

Problem

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Conclusion

A New Modeling Approach for Scheduling Stamping Operations

*Using Composite Variables to
Capture Real-World Complexities*

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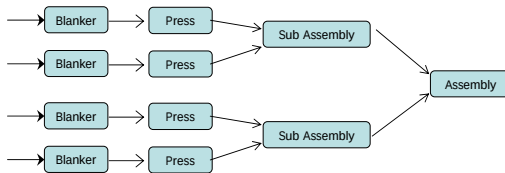
Problem: Plant Overview

Problem

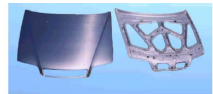
Model

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Automotive Stamping Plant - Part of the automotive supply chain that produces parts that compose the frame of vehicles.



Example Plant Layout



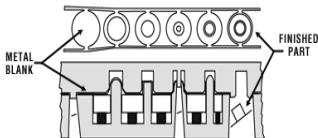
Example Products

Problem: Stamping Press

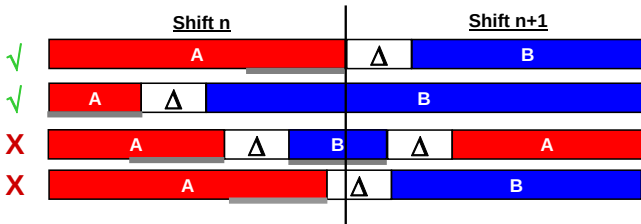
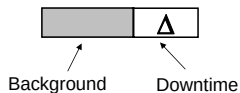
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Die Set Changeover



Initial Focus: Solve the single press line problem.

Problem: Decisions, Goal, Rules

■ Decisions

- Sequence and duration of jobs on the press line

■ Goal

- Minimize Cost
 - Labor costs (direct, indirect)
 - Inventory

■ Rules

- Customer Constraints
 - Demand due dates
- Production Constraints
 - Press line parameters
 - Job requirements
 - Direct labor requirements
- Changeover Constraints
 - Job setup time
 - Indirect labor requirements
- Time Constraints
 - Specified planning horizon
 - Repeatable

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Problem: Challenges Motivate Composite Variable Modeling

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Model Challenges

- Capture changeover constraints
 - Previous job must:
 - Be set on the press at least the background (with/without idle)
 - End early enough in the shift for changeover
 - Difficult to model using traditional approaches
 - Large number of variables and constraints

Composite Variables

- Capture complexity in definition
- Successful applications
 - Airline Crew Scheduling
 - S. Lavoie, M. Minoux, & E. Odier (1988)
 - A. Cohn & C. Barnhart (2003)
 - Freight Transportation
 - A. Cohn, S. Root, & A. Wang (2005)
 - Manufacturing
 - Little if any application

Model: Composite Variable Definition

VARIABLE = SHIFT SCHEDULE

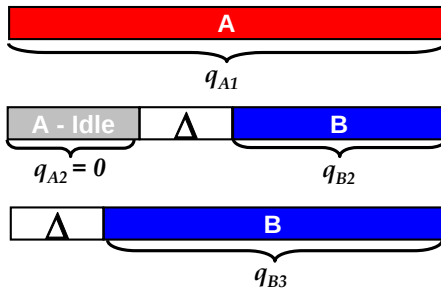
Shift Schedule: A set of *feasible* events in a eight hour shift.



Model: Composite Variable Definition

VARIABLE = SHIFT SCHEDULE

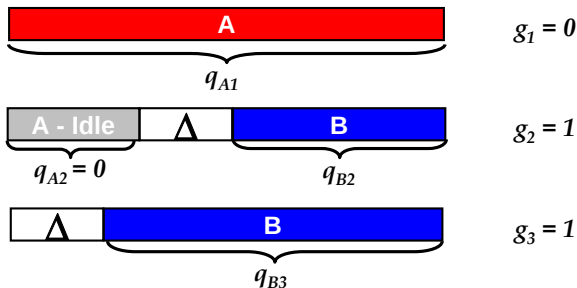
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Model: Composite Variable Definition

VARIABLE = SHIFT SCHEDULE

Shift Schedule: A set of *feasible* events in a eight hour shift.



