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MIXED-MODEL PRODUCTION SYSTEM DESIGN FOR AIRCRAFT ASSEMBLY

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ABSTRACT

With the advancement of flexible fixture and flexible tooling, mixed production has become possible for aircraft assembly as the manufacturing processes of different aircraft/sub-assembly models are similar. However, due to the low volume and complex constraints of aircraft assemblies, how to model the problem and produce a practical solution has been a great challenge. To tackle this challenge, this work proposes a methodology for designing the mixed production system, and a new scheduling approach is proposed by using combined backward and forward scheduling methods. These methods are validated through a real-life industrial example. As a result, the number of workstations is reduced by 50%, and the cycle time for making a fuselage is reduced by 38% by using the new mixed-model system.

Keywords: Mixed-model, Aircraft assembly, Production system design

1 INTRODUCTION

Aerospace enterprises are striving for flow-line production as occurred in automotive industry in order to improve their productivity. However, flow-line production is mainly useful for large volume production but may not be suitable for aircraft assembly considering the low volume and high variety nature in aerospace production. With the advent of flexible tooling, mixed-model production has been identified as the possible solution for aircraft production, as mixed-model production system can produce a number of distinct but similar products on the same production line (Jin et al. 2012). Obviously, designing such a system is not an easy task, because aerospace production is characterized by low volume, large scale, large number of operations associated with varied processing times, labour intensive, parallel machines, and many constraints such as tooling/precedence/dependency/routing constraints.

Currently, dedicated workstations are utilized to manually assemble each individual panel separately. As different panels (even for the same aircraft model) are associated with significantly varied processing times, some workstations has to be idle for waiting for the other panels. This makes the system have a high level of WIP (work in progress), and an inefficient workstation utilization. In addition, the current system impedes the deployment of automation because of the lack of division of work. A mixed model production line, which produce different product models in the same line, will be suitable for the aircraft panel assembly production, in order to reduce the manufacturing cost. In literature, the research in mixed production mainly focused on two types of production systems, i.e., job shops and flow lines. In job shops, most research is trying to generate an optimal scheduling strategy for minimizing setup time or make span of production systems to cope with a large number of product models (Heike et al. 2001; Khan and Day 2002; Boysen et al. 2008). In flow lines, most literature focuses on long to medium term problems in assembly production system design with only 2-3 product models for large volume industries, such as the automotive and chemical industry (Heike et al. 2001; Bukchin et al. 2002; Becker and Scholl 2006; Petrovic and Duenas 2006). There has been very few papers yet studying the unique aerospace production system which is neither a job shop or a flow line due to the dependency in between different product models (e.g. four different panel assemblies for making a fuselage barrel). There is a great gap in between the academic research and industrial applications (Boysen et al. 2008). Existing academic algorithms which most utilizes simplified models cannot be applied to industrial problems.

To fill the knowledge gap, this work is to propose a practical methodology for designing mixed model flexible assembly lines for aircraft assembly. This method includes three major steps, i.e. work content analysis, capacity requirement analysis and workstation layout design, and scheduling. The methodology is validated through a real-life industrial example. The productivity and cost gains resulted from the mixed-production system are presented in comparing to the current production line.

2 PROBLEM STATEMENT

Figure 1 shows a schematic diagram of a production line for producing fuselages. It can be observed that the production line involves a flow-line system as well as some parallel machines. Note that the figure only shows a general process, and it would be much complex at each stage for producing multiple aircraft models. In the herein paper, we are targeting at the panel assembly stage, where a number of different panels are produced according to downstream process demands. Currently, dedicated workstations are employed for panel assemblies in the current production system. For example, one fuselage of an aircraft model is composed by 4 barrels and each barrel is composed by 4 panel assemblies, so there are 16 workstations dedicated for producing the 16 panel assemblies, and the operators are cross trained and can work on different workstations. Although these panel assemblies are similar in shape and operations, the work for each panel, which need to be processed up to 30-94 hours, is not further divided. This has been a barrier for the specialization of each operator, and lead to the loss of automation opportunities. To improve the productivity, this work aims to propose a methodology of mixed model production to revolutionize the current assembly system.

