Areas of Application
   - Manufacturing
   - Food and Drink
   - Process Industries
   - Supply Chain plus innovative example
   - Sustainability
   - Agriculture
3. Practical Issues and Implementation
   - Data, Stability and Human issues
   - IT and System Implementation

Some reviews relevant to applications

- Stadtler (2005): Good applied discussion of linkage between supply chain management (SCM) and advanced planning systems (APS).
- Jans and Degraeve (2008): Still-relevant overview on the single-level DLSP, focusing on modelling industrial extensions.
- Copil et al. (2017): Very useful review of simultaneous LS and scheduling problems, with good discussion of applications of GLSP (small-bucket) & CLSP (big-bucket) and in various industries.
- Brahimi et al. (2017): Comprehensive survey of single-item DLSP and recent extensions, including integration with other decisions.
- Tomotani and de Mesquita (2018): LSS in Brazilian Industry.
  - Survey of 57 professionals.
  - Companies want to maximise service level, then inventory reduction.

Scheduling of lots & setups is usually considered alongside lot-sizing.

Desire for reality implies increasingly complex models, ... but often ... just a [stationary] bottleneck stage is modelled in multistage systems.

Manufacturing I

Many model variants. Some recent classifications are in:

- Glock et al. (2014)
- Table 2 in Copil et al. (2017)

Application Examples:

- Textiles - spinning: Camargo et al. (2014)
- Textiles - knitting: Pimentel et al. (2010)
- Wood floors: Tiacci and Saetta (2012)
- Semiconductors: Quadt and Kuhn (2005, 2009); Xiao et al. (2013)
- Sandpaper: Gupta and Magnusson (2005)
- Car windshield interlay plastic sheets: Lang and Shen (2011)
- Automotive breaking equipment: Hu and Hu (2016)
- Personal Protection Equipment: Luche and Perhs (2016)

Manufacturing II

Two stages: Process-type campaign planning at furnaces, then LSS at mouding machines.

- Glass containers:
  Almada-Lobo et al. (2008).
  Toledo et al. (2013, 2016).
  de Souza Amorim et al. (2018).
- Small metal foundries: Araújo et al. (2008) .
  Hans and van de Velde (2011). Sand mold casting only.
  Camargo, Mattiolli and Toledo (2012).
  Stawowy and Duda (2017).
  Li, Guo, Liu, Du and Wang (2017).
- Tires: Jans and Degraeve (2004). Mould LSS only.

LS integrated with Cutting Stock:

- Paper rolls: Leão et al. (2017)
- Furniture: Vanzela et al. (2017)
- Review: Melega, de Araújo and Jans (2018)

Food and Drink I

Camargo, Toledo and Almada-Lobo (2012):

Many real-world problems have (quasi-)continuous production at a 1st stage,

and then a discrete manufacturing at a 2nd stage.

Examples:

Soft-drink syrups, glass, alloys and fibres are non-discrete products (e.g, litres, tonnes, etc),

but end-products are discrete units (e.g., number of bottles, items, yarn packages).

- Cider: Clark (2003).
  Brewery: Baldo et al. (2014, 2017).
- Soft drinks: Toledo et al. (2009); Ferreira et al. (2009, 2010, 2012); Maldonado et al. (2014); Toledo et al. (2014)
- Fruit-based beverages: Toscano et al. (2017).

Food and Drink II

- Milk: Touil et al. (2016).
  Yoghurt: Perishable with dynamic demand. Marinelli et al. (2007); Kopanos et al. (2011, 2012b); Sel et al. (2015).
  Ice cream: Kopanos et al. (2012a)
- Cheese: Stefansdottir et al. (2017)
- Tobacco: Pattloch et al. (2001)
- Catering (Perishability): Amorim et al. (2013)

Process Industries I

Different from Manufacturing LS:

- Formulation/Recipe-based blending production, rather than of discrete parts.
- Expensive installed capacity that is often not flexible.
- Frequently very large setup times and costs.
- Sometimes [much] larger value added at a given stage.

So LS can add significant value (Quadt and Kuhn; 2008)

Process Industries II

Campaign planning in process industries:

- Suerie (2005), including period-overlapping setups (Suerie; 2006)
- Forestry in Sweden: Carlsson and Rönnqvist (2005) (without calling it lot sizing)

Large-scale industrial continuous plants: Shaik et al. (2009)

Shipment planning at oil refineries:

- Persson and Göthe-Lundgren (2005) - seems to use LS - check.

