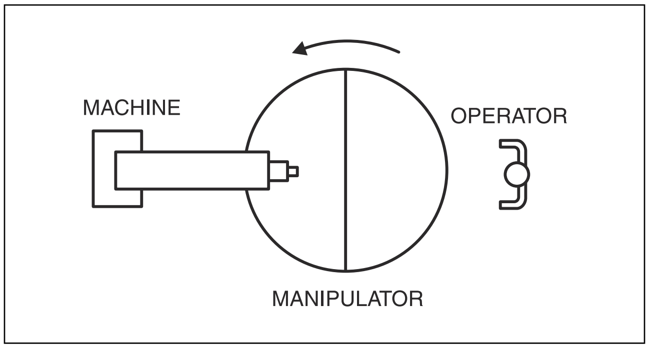


Figure 12.7—Simultaneous Welding Center with Single Operator, Single Machine

Simultaneous Welding Centers

Presented below are examples for the single operator, single machine and multiple operator, multiple machine simultaneous welding centers. In these examples, *CT* denotes cycle time, and *PC* denotes production quantity per cycle.

Single Operator, Single Machine System. Figure 12.7 depicts a typical simultaneous welding center in which a single operator and a single machine work at the same time. In this case, the loading and unloading activities may not take as long as the welding activity or they may take longer. Whichever activity is completed first must wait until the other activity has been completed.

In the operator-machine chart, shown in Figure 12.8, the time delay after completing both welding and unloading and loading before starting another cycle is referred to as the *manipulation time*. This is the time required for the circular manipulator to rotate the part for 180° (in this example). The cycle time is the time required for the operators, welding machines, workpiece manipulators, positioners, and fixtures to complete their corresponding tasks.

In the example, the simultaneous welding center with one operator and one machine produces one weldment per cycle. However, the welding center could produce multiple weldments per cycle with one operator and one welding machine. For instance, an operator could load two workpieces, after which the manipulator rotates 180°. While loading occurs, a single welding machine could move from the first workpiece to the second and weld the two workpieces.

In this case, the welding center is completing one weldment per cycle. The cycle time is calculated as follows:

$$CT = \text{Max}\,(L,\ W) + M \tag{12.7}$$

where

CT = Cycle time, seconds (s);
L = Average unloading and loading time, s; and
W = Average welding time, s; and
M = Manipulation time, s.

Multiple Operator, Multiple Machine System. Figure 12.9 depicts a typical simultaneous welding center comprised of two-machine system in which two operators and the two machines work at the same time. In this case, the workpiece may flow from one machine to another.

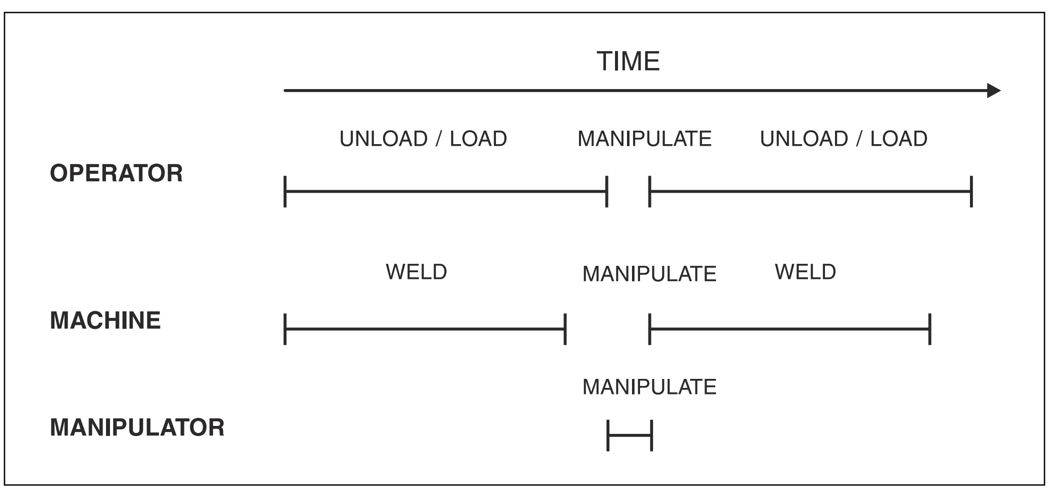


Figure 12.8 Operator-Machine Chart for a Single-Machine and Single-Operator Center

