# MACHINE SCHEDULING AND SPREADSHEET MODELING IN A FASHION MANAGEMENT CLASS

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***Abstract***

*This paper is a result of several semesters of teaching an Operations Management class in the Fashion Management program. Topics like flow shop and parallel machine models are traditionally discussed in an Industrial Engineering class. However, we discussed these topics successfully in a fashion management class by providing examples that our students could relate to. This included examples in apparel production and fashion retailing. The students were also able to learn several logical Excel based formulas while creating spreadsheets for these topics. For the flow shop model, we create a spreadsheet model that reflects all details of the Gantt chart including idle times. In the case of parallel machines, the spreadsheet involves the more complex Nested IF functions. The students showed enthusiasm even when creating the more challenging spreadsheet models.*
***Keywords***: *spreadsheet modeling; Flow shop models; Parallel machines; supply chain.*

## INTRODUCTION

Fashion Merchandising and Management (FMM) is the largest major in the School of Business at Thomas Jefferson University. In addition to specialized coursework in FMM, these majors are also required to take all the core business classes that are typically taken by other traditional business majors. We also have several FMM majors who choose Finance or Accounting as their minor areas of study. Such coursework prepares these students very well when they seek full-time jobs upon graduation. While several of our FMM students obtain jobs in the retailing industry, some of the technically inclined students seek employment in apparel manufacturing and production. Some students eventually start their own boutiques or related entrepreneurial ventures. Since our FMM majors are required to take all business core courses, they are comfortable with quantitative coursework like Business Statistics and Operations.

Microsoft Excel is the most popular software program that is widely used in the industry. Its popularity is attributed to its unparalleled flexibility, versatility, and a wide range of capabilities for data management, analysis and visualization. It is used by financial analysts, retails store managers, project managers, business analysts, accountants to name a few. Due to the increasing use of data-driven decision making even in the retailing sector and business in general, the demand for proficiency in Microsoft Excel has also increased significantly in recent years. Teaching spreadsheets is not specifically about helping students learn spreadsheets but to also help them grow to make more informed decisions as managers in the real world. Educational theory, such as Dale Edgar's Cone of Experience, suggests that learners remember 70-90% of what they say and do (active learning). Excel exercises or projects are considered as active learning (Braun, 2017).

*Operations and Data Analytics* is one of the core business classes which is required for all majors in the School of Business. This course includes the coverage of important topics like Inventory, Forecasting, Linear Programming, Supply chains, Waiting Lines, etc. Since FMM majors take specialized courses in their field, they have a firm understanding of concepts like Supplier Lead Time and opportunity costs (or loss of customer goodwill) due to shortages or late shipments. For example, they know that late shipments from their suppliers can be disastrous when the product is seasonal. This late shipment issue is highlighted in a Harvard Business Case (Hammond & Raman, 2006) which discusses the ski wear supply chain and the impact of late shipments in this highly seasonal business.

Flow shop and parallel machine models are topics that are traditionally found in Industrial Engineering coursework. Some pioneering textbooks provide various methods of scheduling (Bedworth & Bailey, 1982). Some quick and dirty manual methods have since been presented and discussed (Woolsey, 1971, 1982, 1990). Most business students have never visited a production unit. However, we believe that we can discuss these topics with our fashion students by providing real-life examples as well as examples in their field in addition to guiding them to create spreadsheet models.

We discuss two specific concepts in the classroom.

*Concept 1* is about two serial processors better known as the two-machine flow shop model. We first present a pictorial solution by drawing a Gantt chart. We then create a spreadsheet model to reflect all aspects of the pictorial solution. To our knowledge, such a spreadsheet solution is not found in any textbook. More importantly, the students find this spreadsheet model easy to understand. We then ask our students to complete *Assignment 1* on three machines by providing a partial solution and some guidelines. An important hint given is that there will be another Idle Time column that must be included while creating the spreadsheet.