LS and raw materials purchasing/inventory in process industries:

- Cunha et al. (2018)

Process Industry Examples in Harjunkoski et al. (2014)

Detailed discussion of industrial aspects, including usability, interfacing & integration, and rescheduling:

Harjunkoski et al. (2014), "Scope for industrial applications of production scheduling models and solution methods", *Computers and Chemical Engineering*.

LS/Batching is identified as a major part of Production Scheduling.

Examples (some with LS):

- Dairy industry: ice cream manufacturing.
- Petrochemical industry, including Copesul/Braskem in Brazil.
- Production optimization in a pulp and paper plant
- Crude-oil blend scheduling optimization
- Scheduling of drumming facility at Dow
- Scheduling in an integrated chemical complex
- Medium-term scheduling of large-scale chemical plants

Emerging issues in Process Industries from Harjunkoski et al. (2014)

Impact of:

- Sustainability pressures & climate-change
  $\rightarrow$ energy efficiency in process industries
- Energy pricing
- Raw-materials pricing
- Regulation of emissions
- Increasing globalisation (transportation between multiple sites)
- Wealth of process/market data provided by automation.
- Faster-changing markets
  $\rightarrow$ shorter product lifespans
  $\rightarrow$ flexible production systems
- Reconciling model objective(s) with other user concerns

Other Process Industry Examples

Pulp Processing and Paper Manufacturing

- Multi-stage LSS.
  (1) Pulp & “Black liquor”,
  (2a) Energy recovery, (2b) LSS in paper/carboard machine.
  Santos and Almada-Lobo (2012); Furlan et al. (2015)
- 2-stage integrated LSS of Pulp then Paper: Figueira et al. (2013)
- Single-stage with cutting stock for paper: Leão et al. (2017)

Also:

- Annealing of Steel coils in China: Tang et al. (2011)
- Petrochemicals:
  Kadambur and Kotecha (2016); Ghamari and Sahebi (2017)
- Chemicals: Suerie (2005); Transchel et al. (2011)
- Pharmaceutical ingredients: Stadtler (2011)
- Biopharma: Vieira et al. (2016, 2017): LSS using a complex MIP continuous-time formulation based on Resource-Task Network.
- Alloy production: Electro-fused grains of aluminium oxide:
  Luche et al. (2009)

Supply Chains and Logistics I

Glock (2012) reviews Joint Economic LS models in the context of integrated supply chains, such as in the car automotive industry.

Moons et al. (2017) reviews Production and Routing jointly.

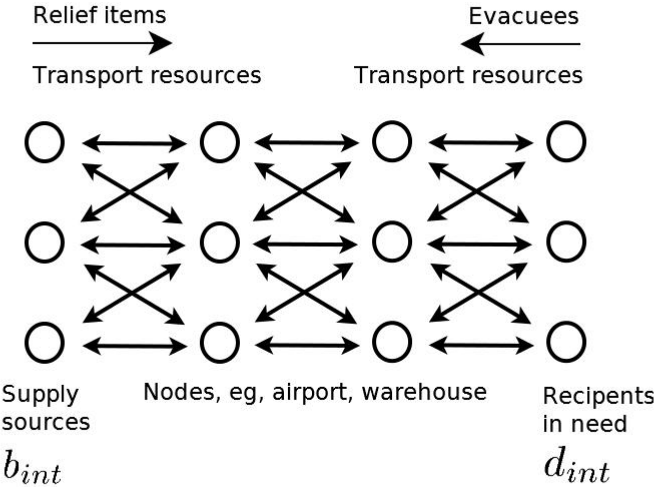
Examples:

- Bus Terminals, Seaport cross-docking, Airport check-in,: Bruno et al. (2014).
- Incoming Materials Routing and Production jointly: Hein and Almeder (2016)
- Outsourcing to third-party for processing: Ferretti et al. (2017)
- Production and Logistics jointly: Chandra and Fisher (1994).
- Integration of Two-stage Production Processes and Distribution of glass containers, steel alloys, soft drinks, fibre spinning, etc: Wei et al. (2017).

