# QRM It's About TIME

## The Competitive Advantage of Quick Response Manufacturing

## Appendix A

Tips for Calculating Manufacturing Critical-path Time (MCT) and Creating MCT Maps

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# APPENDIX A

## TIPS FOR CALCULATING MANUFACTURING CRITICAL-PATH TIME (MCT) AND CREATING MCT MAPS

*(Supplement to the book It's About Time, by Rajan Suri, Productivity Press, 2010)*

I introduce the concept of Manufacturing Critical-path Time (MCT) in Chapter 1 and explain why MCT is fundamental to the theory and implementation of QRM. In this Appendix, I show you via several examples how you can calculate MCT in a typical situation. I will also give you practical tips for calculating MCT and explain the use of a simple tool to help you
estimate MCT when accurate data is not available. Finally, you'll see how to create MCT Maps and understand the importance of MCT Mapping for communicating QRM opportunities to management and employees. Let me briefly revisit the reason for defining and using MCT. As you mhave seen throughout this book, QRM has a singular focus on reducing lead time, but as I also illustrate in Chapter 1 with several examples, "lead time" can mean different things to different people. You can't reduce something if you can't even agree how to measure it. In addition, traditional notions of lead time do not adequately capture waste in the process of how that lead time is actually achieved. Indeed, most definitions of lead time are along the lines of: the time from when an order is transmitted by a customer until the order is received by that customer.
However, this traditional definition has two significant disadvantages: it does not help to understand and eliminate system-wide waste, and it does not give any indication of how order fulfillment is achieved. In other words, the traditional definition of lead time focuses strictly on a result. Consequently, stockpiling finished goods or partially completed components may result in a short lead time. However, this inventory is obviously a waste of working capital. Worse yet, it can result in even greater waste if a quality issue is discovered by the customer, an engineering change
requires material to be scrapped or reworked, or demand falls significantly below what was forecasted and the inventory cannot be used for an extended period. Conversely, if demand greatly exceeds the forecast and the stockpiled components are depleted, supplier lead time can extend significantly beyond the value in the traditional definition, resulting in customer dissatisfaction or even lost sales. None of these issues is captured in the traditional definition. What is needed instead is a lead time metric that focuses on both the outcome and how the outcome is achieved. MCT is just such a metric; it is defined in Chapter 1 but I reproduce the definition here for your convenience: **Manufacturing Critical-path Time (MCT)** is the typical amount of calendar time from when a customer creates an order, through the critical path, until the first piece of that order is delivered to the customer.
Each of the phrases in this definition, such as "the typical amount," has been carefully chosen. I explain the key components of this definition in Chapter 1, so I will not repeat

them here. Before proceeding with the examples in this Appendix, you may find it useful to review that discussion. This Appendix is intended to be read in addition to, not in place of, the material in Chapter 1.

As I also explain in Chapter 1, MCT quantifies an organization's total system-wide waste and provides a simple yet powerful metric with which to measure improvement. Other improvement methods try to identify multiple types of waste. For instance Lean Manufacturing identifies seven types of waste, popularly remembered by the mnemonic "TIMWOOD" for Transportation, Inventory, Movement, Waiting, Overproduction, Overprocessing, and Defects. While it is important to reduce all these different wastes, at the end of a project it is hard to evaluate success if seven different measurements are involved. What if you did really well on three measures but poorly on the other four? Was the project successful? Also these wastes measure the "micro" impact in seven areas, but do not give insight into "macro" system-wide waste. In contrast, MCT provides management with a metric that gives a unified measure of system-wide waste in a single number and thus also makes it easy to evaluate whether improvements have been achieved.

I will now proceed with the examples showing you how to calculate MCT properly and how to use MCT Mapping.

## MCT EXAMPLE–PRODUCT ION OF TRANSMISSIONS AT MADTRAN

Let's consider the example of MadTran, Inc., a hypothetical Madison, Wisconsin–based company that makes transmissions. Management at MadTran has decided to implement QRM, and the QRM Steering Committee has identified a particular line of transmissions as the target of a QRM project. This line is known by the brand name "BadgerTran." Since the company has long lead times in its operations and supply chain, it builds BadgerTran transmissions to forecast and keeps them in a finished- goods warehouse. I will work together with you on this example to calculate MCT for the BadgerTran product.

*Figure A.1* shows the workings of the basic order fulfillment process for a BadgerTran. Remember that the MCT value needs to be stated in calendar time. For simplicity, I will begin with the situation where the company works 7 days a week, so that calendar time and working time are the same. Later I will show you how to convert to calendar time in the more typical situation of a 5-day workweek and one or two shifts per day, as well as for even more complicated situations where different sections of your business have differing work schedules.

When a customer issues an order for a BadgerTran, it is received by Customer Service, which typically takes a day to process the order. Customer Service then issues instructions to Finished Goods to fulfill the order. Finished Goods takes 2 days to pack and ship the order, after which it takes 3 days of transportation time to get the order to the customer. If you add up the times shown in the figure, you get a total of 6 days. So my question to you is: Does MCT equal 6 days for the BadgerTrans?

If you have read Chapter 1 carefully, I hope you answered "No!" As I explained there,

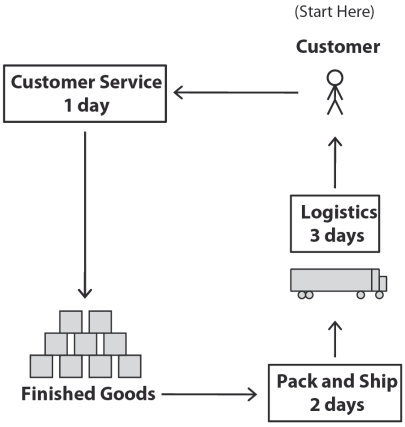


*Figure A.1*

*Basics of order fulfillment process for the BadgerTran product.*

"through the critical path" means that you have to make things from scratch, so in calculating the MCT value you cannot assume that you will ship from the finished-goods inventory; you have to calculate how long it takes to make those transmissions. (The reasons for doing this were explained at length in Chapter 1.) So in *Figure A.2* I give you a more detailed view of the order fulfillment process.

One way to think about this process is to ask the question: "What if the particular transmissions the customer ordered were not in stock–how long would it take to get the order fulfilled?" In this case Customer Service would pass the order on to the Planning Department, which would then schedule and release the appropriate jobs to Manufacturing.