*Concept 2* is about parallel (and identical) machines. Here, we review two numerical examples in the classroom. One example is to minimize the flow time of a set of jobs on three identical machines. The second numerical example is to sequence the jobs using the due-date rule to calculate tardiness and number of tardy jobs. These are also solved pictorially by drawing Gantt charts. We then create spreadsheet models that reflect the pictorial solutions. The students are then asked to complete *Assignment 2*, which involves solving a similar problem but with four machines.

For both Assignments, the students submit manual as well as spreadsheet-based solutions.

## CONCEPT 1: A 2-MACHINE FLOW SHOP MODEL

This model involves two machines (or stages). Jobs must be processed on both machines by first going to Machine 1 (M1) and then to Machine 2 (M2). Interestingly, there is a simple real-life example provided by Martinich (1997). We refer to it as Numerical Example 1 and is presented below. Our fashion students relate to this model immediately when we also refer to *cutting* and *sewing* as another example of two important stages involved in apparel production.

### *Numerical Example 1*

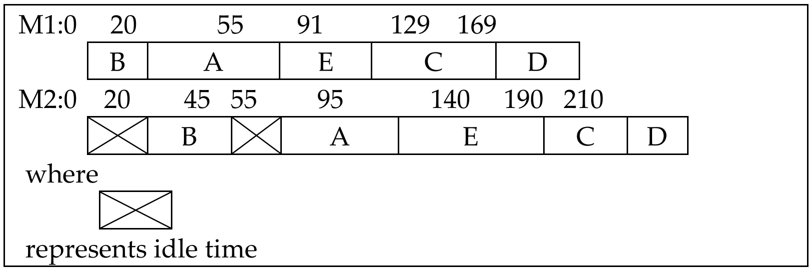
Joe has five loads of laundry to do before he can go to the beach. Based on the colors and fabrics, he has estimated the washing and drying times for each load (Table 1). All loads must first be washed and then dried (clothes that have been washed can sit in a basket waiting to go to the dryer so that the washer can be used.) Determine the optimum sequence to minimize make span and find the total completion time of all jobs.

TABLE 1

| Load | Washer | Dryer |
|---|---|---|
| A | 35 | 40 |
| B | 20 | 25 |
| C | 38 | 50 |
| D | 40 | 20 |
| E | 36 | 45 |

Since our main contribution is to create a spreadsheet model to closely reflect the Gannt chart, we will not delve into Johnson's Rule for the optimum sequence. This rule is found in various textbooks. Using Johnson's Rule, the optimum sequence to minimize make span is: B – A – E – C – D. And Figure 1 below presents a Gannt chart which clearly shows the start and end times of each job on the two machines. The Gantt chart also displays Idle times on M2.

FIGURE 1




We present a detailed Excel solution for the above example in Appendix – A**.** Our spreadsheet uses Excel formulas to calculate completions times of each job on both machines. It also calculates the Idle times on M2. Appendix – A also has Assignment 1 related to a 3-machine flow shop that the students must complete.

## CONCEPT 2: PARALLEL MACHINES MODELS

Consider a set of *N* jobs having different processing times and a set of *M* identical (and parallel) machines which can process any of these jobs. If N ≤ M, then the N jobs are randomly assigned to one of the M machines and they get processed with no job waiting in line. If N > M, then the first M jobs are randomly assigned to the M machines and the remaining jobs are waiting for the next available machine to be processed. These waiting jobs can be said to be in a queue (i.e., waiting line) and the job that is first in this queue will go to the first available machine.

Specifically, let us consider N jobs and M machines where N > M and all the M machines are available. The goal is to minimize the flow time. Job flow time is defined as how long a job is in the system (i.e., from the time it entered the shop until the time it leaves the shop after being processed).

