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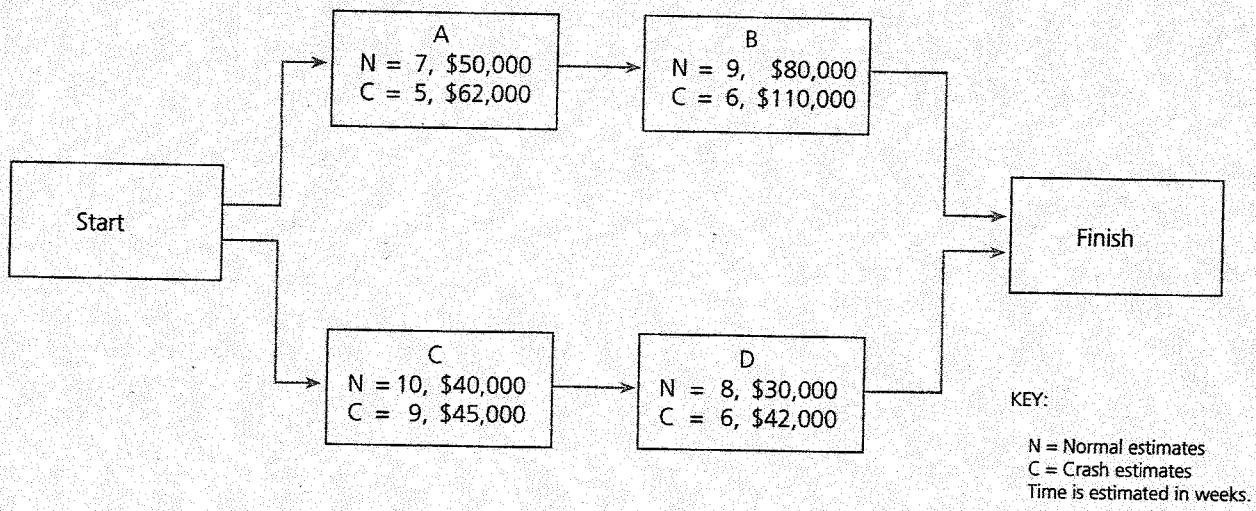
# APPENDIX 1 Time–Cost Trade-Off

The time–cost trade-off methodology is used to reduce the project duration incrementally with the smallest associated increase in incremental cost. It is based on the following assumptions:

1. Each activity has two pairs of duration and cost estimates: normal and crash. **Normal time** is the estimated length of time required to perform the activity under normal conditions, according to the plan. **Normal cost** is the estimated cost to complete the activity in the normal time. **Crash time** is the shortest estimated length of time in which the activity can be completed. **Crash cost** is the estimated cost to complete the activity in the crash time. In Figure 7.14, each of the four activities has a pair of normal

**FIGURE 7.14 Network with Normal and Crash Times and Their Costs**

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18. What are the normal and crash times and costs for activities B, C, and D in Figure 7.14?

| | *Normal Time* | *Normal Cost* | *Crash Time* | *Crash Cost* |
|---|---|---|---|---|
| *Activity B* | ___ | ___ | ___ | ___ |
| *Activity C* | ___ | ___ | ___ | ___ |
| *Activity D* | ___ | ___ | ___ | ___ |

time and cost estimates and a pair of crash time and cost estimates. The estimated normal time to perform activity A is seven weeks, and its estimated normal cost is $50,000. The crash time for this activity is five weeks, and the cost to complete the activity in this duration is $62,000.