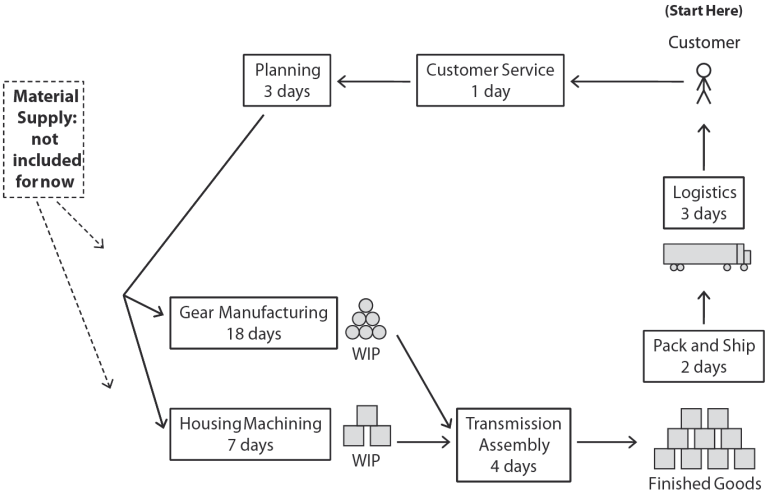


*Figure A.2*

*More detailed view of order fulfillment process for purposes of MCT calculation.*

To keep this example simple, let's say only two major components are fabricated in-house: gears are machined from purchased blanks and housings are machined from purchased castings. All other components of the transmission are purchased. The housings, gears, and other purchased components then proceed to an assembly area where the transmissions are assembled and sent to Finished Goods. Of course at this point you could extend the MCT measure back into your supply chain by asking a similar question: If some of the raw material was not available, how long would it take to procure it? This is where my first tip comes in.

**Limit the Scope of the MCT Calculation**

While the broadest definition of MCT spans your whole enterprise and its supply chain, as I explain in Chapter 1, you can apply MCT to sections of your business. Based on the aims and scope of your QRM effort at any point in time, you can "draw a box around" the section of the business that is of concern and use the concepts here for that section, expanding the scope as needed later. So you should not be daunted by the broad scope of the MCT definition; you can start small and then grow your measurement in successive projects.

For our first example, let's say that the scope of MadTran's initial QRM project is limited to in-house improvements, so we will not look at the supply chain at this point in time; this is also indicated in *Figure A.2*. In the section "Extending the MCT Analysis to Include the Supply Chain," I will extend this example to include part of the supply chain.

Let's now look at the gear and housings fabrication areas, which each consist of several machining operations. At each operation in manufacturing, you need to be sure to include a number of different types of times. First there is the time that the job waits in queue in front of the operation until its turn comes up. Then there is setup (changeover) time and time to make the first piece. Now note that although the MCT definition is based on the first piece reaching the customer, if you make parts in batches, that first piece doesn't leave the operation right away. So you have to include time for the rest of the batch to be made. In other words you have to calculate the operation time for the whole batch, the way it is made today. In addition, you have to include the time this batch waits before it is moved to the next operation. Finally you need to include material-handling time. Then you start again with this sequence of times at the next operation. If this seems like a lot of detailed data gathering, the next tip will help.

**Remember That Higher-Level Calculations Are Good Enough (Initially)**

In Chapter 1, I stated two reasons why rough values are good enough for initial estimates of MCT–briefly they are that (a) the aim is to get a ballpark estimate that highlights the magnitude of the main improvement opportunities; and (b) a key insight is to contrast the large value of MCT with the small amount of touch time, and since the touch time is usually only 5% or less of the MCT, it is not necessary for the MCT value to be extremely accurate in order to convey this difference.

With this in mind, it may be possible to avoid operation-by-operation calculation of MCT as in the preceding paragraph, if alternative data is available. At MadTran, let's say that the MRP system records the date and time that a job is released to the gear-manufacturing area. Then when the gears are completed and ready to be moved to assembly, the job is logged out of the gear area after the last operation. This means that you can analyze historical data to get the average time spent in the gear area by a job without needing to look at each operation. Let's say you analyze this data for the past 6 months for both gears and housings and get an average of 18 days for Gear Manufacturing and 7 days for Housings Machining. Similarly you get 4 days for Transmission Assembly. This data will suffice for now. Note: This tip doesn't imply that if you are able to get such highlevel data, you won't ever need to go into more detail. If the time spent in an area appears to be a large contributor to MCT, you will definitely need to drill down deeper and investigate the components of that time. However, you can make this decision later using the MCT Maps I show you later in this Appendix. For now, the high-level values will suffice and are shown in *Figure A.2*.

If at some stage you decide that you need more detailed data on job Flow Times through each operation–either in the office or on the shop floor–a technique called tagging can help you gather this data. See "For Further Reading" at the end of this Appendix for more details.

After the gears are completed, they are moved to a staging area where they wait until they are needed for transmission assembly; the same is true for housings. Note that this is not planned inventory, such as when you build ahead for stock items. Rather, this is work-in-process (WIP).

In any manufacturing operation, such WIP could be there for several reasons, prime among them being: due to variability in lead times through the fabrication areas, planners insert safety time into the schedule and the gears and housings are started quite a bit ahead, and so by the time they are completed they are often early and have to wait for the transmission assembly start date; the transmission assembly schedule changes during this long period so these components are needed later than originally expected; the transmissions for which these gears are destined are held up waiting for other components from suppliers and those needed to be assembled before the gears; and so on.

Note that the high-level data is from the start to finish within each area, so it includes any WIP that is within that area, but it does not include the WIP just described that gathers between areas. You need to be alert to such situations, as the next point explains.

**Don't Forget the WIP**

If there are staging points for intermediate inventory, or just places where WIP gathers on the shop floor while jobs wait to be scheduled, either make sure the times you collected include the time spent by jobs in such WIP areas, or else you will need to explicitly add these times into your MCT calculation.

Often companies don't collect actual data on time spent in WIP and we'll assume that is the case here, so that I can show you another useful tool for MCT calculation.

If you have thought through this example though, you might protest and say, "You just told us that we know when a gear job was logged out of the gear area, and we also know when a job is started in the assembly area, so can't we just use the difference between those two times to derive the time spent in WIP?" Indeed, you might be right, but often in manufacturing other events can interfere with this logic. At MadTran they often get hot jobs or experience other unanticipated schedule changes. In such cases the components for the newly scheduled jobs may not be available and the supervisor in assembly is told to "steal" parts destined for other jobs. Thus a batch of gears that is earmarked for a given assembly job is broken into and partly used for a different job. To make up for this, Planning releases a new job with a few gears to be added back into the original batch. As you think about this situation, you realize that jobs lose identity and the data on the job may not reflect what actually happened to the parts in the job. Hence the job start and end data in the computer system does not easily tell you what is actually in WIP, or else you might have to do a lot of processing and detective work on historical data to decipher what really happened and calculate the right value. In such cases an alternative and relatively simple tool can help you out.

**Use Little's Law to Get Quick Estimates**

While this rule is called Little's Law from the last name of the researcher who proved it, it's actually a big law because it finds a lot of uses! This law gives you a simple connection between WIP, Flow Time, and Flow Rate–if you know any two of these, you can derive the third. Here we will use it to estimate the time that jobs spend in WIP.

Consider any "subset" of your enterprise–examples of a subset would be an area of the shop floor, a portion of a warehouse, or a set of departments in the office. Also, subset could refer to certain types of jobs, for instance "All jobs for Customer X." You can combine these concepts to create a subset such as "All jobs for Customer X that are in Area Y." For the chosen subset I will define three quantities related to jobs going through this subset (see *Figure A.3*):

- Flow Rate is the average rate at which jobs pass through this subset–for example, 10 jobs per day.
- Flow Time is the average time that jobs spend in this subset–for example, 3.5 days.
- WIP is the average number of jobs that are in this subset at any given time–for example 35 jobs.