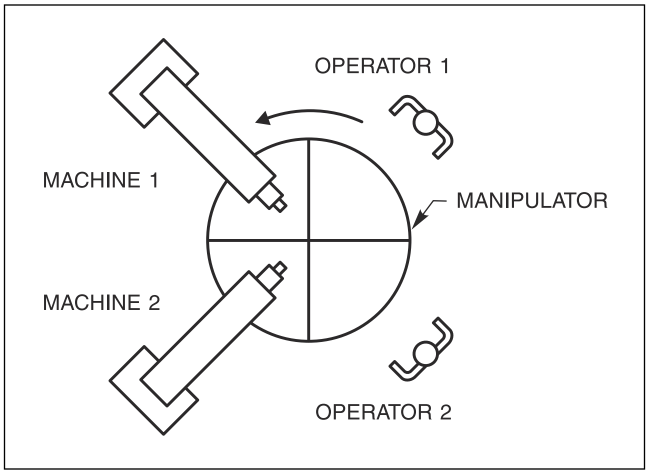


Figure 12.9—Simultaneous Welding Center with Multiple Operators and Multiple Machines

The following variables are used here to calculate cycle time for the two-operator, two-machine machine system:

L_1 = Average unloading and loading time for Operator 1, s;
L_2 = Average unloading and loading time for Operator 2, s;
W_1 = Average welding time for Machine 1; s and
W_2 = Average welding time for Machine 2, s.

The output of a center with multiple operators and multiple machines can further be divided into the following two subclasses, depending on workpiece flow: (1) workpieces flowing from machine to machine and (2) individual parts workpieces welded on a single machine. The primary difference between these two subclasses is the number of weldments produced per cycle.

In the case of workpiece flow from machine to machine, two operators and two machines work at the same time. Operator 1 mostly loads, and Operator 2 unloads the workpieces. The workpiece flows from one machine to another to complete the welding operation. In this example, the manipulator rotates 90° each cycle. Depending on the type and complexity of the product, the manipulator can rotate at any angle. This particular center produces one weldment per cycle.

The following equation is used to estimate cycle time for the multiple operator, multiple machine system in which the workpieces flow from machine to machine:

$$CT = \text{Max}\,(L_1,\ L_2,\ W_1,\ W_2) + M \tag{12.8}$$

where

CT = Cycle time, s;
L_1 = Average unloading and loading time for Operator 1, s;
L_2 = Average unloading and loading time for Operator 2, s;
W_1 = Average welding time for Machine 1, s;
W_2 = Average welding time for Machine 2, s; and
M = Average manipulation time, s.

In the subclass in which individual workpieces are welded on a single machine, two operators and two machines work at the same time. The workpieces do not flow from machine to machine but are welded individually on each of the machines. The manipulator rotates 180° for each cycle. Operators 1 and 2 load and unload the workpieces while the two machines weld individually. This welding center produces two weldments per cycle.

The cycle time for the multiple operator, multiple machine system in which the workpieces are welded individually on each of the machines can be estimated with the following equation:

$$CT = \text{Max}\,(L_1,\ L_2,\ W_1,\ W_2) + M \tag{12.9}$$

where

CT = Cycle time, s;
L_1 = Average loading and unloading time for Operator 1, s;
L_2 = Average loading and unloading time for Operator 2, s;
W_1 = Average welding time for Machine 1, s;
W_2 = Average welding time for Machine 2, s; and
M = Average manipulation time, s.

It should be noted that the cycle time estimates for these two subclasses are identical even though the number of weldments produced per cycle varies.

General Formulas for Simultaneous Welding Centers

Simplified equations that are used to estimate cycle time for a simultaneous weld manufacturing center comprised of two or more operators or welding machines are presented below. These expressions are not affected by the number of weldments produced per cycle.

