

Models and Algorithms for Scheduling in Automotive Stamping Plants

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Goals

- Immediate focus is on scheduling stamping operations in an automotive manufacturing environment
- Broader class of problems: scheduling sequential, interdependent events within a complex system
 - ◆ How can the stamping research be generalized?

Primary Objective

- Objective is not to find “provably optimal” solutions
- We want solutions that:
 - ◆ are high-quality
 - ◆ have reasonable run times
 - ◆ realistically model the real world
 - ◆ are “easily implementable”

Math Programming Approach

■ MP pros:

- ◆ Global viewpoint
- ◆ General solution techniques
- ◆ Established commercial solvers

■ MP cons:

- ◆ Large numbers of constraints, variables
- ◆ Non-linearities
- ◆ Weak LP relaxations
- ◆ No exploitation of problem-specific structures

Customized Scheduling Algorithms

■ Pros:

- ◆ Exploit problem structure
- ◆ More realistic
- ◆ Fast run times, convergence

■ Cons:

- ◆ Feasibility?
- ◆ Solution quality?
- ◆ Adaptability?

Hybrid Approach

- Leverage benefits of both math programming and application-specific heuristics
- *Composite variable definitions*
 - ◆ Capture model complexity within the variable definition
 - ◆ E.g. instead of “ $x_{pt} = 1$ if part p starts at time t ”, might have “ $y_{sd} = 1$ if sequence s is used on day d ”

Hybrid Approach

- MP-based *master problem*
 - ◆ Global vision
 - ◆ Captures “higher level” relationships
 - ◆ Dual information
- Don't enumerate all variables
 - ◆ Use application-specific algorithms to generate
 - ◆ Focus on generating good choices
- Benefits
 - ◆ Tractability
 - ◆ Trade-off between run time and solution quality
 - ◆ Realism, implementability
 - ◆ Leveraging user expertise

Hierarchy

- At the micro level, we take this approach in solving the problem for individual press lines
- At the macro level, we will take this approach in solving the problem for all press lines in a single facility
- At the “super-macro” level, can we take this approach in considering the full assembly process?

Stamping Plant Application

Automotive Stamping Plant

Step 1

Sheet Metal Blanking

Forms coils of sheet metal into blank



Step 3

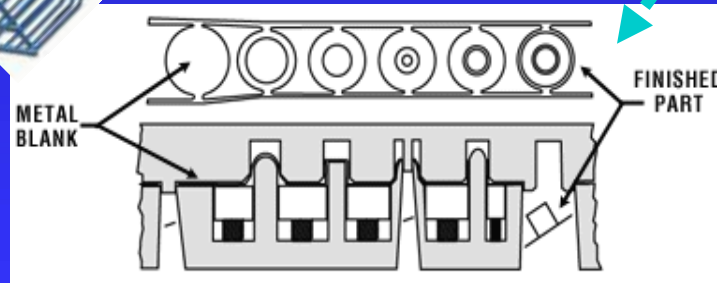
Sub-Assembly/Assembly

Pressed parts undergo additional operations
(e.g. adding nuts and bolts)

Step 2

Sheet Metal Stamping

Forms sheet metal into 3D parts



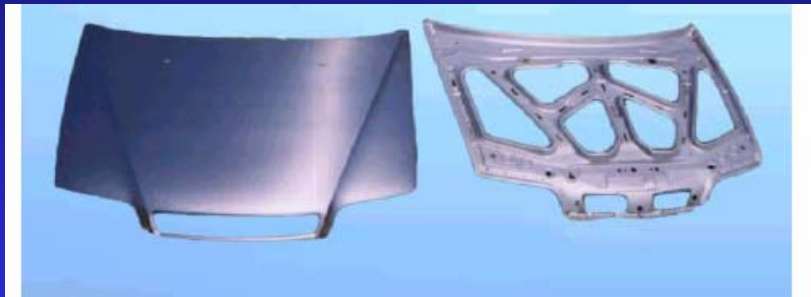
Racks

Move parts between
workstations

Diagrams from <http://www.advantagefabricatedmetals.com> and <http://www.maybury.com/>

Stamping Plant Application

■ Automotive Stamping Plant – Example Parts



Diagrams from <http://www.advantagefabricatedmetals.com> and <http://www.maybury.com/>

Problem Statement

- How can we schedule a set of products on a given press line so that we satisfy:
 - ◆ One product at a time
 - ◆ All demands met
 - ◆ Implicit and explicit changeover times incorporated
 - ◆ Combined inventory, labor, and changeover costs minimized

Modeling Challenges

- How to represent both sequencing of products and lengths of runs?
- How to capture explicit changeover?
- How to capture implicit changeover?