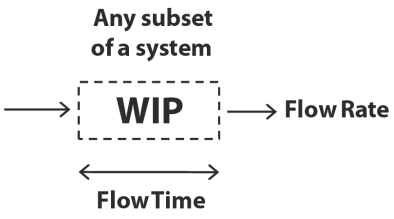


*Figure A.3*
*Illustration of quantities used in Little's Law.*

It is important that consistent units are used across these three quantities. For example, if you measure Flow Rate in jobs, then WIP should be in jobs as well. On the other hand, if you are applying this to the shop floor and jobs could have very different batch sizes, you might prefer to use pieces instead of jobs. Then your Flow Rate would have to be measured in pieces per unit of time (e.g., pieces per day), and the WIP would be in pieces. Similarly, let's take examples of the time unit for this situation. If you measure Flow Rate in pieces per day, then Flow Time should be in days. However, if you prefer to measure Flow Rate in pieces per week, then the Flow Time should be in weeks.

With these concepts in place, I can now state Little's Law. It says simply that for this subset

WIP = Flow Rate x Flow Time

Or, if you specifically want to derive Flow Time from the other data, then you would rewrite this as

Flow Time = WIP : Flow Rate

This is intuitively reasonable as a simple example shows. Suppose you have around 400 pieces in WIP, and each day about 50 pieces are used up. How long would it take for a part to flow through this WIP? Using the law the answer is 8 days, which is what you would most likely have come up with just using commonsense arguments.

So now let's use this law to assist with MCT calculations. If good data for WIP times is not available, you can do one of two things. You can actually walk out to the relevant area of the shop floor and physically count the jobs out there–this may seem tedious, but remembering that we are looking for ballpark estimates it usually takes only 10 to 15 minutes to do this and come up with a good enough number. Or your MRP system may record jobs by their status and you can generate a report of all jobs that are in the status of being out of fabrication but not yet in assembly. (Of course you need to be sure that this report will not suffer from the issues described earlier: specifically the "stolen" pieces should have been subtracted from the quantity on-hand in the MRP system so that it has the right counts, or else you might have to do the physical count instead.) In either case, you should get these observations several times over a period, and then take their average.

Now I will show you how to apply this to the MadTran example. Let's say on average MadTran ships 20 BadgerTrans per day, and each requires five gears and one housing. You go out and count the WIP for gears and housings once a week for a month, and the average of your four observations is 500 gears and 60 housings. So what is the Flow Time through the Gear WIP and the Housings WIP areas?

To test your understanding thus far, try to arrive at the answer using Little's Law before reading further ...

If you've had a chance to think about the answers, let's work together to
derive them and see if you got them right! Based on the preceding data, the Flow Rate of gears is 100/day and that of housings is 20/day. The gear WIP is 500, so using the second version of the law we get the following: The Flow Time through the Gear WIP is 500/100, which equals 5 days. Similarly, the Flow Time through the Housings WIP is

60/20, which equals 3 days.
So you see how Little's Law gives you an easy way to derive Flow Times through various parts of your organization where you may not have good data, and thus estimate the contributions to MCT from such areas.

**To Apply Little's Law Correctly, Be Aware of These Issues**
In order to apply Little's Law and get reasonable answers, you need to be cognizant of a few issues:

- The three values in the law are all averages. • For your purposes of MCT estimation, ballpark values are good enough all around.
- Stated in technical terms, the values need to be steady state values. Intuitively this means that there is no significant ramp up or ramp down of flow through the area during the period under consideration.
- There needs to be "conservation of mass" in the subsystem; that is, jobs or material don't go into the system and disappear! This is not as absurd as it seems–for example in manufacturing, if a batch of 100 pieces goes into an area but then 30 pieces in the batch are found to be defective and scrapped, only 70 pieces will move on to the next operation. Remembering that we are looking only for ballpark estimates, as long as all jobs are accounted for and scrap is minimal, this should not be an issue in most cases.
- You can define your subset by area, or type of job, or both–but then remember to keep all units consistent. For example if you are doing the calculation only for jobs for Customer X, then WIP should include only Customer X's jobs, and Flow Rate should be the average number of Customer X's jobs going through the area.

Now let's continue with the MadTran example. Following the process flow in *Figure A.2* we now come to Transmission Assembly, which contributes 4 days to the MCT. From here jobs go to Finished Goods and then they are shipped.

**Include All Instances of Inventory**
Remember to include time spent in all types of inventory including raw material, WIP, and finished goods. Traditionally in businesses inventory is used to provide fast response to customers; that is, it reduces the response time. But as far as MCT is concerned, inventory adds to the MCT value. The reason for this is explained in Chapter 1, but briefly it is that this inventory represents waste and could end up being a liability under several circumstances. Essentially, building inventory is the wrong way to reduce response times, and the MCT metric highlights this.
For the MadTran example, we decided to exclude raw material from the initial analysis, and we have already calculated the WIP times. So what remains is the MCT contribution from Finished Goods. Again, Little's Law comes in handy here. When companies make to stock and ship from stock, in most cases jobs in the MRP system terminate when they reach the warehouse. The pieces in the job join other identical pieces in a bin and lose their identity. Then new jobs are associated with orders to pick parts. Thus there is no connection between the flow in and the flow out and you can't determine how long

a particular piece has been in inventory. On the other hand, your MRP system does keep count of how many pieces there are in Finished Goods–this is essential in order to decide if you can ship products to a customer or whether you need to make more. So once again, you can take samples of these inventory values over a period of time to get an average of your finished-goods inventory for the items in your subset.

In the MadTran example let's say the average of a few observations tells us that there are typically 220 BadgerTrans in Finished Goods. Based on the shipping rate of 20/day, we can calculate the Flow Time through Finished Goods. Little's Law tells us that it is 220/20 = 11 days. We now have all the components of time that we need to calculate MCT for the portion of MadTran's operation that is currently being reviewed. These times are indicated in *Figure A.4*. As you follow the process starting from the customer and working around the figure, you realize that the process splits into two paths. So which path do we use for MCT calculation?

**Use the Longest Path**

If the order fulfillment requires multiple components and/or multiple activities in parallel, the MCT metric requires that you look for the longest path, identify it as the critical path, and use the calculation along that path as the MCT value.

