Towards green scheduling: A decision support for trade-off analysis between makespan and energy consumption

Afshin Mansouri [1] Emel Aktas [1] Umut Besikci [2]

[1]Brunel Business School, Brunel University London, UK
[2]Faculty of Engineering and Natural Sciences, Sabanci University, Turkey

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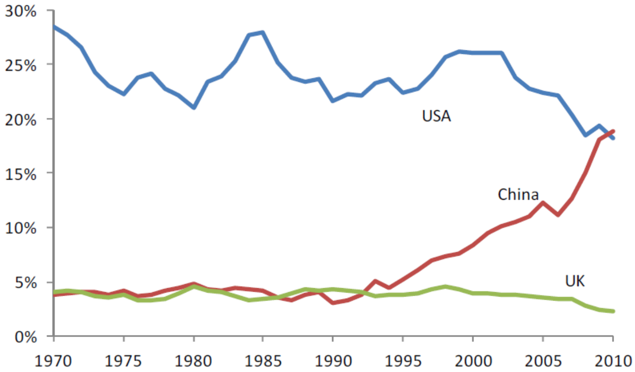
Outline

Sustainability Concerns in Manufacturing

- Challenges
  - Increasing energy cost
  - Scarcity of energy, resources, and material
- Manufacturing sector:
  - The third largest sector in the UK economy
  - Over 11% of the national economy
  - More than 8% of total UK employment
- Transition to a low-carbon economy
- Energy considerations for resource efficient manufacturing
- One third of world energy is consumed by manufacturing sector
- 36% of global CO_2 emissions by manufacturing sector (OECD-IEA 2007)

Manufacturing: A Global Driver



Manufacturing's global contribution (Mellows-Facer & Maer 2012)

Commitment of Developed Economies

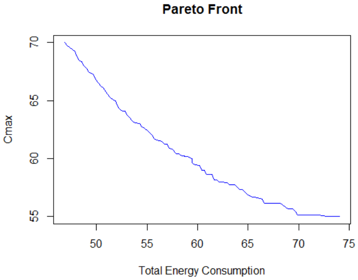
- The Kyoto Protocol target for 37 industrialized countries and the European community for reducing Greenhouse Gas (GHG) emissions by 5% against 1990 levels over the five-year period 2008-2012.
- Carbon Reduction Commitment scheme aims to reduce CO2 emissions from the target organisations in UK by at least 4 million tonnes per year by 2020. (www.carbontrust.com)

An Immediate Need

- Carbon footprint reduction has high priority for a major UK biscuit manufacturer with core markets in Europe in line with their strategy to minimize impact on the environment
- Baking profile can influence up to 25% of total energy
- Key decision variables
  - Line process rates which may be driven by pack size
  - Changeovers (ie milk to plain chocolate) pause the process (the time requirement depends on the sequence)
  - Baking profile

Characteristics of the Problem

- Multiple products
- Different running speeds
- Conflicting criteria: C_{max} (or Makespan) and Total Energy Consumption (TEC)
- Two machine sequence dependent permutation flowshop ($F2|ST_{sd}|C_{max}$, TEC)

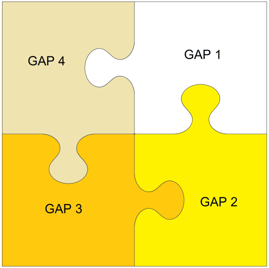


Summary of the Literature

- Yu (2010) defined Green Scheduling as "modern scheduling which considers resource consumption and environmental effect"
- Survey on scheduling problems with setup times / costs (Allahverdi et al. 2008)
- Minimizing Total Energy Consumption and Total Completion Time (Yildirim & Mouzon 2011)
- Energy consumption characteristics driven by task flow in machining (He et al. 2012)
- Energy consumption model and energy optimization in manufacturing (Dietmair & Verl 2009)

Four Interrelated Gaps

- Gap 1: Automatic access to data and analysis (Mani et al. 2012)
- Gap 2: Modelling carbon footprint (Jayal et al. 2010, Neto et al. 2010, Dekker et al. 2011, Tsoulfas & Pappis 2008)
- Gap 3: Optimization techniques(Mani et al. 2012, Sbihi & Eglese 2007)
- Gap 4: Decision support tools



Multi-Objective Optimization (MOO)

$$Min\ \{f_1(\tilde{x}), \ldots, f_m(\tilde{x})\};$$
$$\text{st: } \tilde{x} \in \{Feasible\ Set\}$$

Dominance Relation

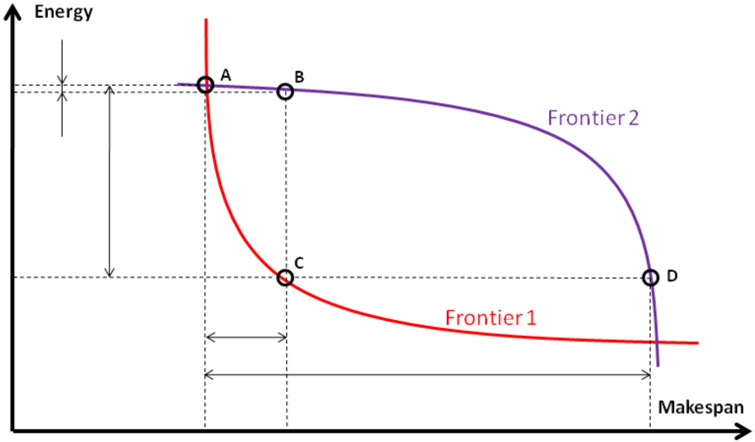
$\tilde{x}$ dominates $\tilde{y}$ ($\tilde{x} \succ \tilde{y}$) iff:

- $f_i(\tilde{x}) \leq f_i(\tilde{y});\ \forall\ i \in \{1, \ldots, m\};$
- $\exists\ i \in \{1, \ldots, m\} \mid f_i(\tilde{x}) < f_i(\tilde{y}).$

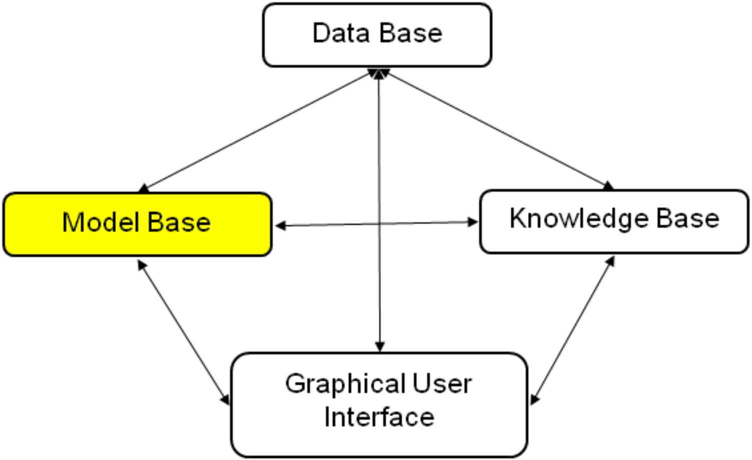
Pareto Frontier

Non-dominated solutions constitute the Pareto frontier in the objective space.

Pareto Frontier and Trade-off Analysis



MOO in a Decision Support Framework



Bicriteria MILP Model

- Min C_{max} and TEC
- s.t.
  - Timing Constraints;
  - Balance Constraints (for binary variables);
  - Binary and non-negativity constraints.

Complexity

Flowshop scheduling with sequence-dependent setups to minimize C_{max} is a special case of TSP and therefore NP-hard.

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Initiation and Evolution

- Two Dimensional Chromosome Structure

Job string:	J_1	J_2	...	J_n
Speed on Machine 1	$y_{11\ell}$	$y_{12\ell}$	...	$y_{1n\ell}$
Speed on Machine 2	$y_{21\ell}$	$y_{22\ell}$	...	$y_{2n\ell}$

- Random initial population
- Non-dominated sorting (Deb 2009) to calculate fitness values
- Elitist strategy to preserve non-dominated solutions
- Genetic operators
  - Order cross-over Michalewicz (1998) for recombination
  - Four Mutation Strategies: Inversion, Insertion, Swap and Alteration

Parameter Setting

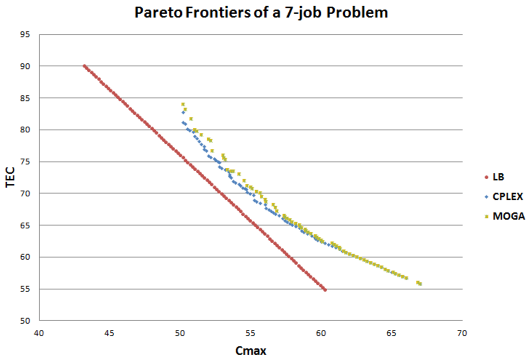
Benchmarking MOGA with CPLEX in small problems, the following parameter set found to be effective:

- Population size = $4 \times n$
- Maximum execution time = $5 \times n$ seconds
- Crossover rate = 0.7
- Mutation Strategies:
  - Insertion rate = 0.08
  - Inversion rate = 0.10
  - Swap rate = 0.02
  - Alteration rate = 0.10

Lower Bounds

- LB on C_{max}: for a no-setup single-speed version of the original problem wherein jobs are processed at the *highest* speed (v_1) after the *shortest* possible setups.
- LB on TEC: for a no-setup single-speed version of problem P in which jobs are processed at the *lowest* speed following the *shortest* possible setups.
- The straight connecting the above two LBs is a lower bound for the Pareto frontier.

Sample Comparison in a Small Problem



Performance

MOGA: 35s, 4.06% distant with LB; CPLEX: 2610s, 3.41% distant with LB

Comparisons in Large Problems

Jobs	CPU Time (s)*	Distance with LB (%)	
		MOGA	Random Search
10	50	16.64	63.14
20	100	22.51	62.57
30	150	31.47	70.07
40	200	43.70	72.68
50	250	39.48	73.58
60	300	42.84	72.91
70	350	51.74	73.72
80	400	45.39	71.64

* On a Pentium 2.67GHz with 4GB RAM

Summary

- Contributions
  - Extending the literature on Green Scheduling
  - Mathematical modelling of Total Energy Consumption, a sustainability metric alongside Makespan, a measure of service
  - Defining lower bounds on energy and Makespan
  - Developing MOGA to facilitate trade-off analysis in large problems
- Future Work
  - Improving performance of MOGA
  - Possible tightening of the Lower Bounds
  - Embedding MOGA in DSS framework for trade-off analysis
  - Tackling other problems for reducing carbon footprint in manufacturing supply chains

Thanks for your attention!

Questions or Comments?

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