According to customer demands, auto-riveting stage have been identified as the CCR (Capacity Constraint Resource) in the system. Scheduling panel assemblies through the multiple auto-riveters has been defined as a parallel machine problem, and one new dispatching technique has been developed to minimize waiting time of the post auto-riveting processes in our previous work (Briggs et al. 2012). This paper will focus on the design of mixed production system at the panel assembly stage prior to the auto-riveting stage.

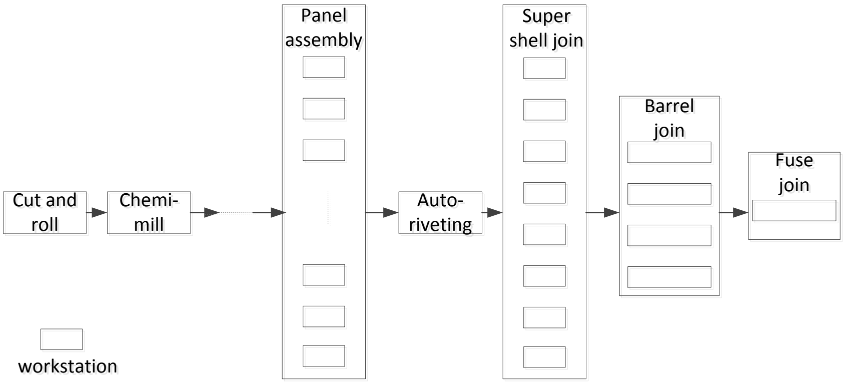

Figure1: Schematic diagram of production line of aircraft fuselages

3 METHODOLOGY AND VALIDATION

3.1 Work Content Analysis

The panel assembly processes are defined by method engineers and recorded in the Engineering Process Reports (EPR), which consists of 50-70 pages of texts for each panel. Shop-floor operators are following the instructions of EPR for assembling the aircraft panels. To estimate processing times, operations are classified into a number of categories, and standard time associated with each standard operation is predicted by using MOST (Maynard Operation Sequence Technique) through a knowledge based system (Jin et al. 2009). As these standard operations are too granular to be used for precedence analysis, five typical types of operations are defined after a thorough analysis of the panel assembly processes as: Locate and Drill (LD, represented in green in the precedence diagram), Window Coaming (WC, in Grey), Dismantle and De-burr (DD, in Orange), Wet Assembly and Hilite Installation (WH, in Red), and Manual Riveting (MR, in White). After reviewing all the EPRs of all 16 panels and collecting all the time data for around 60,000 standard operations, the precedence diagrams are also drawn with task elements associated with their processing times, as shown in Fig. 2 Note that the normalized processing times have been used.