So let's find the longest path. Although in this case it might be obvious, in more complex process flows you may have to do the calculation in detail for all paths, so I'll do the calculation for both paths as an illustration. I'll start with the path involving the gears. Beginning with the customer, the total time around *Figure A.4* is:

1 + 3 + 18 + 5 + 4 + 11 + 2 + 3 = 47 days (path with gears)

For the other path, the one with transmissions, the values are:

1 + 3 + 7 + 3 + 4 + 11 + 2 + 3 = 34 days (path with transmissions)

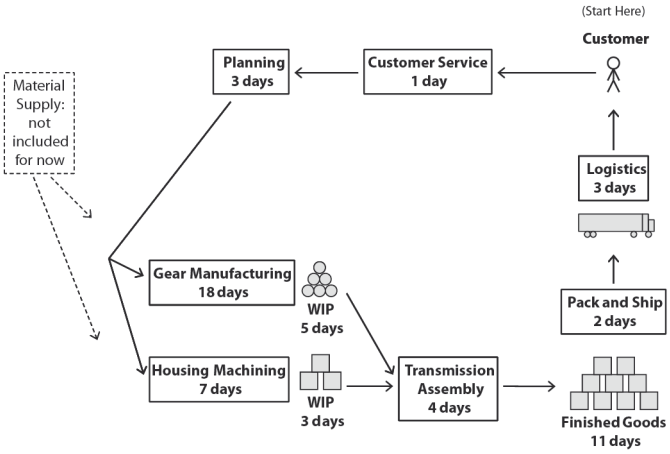


*Figure A.4*

*Process flow for BadgerTran product with all relevant times indicated.*

Hence the MCT for the BadgerTran product (for the section of the business that we are considering) is the greater of these two, or 47 days. This is the answer you need and we have completed the initial MCT calculation. Note that in addition to giving us the 47 day number, the MCT calculation has also pointed out that the critical path involves the gears. This is an important insight in terms of convincing management where to focus its improvement efforts, and I will show this even more clearly using an MCT Map next.

In order to construct the MCT Map, we need one more piece of the puzzle and that is the touch time in each of the areas. As always, rough estimates are good enough–and in particular, if you remember from Chapter 1 that touch times typically account for a very small fraction of the total time, there is even more reason not to worry about very accurate data for these. There is one important rule to follow though.

**Calculate Touch Time Based on Making One End Item**

If you make parts in batches, it is important not to count the run time for the whole batch as touch time. You must count only the run time for the items needed to make one end product. Of course setup is needed even if you make one piece, so you can count this as part of the touch time.

There are two reasons for this rule. The first is related to the end goal in QRM. You want to be able to make customized orders in quantities of one to serve individual customer needs. Using one end product as a basis for calculating touch times helps to show how far removed you are from this goal. The second reason is that in most companies batch sizes are there for historical reasons or incorrect cost-based calculations, and you don't want to clutter your data with the traditional decisions that are in operation right now.

At MadTran, a few interviews along with some quick data gathering provide the following rough data for touch times related to the BadgerTran product:

- Customer Service spends about half an hour on each order. Since the department works 8 hours a day, this equates to 1/16 of a day of touch time. (While you can see this intuitively, in the Appendix I will explain in more detail how to properly convert from working time to calendar time.)
- In Planning, the job goes to three people, each of whom spends about 20 minutes on the job, or an hour total. Since this department also operates for 8 hours a day, this equates to 1/8 of a day.
- In Gear Manufacturing, the total of all setup times and run times for all operations is about 2 days. Note that each BadgerTran needs five gears so the run time is calculated for the five gears.
- In Housings Machining, the total of all setup times and run times for all operations is about 1 day. In this case the run times used are for machining one casting only.
- In Transmission Assembly, the total of all setup times and run times for all operations is about ½ of a day. Here too the run times are for one BadgerTran only.
- In Packing and Shipping, the total of all setup times and run times for all operations is about 4 hours or also ½ of a day. Again the run times are calculated based on packing and shipping one BadgerTran.

- Finally, for the current analysis we will not look into the details of the logistics and assume all 3 days are touch time for now.

With the touch time data in place, as well as the MCT values calculated earlier, I am now ready to show you what is probably the most valuable result of this exercise: the MCT Map for BadgerTran; see *Figure A.5*.

**Use an MCT Map to Present MCT Data to Management and Employees**

The MCT Map is a powerful way to present initial data to management and employees and get them to buy in to the need for QRM efforts. In looking at *Figure A.5*, several insights are readily apparent.

- It is clear that touch time ("gray space") is a very small proportion of the total MCT. Thus the cost-based focus of improving worker efficiencies is clearly not the solution, as discussed in detail in Chapter 1. The MCT Map makes a strong visual case for this and for the fact that a time-based approach is needed rather than a costbased one.

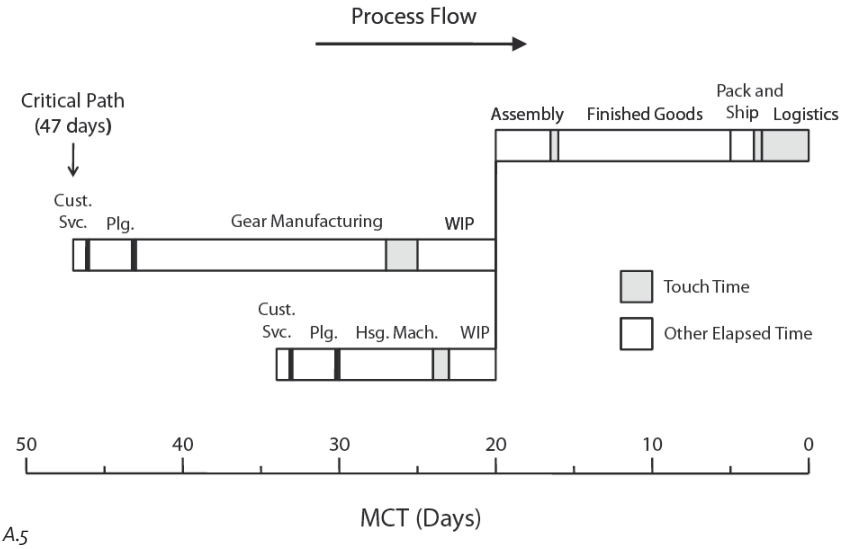


*Figure A.5*

*Initial MCT map for BadgerTran product.*

- Conversely, it is clear that the remaining elapsed time represents a significant opportunity. This "white space" is the result of many traditional policies as discussed in the first four chapters of this book. In those chapters I also gave you the QRM policies that need to take the place of the traditional ones in order to reduce this white space. The MCT Map helps to drive home this point.
- The map shows the multiple process paths that go into delivering the end product. In fact, the reason that time is plotted from right to left on the MCT Map is because this makes it easy to follow cumulative time on any of the paths. We choose to plot MCT Maps so that the process flows from left to right, since we are used to reading from left to right. If we now plot time from left to right also, then the map would

end at the MCT value (e.g., 47 days). Only the critical path would now start at 0; other paths would start at various other times. This would make it hard to see how long any other path is. Because of the way we plot time in an MCT Map, you can clearly see from the time axis how long each path is.

- The MCT Map clearly shows the critical path and you can see which products and operations are on this path.
- The fact that the MCT Map represents time proportionally allows you to see what the major contributors are to the total MCT value. For instance, in the BadgerTran MCT Map, you can immediately see that gear manufacturing represents the biggest opportunity for improvement, and after that the finished goods account for the next biggest contribution to MCT. The MCT Map thus points you toward potential QRM projects, as I discuss in the next paragraph.
- There is a Web-based tool that is publicly available that automates the drawing of MCT Maps and makes it easy to analyze many alternatives. See "For Further Reading" for more on this.

