Chapter 13
Product Wheels in Manufacturing Operations Planning

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Abstract This chapter discusses a production planning method known as "product wheels." We define "product wheels," discuss how they are used, and show the value the technique provides to production operations. We look at the importance of product families in planning production, particularly where set-up costs and time are critical. We examine the question of product sequencing—and why that aspect of manufacturing planning is seldom as difficult and data intensive as the mathematics (e.g., traveling salesman problem) might imply. The chapter analyzes how variants of Economic Order Quantity ("EOQ") and "EOQ with Joint Replenishment" [E.A. Silver heuristic (1976)] can be used (balancing costs of cycle stock inventory versus transitions) to get early results that lead us towards the formulation of a cost-effective wheel. We also look at the problem of balancing wheels for capacity feasibility when product campaigns cycle at different frequencies.

Keywords Product wheels • Production planning • Setup cost

13.1 Introduction

Many manufacturing operations must produce a wide variety of products or materials, which poses a number of challenging questions:

1. What should I make next, after I'm finished making the current product?
2. Is there an optimum product sequence to follow which will reduce transition cost and time?
3. If I decide to follow a fixed sequence, is there an optimum cycle over which I should produce all my "runners" (high volume products)?

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G. Rabadi (ed.), *Heuristics, Metaheuristics and Approximate Methods in Planning and Scheduling*, International Series in Operations Research & Management Science 236, DOI 10.1007/978-3-319-26024-2_13

4. How frequently should I produce my "repeaters" and "strangers" (medium and low volume products)?
5. How do I best integrate the scheduling of make-to-order (MTO) products into my largely make-to-stock (MTS) schedule?

PRODUCT WHEEL ATTRIBUTES

- The overall cycle time is fixed
- The cycle time is optimized based on business priorities
- The sequence is fixed – products are always made in the same order
- The sequence is optimized for minimum changeover loss
- Spokes will have different lengths, based on the Takt for each product
- The amount actually produced can vary from cycle to cycle, based on actual consumption
- Some low-volume products may not be made every cycle
- When they are made, it's always at the same point in the sequence
- Make-to-order and Make-to-stock products can be intermixed on a wheel

Many large companies have found that the best way to deal with all of these concerns in an integrated way is through the use of product wheel scheduling (King and King 2013).

There is also the challenge to level production. It is a very well-understood principle within the lean manufacturing community that production should be levelled, i.e., that peaks and valleys should be minimized, to minimize the waste of resources needed during production peaks during the valleys, a concept called "Heijunka" (Womack and Jones 1996). It is also a core principle that production be synchronized with customer demand, known as "Takt." This presents operations with an apparent paradox. They need to produce to customer demand, which has variation, while at the same time removing variation from the rate of production. These conflicting forces can be reconciled by integrating customer demand over some reasonably short time and levelling production to that demand. But what is a reasonable time period? Product wheels provide a very effective way to determine the optimum period.

Another reason product wheels are used in many operations is that wheels make it easy to order raw materials and plan for meeting demand. Modern ERP systems can certainly handle material orders and sales planning without depending on regular production cycles. However both vendors and customers often become accustomed to a certain rhythm of production and the likelihood of error is reduced when that rhythm continues. “Economy of repetition” is part of the rationale for product wheels. Technically, repetition may not be necessary—but because of human nature it’s often a good idea.

13.2 Product Wheels Defined

A product wheel is a visual metaphor for a structured, regularly repeating sequence of the production of all of the materials to be made on a specific piece of equipment, within a reaction vessel, within a process system, or on an entire production line. The overall cycle time for the wheel is fixed. The time allocated to each product campaign (a “spoke” on the wheel—continuous operation on a single product) is relatively fixed, based on that product’s average demand over the wheel cycle. The sequence of products is fixed, having been determined from an analysis of the path through all products which will result in the lowest total transition time or the lowest overall transition cost. Figure 13.1 depicts product wheel components.

The spokes can have different lengths, reflecting the different average demands of the various products: high demand products will have longer spokes (campaigns) than lower demand products.

Product wheels support a pull replenishment model. That is, the wheel will be designed based on average historical demand or on forecast demand for each