Supply Chains and Logistics II

- Choosing ship sizes to transport calcium carbonate slurry: Dauzère-Pérès et al. (2007)
- Joint production and distribution/routing of perishable products Amorim et al. (2012); Li et al. (2016); Li, Chu and Chen (2017); Qiu et al. (2018)
- Joint LS for financial investment collaboration within a SC: Marchi et al. (2016)
- Humanitarian Logistics:
  - Emerging area of research in recent years.
  - Alem, Clark and Moreno (2016): 2018 Best EJOR paper award in Innovative Applications of OR category. See next slides.
  - Moreno, Alem, Ferreira and Clark (2018): Amplification and continuation

Humanitarian Logistics relief supply network



Reality: Multiple Sources of Uncertainty

Victims/Recipients:

- Where are they? At which nodes in the network?
- What is their "demand" over time?

Transport:

- What networks links are operational? With what flow capacity? Some may be partially blocked by fleeing evacuees.
- What transport resources are available, where?
- Lead times may be long, variable, ill-known.

External supplies:

- What relief items will be available when?
- Where? (at which network node?)
- Local procurement possibilities for relief?

Alem, Clark and Moreno (2016) I

Scenario-based 2-stage stochastic network model, adapted from LS, to quickly supply relief aid.

Decisions:

Stage 1 (Pre-disaster). Strategic, but focusing on prepositioning, distribution, & fleet decisions, assuming the location of relief centers & warehouses are well located beforehand:

- Quantity & location of prepositioned emergency aid.
- Overall capacity of each type of vehicle to deliver future aid.

Stage 2 (Post-disaster): Operational, on a rolling-horizon basis with updated information and scenarios as the impact of the disaster becomes clearer and fresh resources become available:

- Flow of emergency aid among network arcs.
- Number and type of vehicles required for aid distribution, procurement issues, inventory and backlogging.

Alem, Clark and Moreno (2016) II

Flexible Objective: Minimize unmet needs of victims and/or:

Stage 1: costs of prepositioning emergency aid & vehicles.

Stage 2: ransportation costs & excessive inventory.

Constraints:

- Lot-Sizing: Balance the inventory and flow of relief and transport resources over consecutive periods at each network node (supply points, warehouses, victim locations)
- Limited amount of emergency aid that can be procured across the relief center nodes.
- Determine the type and number of vehicles required to transport emergency aid through the network, restricting Stage 2 use to the fleet contracted in Stage 1.
- Keep within budget, etc.

Alem, Clark and Moreno (2016) III

Data Requirements:

- Deterministic: types of aid, location of relief centers and warehouses, network arcs, fleet availability, capacities, lead times, unit costs, etc.
- Stochastic:

  Identification of a representative set of scenarios, requiring knowledge and experience of past or similar disasters.

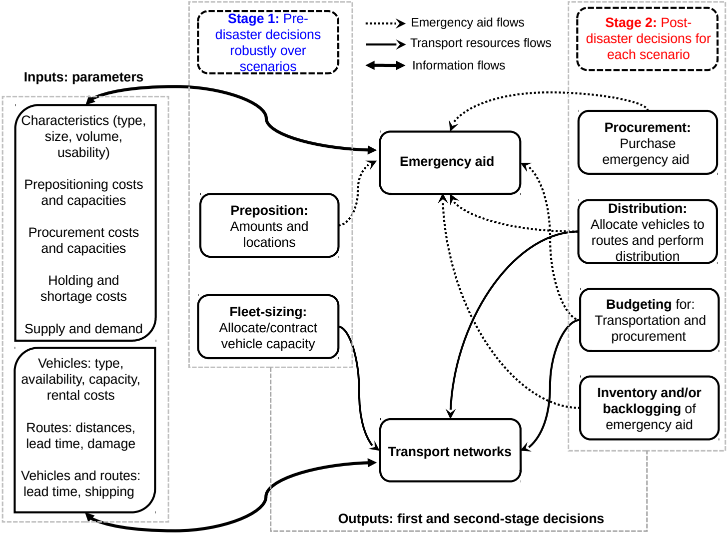
  For each scenario, over time: victim demand, arc availability (damage), budget (donations, federal funding, etc.), undamaged prepositioned supplies, incoming supplies.

  Probabilities (often guestimates) of the scenarios.

  Climate change may cause new scenarios to occur, for example, flooding on a scale not seen before in many regions.

Alem, Clark and Moreno (2016) IV

Overview



Alem, Clark and Moreno (2016) V

Research Question:

Can risk-averse models improve humanitarian operations optimized with the risk-neutral model?

Investigated via:

Classical minimax-regret approach (MinMax): seeks to avoid worst-case outcomes; stable, robust, but conservative.
Useful when scenario probablities are hard to estimate.