Returning to the MadTran situation, after the initial MCT Map highlights improvement opportunities, management may decide to initiate two QRM projects: one, to look at reducing MCT in the gear-manufacturing area, and the other, for the finished-goods area. For the first project, the Planning Team (as described in Chapter 5) might decide to drill down deeper into the gear-manufacturing area and derive a more detailed MCT Map for this area. For instance, this map could follow the path that gears take from operation to operation, and contain "white space" and "gray space" for each step of the gear manufacturing. Once again, such an exercise would highlight the biggest opportunities in this area. Following this exercise, the Planning Team could start investigating solutions such as QRM Cells, rethinking batch sizes, and others described in the main part of this book.

Similarly for the finished-goods area, management might take a more "global" view and ask the question: "Why do we make so much stuff ahead of time?" Another Planning Team could be formed to look into this, and it could explore alternatives such as: "How much would we need to reduce our manufacturing lead time in order to be able to make to order, instead of to stock?" and "Are we forecasting and making big batches because of our own sales policies and incentives?" and so on. Again, many of the QRM principles in this book could be brought to bear on this situation and alternative solutions could be sought out by applying those principles.

If you are familiar with Value Stream Mapping (VSM), I will compare that to MCT Mapping later in this Appendix. For now I'll just point out that an MCT Map is much simpler and visually depicts the flow of time proportionally, so it provides quick and relevant insights to motivate a QRM project and stimulate initial brainstorming for solutions. Although I have stated that MCT Maps are simple, as soon as I brought up the issue of multiple components and multiple paths, you might have wondered, "What if my end product includes hundreds of components; am I going to have to gather data and plot hundreds of paths to get the MCT value?" Again, there is an important commonsense rule to be used here.

**Don't Include Noncritical Items**

If you blindly include all components in your MCT calculation, you can get distracted from the main areas that need improvement. You should exclude all noncritical items from the analysis. Noncritical items are defined at the end of the next paragraph.

Of course the sheer volume of data gathering suggests that you shouldn't try to look at all components. But there is a more important, strategic reason for using this rule. Suppose a transmission assembly requires expensive housings that contribute one month to the MCT as well as some common washers that come from overseas and add four months to the MCT. If you include the washers in the MCT calculation, then the overall value will be determined by the washers and you will focus on those. If you reduced their lead time by a month, your MCT would also go down by a month and you would be happy–and yet you would not have done anything with the housings. The minor components diverted your attention from the real opportunity. But in a situation where it is less obvious, how do you determine whether to include or exclude a component? Clearly you need to have some commonsense rules about what to include in MCT. These rules do indeed exist and state that you should leave all noncritical items out of the MCT calculation. A noncritical item is defined as any item that satisfies all of the following criteria:

- It is of very low cost relative to the end item for which MCT is being calculated.
- It is in plentiful supply across the market or industry.
- Its design or specifications are unlikely to be changed in the near future, or it does not require new functional testing if these do change.

These criteria ensure that noncritical items can be stocked in plentiful numbers without adding much cost or risk to the business; this type of stock is acceptable in QRM. Examples of noncritical items are bolts, screws, washers, paints, and resins, but this also depends on your application–for example, in some cases a fastener such as a bolt may require functional testing if changed and so it would no longer be considered a noncritical item.

Since each industry and each manufacturing operation has its own special characteristics, a QRM Planning Team should also feel free to use additional commonsense arguments to decide if a component should be considered critical or noncritical.

## EXTENDING THE MCT ANALYSIS TO INCLUDE THE SUPPLY CHAIN

For the initial analysis we had decided to exclude the material supply, but now I will extend the MadTran example to include the supply chain. Once again, continuing with the idea of limiting the analysis at each step, let's say we've decided to analyze only the first level of the supply chain. For the components we've already analyzed, this first level means the supply of blanks for the gears and castings for the housings. Also, to keep the example simple we'll assume that the only additional purchased items to be included are shafts. These are already machined by the supplier and are used

directly in the final assembly of the BadgerTran. Let's say that all other components are deemed to be noncritical for this first-level analysis of the suppliers.

*Figure A.6* shows the process flow extended to include the supply of these three items. The first extension is an in-house operation. When Planning determines that more material is needed, this is communicated to Supply Management, which spends on average 4 days in reviewing the material status and getting orders issued to the suppliers. Next we have the contribution to MCT from each of the suppliers. Here you repeat the MCT analysis we did in the first example for MadTran, but now you are the customer, and you analyze the MCT at the supplier's operation in the same way. Also, following the preceding example, for now you don't include the supplier's raw-material supply in this calculation. Again, since you may not have very accurate information at this stage, rough estimates for the supplier's internal times are good enough. (As I explain in Chapter 4, suppliers typically don't see MCT as an invasive metric and are usually cooperative in sharing relevant data with you so that you can estimate their MCT.) Based on these estimates, you find that the delivery of blanks adds 10 days to the MCT, castings–which come from overseas–add 60 days, and shafts add 6 days. These values include all logistics times for the supply of these materials.

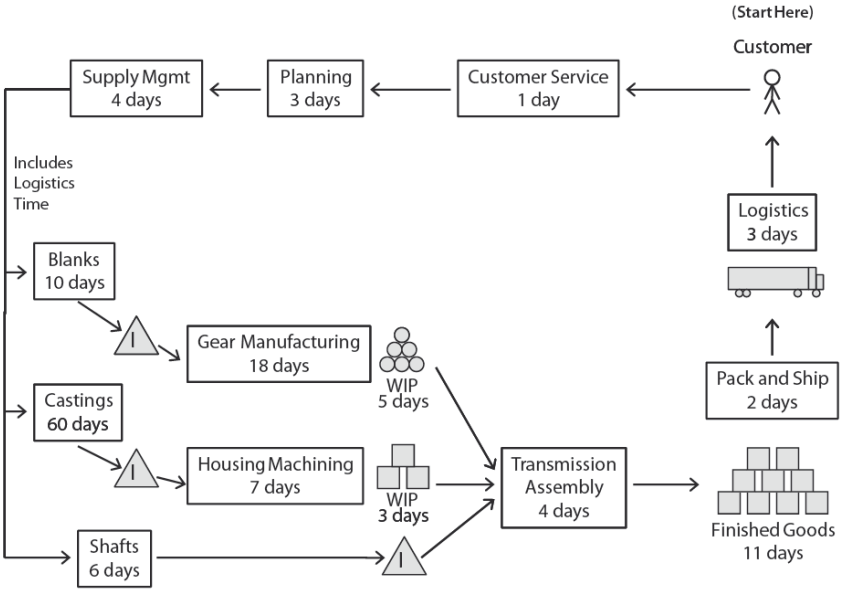


*Figure A.6*

*Process flow for BadgerTran with first-level suppliers included.*

**Remember the Raw-Material Inventory**

Earlier I had mentioned that you need to include time spent in all types of inventory including raw material, work-in-process (WIP), and finished goods. When we decided to leave out the material supply process, we had also ignored the raw-material inventory for the first analysis. Now that we are including the suppliers for some material, we also

have to include the time that material spends in MadTran's raw-material area.