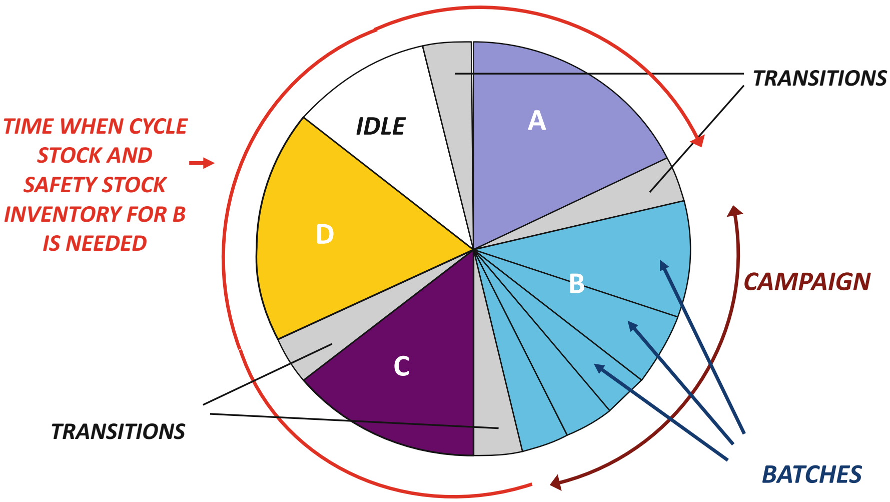

Fig. 13.1 Product wheel components

product, but what is actually produced on any spoke is just enough to replenish what has been consumed from the downstream inventory, in accordance with lean pull principles. Thus the size of each spoke can vary from cycle to cycle based on actual demand, but the total wheel cycle time will remain fixed.

13.2.1 Make to Stock, Safety Stock, and Make to Order

Product wheels are almost always used in "make to stock" operations. Only the cycle stock portion of the inventory is considered for the product wheel analysis. Yet we know that longer product wheels mean a longer "period of risk" and hence larger safety stocks (to maintain a given customer service level). However, safety stock is not included in the product wheel calculations discussed here because it grows relatively slowly with increases in product wheel length. (Safety stock usually increases only by the square root of the product wheel length—unlike cycle stock which is directly proportional to product wheel length.)

When only a small fraction of total demand is "make to order," this demand is sometimes assigned to a production unit along with the "make to stock" products. "Make to order" can be handled by putting "discretionary time" periods into the wheel design. The exact "make to order" products and amounts are not specified until near time for the period to begin. Planning for pre-set "make to order" production periods helps to define customer order lead time for those products, but total "make to order" time on the unit does need to be stable.

13.3 Product Wheels and the Economic Lot Scheduling Problem

The product wheel problem is an expression of the widely studied economic lot scheduling problem. Elmaghraby (1978) wrote a frequently cited review of the problem. Narro Lopez and Kingsman (1991) did another review, and variants of the problem continue to be studied (Teunter et al. 2008). Hsu (1983) showed that the problem is NP-hard.

The heuristic discussed here, simplifies the problem by assuming the user already has a good product sequence—and wants to keep it (or something close to it). Management wants to find the "sweet spot" balancing transition cost and inventory carrying costs, while maintaining capacity feasibility. The economic lot scheduling problem looks for that sweet spot. The heuristic discussed here provides a relatively simple approach—that has been implemented in many production areas.

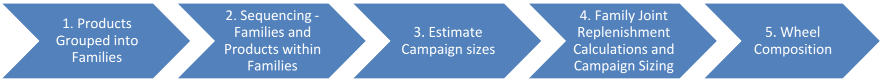

Fig. 13.2 Product wheel 5-STEP methodology

13.4 Product Wheel Methodology

The overall approach discussed, is summarized in the steps shown in Fig. 13.2. The rest of chapter will describe those steps in greater detail. This method for calculating product wheels has proven to be of significant value, having been implemented in manufacturing areas across a number of businesses.

13.4.1 Step 1: Product Families

When there are multiple products assigned to a production unit, they are frequently divided into groups—"families"—according to physical characteristics—size, chemical composition, etc. In a production context the goal is to subdivide the products assigned to a processing unit into families, based on common processing characteristics. All of the products in a family should be able to run sequentially, without requiring major transition time or cost (and the two frequently go together). Within a family product transitions are typically cheap and fast. Between families, however, product transitions are slower and/or more costly.

An example of a product family is products (e.g., polymers) using the same basic chemistry. When changing between products within the family, it may be possible to merely "plug flow" the next product and discard the mixed polymer coming through the line. However between families, it will be necessary to disassemble the production apparatus for a thorough cleanout.

Another example can be found with roll goods. Here a width change for the "mother roll" represents a significant effort, while changes in position of slitting knives, roll tension, packaging, etc., will be less difficult (faster and less costly). Products made from the same width mother roll would be in the same family.

When running product wheels correctly it will be a firm rule that families run in the product wheel sequence—and once a family is started, all of the products within the family that require product will be run. To run a different family's product out of order—within a different family (usually because it's expedited) is referred to as "breaking into the wheel." When intra-family transitions are expensive (time and/or cost) the decision to "break into a wheel" cannot be taken lightly. When a manufacturing line is running at close to capacity, breaking into the wheel may result in a downward spiral when one wheel break for expediting a product, leads to another wheel break, and so forth. Multiple wheel breaks use up line capacity and customer delivery grows worse and worse because there's no longer sufficient capacity to service promised sales. (In a production area already running close to capacity, breaking into a wheel is sometimes compared to "breaking into jail"!)

13.4.2 Step 2: Sequence within the Wheel

The classic analysis of production sequencing might seem to start with looking at all of the products to be produced, developing a matrix of transition costs (or times—or both) and running a traveling salesman algorithm to develop the lowest cost (or minimum transition time) sequence. There are a number of reasons that optimized traveling salesman algorithms are not a priority with production planners—and are actually not done very often in manufacturing operations.