Traditional Variable Approach

- Possible “traditional” variable definitions
 - ◆ $x_{pt}=1$ if product p is produced at time t
 - ◆ $y_{pt}=1$ if product p begins production at time t
 - ◆ $z_{ptq}=1$ if product p begins production at time t and produces quantity q
- All make capturing background changeover difficult!

Composite Variable Approach

- Our composite variable definition:
 - ◆ $x_{ns}=1$ if the n^{th} shift in the planning horizon uses “shift-schedule” s
 - ◆ s is a feasible shift-long set of events, e.g.:
 - ◆ 8 hours of A
 - ◆ 4 hours of A, then a changeover, then 2 hours of B

Basic Model

- Each shift-schedule is feasible with respect to change-overs
- Each shift-schedule has defined labor costs, change-over costs, and production values (which can be used to compute inventory)
- We must choose exactly one schedule per shift
- The schedules must “match products” at their end points
- The schedules must satisfy demand

Basic Formulation – Parameters

- S – Set of shift-schedules
- J – Set of jobs (i.e. product types)
- N – Number of shifts in the planning horizon
- T – Number of days in the planning horizon
- $t[n]$ – Day t that includes shift n
- $d[t, j]$ – Quantity of job j due at the end of the day t
- $c^g[n]$ – Cost of each changeover that occurs in the n^{th} shift
- $c^i[j]$ – Per-unit inventory cost for job j
- $c^w[n, j]$ – Direct labor cost to run job j in shift n

Basic Formulation – Parameters

(cont.)

- $q[j, s]$ – Quantity of job j produced in the shift-schedule s
- $f[j, s] = 1$ if j is the first job on shift-schedule s , else 0
- $l[j, s] = 1$ if j is the last job on shift-schedule s , else 0
- $b[s] = 1$ if shift-schedule s begins with at least two hours of idle time
- $u[s] = 1$ if shift-schedule s is set up to run its last job for less than two hours
- $g[s]$ – Number of change-overs in shift-schedule s

Basic Formulation – Variables

- $x[n, s] = 1$ if shift-schedule s is assigned to the n^{th} shift, else 0
- $i[t, j] \geq 0$ – inventory of job j at the end of the t^{th} day ($i[0, j]$ is the initial inventory)

Basic Formulation – Objective

Minimize the costs of:

■ Change-overs:
$$\sum_n c^g[n] * \sum_s (g[s] * x[n, s])$$

■ Inventory:
$$\sum_j \sum_t c^i[t, j] * i[t, j]$$

■ Direct labor:
$$\sum_j \sum_n c^w[n, j] * \sum_s (q[j, s] * x[n, s])$$

Basic Formulation – Constraints

- Each shift gets one schedule:

$$\sum_s x[n, s] = 1 \forall n$$

- Inventory:

$$\sum_s q[j, s] * x[3t-3, s] + \sum_s q[j, s] * x[3t-2, s] + \sum_s q[j, s] * x[3t-1, s] + i[t-1, j] - d[t, j] = i[t, j] \forall t, j$$

Basic Formulation – Constraints (cont.)

■ “Balance” constraints

$$\sum_s (u[s] * l[j, s]) * x[n, s] \leq \sum_{s'} (b[s'] * f[j, s']) * x[n+1, s'] \forall j, n$$

$$\sum_s (l[j, s]) * x[n, s] = \sum_{s'} (f[j, s']) * x[n+1, s'] \forall j, n$$

Enhancements to the Model

- Define variables to represent first, last product in a shift
 - ◆ Improved branching
 - ◆ Reduction in number of shift-schedules!
- Cuts for improving lower bound
 - ◆ Exploit relationship between inventory and change-overs

Extending the Basic Model

- Capacity constraints
- Scheduled maintenance

Multiple Presslines

- How do schedules for different presslines interact?
 - ◆ Need to share labor force
 - ◆ Need to share resources (e.g. cranes)
- Option One: Extend existing model
 - ◆ Index each shift-schedule by pressline
 - ◆ Link pressline-specific scheduling decisions with labor, resource constraints
 - ◆ Very big, very fractional!

Multiple Presslines (cont.)

- Option Two: Extend the composite variable
 - ◆ Each variable is a *complete schedule* for a given pressline
 - ◆ Select one schedule per pressline
 - ◆ Constraints may be explicit or generated iteratively
 - ◆ Heuristically generate candidate schedules
 - ◆ Exploit “wiggle room” (make some detailed decisions at a secondary level)
 - ◆ Leverage dual information

Conclusions and Future Research

- This *will not* yield a provably optimal solution
- This (probably) *will not* yield useful lower bounds/optimality gaps
- It may yield *feasible* solutions in *reasonable run time* of *good quality* that are *implementable*
- Can the idea be extended higher in the hierarchy?
 - ◆ E.g. each variable represents the schedule of a facility/node within the supply chain