Upon reading the above description in this section, a business major may not be clear about what the above means or where it can be applied. Hence, we provide simple real-life examples of such scenarios. When we enter a bank during peak business hours, we are likely to see three tellers currently serving one customer each and about five customers waiting in a line to go to the next available teller. Interestingly, this is not only found in banks and post-offices but also a very common sight in various apparel and retail stores too. Numerical Example 2 given below is for 3 machines (equivalent to 3 check-out counters in a retail store). We use the first come, first served (FCFS) rule to pictorially illustrate the mathematics of parallel machines. The spreadsheet model is presented in Appendix B.

### *Numerical Example 2*

Consider *three* machines (M1, M2, M3) in parallel and a total of *eight* jobs (A, B, C, D, E, F, G, H). The jobs and their processing times (in hours) are as given in Table 2. Consider these to be *identical* parallel machines implying that the jobs can be processed on any of the three machines.

TABLE 2

| JOB | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Processing Time (P) | 10 | 20 | 11 | 21 | 22 | 50 | 40 | 60 |

At time t = 0, we assume that all machines are ready, and all jobs are available. Note that while the jobs have arrived around the same time, they arrived in the order A, B, C, D, E, F, G, and H. We use the FCFS rule since retail stores, banks, and post-offices implement FCFS sequencing. Such a rule is fair and simple to implement.

**At time *t = 0***: Job A (10) goes to M1; Job B (20) to M2; and Job C (11) to M3. Note that Jobs B or C could also have gone to M1. However, the end result will still be the same in terms of total completion time of all jobs.

Jobs A, B, C will be completed at times t = 10; t = 20; and t = 11 on M1, M2, and M3 respectively.

**At time *t = 10***: Job D (21) goes to M1 and is completed at t = 31;

**At time *t = 11***: Job E (22) goes to M3 and is completed at t = 33;

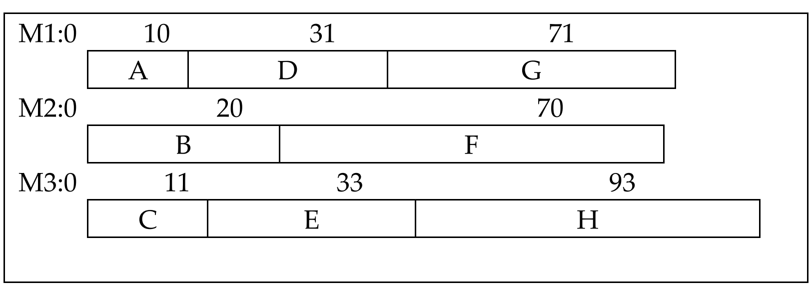
**At time *t = 20***: Job F (50) goes to M2 and is completed at t = 70;

**At time *t = 31***, Job G (40) goes to M1 and is completed at t = 71; and

**At time *t = 33***, Job H (60) goes to M3 and is completed at t =93.

The Gantt chart (Figure 2) displays the start and end times of the eight jobs on the three machines.

FIGURE 2



We present a detailed spreadsheet model for the above example in Appendix – B. This spreadsheet model uses Excel formulas to determine which machine processes the next job and also to calculate the completion times of each job.

Finally, we present Numerical Example 3. This example includes the due-dates of each of the jobs and the goal is to calculate job tardiness and the number of tardy jobs. Tardiness is an important measure of performance. Our students understand how late shipments from suppliers can negatively impact retailers in the case of highly seasonal products.