First of all, there may be hundreds of different products that could either be on order, or need replenishment for a make-to-stock system. Generation of a 100 × 100 matrix (even if just assigning arbitrarily large values to infeasible transitions) is not practical.

Fortunately, product families tend to reduce the problem to manageable (and often trivial) size. Since the bulk of transition expense and time is between families, the problem is often reduced to an "N × N" transition matrix where "N" is frequently in the range of just 3–5. It is also typical that some intra-family transitions are so expensive (or even physically impossible) that they can be immediately ruled out. Thus family sequence for product wheels is often followed for long periods of time (months or even a year or more), even though the product mix may vary over time and new products are introduced within existing families.

A second reason that a traveling salesman algorithm is not frequently used, is the quality of transition cost/time data itself. The precision of the transition data may not justify the rigor of optimization analysis! Even when the manufacturing operation collects transition data, it is likely to be filled with "special cause" and "one-off" situations where lessons are learned and problems overcome. Often "eyeballing the family transition data"—provides "good enough" sequences.

Within a family, transitions are usually much less expensive and time consuming—and the order is less important. Product wheels usually have a sequence within each family as well as a sequence of families. In any given wheel cycle, certain products are likely to be left out due to sales variation, but typically transition cost and time don't vary much within the family.

Besides the planner/scheduler, one of the best sources for determining a minimum cost and time sequence of product families is to ask experienced operators. They are usually the first to question poor sequencing decisions—because they are doing the work required to make "non-optimal" transitions!

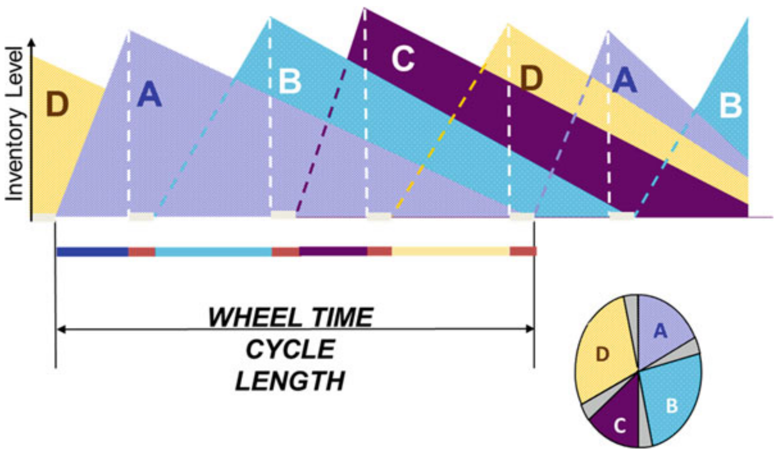

Fig. 13.3 Product wheel inventory plot

13.4.3 Step 3: Estimate Campaign Sizes

Campaign size (sometimes referred to as "Lot Size") is the quantity of a given product to be run during each spoke of the wheel. See Fig. 13.3. One of the goals of running product wheels is to run approximately the same campaign size on approximately the same time cycle. For instance if the wheel "turns" every 30 days, then enough will be produced to bring the cycle stock up to 30 days of sales (plus enough to replace any safety stock used during the cycle) approximately every 30 days.

The primary tradeoff in running product wheels is the balance between costs of carrying cycle stock versus transition costs. (Safety stock also increases with increasing wheel length—but much less than linearly—and is usually ignored in the calculations.) This inventory-transition tradeoff is the same tradeoff made with the well-known "Economic Order Quantity" ("EOQ") (Harris 1913). More applicable is an EOQ variant—the Economic Production Quantity (or Economic Production Lot) equation (Taft 1918) shown below:

$$\text{Economic Production Quantity} = \sqrt{\frac{2AD}{vr\,(1 - D/m)}}$$

where A, transition cost; D, demand rate in units/time period; v, unit cost of item ($/unit); r, fractional carrying cost of inventory per time period; m, production rate in units/time period.

Note that the D/m term goes to zero for purchased items, to give the form of the more familiar EOQ.

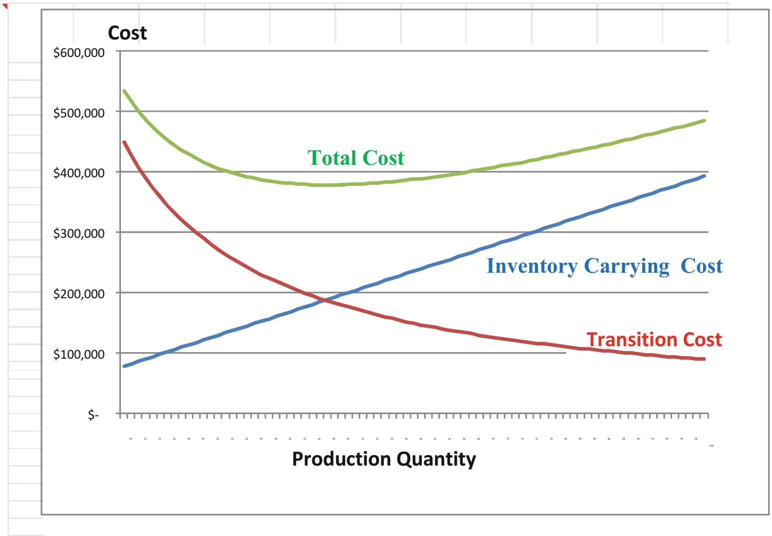

Fig. 13.4 Economic Order Quantity (EOQ) costs

The function is typically graphed as shown in Fig. 13.4.