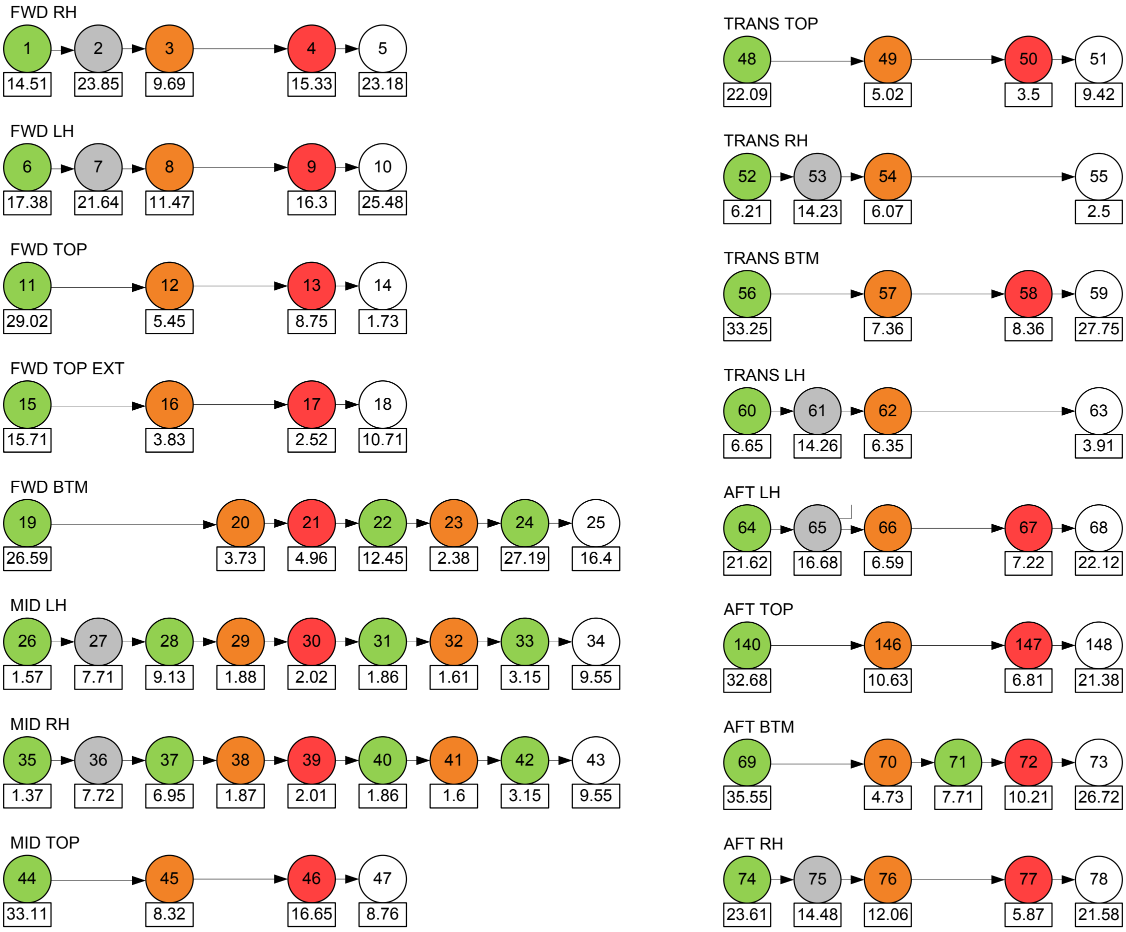

Figure 2: Precedence diagrams of aircraft panel assemblies

Note that the adjacent operations of the same type have been summed up and some closely relevant operations have been combined together to simply the precedence. Based on these precedence diagrams of the 16 panels, one joint precedence diagram is developed to show all possible process routings as shown in Fig. 3. It is observed that the dominant process flow is formed by Locate&Drill, Dismantal & Deburr, and Manual Rivet, because all panels need to pass through these operations sequentially. To have a better picture on the weight of each route, the processing times associated with each operation category for each panel is summarized in Table 1. It is clearly shown that 50% of panels (8 panels) will need the Window Coaming operation. Locate& Drill Operations will be needed at five locations in the precedence, but only for a small number of panels for the L&D except the beginning one. D&D operations are required by only three panels associated with five hours processing time in total.

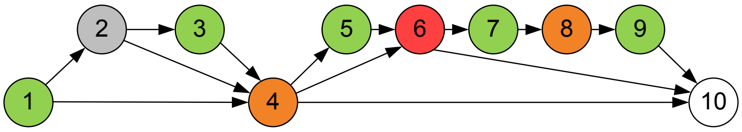

Figure 3: Joint precedence diagram of a set of 16 panels of the fuselage

3.2 Capacity Requirement Analysis and Workstation Layout Design

With the precedence diagrams obtained, the next step is to conduct the capacity requirement analysis. In the herein question, customers demand to produce five sets of panel assemblies in eight weeks (1400 hours). In order to meet the demand, the number of workstations n_j for the j$^{\text{th}}$ machine is determined by the following equation.

$$n_j = \frac{\sum_{k=1}^{10}\sum_{i=1}^{16} t_{i,j}^{k}}{t_A} \tag{1}$$

where $t_{i,j}^{k}$ represents the process time of the i$^{\text{th}}$ job on the j$^{\text{th}}$ machine (category of operation) for the k$^{\text{th}}$ fuselage, and t_A the total available time (1400 hours in this case). As a result, the capacity requirements of each machine are listed out in Table 2. Based on the joint precedence diagram and the demanded capacity, the workstation layout is designed as shown in Fig. 4. It can be observed that the mixed model production system consists of three parallel machines of LD, two parallel machines of MR, a flow system over up to five different type of machines, as well as reentrant to the LD machine.