2. An activity's duration can be incrementally accelerated from its normal time to its crash time by applying more resources—assigning more people, working overtime, using more equipment, and so on. Increased costs will be associated with expediting the activity.
3. An activity cannot be completed in less than its crash time, no matter how many additional resources are applied. For example, activity A cannot be completed in less than five weeks, no matter how many more resources are used or how much money is spent.
4. The resources necessary to reduce an activity's estimated duration from its normal time to its crash time will be available when needed.
5. Within the range between an activity's normal and crash points, the relationship between time and cost is linear. Each activity has its own *cost per time period* for accelerating the activity's duration from its normal time to its crash time. This acceleration cost per time period is calculated as follows:

$$\frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$$

**Reinforce Your Learning**

19. What are the cost-per-week rates to accelerate activities B, C, and D in Figure 7.14?

For example, in Figure 7.14, the cost per week to accelerate activity A from its normal time to its crash time is

$$\frac{\$62{,}000 - \$50{,}000}{7 \text{ weeks} - 5 \text{ weeks}} = \frac{\$12{,}000}{2 \text{ weeks}} = \$6{,}000 \text{ per week}$$

The network diagram in Figure 7.14 has 2 paths from start to finish: path A–B and path C–D. If we consider only the normal duration estimates, path A–B will take 16 weeks to complete, whereas path C–D will take 18 weeks to complete. Therefore, the earliest the project can be finished based on these time estimates is 18 weeks—the length of its critical path, made up of activities C and D. The

total project cost, based on the cost associated with performing each activity in its normal time, is

$$\$50{,}000 + \$80{,}000 + \$40{,}000 + \$30{,}000 = \$200{,}000$$

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20. If all the activities in Figure 7.14 were performed in their crash times, what would be the total project cost?

If all the activities were performed in their respective crash times, path A–B would take 11 weeks and path C–D would take 15 weeks. The earliest the project can be finished based on the crash time estimates is 15 weeks, which is 3 weeks earlier than if the activities were performed in their normal times.

It is usually not necessary or even constructive to crash all the activities. For example, in Figure 7.14, we want to crash only the appropriate activities by the amount necessary to accelerate project completion from 18 weeks to 15 weeks. Any additional crashing of activities will merely increase total project cost; it will not reduce the total project duration any further because that is determined by the length of the critical path. In other words, expediting activities not on the critical path will not reduce the project completion time but will increase total project cost.

*The objective of the time–cost trade-off method is to determine the shortest project completion time based on crashing those activities that result in the smallest increase in total project cost.* To accomplish this, it is necessary to shorten the total project duration, one time period at a time, crashing only those activities that are on the critical path(s) and have the lowest acceleration cost per time period. From Figure 7.14, we previously determined that, based on normal time and cost estimates, the earliest the project could be completed is 18 weeks (as determined by the critical path C–D), at a total project cost of $200,000. The cost per week of accelerating each of the activities is

| | |
|---|---|
| Activity A | $6,000 per week |
| Activity B | $10,000 per week |
| Activity C | $5,000 per week |
| Activity D | $6,000 per week |

To reduce the total project duration from 18 weeks to 17 weeks requires first identifying the critical path, which is C–D, and then determining which activity on the critical path can be accelerated at the lowest cost per week. Activity C costs $5,000 per week to accelerate, and activity D costs $6,000 per week to accelerate. Therefore, it is less expensive to expedite activity C. If activity C is crashed 1 week (from 10 weeks to 9 weeks), the total project duration is shortened from 18 weeks to 17 weeks, but the total project cost increases by $5,000 to $205,000.

To shorten the total project duration by one more time period, from 17 weeks to 16 weeks, we must again identify the critical path. The durations of the 2 paths are 16 weeks for A–B and 17 weeks for C–D. Therefore, the critical path is still C–D, and it must be reduced again. Looking at path C–D, we see that although activity C has a lower acceleration cost per week than activity D, we cannot accelerate activity C any further because we reached its crash time of 9 weeks when the project was reduced from 18 weeks to 17 weeks. Therefore, the only choice is to accelerate activity D by 1 week, from 8 weeks to 7 weeks. This reduces the duration of critical path C–D to 16 weeks, but the total project cost increases by $6,000 (the cost per week for accelerating activity D), from $205,000 to $211,000.