In most companies, specific items of raw material don't retain their identity through a stocking point–in other words, typically when a batch of blanks arrives, this batch gets get added into the stock of the same types of blanks that are already there. Then, when some blanks are needed in production, the required number of pieces are picked from this stock. Thus there aren't individual orders or parts that you can follow through the raw-material stock, and in most cases your MRP system will not have times that you can use to calculate MCT. So how do you proceed? You might have guessed it–you can use Little's Law. Although the MRP system doesn't track times for individual pieces, it certainly tracks the inventory on hand, and we can use this data as follows.

Let's say that the past month is reasonably representative of MadTran's operation. From the MRP system we extract historical data for the rawmaterial inventory on each day of the month and calculate the average values for the three purchased items. These averages turn out to be: 800 blanks, 400 castings, and 180 shafts. Also, remember I told you that the company ships about 20 BadgerTrans per day and each transmission needs five gears (each gear needs 1 blank) and one housing (each needs 1 casting). Also, each transmission needs 3 shafts. For the application of Little's Law these numbers imply that the average Flow Rate of blanks is 100/day, of castings is 20/day, and of shafts is 60/day. Now let's apply the law to get the Flow Time of these three items through the raw-material inventory:

Time in inventory for blanks = 800 : 100 = 8 days

Time in inventory for castings = 400 : 20 = 20 days

Time in inventory for shafts = 180 : 60 = 3 days

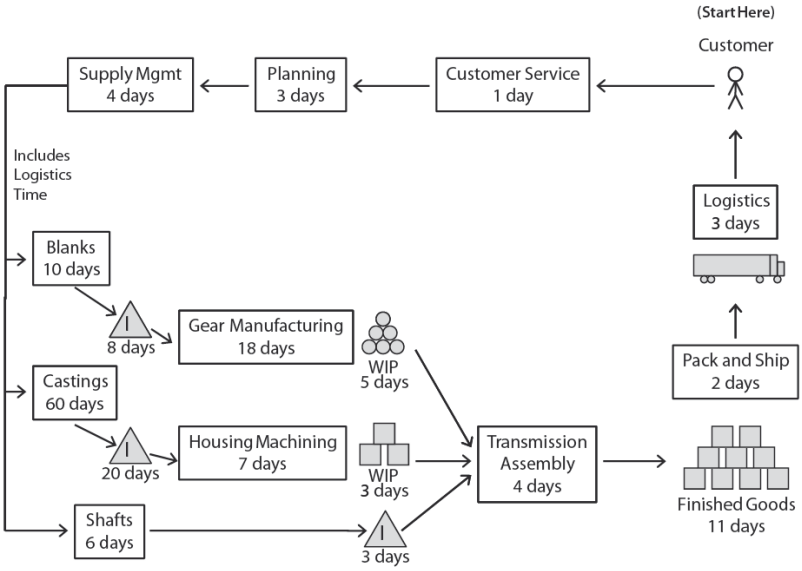


*Figure A.7*

*Process flow for BadgerTran including all times for first level of material supply.*

As an observation, the large number of days of castings inventory (relative to the other items) is a consequence of the long replenishment time from overseas and the fact that Planning wants to keep a greater safety stock for these items.
Let's put these numbers into the process flow and calculate MCT. *Figure A.7* shows the entire flow with the new numbers included. Now there are three paths around the diagram, so once again, let's find the longest path. I'll do the calculation for all three paths to illustrate the details, starting with the path involving gears. Beginning at the customer, the total time around *Figure A.7* is:

1 + 3 + 4 + 10 + 8 + 18 + 5 + 4 + 11 + 2 + 3 = 69 days (path with gears)

For the second path, the one with transmissions, the values are:

1 + 3 + 4 + 60 + 20 + 7 + 3 + 4 + 11 + 2 + 3 = 118 days (path with transmissions)

For the last path with the shafts the values are:

1 + 3 + 4 + 6 + 3 + 4 + 11 + 2 + 3 = 37 days (path with shafts)

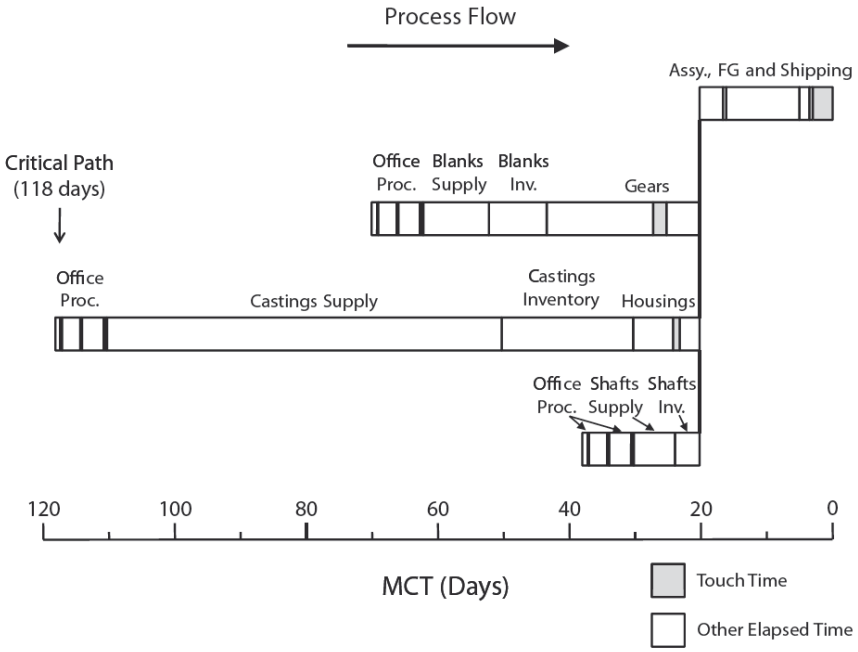


*Figure A.8*
*MCT map for BadgerTran including first level of material supply.*

Hence the MCT for MadTran (including the first level of suppliers) is the largest of these three values, or 118 days. As before, the best way to see all these values is to create an MCT Map, and this is shown in *Figure A.8*. Note that the critical path now involves

the housings. The MCT Map clearly shows the large contribution from the castings, and this will put a spotlight on the sourcing decision that is causing these very long replenishment times. It may well result in reexamination of this decision and application of some of the time-based supply management strategies described in Chapter 4.

**If Raw Material Is Used for Multiple Products, Use Little's Law and Remember the Subset Rule**

What if you have raw material such as sheet metal that is stocked for use in multiple products, but you want to calculate MCT for only one of those products because it is in the FTMS for a QRM project–in this case, how can you use Little's Law? The subset rule explained earlier turns out to be very powerful, as I will illustrate with another example.