Two state-of-art risk risk measures that allow to search for stochastically non-dominated solutions:

- Conditional Value-at-Risk (CVaR)
- Semideviation (SD)
- Both CVaR and SD use a weight $\phi \in [0, 1]$ to trade off expected value and risk.

Alem, Clark and Moreno (2016) VI

Conditional value-at-risk (CVaR)

- Uses the expected cost of exceeding VaR at confidence level u (e.g., 95%).
- VaR is the maximum possible loss if one excludes worse scenarios whose probability is less than $(1 - u)$ (e.g., 5%) over the horizon.
- As u increases, fewer worse scenarios are taken into account.

Semideviation (SD) measures fluctuations below the mean.

Both CVaR and SD are mean-risk models whose objective function produce risk-neutral solutions for $\phi = 0$, solutions that are totally risk-averse for $\phi = 1$, or in between for $0 < \phi < 1$.

Alem, Clark and Moreno (2016) VII

Tested with 40 scenarios and 17 instances/cases, generated with world-wide historical data and from the 2011 floods and landslides in the *Serrana* region of *Rio de Janeiro* state, Brazil.

Risk-Neutral Results:

- Increasing the prepositioned capacity also helps to improve the fleet usage via contracting a smaller fleet of vehicles in Stage 1, but using the overall vehicle capacity more efficiently in Stage 2.

Risk-Averse Results:

- SD model presents the lowest price of risk aversion, but its average and best performances across all instances are clearly dominated by the CVaR model in terms of unmet demand and second-stage costs.
- CVaR provides the best improvement in unmet demand and second-stage costs in most instances.
- Minimax-regret model produces higher increase in objective values, and fails more often in improving both unmet demand and costs, providing the worst overall performance.

Alem, Clark and Moreno (2016) VIII

Overall Conclusion:

Compared to the risk-neutral results, the overall trend of the risk-averse models is twofold:

1. increasing first-stage costs
2. decreasing the standard deviation of the second-stage costs

Model can help plan and organise relief to provide good service levels in most scenarios.

Insight into how this depends on the type of disaster and resources.

Tests provided further insights and pointers to the impact of single-factor changes, for example, levels of pre-positioning.

Model can improve equity (fairness) in distribution by enforcing risk aversion.

But ... still to be used in practice in a disaster situation.

Sustainability

- Considering carbon emissions: Absi et al. (2013); Wang and Choi (2016); He et al. (2015); Zouadi et al. (2017)
- Energy constraints: Rapine et al. (2017)
- Clean Biofuel production: Kantas et al. (2015)
- Bicycle manufacturing balancing energy use with production costs: Schenker et al. (2015)
- Rest time of workers: Battini et al. (2017)
- Remanufacturing: Golany et al. (2001); Teunter et al. (2006); Retel Helmrich et al. (2014); Kilic et al. (2018).
- Water Capture and Distribution: Toledo et al. (2008).
- Sustainability and Recycling - Molded pulp packaging: Martínez et al. (2016).
- Section 9.5 of Brahimi et al. (2017) has a brief review.

Agriculture

Examples:

- Tomato processing: Rocco and Morabito (2014, 2016a,b)
- Dairy farming: Gameiro et al. (2016), with lot sizing not explicitly identified as such.
- Sugar cane:
  Harvesting & Milling of Sugar and Ethanol fuel: Paiva and Morabito (2009).
  Harvesting: Junqueira and Morabito (2017)
- Hen eggs: Boonmee and Sethanan (2016)
- Poultry: Taube-Netto (1996).
  Runner-up in 1994 Franz Edelman Prize from INFORMS.
- Animal feed with non-triangular setups: Menezes et al. (2011); Clark et al. (2014).

Practical Issues and Implementation of Lot-Sizing

Data

- Availability
- Accuracy
- Updating $\rightarrow$ Rolling horizon?

Level of detail

- Near-term: Lot Sizing and Detailed Scheduling
- Mid-term: Lot-size Planning, maybe in Aggregate
- Long-term: Resource Allocation and Investment

So ... Operational Use? ... or Policy/Practice Insights?

Operational Use: must be more than an aid to human judgement / intuition, so that the user finds the model to be actually useful over time in quite different situations.

Questions for Reflection

1. What industries or applications are there for LS that were not mentioned above? For example, can we project/adapt LS models to, say, accounting & finance, or the health sector?
2. What value has actually been added that can be explicitly attributed to LS?

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