**TABLE 7.1 Time–Cost Trade-Off**

| PROJECT DURATION (WEEKS) | CRITICAL PATH(S) | TOTAL PROJECT COST |
|---|---|---|
| 18 | C–D | **$200,000** |
| 17 | C–D | $200,000 + $5,000 = **$205,000** |
| 16 | C–D | $205,000 + $6,000 = **$211,000** |
| 15 | C–D, A–B | $211,000 + $6,000 + $6,000 = **$223,000** |

Once again, let us reduce the project duration another week, from 16 weeks to 15 weeks. If we look at our 2 paths, we see that they are now of equal duration (16 weeks), so we now have 2 critical paths. To reduce the total project duration from 16 weeks to 15 weeks, it is necessary to accelerate each path by 1 week. In looking at path C–D, we see that the only activity with any remaining time to be crashed is activity D. It can be crashed 1 more week, from 7 weeks to 6 weeks, at an additional cost of $6,000. To accelerate path A–B by 1 week, we have a choice of crashing activity A or activity B. Activity A has a $6,000 cost per week to accelerate, compared with a $10,000 per week rate for activity B. Therefore, to reduce the total project duration from 16 weeks to 15 weeks, we need to crash activities D and A 1 week each. This increases the total project cost by $12,000 ($6,000 + $6,000), from $211,000 to $223,000.

Let us try again to shorten the total project duration by 1 week, from 15 weeks to 14 weeks. We again have 2 critical paths with the same duration, 15 weeks. Therefore, they must both be accelerated by 1 week. However, in looking at path C–D, we see that both activities are already at their crash time—9 weeks and 6 weeks, respectively—and therefore cannot be expedited any further. Accelerating path A–B would thus be of no value, because it would increase the total project cost but not reduce the total project duration. Our ability to reduce the total project duration is limited by the fact that path C–D cannot be reduced any further.

Table 7.1 displays the incremental acceleration in total project completion and the associated incremental increase in total project cost. It indicates that reducing the total project duration by 1 week would increase the total project cost by $5,000. To reduce it by 2 weeks would cost $11,000, and to reduce it by 3 weeks would cost $23,000.

If all 4 activities were crashed, the total cost of the project would be $259,000, but it would still not be completed any earlier than 15 weeks. Using the time–cost trade-off method, we were able to reduce the project duration from 18 weeks to 15 weeks at an additional cost of $23,000 by selectively crashing the critical activities with the lowest acceleration cost per time period. Crashing all the activities would have resulted in a waste of $36,000 because no reduction in total project duration beyond 15 weeks could be achieved.

## SUMMARY

The time–cost trade-off methodology is used to reduce the project duration incrementally with the smallest associated increase in incremental cost. It is based on the assumptions that each activity has a normal and a crash duration and a normal and a crash cost estimate, that an activity's duration can be incrementally accelerated by applying more resources, and that the relationship

between time and cost is linear. Normal time is the estimated length of time required to perform the activity under normal conditions; normal cost is the estimated cost to complete the activity in the normal time. Crash time is the shortest estimated length of time in which the activity can be completed; crash cost is the estimated cost to complete the activity in the crash time.