The problem with using the "Economic Production Quantity" calculation above for product wheels is that each product is analyzed individually, whereas in a "wheel" the products run cyclically—*on the same basic cycle*. Nevertheless, the "Economic Production Quantity" gives at least a starting point for estimating favorable product campaign sizes (and hence campaign frequencies). (In the rare case that all products have the same production frequency—that frequency would be the answer on how often to "turn the wheel.")

13.4.4 Step 4: Product Families—"Joint Replenishment"

Edward Silver has written a number of very practical articles on coordinating "joint replenishment" in the context of economic production quantity. Specifically, he has published a "simple method" (Silver 1976) for calculating how often to produce a family of products (product family cycle length) and which products to produce every time the family is produced, every second time, every third time, . . . (product frequency in family). This method (sometimes referred to as "EOQ Family") is getting closer to solving the product wheel problem, but still does not directly solve the problem. The product family cycle length is very likely to be different between families. If the product family cycle lengths happen to be integer multiples of one another, then the families might possibly be arranged in "product wheel cycles." However even this solution still may not be feasible. If some product families don't run every base cycle, or the product frequency in family is not "1" for every product, the cycles are likely to require different processing times and some cycles could exceed the base cycle length.

13.4.5 Using Silver's Joint Replenishment Heuristic to Determine "Product Wheel Length"

13.4.5.1 Example Joint Replenishment Solution

The following example shows an implementation of Silver's Joint Replenishment heuristic (sometimes referred to as "EOQ Family") implemented in a spreadsheet (Tables 13.1 and 13.2). (This implementation uses visual basic calculations as part of the spreadsheet analysis.)

We define *Product Wheel Length* as the target time for cycling through the wheel. We define *Campaign Cycle* as the time between starting cycles (campaigns) of an individual product. Thus the *Campaign Cycle* for every product will be equal to an integer multiple (usually 1) of *Product Wheel Length*. The Joint Replenishment solution suggests limits for an estimate of optimal *Product Wheel Length* in the "EOQ Family: Product Family Cycle Days" column—looking (only) at those products that are produced every turn of the wheel (=1 in the "EOQ Family: Frequency . . . " column). (Commercial factors such as shelf life and storage capacity also limit *Product Wheel Length*.) For the example in Tables 13.2 and 13.3, we would look at using *Product Wheel Lengths* in the range of 19–42 days.

It is straightforward to extend the Joint Replenishment Spreadsheet to perform product wheel cost analysis (looking at cost of transitions plus cost of carrying cycle stock). With that cost model we can plug in different values of *Product Wheel Length* and quickly evaluate a number of alternatives in the range.

We use the following rules for selecting *Campaign Cycles* for each product.

Define (based on Joint Replenishment results):

- *Product Frequency* = Value in column "EOQ Family: Product Frequency . . ."
- *Product Cycle* = Value in "EOQ Family: Total Days . . ." for that product
- *Family Cycle* = Value of *Campaign Cycle* for those product s in the family with a *Product Frequency* = 1

Calculate the *Campaign Cycle* (days between campaigns) for each product, as shown in the three steps below. Note that *Campaign Cycle* will be an integer multiple of *Product Wheel Length*. Also every product in a family will be an integer multiple of one another. Calculate *Campaign Cycle* first for products having *Product Frequency* =1, so that a *Family Cycle* value can be determined for each family.

1. If *Product Cycle* <= *Product Wheel Length*, set *Campaign Cycle* = *Product Wheel Length*

Table 13.1 Input data

Product name	Family number	Forecast annual demand	Cost per unit	Family setup cost	SKU setup cost	Days setup time for family	Days setup time for SKU	Inventory carrying costs	Days available for production
Prod1	1	459,281	$32.78	$5184	$91	0.02		25 %	335
Prod2	2	310,254	$22.48	$9500	$125	0.04		25 %	335
Prod3	2	247,557	$22.77	–	$18,200	0.04		25 %	335
Prod4	2	403,498	$21.16	–	$240	0.02		25 %	335
Prod5	2	122,291	$23.59		$95	0.02		25 %	335
Prod6	2	122,291	$22.1		$86		0.001	25 %	335
Prod7	2	161,000	$28.25		$200	0.02		25 %	335
Prod8	2	294,917	$25.44	–	$1250	0.02		25 %	335
Prod9	2	361,843	$27.42	–	$500			25 %	335
Prod10	3	67,206	$28.83	$30,368	$500	1.00		25 %	335
Prod11	3	502,058	$27.02	–	$500			25 %	335
Prod12	3	32,300	$27.99		$15,000			25 %	335