*Numerical Example 3*

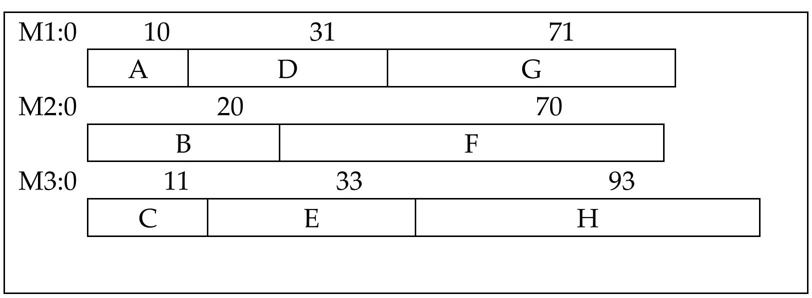
Consider *three* machines (M1, M2, M3) in parallel and a total of *eight* jobs (A, B, C, D, E, F, G, H). The jobs, their processing times (in hours) and due-dates (in hours) are as given below in Table 3. The goal is to reduce tardiness and number of tardy jobs. Intuitively, sequencing the jobs in non-increasing order of due-dates works well in terms of reducing tardiness and/or the number of tardy jobs.

TABLE 3

| JOB | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Processing Time (P) | 10 | 20 | 11 | 21 | 22 | 50 | 40 | 60 |
| Due-Date (D) | 15 | 18 | 25 | 35 | 40 | 45 | 55 | 68 |

Since jobs are processed in the same order as in Example 2, the Gantt chart in Figure 3 is same as Figure 2.

FIGURE 3




Since we have only eight jobs in this example, it is easy to visually see what jobs are tardy. Note that Job A is done at t = 10 and is due only at t = 15. Hence, Job A is not tardy. Job B is done at t = 20 but is due at t = 18. Hence, Job B is tardy and its tardiness = 20 – 18 = 2 hours. Continuing in this fashion, we note that Jobs F, G, and H are also tardy by 25, 16, and 25 hours respectively.

A spreadsheet model with a detailed explanation is presented in Appendix – C. This spreadsheet goes beyond what was created in Appendix – B. So, we do not replicate what we already did in Appendix – B. We use NESTED IF functions to calculate when each job is completed on one of the three machines. Based on the due-date information, we use single IF statements to calculate job tardiness and the number of tardy jobs. Appendix C also includes Assignment 2 related to four parallel machines that the students must complete.

## MANAGERIAL ISSUES

*Flow shop models*: Cutting and sewing are two important stages in apparel production. The shop floor supervisor may have to decide on worker and machine allocations on a daily basis since there can be several customer orders with different due-dates. The worker allocation also depends on the skillset i.e., some workers may specialize in men's clothing while others are experienced in cutting and sewing of women's or children's clothing. When there is sudden and unanticipated demand that needs to be fulfilled, the supervisor may have to consider overtime or hire temporary workers or rent additional machines or outsource some of the work. These are examples of some strategies that may need to be implemented frequently.

*Parallel Machine models*: As discussed earlier, we have assumed parallel machines to be identical machines. This is equivalent to check-out counters found in several retail outlets. The store manager must always make sure that the customer waiting lines are not very long. This is accomplished by opening one or more additional check-out counters during peak times and weekends. Having too many counters open is also not a good strategy. A good manager/supervisor is always trying to strike a balance between reducing customer wait times and minimizing the retail store's costs. Just like in the flow shop model, adding more machines, hiring more people, and outsourcing some work is commonly practiced.

In general, meeting customer deadlines is of utmost importance when it comes to apparel production. In the case of seasonal products, this importance increases exponentially. The supplier can lose a customer forever if a shipment is delayed.

## CONCLUSION

Flow shop and parallel machine models typically find a place in engineering coursework. Most operations management textbooks used by business schools do not even cover parallel machine models. However, we have been able to successfully introduce these topics in a traditional fashion management class. The students were able to appreciate how these concepts are routinely used in the service industry as well as in the fashion and apparel industry. Furthermore, drawing Gannt charts to manually solve these problems enhances their understanding of the Math as they can visually see the entire process. We then focus on these pictorial solutions to create spreadsheet models which enhance their understanding of Excel functions. Most students are then able to complete the two Assignments by putting in some effort. In conclusion, we believe that the students benefit from these topics because of their applications in the fashion field and also because of their enhanced understanding of the more complex Excel functions.

