A New Local Search Procedure for the Minimization of Tool Switches

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Conteúdo

Introduction

- Flexible Manufacturing Systems (FMS) are known for their great flexibility and adaptability on production planning
  - It allows a wide range of item types to be produced;
  - e.g., the same machinery present on a production line can be quickly adjusted to produce an unrelated new set of items.
  - This characteristic is also important when the production must the replanned.

Introduction

- A common type of FMS, mostly employed by the automotive and metallurgical industries, uses **flexible machines**
  - Machines able to perform different types of operations requiring only a few changes on their configuration;
  - Cutting, drilling, etc.

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Introduction

- Each item requires a set of such tools to be produced and the magazine is able to store all tools for a single item
  - All available tools cannot be loaded at the same time on the magazine;
- Between the production of two different item types it may be neccessary to switch tools on the magazine;
- The tool switching imply the interruption of the production line as the machine should be turned off in order to be configured
  - Thus increasing the cost of production.

Introduction

- From a predetermined demand for products, it becomes neccessary to determine a production plan such that the production line meets this demand;
- The plan is divided into jobs and aims to minimize the downtime of the production machines, in order to maximize productivity and reduce related costs;

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Introduction

- The production plan consists of two parts:
  1. Determine the order in which the jobs are processed; and
  2. Decide when to switch tools and what tools will be switched.
- The first one is the **Minimization of Tool Switches Problem**;
- The second one is deterministic polynomial time solvable, using the *Keep Tools Needed Soonest* algorithm.

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Problem Data

- The set of jobs $T = \{1, \ldots, n\}$;
- The of set tools $F = \{1, \ldots, m\}$;
- The subset of tools T_j needed to process job $j \in T$;
- The magazine capacity C.

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Formal Definition

- The *Minimization of Tool Switches Problem* (MTSP) is defined on a binary sparse matrix M:
  - The n rows correspond to the tools and the m columns correspond to each job;
  - Entry $m_{ij} = 1$ if tool i is loaded in the machine during job j processing and $m_{ij} = 0$ otherwise.
- A solution is represented by a permutation π of the elements of T and a tool switching plan, resulting in M_π;
- The number of inversions in M_π is the number of tool switches.

An Example

Jobs	1	2	3	4	5
Tools	1	1	3	2	1
	2	3	4	3	4
	4	5	7	5	6
	7			6	
Capacity = 4					

A Solution Example

π	1	3	5	2	4
Tools	1	$\underline{1}$	1	1	0
	1	0	0	0	1
	0	1	1	1	1
	1	1	$\underline{1}$	0	0
	0	0	0	1	1
	0	0	1	$\underline{1}$	1
	1	1	0	0	0

- Underlined tools denote they are loaded in advance;
- 8 tool switches (the initial four also counts).

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Motivation

- It is NP-hard;
- Its practical application in VLSI design industry
  - Printed circuit board assembly;
  - The assembly tasks are jobs and components are tools.

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Proposed Methods

- A graph search for generating an initial solution;
- A new local search method;
- An Iterated Local Search.

Current State of the Art

- Metaheuristic: Clustering Search + Variable Neighborhood Search + Biased Random Key Genetic Algorithm (2016);
- Exact: Branch & Bound (2009), Integer Linear Programming (2015).

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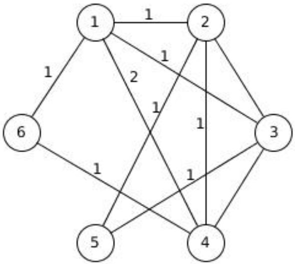
Graph Model

- Nodes represent tools;
- Edges connects tools used in a same job;
- No loops or parallel edges;
- Weights are defined by the frequency of tools;
- Each job induces a clique.

Jobs	1	2	3	4	5
Tools	1	1	3	2	1
	2	3	4	3	4
	4			5	6



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Graph Search

- The main idea is to search for tools that must be kept together in the solution, avoiding switches;
- Breadth-first search (BFS) in non-decreasing weight of edges order.

Jobs Sequencing

- The BFS returns a list of tools;
- The jobs sequence is determined in a greedy fashion:
  - The list of tools is traversed, and once all tools of a specific job are found, it is sequenced.
- Two tie breakers:
  1. Higher number of tools (if no job sequenced yet);
  2. Lower number of switches.

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Local Search

- Each consecutive pair of 1-blocks in a same row denotes an inversion
  - Minimizing 1-blocks number is a different problem.
- 1-blocks columns are inserted before/after the other 1-blocks;
- The best move is performed.

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Iterated Local Search

- Classic version;
- Local search – only non deteriorating movements;
- Perturbation: 2-opt of columns
  - Randomly selected, 20% of the columns.
- All parameters tuned using the irace package.

Methods

- Iterated Local Search (ILS);
- Biased Random Key Genetic Algorithm + VND + Clustering Search (BRKGA + CS).

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ILS

- Intel Core i5 3.2 GHz processor;
- 8 GB RAM;
- Ubuntu 15.10 LTS;
- Codes written in C++, compiled with gcc 4.8.4 and the -O3 optimization option.

BRKGA + CS

- Intel Core i7 3.4 GHz processor;
- 16 GB RAM;

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Instances

Two different data sets from the literature were considered, a total of 1670 instances.

- Yanasse (A, B, C, D, E): 1510 artificial instances;
- Crama (C_1, C_2, C_3, C_4): 160 artificial instances.

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Average gap from Optimal Solutions (20 runs)

Method	A	B	C	D[a]	E
ILS	0.00%	0.00%	0.00%	0.00%	0.00%
BRKGA + CS	0.00%	0.00%	0.00%	0.05%	0.00%

[a] Considering only known optimal solutions.

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Average Running Times (20 runs)

Method	A	B	C	D	E
ILS	0.15s	0.26s	2.14s	6.45s	0.70s
BRKGA + CS	3.71s	4.05s	9.83s	27.66s	6.54s

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Average gap from Best Known Results (20 runs)

Method	C_1	C_2	C_3	C_4
ILS	0.00%	0.00%	0.031%	0.00%
BRKGA + CS	0.00%	0.00%	0.00%	0.34%

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Average Running Times (20 runs)

Method	C_1	C_2	C_3	C_4
ILS	0.09s	1.11s	168.71s	1063.47s
BRKGA + CS	2.42s	11.58s	123.15s	541.10s

Conclusion

- The proposed ILS was able to match a large part of the best results available on the literature and to improve some of them;
- Running time increased on large instances;
- Future work includes:
  - TSP model + solver;
  - New formulations;
  - New lower bounds.

Acknowledgments

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Questions?

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danke
謝謝
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Баярлалаа
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