# SIMULATION OF LEVEL SCHEDULING OF LARGE COMPOSITE PARTS

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## ABSTRACT

This study analyses the effects of a level scheduling scheme on two large aerospace composite part manufacturers. The key findings show that the linked sequence produced statistically higher results in schedule efficiency and loading efficiency than the random sequence. Further, loading type was also statistically significant, with area loading providing higher efficiencies.

Key Words: Scheduling, heijunka, level-loading, lean manufacturing

## INTRODUCTION

To stay competitive in today's environment, manufacturing companies are choosing to adopt a lean philosophy. This is especially true in the aerospace industry [1]. However, one aspect of lean manufacturing that is especially problematic for the aerospace manufacturers is how to level their production schedules while simultaneously meeting the demands of a capacity-constrained production schedule. Whereas, lean level schedules, or *heijunka*, were developed in high volume, moderate mix production lines, aerospace manufacturing builds individual aircraft at a rate of just two to four per month. It is impractical to use traditional, mixed-model level scheduling in this type of low volume industry. In addition, the fact that aerospace composite assembly lines are capacity-constrained by large machining centers and large autoclave curing chambers makes running small, level-loaded batches costly and time consuming. In this paper we propose a scheduling scheme that achieves the intent of lean level scheduling, while still achieving higher capacity utilization than is typically found in current aerospace composite structure manufacturing processes.

### Traditional Level Scheduling

In a pull system, only the required amounts of parts are produced with limited work in process. The goal of a pull system is to create a part mix sequence to match the customer demand ratio in the smallest increments possible. This has the additional benefit of stabilizing the workforce [2]. If the weekly schedule calls for 50 parts of A, 100 parts of B, and 75 parts of C, then one would produce 2 parts of A, 4 parts of B, and 3 parts of C twenty five times. While this approach is effective in a high volume manufacturing industry, it cannot be directly applied to industries with a low volume [3].

## Level Scheduling in Low Volume Manufacturing

One of the major assumptions of a traditional level scheduling system is that by creating an even distribution of parts it will create an even distribution of workload to both the equipment and the workforce. In an industry with low volume production this will not always be the case because of the long time frames involved. Instead of the previous example with 50 parts of A, 100 parts of B, and 75 parts of C; one may only have 3 parts of A, 1 parts of B, and 2 parts of C to produce in an entire week. Creating a level schedule with a low number of parts does not balance resources. In low volume manufacturing, a foundation of stability can be achieved by creating a level schedule based upon the attributes of each part. Each part can be broken into individual manufacturing processes or attributes. To help illustrate this process, a hypothetical chart of eight parts and their attributes has been created (Table 1).

**TABLE 1: PART LIST AND INDIVIDUAL ATTRIBUTES**

| Part | Process or Attribute |
|---|---|
| A | Orange |
| B | Orange |
| C | Yellow |
| D | Orange |
| E | Orange |
| F | Orange |
| G | Yellow |
| H | Orange |

Looking at the customer demand of 8 separate parts that require two separate processes, it is possible to produce a level schedule based upon the processes of each part instead of the schedule based upon the individual parts. To get the perfect sequence the lowest common frequency ratio is found based upon the individual processes. For this basic example the sequence would be (O, Y, O, O); repeat this sequence twice for a total of eight parts to be produced. Once the sequence has been developed based upon the attributes of the parts one can apply the sequence back to the individual parts. For this example the first part to be produced is a part with a process of orange, or part A. The next part to be produced is with a process of yellow, or part C. The third part to be produced is with a process of orange or part B. Lastly the final part in the basic sequence to be produced is another orange or part D. Based upon a level sequence, the parts in order to be produced are A, C, B, D. This schedule, based upon the attributes of each part, can create an even distribution flow throughout each piece of equipment and provide consistency throughout the process.

## Objectives

The desired state of the process would include a level part flow through the autoclave in a manner that meets the requirements of the present assembly process with better capacity utilization and stability. The attributes determined for the scheduling scheme are cure cycle (CC), mold size (MQ), source lay-up area (LUA), and if the part is one of an identical pair (IP). This study analyses the effects of the scheduling scheme developed by Djassemi, Olsen, and

Sena [4] on the schedule efficiency, schedule utilization, and area utilization of two large composite part manufacturers. Variations to the scheme include linked, unlinked, and random sequences, and two types of loading techniques—computer aided design (CAD) and area.