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**APPENDIX – A:** ***Excel based formulas for Numerical Example 1***

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | JOB | M1 | M2 | M1Comp | Idle Time | M2Comp |
| 2 | B | 20 | 25 | 20 | 20 | 45 |
| 3 | A | 35 | 40 | 55 | 10 | 95 |
| 4 | E | 36 | 45 | 91 | 0 | 140 |
| 5 | C | 38 | 50 | 129 | 0 | 190 |
| 6 | D | 40 | 20 | 169 | 0 | 210 |

The M1Comp and M2Comp columns calculate the completion times of the jobs on Machine 1 (M1) and Machine 2 (M2) respectively. The gray cells in the above spreadsheet contain the Excel formulas. However, the Excel formulas are written for Rows 2 and 3 only. Row 3 formulas are then copied down to the remaining rows for columns D and E until all jobs are sequenced. We also provide a detailed explanation below for each of these Excel formulas.

**Excel formula for cell D2:** Type "**=SUM(B$2:B2)**". This formula is then copied all the way down in column D. The rationale behind this formula being that M1 is never idle as long as there are jobs to be processed. Thus, the completion time of job B is 20 minutes, completion time of job A is 20 + 35 = 55 minutes and so on.

**Excel formula for cell E2**: Type "**=D2**". This formula calculates the initial Idle time. As we know from the Gantt chart in Figure 1, the initial Idle time on M2 is always equal to the 1st job's completion time on M1. Since Job B's completion time on M1 = 20, initial Idle Time on M2 is also equal to 20 minutes.

**Excel formula for cell F2**: Type "**=E2+C2**". This indicates that the 1st job's completion time on M2 = Initial Idle time on M2 + 1st job's processing time on M2. This is identical to the Gantt chart Math.

**Excel formula for cell E3**: Type "**=IF(D3>F2,D3-F2,0)**". From the Gantt chart, if the 2nd job's completion time on M1 > the 1st job's completion time on M2, then there will be Idle Time. This formula checks for that and also calculates the Idle time (the difference between those two values). If that condition is not satisfied, then Idle time = 0.

**Excel formula for cell F3**: Type "=F2+E3+C3". To verbalize this formula, the completion time of the 2nd job on M2 = Completion time of the 1st job on M2 + Idle time (if any) + the 2nd job's processing time on M2.

Now, Row 3 formulas in Columns E, F are copied down to the remaining rows until all jobs are processed.

**Assignment 1**: The original 4-machine problem (Pinedo, 2012) has been reduced to a 3-machine problem.

John has five jobs to be processed on three machines. The processing time values (in hours) on each of the three machines are given in Table 4 below. Determine the make span and find the total completion time of all jobs if sequenced in the same order in which it is given below i.e., A – B – C – D – E. *Submit a manual solution as well as an Excel based spreadsheet for this problem*.

TABLE 4

| JOB | M1 | M2 | M3 |
|---|---|---|---|
| A | 5 | 4 | 4 |
| B | 5 | 4 | 4 |
| C | 3 | 2 | 3 |
| D | 6 | 4 | 4 |
| E | 3 | 4 | 1 |

**APPENDIX – B:** ***Excel based formulas for Numerical Example 2***

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | JOB | P | M1 | M2 | M3 | |
| 2 | A | 10 | 10 | 20 | 11 | JOBS A, B, C |
| 3 | B | 20 | 31 | 20 | 11 | JOB D |
| 4 | C | 11 | 31 | 20 | 33 | JOB E |
| 5 | D | 21 | 31 | 70 | 33 | JOB F |
| 6 | E | 22 | 71 | 70 | 33 | JOB G |
| 7 | F | 50 | 71 | 70 | 93 | JOB H |
| 8 | G | 40 | | | | |
| 9 | H | 60 | | | | |

The gray cells in the above spreadsheet contain the Excel formulas. However, we need to write Excel formulas for only Rows 2 and 3. Row 3 formulas are then copied down to the remaining rows until all jobs are sequenced.