Model: Composite Variable Definition

VARIABLE = SHIFT SCHEDULE

Shift Schedule: A set of *feasible* events in a eight hour shift.

$$f_{1A} = 1$$



$$l_{1A} = 1$$

$$f_{2A} = 1$$



$$l_{2B} = 1$$

$$f_{A3} = 1$$



$$l_{B3} = 1$$

Model: Variables

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- $x_{ns} = 1$ if shift schedule s is assigned to shift n , 0 otherwise.
- $i_{tj} \geq 0$, denotes the inventory of job j at the end of day t , (hours of production)
- $w_{nj}^f = 1$ if job j is the first job produced in shift spot n , 0 otherwise.
- $w_{nj}^l = 1$ if job j is the last job produced in shift spot n , 0 otherwise.
- $y_{hk}^d = 1$ if direct labor requirement k is scheduled during in the h^{th} shift of the day, 0 otherwise.
- $y_h^c = 1$ if a changeover crew is needed during the h^{th} shift of the day, 0 otherwise.

Model: Formulation

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$$\min \sum_h c_h^c * y_h^c + \sum_h c_h^d * \sum_k m_k * y_{hk}^d + \sum_j \sum_t c_{tj}^i * i_{tj}$$

- Minimize indirect labor, direct labor, and inventory cost.

s.t.

$$\sum_s x_{ns} = 1 \quad \forall n \in N$$

- Select one shift schedule for each shift spot.

$$\sum_s q_{js} * x_{(3t-3)s} + \sum_s q_{js} * x_{(3t-2)s} + \sum_s q_{js} * x_{(3t-1)s} + i_{(t-1)j} - d_{tj} = i_{tj} \quad \forall j \in J, t \in \{2 \dots 10\}$$

$$\sum_s q_{js} * x_{30s} + \sum_s q_{js} * x_{1s} + \sum_s q_{js} * x_{2s} + i_{10j} - d_{1j} = i_{1j} \quad \forall j \in J$$

- Inventory on a day t is the previous inventory plus any production during day t minus the demand on day t .

$$i_{0j} = i_{10j} \quad \forall j \in J$$

- Beginning inventory must equal ending inventory.

Model: Formulation, continued

Problem

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$$\sum_s f_{js} * x_{ns} = w_{nj}^f \quad \forall j \in J, n \in N$$

$$\sum_s l_{js} * x_{ns} = w_{nj}^l \quad \forall j \in J, n \in N$$

- Define the w variables.

$$w_{nj}^l = w_{(n+1)j}^f \quad \forall j \in J, n \in \{1 \dots 29\}$$

- The last job on in a shift spot must be the first job in the following shift spot.

$$w_{30j}^l = w_{1j}^f \quad \forall j \in J$$

- The last job in the horizon must equal the first job of the horizon.

$$\sum_s u_{js} * x_{ns} \leq \sum_{k: m_k \geq a_j} y_{h_n k}^d \quad \forall j \in J, n \in N$$

$$\sum_s g_s * x_{ns} \leq y_{h_n}^c \quad \forall n \in N$$

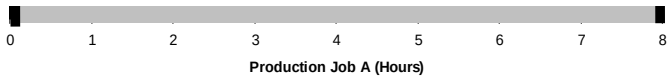
- Direct and indirect labor in the first, second and third shift of the horizon is the maximum required for any job produced during that shift.

Composite Variable Definition: Variable Reduction

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A

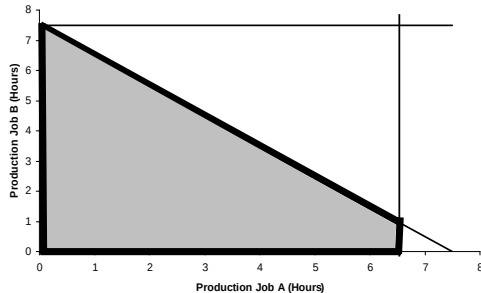
A - Idle

Composite Variable Definition: Variable Reduction

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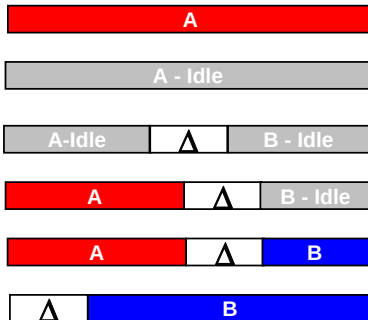
Composite Variable Definition: Variable Reduction

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Result: $0 \leq x_{ns} \leq 1$ is the **proportion** of shift schedule s is assigned to shift n .