## METHODS

### Schedule Scheme

To create a scheduling scheme that uses levels based upon the attributes of each part the following factors are used: (1) CC, (2) MQ, (3) LUA, and (4) IP. CC was separated into four categories of A, B, C, and Other. CCs are the unique combination of autoclave settings for temperature, pressure, profile, and time. The parts were separated by CC because only parts with identical CCs can be placed in the autoclave at the same time. Secondly, the MQ were calculated by taking the surface area of each part and dividing the parts into four equal groups. The parts are separated by surface area to create an even flow by size to the autoclave. The third factor was based on three source LUAs to stabilize output of individual upstream production areas. The final factor of leveling is to determine if the part is one of an IP. If the part has an IP, then the time between operations of the two parts would be maximized so as to allow level utilization of molds and downstream processes that can only handle one part at a time.

### Sequencing Types

This study involves looking at three separate types of sequencing parts. The first is a linked sequence where the part selection is synchronized by factor. The second loading type is an unlinked system where the factors are not synchronized, but still follow a level sequence. Lastly, a random sequence is used for comparison. When assigning parts to their given sequence pattern, a secondary rule was developed if no part matching the required sequence attributes was remaining in the shipset of parts. The random loading sequence was constructed by assigning random numbers to each part in a shipset and sorting.

A 2x3x2 factorial experimental design is used to compare the scheduling systems for two separate aerospace manufacturers' autoclave operation using either a linked, unlinked, or random sequencing along with CAD layout or area loading. Each cell was replicated three times.

### Data Collection and Analysis

Each cell of the 2x3x2 factorial experiment was simulated three times and the resulting three dependent performance variables were calculated. Random selection was used for each sequencing scheme based on the remaining parts with the proper attributes remaining in the shipset.

The schedule performance is tested using analysis of variance (ANOVA). Performance is based on four dependent variables. *Schedule Efficiency (SE)* measures the total cycle time to complete a shipset divided by the hours available in the schedule. In our case, the schedule was weekly (168 hours). An improvement in SE means a shipset can be completed earlier in the week.

*Schedule Utilization (SU)* measures the sum of run time for all autoclaves during the total cycle time for a shipset. A value of 100% for SU means that all autoclaves finish at the same time.

*Loading Efficiency (LE)* measures the total part surface area loaded versus the total autoclave loading surface available for a shipset. In the case of manufacturer X, a high LE value means that autoclave floor space is close to full. In the case of manufacture Y a high LE value means that the individual racks are mostly full.

## RESULTS

The average values for SE are reported in Table 2. Sequence is significant at the p=.006 level. Linked sequences had slightly higher schedule efficiencies than random sequences (66.2% vs 63.8%). Loading was also significant at the p=.000 level. Area loading typically had a higher efficiency than CAD loading, however there was also a significant interaction effect with the manufacturer. For manufacturer X, area and CAD loading did not make as much difference as for manufacturer Y.

**TABLE 2: AVERAGE PERCENTAGES FOR SCHEDULE EFFICIENCY**

| | Manufacturer X | | Manufacturer Y | | |
|---|---|---|---|---|---|
| | **Area** | **CAD** | **Area** | **CAD** | **Avg** |
| **Random** | 63.1% | 62.5% | 67.6% | 61.9% | **63.8%** |
| **Linked** | 66.7% | 66.7% | 69.0% | 62.5% | **66.2%** |
| **Unlinked** | 64.9% | 66.7% | 69.0% | 61.9% | **65.6%** |
| **Avg** | **64.9%** | **65.3%** | **68.5%** | **62.1%** | **65.2%** |
| **Mfg (avg)** | **65.1%** | | **65.3%** | | |

| | Area | CAD |
|---|---|---|
| **Load (avg)** | 66.7% | 63.7% |

Summary values for SU are shown in Table 3. The only factor that was significantly different was manufacturer. Manufacturer X had significantly higher SU. There is also a significant interaction between loading and manufacturer. Once again, manufacturer X is less affected by loading type.