**Excel formulas for Row 2**: Type "**=B2**", "**=B3**", "**=B4**" in cells C2, D2, and E2 respectively. This means we allocate Jobs A, B, C to M1, M2, M3 respectively. The numbers 10, 20, and 11 in cells C2, D2, and E2 indicate the completion times of Jobs A, B, and C.

**Excel formulas for Row 3**: In cell C3, type "**=IF(MIN($C2:$E2)=C2,C2+B5,C2)**". In simple terms, this formula allocates Job D (the 4th job) to the first available machine. Since the first available machine is M1 at time t = 10, Job D is allocated to M1.

In cell D3, type "**=IF(AND(MIN($C2:$E2)=D2,C3=C2),D2+B5,D2)**". This formula with the AND function allocates Job D to M2 only if it is not already allocated to M1. This is to break the ties if more than one machine is available at the same time. In this example, that is not the case. Hence, Job D is not allocated to M2.

In cell E3, type "**=IF(AND(MIN($C2:$E2)=E2,C3=C2,D3=D2),E2+B5,E2)**". This formula allocates Job D to M3 only if it is not already allocated to M1 or M2. This is to break the ties if more than one machine is available at the same time. In this example, that is not the case and hence Job D is not allocated to M3.

**APPENDIX – C:** ***Excel based formulas for Numerical Example 3***

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | JOB | P | D | M1 | M2 | M3 | | COMP. TIME | TARDY? | TARDINESS |
| 2 | A | 10 | 15 | 10 | 20 | 11 | JOBS A, B, C | 10 | NO | 0 |
| 3 | B | 20 | 18 | 31 | 20 | 11 | JOB D | 20 | YES | 2 |
| 4 | C | 11 | 25 | 31 | 20 | 33 | JOB E | 11 | NO | 0 |
| 5 | D | 21 | 35 | 31 | 70 | 33 | JOB F | 31 | NO | 0 |
| 6 | E | 22 | 40 | 71 | 70 | 33 | JOB G | 33 | NO | 0 |
| 7 | F | 50 | 45 | 71 | 70 | 93 | JOB H | 70 | YES | 25 |
| 8 | G | 40 | 55 | | | | | 71 | YES | 16 |
| 9 | H | 60 | 68 | | | | | 93 | YES | 25 |

The gray cells in the above spreadsheet contain the Excel formulas. Since we wrote Excel formulas for M1, M2, and M3 in Appendix B, we will not repeat those formulas here again. We will only focus on columns H, I, and J here.

**Excel formulas for cells H2, H3, and H4:** Type **"=D2"**, **"=E2"** and **"=F2" respectively.**

**Excel formula for cell H5:** Type **"=IF(D3>D2,D3,(IF(E3>E2,E3,(IF(F3>F2,F3)))))**. This formula is then copied all the way down for Column H.

**Excel formula for cell I2:** Type **"=IF(H2>C2,"YES","NO")**. This formula is then copied all the way down for Column I.

**Excel formula for cell J2:** Type **"=IF(H2>C2,H2-C2,0)**. This formula is then copied all the way down for Column J.

**<u>Assignment 2</u>**

Consider *FOUR* machines (M1, M2, M3, M4) in parallel and a total of *eight* jobs (A, B, C, D, E, F, G, H). The jobs and their processing times (in minutes) are as given below in Table 5. The due-dates of these jobs are also given. Use the due-date rule just like in Numerical Example 3 and calculate job tardiness and the number of tardy jobs. Since the data is identical to Numerical Example 3, the total job tardiness is expected to be significantly reduced with four machines. *Submit a manual solution as well as a spreadsheet model for this problem*.

TABLE 5

| JOB | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| Processing Time (P) | 10 | 20 | 11 | 21 | 22 | 50 | 40 | 60 |
| Due-Date (D) | 15 | 18 | 25 | 35 | 40 | 45 | 55 | 68 |