Table 13.2 Joint Replenishment results from Table 13.1 input

Product name	Family number	EOQ family: Campaign size	EOQ family: Product frequency in family (1 = every cycle, 2 = every other cycle, ...)	EOQ family: Total days between product campaigns
Prod1	1	24,316	1	17.7
Prod2	2	17,290	1	18.7
Prod3	2	27,591	2	37.3
Prod4	2	22,486	1	18.7
Prod5	2	6815	1	18.7
Prod6	2	6815	1	18.7
Prod7	2	8972	1	18.7
Prod8	2	16,435	1	18.7
Prod9	2	20,165	1	18.7
Prod10	3	8494	1	42.3
Prod11	3	63,452	1	42.3
Prod12	3	12,247	3	127.0

2. If *Product Frequency* = 1 and *Product Cycle* > *Product Wheel Length*, then set the *Campaign Cycle* to the nearest integer multiple of the *Product Wheel Length*
3. If *Product Frequency* > 1, then set the *Campaign Cycle* = *Family Cycle x Product Frequency*

Table 13.3 shows annual cost calculations for three candidate values of *Product Wheel Length*: 21, 28, and 35. The column "Wheel to use for annual cost evaluation: Days between product production" is the *Campaign Cycle* for each product, calculated using the steps above. The user would in like manner try a variety of *Product Wheel Length*s to find one that produces a low total annual cost and works within the limitations of the production process (for instance minimum campaign size).

13.4.5.2 Capacity Versus *Product Wheel Length*

One of the first results to check with this method is to ask if there's sufficient capacity. Very low transition costs will drive the heuristic to produce very short campaigns—potentially taking up significant production unit time in transition. Increasing the *Product Wheel Length* reduces utilization—but at the cost of greater inventory carrying cost. Typically when using the heuristic described, one calculates capacity as part of the spreadsheet calculation. If there's not sufficient capacity, then increase the input *Product Wheel Length* and recalculate the *Campaign Cycles* for the wheel.

Table 13.3 Total annual cost and capacity calculations

Product name	Family number	EOQ family: Campaign size	EOQ family: Product frequency in family (1 = every cycle, 2 = every other cycle, ...)	EOQ family: Total days between product campaigns	Product wheel length = **21**: Wheel to use for annual cost evaluation: Days between product production	Product wheel length = **21**	Product wheel length = **28**: Wheel to use for annual cost evaluation: Days between product production	Product wheel length = **28**	Product wheel length = **35**: Wheel to use for annual cost evaluation: Days between product production	Product wheel length = **35**
Prod1	1	24,316	1	17.7	21.0		28.0		35.0	
Prod2	2	17,290	1	18.7	21.0		28.0		35.0	
Prod3	2	27,591	2	37.3	42.0	Annual demand	56.0	Annual demand	70.0	Annual demand
Prod4	2	22,486	1	18.7	21.0	3,084,496	28.0	3,084,496	35.0	3,084,496
Prod5	2	6815	1	18.7	21.0		28.0		35.0	
Prod6	2	6815	1	18.7	21.0	Annual capacity	28.0	Annual capacity	35.0	Annual capacity
Prod7	2	8972	1	18.7	21.0	7,473,880	28.0	7,625,321	35.0	7,452,726
Prod8	2	16,435	1	18.7	21.0		28.0		35.0	
Prod9	2	20,165	1	18.7	21.0		28.0		35.0	
Prod10	3	8494	1	42.3	42.0	Total annual cost	56.0	Total annual cost	35.0	Total annual cost
Prod11	3	63,452	1	42.3	42.0	$ 1,506,428	56.0	$ 1,556,833	35.0	$ 1,665,156
Prod12	3	12,247	3	127.0	126.0		168.0		105.0	

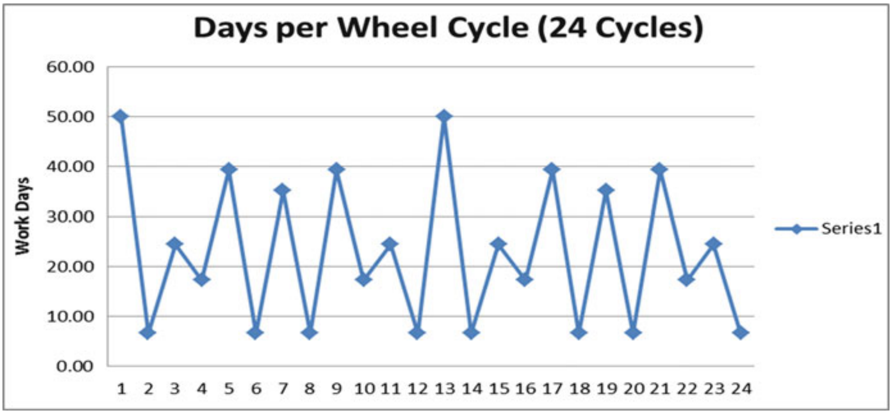

Fig. 13.5 Showing the days required to run each cycle of the wheel described in Table 13.4. Product wheel cycles are on the *X*-axis

13.4.6 Step 5: Wheel Composition

The principle that Silver's algorithm uses—production of a product family will cost less when we run low demand products less frequently than high demand products—makes common sense. However we see from the results in Table 13.2, that "Prod3" should run about every second product wheel cycle and Prod12 every third wheel cycle to achieve minimum total cost (transition cost plus inventory carrying cost). When there are multiple products that do not run every wheel cycle, it raises the problem of how to "balance" successive wheel cycles.