Computational Results

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■ Data Set Summary

- Ford Motor Company largest stamping facility
- 26 Press Lines: 5 Quick Set, 21 Tandem
- Number of jobs range: 2 - 13
- Required direct labor options range: 1 - 4

■ Computational Results

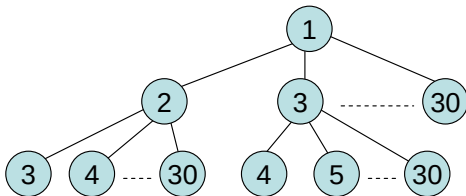
- Implemented in CPLEX 10.0
- Each instance was solved to 0.05% optimality gap
- Run time ranges between 5 seconds and 13 hours
 - Run times increase with:
 - ↑ number of jobs
 - ↑ required direct labor options
 - ↓ downtime duration

Model: Alternate Branching Strategy

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■ Motivation

- Strengthen LP relaxation
- New way to look at tree

■ Benefits

- Finds multiple solutions
- Solutions differ in changeover locations

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- **Press line scheduling problem**

- Tradeoff between changeovers and inventory
- Complex changeover constraints

- **New modeling approach**

- Composite variables
 - Shift Schedule
 - Embedded changeover constraints
 - Variable number reduced using extreme points
- Solves real-world instances
 - Most instances solve in less than 25 minutes
 - Run times increase motivated alternative branching strategy
- Flexible
 - Can be used in other single server environments
 - Horizon broken in discrete blocks (i.e. shifts)
 - Only update shift schedules

Future Work

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- **Alternate Branching Strategy**
 - Complete computational tests
- **Press Line Stage Problem (Parallel Machines)**
 - Use feasible solutions to single press problem
- **Plant Problem (Job Shop)**
- **Introduce more real-world complexity**
 - Racks, labor breaks, etc.

Acknowledgements

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- **Craig Morford**, MP&L Assistant Plant Group Manager, Ford Motor Company
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Questions

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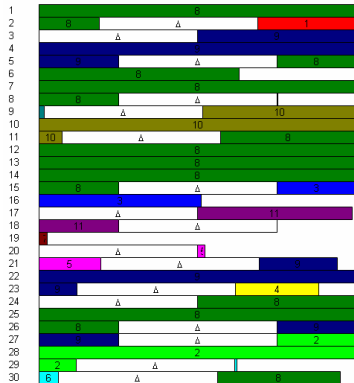
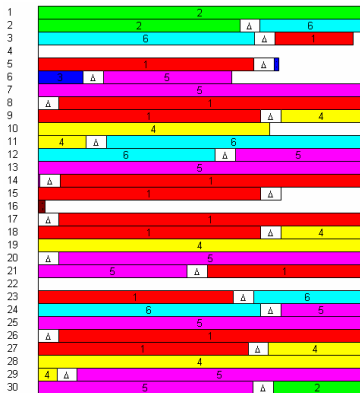
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Schedule Examples

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Model: Assumptions

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- All demand will be met
- There is never a shortage of raw materials.
- There is no constraint on the number of racks per product.
- There are three eight hour shifts through out the day.
- Products are only due at the end of the second shift on each day.
- Products can be produced in a shift to satisfy demand due at the end of that shift.
- Direct labor for the first, second and third shift is determined by the job with the largest labor requirement in each shift respectively.
- There can be at most one changeover per shift.
- Labor breaks are not scheduled.
- For each changeover, both the downtime and the background occur completely within the shift.
- There are only two types of press lines - Tandem and Quick Set

Model: Parameters

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- S - shift schedules, $s \in Z^+$
- J - jobs, $j \in Z^+$
- N - eight hour shift spots, $n \in \{1 \dots 30\}$
- T - days, $t \in \{1 \dots 10\}$
- H - shifts in a day, $h \in \{1 \dots 3\}$
- K - labor requirements $k \in Z^+$
- $f_{js} = 1$ if job j is first in shift schedule s , 0 otherwise.
- $l_{js} = 1$ if job j is last in shift schedule s , 0 otherwise.
- q_{js} is the quantity of job j produced in shift schedule s (hours).
- $u_{js} = 1$ if $q_{js} > 0$ in shift schedule s , 0 otherwise.
- h_n is the h^{th} shift of the day (1, 2, 3) that corresponds to shift n .
- g_s is the number of downtime periods in shift schedule s .
- a_j is the number of direct laborers needed to produce job j .
- m_k is the k^{th} direct laborer requirement.
- d_{tj} is the quantity of job j due at the end of day t (hours).
- c_{tj}^i is the cost of inventory of job j (dollars per unit per day).
- c_h^d is the direct labor cost during shift h (dollars per laborer).
- c_h^c is the changeover crew cost during shift h (dollars per crew).

Model: Improving Constraints

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$$w_{11}^I + w_{21}^I + w_{31}^I \geq 1$$

- Symmetry Constraint: The first job is produced in the first day.

$$\sum_n \sum_s (f_{js} * (1 - l_{js})) * x_{ns} \geq 1 \quad \forall j \in J$$

$$\sum_n \sum_s (l_{js} * (1 - f_{js})) * x_{ns} \geq 1 \quad \forall j \in J$$

- Each job is set up at least once in the horizon.