

Using an Assembly Sequencing Application to React to a Production Constraint: a Case Study

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ABSTRACT

Ford Motor Company's assembly plants build vehicles in a certain sequence. The planned sequence for the plant's trim and final assembly area is developed centrally and is sent to the plant several days in advance. In this work we present the study of two cases where the plant changes the planned sequence to cope with production constraints. In one case, a plant pulls ahead two-tone orders that require two passes through the paint shop. This is further complicated by presence in the body shop area of a unidirectional rotating tool that allows efficient build of a sequence "A-B-C" but heavily penalizes a sequence "C-B-A". The plant changes the original planned sequence in the body shop area to the one that satisfies both pull-ahead and rotating tool requirements. In the other case, a plant runs on lean inventories. Material consumption is tightly controlled down to the hour to match with planned material deliveries. When an inevitable delay of receipt of inbound shipment of a particular part is expected, the plant must somehow react to alleviate that part's shortage and avoid assembly line stoppage. The plant reacts by changing the originally planned assembly sequence to the one that slows down the rate of installation of that part until the receipt of shipment from a supplier; afterwards, the plant accelerates the rate of installation of that part. We'll briefly discuss the sequencing application that allows a plant to react to the ever changing production environment.

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INTRODUCTION

Today's vehicles are often marketed in multiple body styles, colors and trims. For example, a 2016 Ford F-150 [3] is offered in three cab styles, three box sizes, ten exterior colors, and numerous versions, packages, equipment groups, and stand-alone options, yielding millions of orderable configurations.

Original equipment manufacturers (OEMs) build vehicles at a mixed-model assembly plant through three major processes: body assembly, painting, and final assembly. At each step, work is carried out in individual workstations; vehicles are moved from workstation to a workstation by conveyor. Workloads are different for each process and each workstation, and may include sequence-dependent setup times. Each major process in the assembly plant has its peculiarities that must be accounted for in order to establish an efficient production schedule. The typical flow of an automotive assembly plant is illustrated in [Figure 1](#).

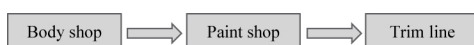


Figure 1. Typical structure of an automotive assembly plant.

Body shop is where the stamped body parts are welded together into a vehicle's body. Most work in this area is done by robots. This area typically sports a negligible defect rate and negligible disruptions to the originally planned sequence. Job scheduling considerations for this area include minimizing the inter-unit setup and waiting times, in order to maximize throughput.

Paint shop is where the body is painted in the paint booth and then is dried in the oven. The paint process notoriously has a significant defect rate, so, many units undergo spot paint repair or full repaint leading to disruptions to the originally planned sequence of units. In addition to those unplanned disruptions, two-tone units may require more than one pass through the paint shop. Job scheduling considerations for this area include batching together the units of same color to minimize expensive paint flushes.

Final assembly and trim line is where all parts are installed, transforming a painted body shell into a finished vehicle. The work in this area is mostly manual; workers in each station have limited time to complete work on any given vehicle; workstations have limited space for keeping part inventories. The overarching job scheduling goal for the trim line is to avoid line stoppages due to any station's over-cycling; the peak workload at any particular workstation must not exceed the line's tact time.

Monden [5] identified two main considerations regarding mixed-model assembly line planning:

1. Leveling the load (total assembly time) on each process within the line.
2. Keeping a constant speed in consuming each part on the line.

A widely used approach to sequencing is to create separate sequences for the body, paint and trim areas and to maintain a buffer of bodies between the body shop and the paint shop, and a buffer of painted bodies between the paint shop and the final assembly area. The buffers serve two purposes: first, they decouple the areas of the plant, allowing body, paint and trim areas to work different shifts and different jobs per hour (JPH) speeds. Second, they allow re-sequencing between the work areas to satisfy each area's specific constraints. For example, the painted bodies buffer allows to alleviate sequence disruptions in the paint shop and partially restore the originally planned sequence of units in the trim line. Typically, a sequence for the trim area is created ahead of time by the OEM's central office and passed to the plant; then the plant is responsible for creating the body and paint shops sequences. (In this work we won't be addressing algorithms controlling the re-sequencing functionality of buffers.)