As we've seen, a production unit may be assigned some products that "optimally" run every "turn of the wheel" (*Campaign Cycle* = *Product Wheel Cycle*), others that should run only half as frequently as the "big sellers," and still other very low volume products and product families that should run only every third or fourth cycle. The issue now is which product families should run together in what cycles. Should the "every second cycle" products run on the first and third wheel cycles—or second and fourth? This is the same as asking—"which of those families should start on the first cycle and which on the second?" Note that all products in a *family* need to be coordinated to run on either the same cycles, or for low volume products, on a subset of those cycles—in order to minimize family transition costs.

The potential problem (that is certainly seen in real life) is that the wheels can end up very "unbalanced"—with some product wheel cycles ("turns of the wheel") requiring much more time than other cycles. For instance a nominal 25-day product wheel could have wide swings in duration from cycle to cycle—requiring the wheel's nominal 25 days of cycle stock to last for 50 days or more on some cycles.

The following is an example of a product wheel design made with all families starting in cycle 1 (default solution). (A larger example problem is used here,

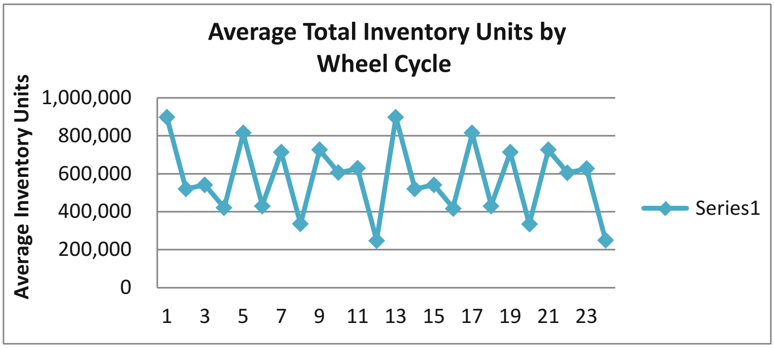

Fig. 13.6 Showing the inventory swings produced by the product wheel plan in Table 13.4. Product wheel cycles are on the *X*-axis

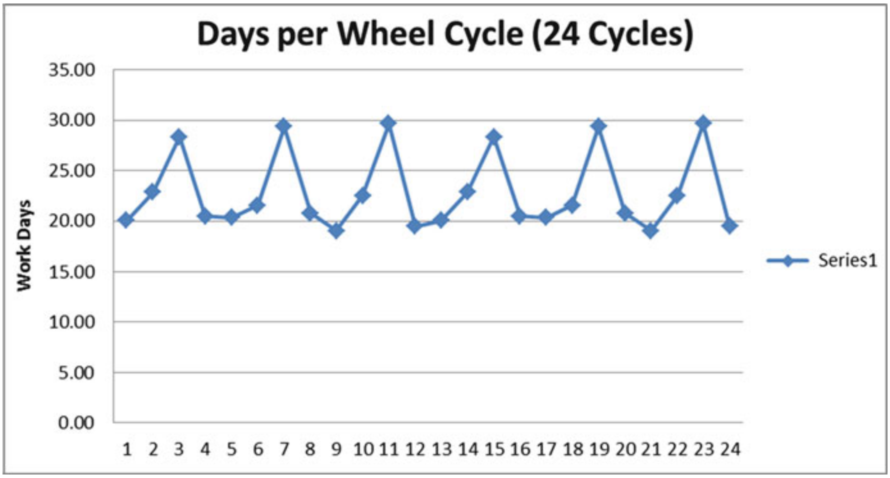

Fig. 13.7 Showing the days required to run each cycle of the wheel described in Table 13.5. Product wheel cycles are on the *X*-axis

to illustrate the problem more clearly.) Cycle durations range from 8–50 days. Obviously total inventory makes similar swings (with some products likely to run out) (Figs. 13.5, 13.6, and Table 13.4).

With judicious selection of starting cycles (by observing what frequencies that families run, and putting families into different starting cycles), the extremes of cycle durations can be avoided (Figs. 13.7, 13.8, and Table 13.5).