Table 1: Breakdown of processing times (in hrs) at the respective category for each panel

Product/Work Group	Locate & Drill	Window Coaming	Locate & Drill	Dismantle & Deburr	Locate & Drill	Wet Assemble	Locate & Drill	Dismantle & Deburr	Locate & Drill	Manual Rivet	Total
FWD RH	14.51	23.85		9.69		15.33				23.18	86.56
FWD LH	17.38	21.64		11.47		16.3				25.48	92.27
FWD TOP	29.02			5.45		8.75				1.73	44.95
FWD TOP EXT	15.71			3.83		2.52				10.71	32.77
FWD BTM	26.59			3.73		4.96	12.45	2.38	27.19	16.4	93.7
MID LH	1.57	7.71	9.13	1.88		2.02	1.86	1.61	3.15	9.55	38.48
MID RH	1.37	7.72	6.95	1.87		2.01	1.86	1.6	3.15	9.55	36.08
MID TOP	33.11			8.32		16.65				8.76	66.84
TRANS TOP	22.09			5.02		3.5				9.42	40.03
TRANS RH	6.21	14.23		6.07						2.5	29.01
TRANS BTM	33.25			7.36		8.36				27.75	76.72
TRANS LH	6.65	14.26		6.35						3.91	31.17
AFT LH	21.62	16.68		6.59		7.22				22.12	74.23
AFT TOP	32.68			10.63		6.81				21.38	71.5
AFT BTM	35.55			4.73	7.71	10.21				26.72	84.92
AFT RH	23.61	14.48		12.6		5.87				21.58	78.14
Total	320.92	120.57	16.08	105.59	7.71	110.51	16.17	5.59	33.49	240.74	977.37
Panel Routing	100%	50%	13%	100%	6%	88%	19%	19%	19%	100%	

Table 2: Capacity requirement analysis for the proposed mixed-model

WORKGROUP (machines)	LOCATE & DRILL	WINDOW COAMING	DISMANTLE & DEBURR	WET ASSEMBLE	MANUAL RIVET
WORKGROUP LOAD PER SET	394.37	120.57	111.18	110.51	240.74
CALCULATED WORKSTATION REQ	2.82	0.86	0.79	0.79	1.72
THEORETICAL MIN WORKSTATION REQ	3	1	1	1	2
EXPECTED WORKSTATION UTILIZATION	94.3%	86%	79%	79%	86%