## QUESTIONS

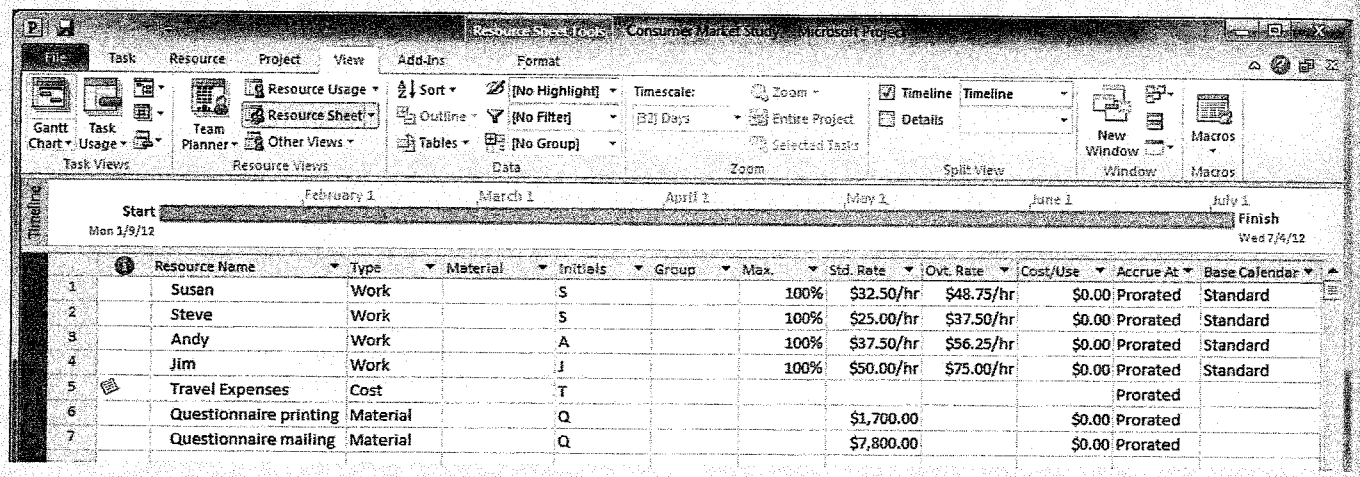
1. What is the time–cost trade-off methodology, and when is it used?
2. Why do you need both normal and crash times and costs for this procedure?
3. Assume that an activity has a normal time of 20 weeks, a normal cost of $72,000, a crash time of 16 weeks, and a crash cost of $100,000. By how many weeks, at most, can this activity's duration be reduced? What is the cost per week to accelerate this activity?
4. Why is it not appropriate to crash all of the activities in a project to achieve the shortest project schedule?

# APPENDIX 2 Microsoft Project

In this appendix, we will discuss how Microsoft Project can be used to support the techniques discussed in this chapter, based on the Consumer Market Study example. To retrieve your project information, on the File menu, click Open and locate the consumer market study file you saved in Chapter 6 when you set the baseline after resource leveling. We are now ready to enter costs for resources, produce cost reports, and examine cash flow and earned value.

Microsoft Project calculates the costs of the project by using rates for work, material, and cost resources that are entered on the Resource Sheet or on the Resources Tab in the Task Information window after double-clicking on the task name. Recall that to access the Resource Sheet, click on Resource Sheet in the Resource Views group on the View ribbon. The rates for work resources and for material resources are recorded on the Resource Sheet by entering in the standard rate in the Std. Rate column for each resource and overtime rates, if they apply. The rate for work resources is cost per hour. The rate for material resources is cost per use. Figure 7A.1 shows the standard and overtime rates on

**FIGURE 7A.1 Resource Sheet with Work and Material Rates**



| | Resource Name | Type | Material | Initials | Group | Max. | Std. Rate | Ovt. Rate | Cost/Use | Accrue At | Base Calendar |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Susan | Work | | S | | 100% | $32.50/hr | $48.75/hr | $0.00 | Prorated | Standard |
| 2 | Steve | Work | | S | | 100% | $25.00/hr | $37.50/hr | $0.00 | Prorated | Standard |
| 3 | Andy | Work | | A | | 100% | $37.50/hr | $56.25/hr | $0.00 | Prorated | Standard |
| 4 | Jim | Work | | J | | 100% | $50.00/hr | $75.00/hr | $0.00 | Prorated | Standard |
| 5 | Travel Expenses | Cost | | T | | | | | | Prorated | |
| 6 | Questionnaire printing | Material | | Q | | | $1,700.00 | | $0.00 | Prorated | |
| 7 | Questionnaire mailing | Material | | Q | | | $7,800.00 | | $0.00 | Prorated | |