The improvement in wheel composition came from balancing the family days of production among the starting cycles. (When there are more products, it's usually easier to get better balance.) The rules for assigning products to starting cycles are:

Table 13.4 Produced from a spreadsheet program to "cost out" different wheel lengths

Product name	Wheel to start production on: first wheel (=1), second wheel (=2), …	Produce every wheel (=1), every other wheel (=2), …	Avg. days production during campaign	Family setup (0 or 1)	Family setup time (Days)	SKU setup (Days)	Safety stock	Demand rate (Units/Day)	Days per campaign	Family number
P1	1	2	3.53	1	0.02		2103	1258	3.55	1
P2	1	3	3.72	1	0.04		1095	850	3.76	2
P3	1	3	2.97	1	0.04		1245	678	3.02	3
P4	1	2	2.99	1	0.02		1847	1105	3.01	4
P5	1	3	1.35	1	0.02		615	335	1.37	5
P6	1	3	1.41			0.00	615	335	1.41	5
P7	1	2	2.18	1	0.02		737	441	2.20	6
P8	1	2	2.17	1	0.02		1350	808	2.19	7
P9	1	2	2.66				1656	991	2.66	7
P10	1	1	0.69	1		0.02	780	524	2.69	8
P11	1	4	2.05	1	0.02		746	376	2.07	9
Discretionary	1	2	1.15	1	0.01			0	1.16	10
P12	1	2	3.07	1	0.02		1826	1093	3.09	11
P13	1	4	1.68	1	0.02		560	282	1.70	12
P14	1	1	3.98	1	0.02		4319	2901	4.00	13
P15	1	3	1.04	1	0.02		467	255	1.06	14
P16	1	4	1.03	1	0.02		366	184	1.05	15
P17	1	4	7.65				2731	1376	7.65	15
P18	1	4	2.34				1382	420	2.34	15

Note that the "Starting Cycle" in column 2, defaults to "1" for all products

Table 13.5 Same output from a product wheel "costing" spreadsheet as Table 13.4

Product name	Wheel to start production on: first wheel (=1), second wheel (=2), ...	Produce every wheel (=1), every other wheel (=2), ...	Avg. Days production during campaign	Family setup (0 or 1)	Family setup time (Days)	SKU setup (Days)	Safety stock	Demand rate (Units/Day)	Days per campaign	Family number
P1	2	2	3.53	1	0.02		2103	1258	3.55	1
P2	1	3	3.72	1	0.04		1095	850	3.76	2
P3	2	3	2.97	1	0.04		1245	678	3.02	3
P4	1	2	2.99	1	0.02		1847	1105	3.01	4
P5	3	3	1.35	1	0.02		615	335	1.37	5
P6	3	3	1.41			0.00	615	335	1.41	5
P7	2	2	2.18	1	0.02		737	441	2.20	6
P8	1	2	2.17	1	0.02		1350	808	2.19	7
P9	1	2	2.66				1656	991	2.66	7
P10	1	1	0.69	1		0.02	780	524	2.69	8
P11	2	4	2.05	1	0		746	376	2.07	9
Discretionary	2	2	1.15	1	0			0	1.16	10
P12	2	2	3.07	1	0		1826	1093	3.09	11
P13	1	4	1.68	1	0		560	282	1.70	12
P14	1	1	3.98	1	0		4319	2901	4.00	13
P15	2	3	1.04	1	0		467	255	1.06	14
P16	3	4	1.03	1	0		366	184	1.05	15
P17	3	4	7.65				2731	1376	7.65	15
P18	3	4	2.34				1382	420	2.34	15

But column 2 has been adjusted to smooth product wheel cycle length

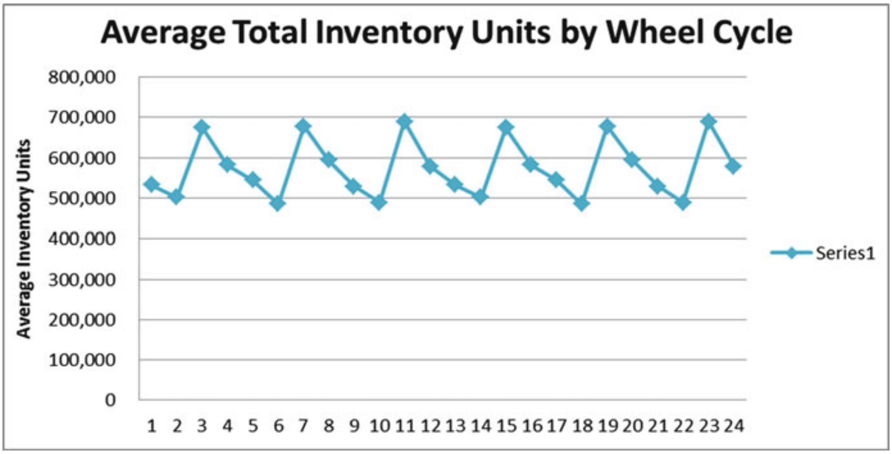

Fig. 13.8 Showing the inventory swings produced by the product wheel plan in Table 13.5. Product wheel cycles are on the *X*-axis

1. To minimize family transition costs, higher volume products in a family (run every time the family runs) should begin in the same cycle. Low volume family products (that run less frequently) should run on a subset of the cycles where the high volume products of the same family run.
2. Products cannot begin in a cycle that exceeds their frequency. (For instance products made every other wheel can only start in cycles 1 or 2—not 3. Products made every third wheel can only start in cycles 1, 2, or 3. . .)