3.3 Scheduling

This section is to design a suitable schedule to meet the CCR demand, which is defined by the due date $d_{i,j}^k$ of the list of the panel assemblies. As each panel assembly is associated with varied operations and processing times, a fixed cycle time cannot be obtained. So this production system is essentially an unpaced asynchronous line, in which workpieces should be transferred whenever the required operations are completed rather than being bound to a given time span. In order to minimize waiting time, buffers may be needed in between workstations, which will influence the schedule planning considerably. The scheduling problem in unpaced asynchronous lines has been identified as a challenging research area to be studied (Boysen et al. 2008). For the herein case, due to the extra due date constraints, the problem becomes even more complex. To solve the problem, a combined backward and forward scheduling method is proposed here. The backward scheduling is employed to find the required processing order of each panel in each station in order to the due dates. Based on the resulted order, the forward scheduling is to minimize the waiting time in the whole mixed system and guiding buffer allocations. A simulation model is built up in Delmia Quest for implementing the forward schedule. Due to the space limitation, only the results are presented here. Table 3 shows the completion time for the panel assemblies through the mixed production system within the 1400 hours time frame. It can be seen that a warm-up period is needed before the cycle time dropped to below 140hours/set, and the cycle time may vary between 114.65 to 149.40 hours/set after finishing the first two sets. The WIP level (the total number of panels in the system) in increasing over time up to 27 panels, which is a little bit high as it is more than one fuselage requirement. The station utilization rate is very high, which is close to our expectation. To reduce the system WIP, a constant WIP rule is used for controlling the panel input to the system but still with the same order. As a result, the WIP can be reduced to 16 for achieving a cycle time of around 137 hours/set, although over time is needed to produce the 10 sets, as shown in Table 5. The machine utilization is a little bit lower than the asynchronous schedule, as shown in Table 6. Both the two scheduling methods are quite close to the design expectation. The selection from the two will depend on the trade-off. Comparing to existing dedicated production system, the number of workstations is reduced from 16 to 8, and the cycle time (after the initial warm-up period) is reduced by 39% from 216 hours to 137 hours, although the variations and uncertainties have not been considered in the newly proposed mixed assembly system.

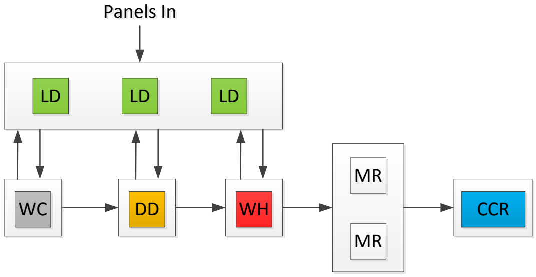

Figure 4: Workstation layout of the mixed-model production system

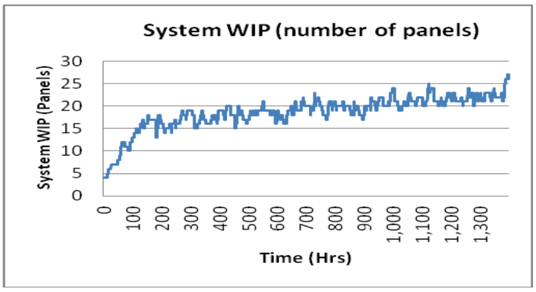

Figure 5: System WIP for asynchronous schedule

Table 3: Completion and Cycle time for each set of aircraft panels under asynchronous schedule

Set No.	1	2	3	4	5	6	7	8	9	10
Completion time (hrs)	205.56	376.16	493.69	621.82	736.77	883.42	1005.32	1154.72	1278.62	1394.28
Cycle time (hrs)	205.56	170.60	117.53	128.13	114.95	146.65	121.90	149.40	123.90	115.66

Table 4: Workstation Utilization for asynchronous schedule

LD1	LD2	LD3	WC	DD	WH	MR1	MR2
100.00	100.00	100.00	89.73	81.98	81.13	87.61	84.59

Table 5: Completion and Cycle time for each set of aircraft panels in a CONWIP system

Set No.	1	2	3	4	5	6	7	8	9
Completion time (hrs)	205.56	366.71	507.92	646.20	782.89	919.92	1057.20	1194.23	1331.51
Cycle time (hrs)	205.56	161.15	141.21	138.29	136.69	137.03	137.28	137.03	137.28

Table 6. Workstation Utilization in a CONWIP system

LD1	LD2	LD3	WC	DD	WH	MR1	MR2
95.78	94.77	96.77	85.65	78.77	78.00	82.28	84.43

4 CONCLUSION

This article presents a methodology for design a mixed production system of aircraft assembly, which appears to be the first in assembly line design considering the dependency constraints of mixed products. The methodology consists of three main stages: work content analysis, capacity requirement analysis and scheduling. The techniques for implementing the three stages are presented. The methodology is validated through a real life case study. As a result, the number of workstation is reduced by 50%, and the cycle time is also reduced by 39% comparing to the current production. The method is equally well applied to other manufacturing sectors such as heavy machinery and train carriage assemblies.

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