Suppose you need to estimate the MCT for a particular product line, TransUW, which requires specialized gear blanks; let's call them SPL blanks. These SPL blanks are also used by several other product lines, and the raw-material inventory is shared by all these product lines. That might confuse you because now you want to find the Flow Time for blanks that go into only the one product line, but all the blanks are lumped together in inventory. So you don't really know how many of the blanks are for the TransUW product (in fact none of them are earmarked for any particular product) and you can't use Little's Law. This is where the fact that you can apply Little's Law to any subset of your business comes in handy. The key is to make sure that all definitions used are consistent for the subset. I will calculate the Flow Time through the blanks inventory by using other data that is known to us. We do know the total inventory of all SPL blanks since that is recorded in the MRP system. Let's say that over the past month this inventory has an average value of 140 blanks. Also, let's say that the usage of these blanks is only for production of gears and not for any other purpose, so that the Flow Rate through the SPL blanks inventory is directly tied to production. Now let's define our subset as "All gears that use SPL blanks" and calculate the average production rate for all these gears over a representative period. Production data (how much you made of each product) is a critical metric for manufacturing companies, so this is certainly known. Suppose the average production of all gears that use SPL blanks is 14/day. From the preceding statements this also equals the Flow Rate of SPL blanks through inventory. Now we can apply Little's Law to get:

$$\text{Time in inventory for SPL blanks} = 140 : 14 = 10 \text{ days}$$

At this point you might protest, "But this number is for all SPL blanks, not just the ones used in the TransUW." The key insight here is that it doesn't matter in which product a blank is used. Think of it this way: this is the average Flow Time for an SPL blank going through inventory. When an SPL blank is picked from inventory, on average this is the time it has spent there, so this is true whether the blank is used for the TransUW or any other product.

This is just one example of how to apply the subset rule. Here we looked at a larger subset to derive a value for a section of products. You can also do this in reverse. You can look at a whole area of your shop floor and then use values for only one product

line. For example, if an area processes many different products, but you are interested only in aluminum housings, then as long as you look at only the WIP of such housings in this area, and the production rate of these housings, then you can calculate the Flow Time for aluminum housings through the area, regardless of what other products or other WIP may be in the area. Finally, I return to the issue of converting from work time to calendar time and explain the method used in more detail.

**Convert All Times to Calendar Time Using Simple Rules**

Remember that MCT is measured in calendar time, for reasons explained in Chapter 1. This does require some analysis because your office staff might work 5 days a week for one shift, your factory might run 6 days a week with two shifts, and some areas of the factory like heat treat might even run 24 hours a day, 7 days a week. Transportation systems such as railroads or boats operate 24/7 as well. All this probably makes your head spin as you wonder how complicated it might be to convert everything to calendar time in a consistent way. Actually the conversion is not difficult as long as you follow some simple rules. First, I have explained in several places that the MCT value is meant to be reasonably representative and doesn't have to be exact. So the first rule for conversion is: "Use common sense to keep it simple, and don't sweat the details."

If your data is already in calendar time, then you don't need to do anything further. In the BadgerTran example, the total time through Gear Manufacturing was calculated from time stamps in the MRP system. These dates and times are already on a calendar basis, so subtracting the starting time stamp from the ending time stamp automatically gives you calendar days.

Combine these two rules with the fact that you are looking for an average and this makes things simpler. For example, if it usually takes 2 working days to respond to an order, then if that order is received on a Monday you will ship on Wednesday, for an MCT of 2 calendar days. But say you don't work on weekends and the order comes in on Friday, then you will ship on Tuesday for an MCT of 4 calendar days. So which is the right value, 2 days or 4 days? The answer is, if you work with averages computed from enough observations over time, it doesn't matter because it will all average out.

Suppose you don't have accurate data logged into the MRP system and you decide to estimate the Flow Time through Gear Manufacturing by adding together individual times at each operation (queue time, setup time, processing time, and so on as listed earlier). Now you have to be careful about converting to calendar days, but a few examples will show you how to do it. Let's assume all your operation times are in hours and one shift is 8 hours.

- A machining operation runs one shift, 5 days a week. This means that it operates for 40 hours in a week. A calendar week is 7 days. So the basic equivalence you need to use is that 40 hours of operation contributes 7 days to the MCT value, or each hour of operation equals 7/40 calendar days. Let's take an example. For the TransUW, at this operation the total of queue time, setup time, and processing time for a batch equals 12 hours. This works out to 12 x 7/40 calendar days, or 2.1 calendar days.
- You can use a similar approach for work centers with other schedules. From the

preceding example, you can see that the method to be used is simple and is as follows. As before, I'll assume we are using hours for our measurements at the operation level. Calculate how many hours a week the work center runs. Let's say this number is *H* hours. Now calculate the Flow Time through this operation using the data you have; this will be in hours. Multiply this value by (*7/H*) and you get the calendar days that you need for the MCT calculation.

- Now I'll go over a different situation, one that involves road transportation. Suppose you deliver orders to a particular customer using trucks. The shipping time quoted to you by the trucking company is 3 days and the trucks run every day except Sunday. We'll assume for this example that if a trucker is en route on a Sunday, he or she will stop wherever they are and take the day off, and then continue. Once again you have the situation that if you ship a job on Monday, it will take 3 calendar days to get to your customer, but if you ship on Friday, it will take 4 calendar days since the truck will not move on Sunday. So which number should you use? Recall once more that we don't need the answer for one order, but rather an answer that is an average over many orders. Hence, using similar logic as before, you can see that on average, 6 "trucking days" equal 7 calendar days. Thus one "trucking day" equals 7/6 calendar days. So the 3-day trucking time converts to 3 x 7/6 = 3.5 calendar days for the MCT calculation.

In applying Little's Law, be sure to think about the units of time that you are using. As long as you are consistent in the way you use the units, and are careful to think about how they relate to calendar days, you should not have a problem. Two examples help to bring out things to watch out for.

- You use the total weekly production to calculate the Flow Rate (pieces per week) used in applying Little's Law to some WIP. You apply the law and get the Flow Time through that WIP, which will be in weeks in order to be consistent. Now you multiply that by seven and you have calendar days. This seems straightforward, but the next example shows that there are pitfalls if you are not careful.
- Instead of the preceding, you calculate the daily production and use that for the Flow Rate in pieces per day. Since the unit is days, you know that you get your Flow Time in days, so you might just proceed with using this number. However, if you run your factory only 5 days a week, you are not done with the calculation! You need to multiply this Flow Time by 7/5 in order to get the right value for the MCT contribution. (If you don't see this intuitively, perhaps this will help. Say the Flow Rate is R pieces/day. Since you run 5 days a week, this equals *R x 5* pieces/week. Converting to calendar time with 7 days a week, your average Flow Rate is now *R* x 5 /7 pieces per calendar day. When you use Little's Law, you divide by the Flow Rate, so the 5/7 in the denominator is the same as a multiplier with the value 7/5.)

**For Customers Who Give You Rolling-Horizon Forecasts, Consider a Large Surge in the Forecast**

When a customer places an order for an engineered product, or for a product that you only make to order, it is clear when to start the MCT clock. But it is less clear what to

do in the situation where your customer requires regular deliveries and gives you a rolling-horizon forecast that is updated weekly or even daily. In this case the forecast may have been presented months in advance, and it is up to you to decide when to start building the product. So when does the MCT clock start ticking? For this case you have to consider the following hypothetical situation: If this customer changed its forecast and requested a big surge in delivery quantities, and in addition you did not have prebuilt items in stock to satisfy this surge, what are all the processes that would be needed and how long would it take to fulfill this order starting from the time the surge was communicated to you? This will assist you in deciding not only when to start the clock but also deciding what to include in the MCT calculation–such as planning, scheduling, supply management, and other processes in addition to all the usual manufacturing operations.