Excel graphical analysis like that above shows where the problem is—and allows testing different solutions. However, even a small problem like the one above can be difficult to minimize by trial and error.

13.5 Data Considerations

13.5.1 Transition Time and Cost

Correct transition cost data is critical to any EOQ related method. Costs for yield loss (extra raw materials, energy, and waste disposal) and maintenance materials, are usually readily available. Manufacturing labor is usually *not* charged to transitions (unless overtime is required or labor is truly a "variable cost" in the short term). The most frequent (and largest) error in transition cost calculation is when the analyst charges the opportunity cost of time on the production line—when the business is not "oversold." (If there's not a buyer for the extra product that would have been made in place of stopping for the transition, then it's obviously *not* allowable to charge for the time as a cost of the transition.) If the market for products made on the line does become oversold, then the transition cost should include the opportunity cost of the transition time (margin on the product that could have been produced in place of the transition)—which usually drives the transition cost much higher than before.

Transition time and cost obviously relate to both the product being transitioned "from," and the product being transitioned "to." Product wheel methodology is to run the same sequence repetitively. However, it is possible that some products may only run in every second or third "turn" of a wheel—and thus a given product may not always be preceded by the same product. This product wheel heuristic depends on the user to determine when the transition cost and time used for calculation is not appropriate for the actual order in the wheel. In these cases the user should adjust the transition cost and time and repeat the analysis. (Changes in transition cost could impact the prescribed wheel length. Changes in transition time only impact capacity feasibility.)

13.5.2 Demand and Uptime Variability

Product wheel planning can be maintained in the face of demand surges by: (1) planning for "slack time" in the wheel and (2) allowing the wheel to run a little longer than planned (using safety stock to cover sales and shortening subsequent wheel "turns" when possible). Production planners are warned to be aware of substantial shifts upward in average demand—and to recalculate wheel lengths (and offload production to other facilities) when such a shift occurs.

Uptime losses are typically separated into two classes: "short" routine outages, and much longer (sometimes catastrophic) outages that occur with much lower frequency. Short, routine outages are counted as "normal" downtime and production rates are factored down to account for these. Some lower frequency outages may be covered by safety stock when they are not routine. However very low frequency, long duration "catastrophic" outages are more often responded to *ad hoc* (and may be grounds for declaring a *Force Majeure* and serving customers accordingly).

13.6 Revising Product Wheels

Industrial data, particularly demand data, is never static. Developing and revising product wheels is an ongoing effort. Spreadsheet calculations and particularly Silver's Joint Replenishment heuristic can be built into spreadsheet tools and offer a rapid means for approximate solutions that are usually as "good as the data." Product wheels should be recalculated whenever:

1. Total demand changes by 10–20 %—or changes enough that the current wheels need to be lengthened to keep from running short of capacity. Note that during a given planning period, increased demand for individual products will often be balanced by decreased demand for others—leaving the product wheel cost effective and feasible.
2. Products are shifted between production units (usually in response to demand changes).
3. Transition times and/or costs change significantly.
4. Process efficiencies significantly reduce processing times.

Product wheel composition remains a challenge, and offers opportunity for improvement over current manual analysis.

13.7 Summary

Prior to introducing product wheels into their scheduling logic, many operations tended to treat each day's or each week's production plan as a totally new thing, to be scheduled from scratch. They would try and follow the ideal transition sequence, but often found themselves forced to "break in" to the sequence when a particular product ran out. With wheels, they quickly learn that all of the routine products are pre-planned to cover expected demand, so they can focus their attention on the few unique situations that require special attention. And they now have enough mental bandwidth to deal with these abnormal situations and crises appropriately.

PRODUCT WHEEL BENEFITS

1. Leveled production
2. Improved changeovers via optimized sequences
3. Increased usable capacity
4. Optimized campaign lengths
5. More realistic inventory target setting
6. Reduced inventory
7. Improved delivery performance
8. A higher degree of regularity and predictability in operations
9. A credible mathematical basis to support decision making

A number of innovative companies have employed product wheels to great advantage: DuPont (chemicals, paints, sheet goods, extruded polymers), Dow (chemicals), AstraZeneca (pharmaceuticals), ExxonMobil (oil and gas), and APPVION (paper products). The sidebar shows the benefits they have found from wheel scheduling. As a specific example Dow Chemical typically sees inventory reductions of 10–20 %, 10–25 % higher customer fill rates, 30–40 % shorter lead times, and greater predictability and stability. The latter benefits are what some users appreciate the most, the dramatic reduction in the "noise level" in the system, the fact that scheduling chaos has been replaced by stability, predictability, and fixed patterns which allow everyone to get into a production rhythm.

13.8 Acknowledgement

The authors wish to thank Dr. Rami Musa, DuPont Co. for valuable suggestions to this chapter.

Some of the material in the *Introduction*, *Product Wheels Defined*, and *Summary* sections was adapted with permission from *The Product Wheel* Handbook—*Creating Balanced Flow in Multi-Product Process Operations*. Productivity Press, 2013.

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