An alternative approach is to find a sequence that simultaneously satisfies requirements of body, paint and trim areas. Under this approach, we'd still require the de-coupling capabilities of buffers, but their costly re-sequencing capability could be reduced or eliminated altogether. Practicality of this approach largely depends on the degree of variability in the paint process: the larger the rate of paint defects, the bigger re-sequencing capacity is required between the paint and trim areas, and the dimmer are the chances of using a single sequence through the whole plant.

Automotive OEMs routinely face a job sequencing problem: given a daily or weekly set of production vehicle orders, find the sequence in which vehicles are to be built, so that to maximize the overall plant's efficiency [7]. Scheduling and sequencing of vehicles is a difficult task due to the wide variety of vehicle characteristics, options, and accessories. The problem complexity grows exponentially, as more constraints need to be considered simultaneously. There is therefore a need for computationally efficient methods for scheduling and sequencing so as to allow vehicles to be assembled in an efficient manner.

Various classes of algorithms have been tried for mixed-model assembly lines sequencing:

- Under greedy heuristics such as Toyota goal chasing [3], a solution is quickly obtained in one "pass" but may exhibit uneven quality (a so-called "boundary", or "cherry-picking" effect).
- Under mathematical or constraint satisfaction programming methods, one must relax some constraints for a problem to become feasible since real-world sequencing problems are often over-constrained [1].
- Under stochastic search heuristic methods, the entire solution space is iteratively sampled to come up to a solution of an evenly favorable quality [2], [4], [6].

We developed a sequencing application that builds upon earlier work [4] and uses stochastic search heuristic. The application can be run by plant personnel in order to modify the centrally planned production schedule "as needed", in reaction to the changing production environment.

In this paper we won't be covering any details of the sequencing algorithms. Rather, in the rest of the paper we present two cases of using the sequencing application.

CASE 1: A UNIDIRECTIONAL ROTATING TOOL IN THE BODY SHOP

This case concerns an assembly plant building a vehicle in four distinct body styles that we'll designate by letters A, B, C, and D. The OEM's central office, several days in advance, develops and sends to the plant a good sequence in which vehicles are to be assembled in the trim line. However, vehicles that are ordered in two-tone exterior color require an additional pass through the paint shop.

To allow more time to be spent in the paint shop, the plant starts those units several hours earlier in the body shop, in other words, pulls them ahead. Following the pull ahead operation, the resulting body shop sequence would typically require re-sequencing to accommodate the body shop's constraints and improve throughput. Since at the time there was no automated solution for re-sequencing by the plant personnel, schedulers at the plant had to daily perform the re-sequencing by hand (see Figure 2). It was time-consuming and difficult, and despite all heroic efforts put in manual re-sequencing, the resulting body shop's sequence still contained notable inefficiencies. The body shop's JPH throughput metric was below target. The plant sorely needed an automated re-sequencing tool that could be used locally by plant personnel to improve the efficiency and quality of the body shop schedule.

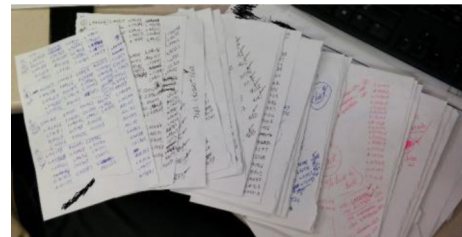


Figure 2. The paper sheets that the plant scheduler created every day as he attempted to solve the puzzle of body shop re-sequencing by hand.

The chief sequencing constraint in the body shop was due to a certain station that relies on two physical rotating fixtures, schematically shown in Figure 3. The three facets of the left triangle fixture are specialized: one facet only accepts an 'A' body part, the other facet only accepts a 'B' body part, and the third facet only accepts a 'C' body part. The three facets of the right triangle fixture are specialized to only accept a 'D' body part. The left triangle fixture is engaged when producing one of the body types A, B, or C. The right triangle fixture is engaged when producing a body type D. By the nature of the process, the fixtures rotate unidirectionally: the left fixture rotates clockwise, the right fixture rotates counterclockwise. Each fixture has a dedicated load area and a welding robot. The two fixtures share the common unload area that can serve only one fixture at a time: it allows to unload either a welded part from the left triangle or a welded part from the right triangle, but not both parts simultaneously.

Consider the current state of the left triangle fixture in Figure 3. The flow of materials and parts is from the bottom to the top, as shown in the diagram: from the inventory to the load area to the welding robot to the unload area.