**TABLE 3: SCHEDULE UTILIZATION AVERAGES**

| | Manufacturer X | | Manufacturer Y | | |
|---|---|---|---|---|---|
| | **Area** | **CAD** | **Area** | **CAD** | **Avg** |
| **Random** | 89.60% | 90.20% | 86.20% | 85.00% | **87.8%** |
| **Linked** | 95.10% | 95.10% | 88.00% | 81.80% | **90.0%** |
| **Unlinked** | 92.40% | 95.10% | 88.00% | 82.80% | **89.6%** |
| **Avg** | **92.4%** | **93.5%** | **87.4%** | **83.2%** | **89.1%** |
| **Mfg (avg)** | **92.9%** | | **85.3%** | | |

| | Area | CAD |
|---|---|---|
| **Load (avg)** | 89.9% | 88.3% |

A summary of LE results are shown in Table 4. All three main effects are significant at least at the p = .05 level. The interaction of loading type and manufacturer is also significant. Similar to scheduling efficiency, linked sequencing values are significantly higher than random (82.8% vs 80.4%), but unlinked is not significantly different from random or linked. Area loading is significantly higher than CAD loading. Manufacturer Y has significantly higher LE than manufacturer X. As always, manufacturer X is less affected by loading type as indicated by the significant interaction between manufacturer and loading type.

**TABLE 4: LOADING EFFICIENCY AVERAGES**

| | Manufacturer X | | Manufacturer Y | | |
|---|---|---|---|---|---|
| | Area | CAD | Area | CAD | Avg |
| Random | 75.60% | 76.90% | 91.00% | 78.20% | **80.4%** |
| Linked | 78.00% | 78.00% | 93.60% | 81.40% | **82.8%** |
| Unlinked | 76.70% | 78.00% | 93.60% | 79.20% | **81.9%** |
| Avg | **76.8%** | **77.6%** | **92.7%** | **79.6%** | **81.7%** |
| Mfg (avg) | **77.2%** | | **86.2%** | | |

| | Area | CAD |
|---|---|---|
| Load (avg) | 84.8% | 78.6% |

## DISCUSSION AND CONCLUSIONS

The sequence variable (linked, unlinked, random) was statistically different in schedule efficiency and loading efficiency. Of the three types of sequences, the linked sequence produced statistically higher results in schedule efficiency and loading efficiency than the random sequence. When comparing the linked sequence and the unlinked sequence, there was not enough evidence to show the two sequencing types are different. While the linked sequence produced higher efficiencies overall, it is also the least transparent and most time consuming to calculate. The unlinked would be the easiest to implement and still achieve the intent of a lean level schedule, while still achieving higher capacity utilization.

The loading type was statistically different in scheduling efficiency and loading efficiency. Area loading typically had higher efficiencies than CAD loading, however there was also a significant interaction with the manufacturer. For manufacturer Y there were large differences between area and CAD loading techniques, but for manufacturer X, loading did not have as significant an effect. The two manufacturers in the study used two different approaches when loading their autoclaves. Manufacturer X rolled the layed-up molds straight into the autoclave. Manufacturer Y used a system of racks. For the area loading, the parts were loaded until the maximum surface area was reached. While this approach produces the highest utilization, it is not as representative of operators actually fitting parts in an autoclave where unusable space exists between each of the parts. Evaluation of the CAD versus area loading of the racks at manufacturer Y indicated that area loading produced significantly higher loading efficiencies than the CAD loading (92.7% vs. 79.6%). This large difference is due to a wider variety of geometric shapes of the parts. Manufacturer X was less susceptible to this phenomenon. At manufacturer X they do not use a rack system; instead, they roll the molds straight into the floor of the autoclave. When conducting the CAD loading technique at manufacturer X, there were less cut off points for parts to be pushed back because they do not use a rack system; therefore, there was less empty space between parts and the loading efficiencies were relatively equal between the two loading types.

The manufacturer variable also proved to be statistically significant when looking at the schedule utilization. Manufacturer X had a slightly higher schedule utilization compared to manufacturer Y (92.9%, 88.3%). Manufacturer X had a very uneven distribution in the size of parts. There was very little difference in the size of parts in the third and fourth MQs with a few very large parts in the fourth quartile. When the very large parts were arranged next to each other in the schedule, the autoclave could not fit both, so two partially empty runs were produced. This occurrence did not happen in the linked schedule because the parts were distributed evenly by size to the autoclave, but did occur in the random sequence, which caused an extra run of the autoclave to be required.

Overall, this study provides direction for managers that are trying to achieve high levels of output and still obtain the benefit of a level schedule in a manufacturing environment of large structures run infrequently in batches.

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