## MCT MAPPING IS SIMPLER THAN VALUE STREAM MAPPING AND PRESENTS TIME PROPORTIONALLY FOR GREATER VISUAL IMPACT

If you are familiar with Value Stream Mapping (VSM), a tool that is popular as part of the Lean Manufacturing tool kit, there are some synergies with MCT Mapping but also some important differences. VSM also visually depicts the entire process flow, but usually the maps contain a lot more detail than MCT Maps. Also, since time is indicated on the Value Stream Maps through numeric values and not proportional bars, it is difficult to immediately pick up where the major sources of time are, or to identify the relative contributions from different processes. In contrast, MCT Maps are simpler, represent time proportionally, show the various paths clearly, and visually highlight what the biggest contributors are to the overall timeline. Furthermore, with the complexity and number of entities shown on a Value Stream Map it is not entirely clear what the targets of improvement should be, while with the QRM mind-set and an MCT Map on hand the goal is identified with one single number–the MCT–and the goal is clear: reduce this number!

The two approaches are not contradictory–if you have already developed Value Stream Maps you can easily convert them to MCT Maps to help motivate the QRM thinking (see "For Further Reading"). If you have not used VSM, then you can just start with the MCT Mapping since it is simpler and easier to do and will be sufficient to drive your QRM project. This is particularly true when you use MCT Maps to illustrate the "Current State" of your operations, and then the "Future State" that is expected to result from the proposed QRM projects. I'll illustrate this with the BadgerTran example.

Let's return to the first MCT Map for BadgerTran where we are considering only in-house operations and not tackling any supply issues yet. Let's say that in order to reduce the MCT along the critical path, several QRM projects are proposed. These include a Q-ROC for the up-front office processes, a QRM Cell for certain gears including all the BadgerTran gears, and a rethinking of policies leading to the current high finished-goods inventory

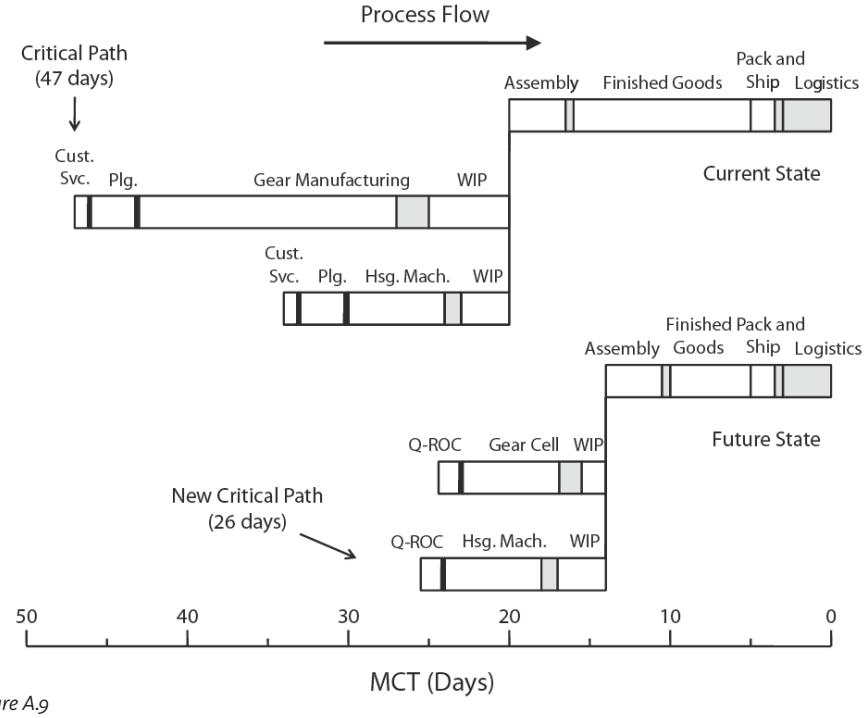


*Figure A.9*

*Current state and future state MCT maps for proposed set of QRM projects.*

for the BadgerTrans product. The impact of these projects on MCT is estimated. In addition to the direct reductions in these areas, it is also anticipated that with the quicker response through the Gear Cell, gears will be made closer to final assembly time; there will be less variability in the Flow Time as well as in the final assembly schedules, and so there will be much less Gear WIP. Finally, in addition to examining policies related to finished goods, with the shorter overall MCT the safety stock levels can be reduced as well. The impact of all these items is quantified and presented in a Future State MCT Map. *Figure A.9* shows both the Current State and Future State Maps together. You can see that this is a powerful way of demonstrating how the QRM projects will positively impact your operations. It also shows that after these projects are successfully completed, the new MCT will be 26 days, and also, the new critical path will involve the housings, so they should be the target of the next set of QRM projects.

## FOR FURTHER READING

The MCT metric was first published in an article by Paul Ericksen and myself in the context of supply chain management ("Managing the Extended Enterprise," by P. D. Ericksen and R. Suri, Purchasing Today, Vol. 12, No. 2, February 2001, pages 58–63). This article goes into detail about the drawbacks of traditional supply management metrics and why MCT is an important metric for supply management professionals to use.

The next article ("Filling the Gap: Rethinking Supply Management in the Age of Global Sourcing and Lean," by P. D. Ericksen, R. Suri, B. El-Jawhari, and A. J. Armstrong, APICS–The Performance Advantage, Vol. 15, No. 2, February 2005, pages 27–31) gives a managerial-level overview of both the need for shifting to time-based supply management as well as the importance of using MCT as the key metric in this effort. It is also more up-to-date and looks at these issues in the context of global supply chains and overseas sourcing.

The next reference ("Manufacturing Critical-path Time [MCT]: The Enterprisewide Metric to Support Order Fulfillment and Drive Continuous Improvement," by N. J. Stoflet and R. Suri, Technical Report, Center for Quick Response Manufacturing, University of Wisconsin–Madison, December 2007) is a technical report that focuses on MCT. It justifies the use of MCT as a robust, unifying, and enterprise-wide metric to be used to support order fulfillment and drive continuous-improvement projects. It also contains very detailed rules about calculating MCT in practice as well as for how to correctly convert existing Value Stream Maps to MCT Maps.

At www.qrmcenter.org, you'll find a tool that makes it easy to construct MCT Maps, to store them, and also to compare Current State and Future State Maps. This tool is available free of charge at the Web site of the Center for Quick Response Manufacturing.

If you don't have good data available for how long it takes jobs to go through office or shop floor areas, you should consider using a technique called tagging. Tagging involves attaching tracking documents to jobs. Used correctly, it can provide good data and insights, but there are several pitfalls that can make a tagging exercise a failure–and worse still, it could put off your employees making it harder for you to proceed with the QRM project. See pages 340–347 of Quick Response Manufacturing: A Companywide Approach to Reducing Lead Times, by R. Suri (Productivity Press, 1998) for several pointers to help you use tagging successfully, and also for ideas on how to analyze the tagging data. In addition to the authors mentioned above, Ananth Krishnamurthy, Mike Ketter and Sean Ketter contributed to development of the MCT metric and the examples in this Appendix (see the "Acknowledgments" section of the book).