Single Operator, Multiple Machine System. The following equation is used to estimate cycle time is for a simultaneous welding center with a single operator tending multiple welding machines:

$$CT = \text{Max}\left(L,\ W_1,\ W_2, \ldots\ W_m\right) + M \quad (12.10)$$

where

CT = Cycle time, s;
L = Average loading and unloading time, s;
W_1 = Average welding time for Machine 1, s;
W_2 = Average welding time for Machine 2, s;
W_m = Average welding time for welding machine m, s;
m = Total number of welding machines; and
M = Average manipulation time, s.

Multiple Operator, Single Machine System. The following equation is utilized to estimate cycle time for a welding center with multiple operators tending a single welding machine:

$$CT = \text{Max}\left(L_1,\ L_2, \ldots\ L_n, W\right) + M \quad (12.11)$$

where

CT = Cycle time, s;
L_1 = Average loading and unloading time for Operator 1, s;
L_2 = Average loading and unloading time for Operator 2, s;
L_n = Average loading and unloading time for operator n, s;
n = Total number of operators;
W = Average welding time for the welding machine, s; and
M = Average manipulation time, s.

Multiple Operator, Multiple Machine System. The following expression is used to estimate the cycle time for a welding center in which multiple operators tend multiple machines:

$$CT = \text{Max}\ (L_1,\ L_2, \ldots\ L_n,\ W_1,\ W_2, \ldots\ W_m\ ) + M \quad (12.12)$$

where

CT = Cycle time, s;
L_1 = Average loading and unloading time for Operator 1, s;
L_2 = Average loading and unloading time for Operator 2, s;
L_n = Average loading and unloading time for operator n, s;
n = Total number of operators;
W_1 = Average welding time for Machine 1, s;
W_2 = Average welding time for Machine 2, s;
W_m = Average welding time for welding machine m, s;
m = Total number of welding machines; and
M = Average manipulation time, s.

A weld manufacturing center with three operators and four welding machines illustrates the application of Equation (12.12). Two operators place workpieces in two fixtures to load two machines, and the other operator unloads the weldments. While loading and unloading occur, the four welding machines complete all welds on the two workpieces that were loaded on the previous cycle. Thus, this welding center produces two weldments per cycle.

Consider the case in which the following times (in seconds) were expended by each of the following:

L_1 = Average loading and unloading time for Operator 1 = 20 s;
L_2 = Average loading and unloading time for Operator 2 = 20 s;
L_3 = Average loading and unloading time for Operator 3 = 25 s;
W_1 = Average welding time for Machine 1 = 27 s;
W_2 = Average welding time for Machine 2 = 27 s;
W_3 = Average welding time for Machine 3 = 31 s;
W_4 = Average welding time for Machine 4, = 31 s; and
M = Average manipulation time = 2 s.

The application of Equation (12.12) for this case results in the following:

$$CT = \text{Max}\ 20,(20,\ 25,\ 27,\ 27,\ 31,\ 31) + 2$$
$$= 33 \text{ seconds} \quad (12.13)$$

where CT denotes cycle time in seconds. Thus, Equation (12.12) provides an estimated cycle time of 33 seconds, and two weldments are fabricated per cycle.

A tandem or serial welding machine center with ten machines provides another example of the application of this method. One operator (e.g., Operator 1) loads a workpiece on each cycle. The workpiece travels down the tandem line on successive cycles, and ten welding machines complete all welds over a time period consisting of ten cycles. After ten cycles of welding, an operator (e.g., Operator 2) unloads the workpiece. The following times are assumed for this case:

Average loading and unloading time for Operator 1 (L_1), s = 40;
Average loading and unloading time for Operator 2 (L_2), s = 18;
Average welding time for Machine 1 (W_1), s = 28;
Average welding time for Machine 2 (W_2), s = 29;
Average welding time for Machine 3 (W_3), s = 7;

Average welding time for Machine 4 (W_4), s = 6;
Average welding time for Machine 5 (W_5), s = 25;
Average welding time for Machine 6 (W_6), s = 20;
Average welding time for Machine 7 (W_7), s = 21;
Average welding time for Machine 8 (W_8), s = 19;
Average welding time for Machine 9 (W_9), s = 12;
Average welding time for Machine 10 (W_{10}), s = 15; and
Average manipulation time (M), s = 3.

Thus, the cycle time for this weld manufacturing system can be estimated as follows:

$$CT = \text{Max } 40(18, 28, 29, 7, 6, 25, 20, 21, 19, 12, 15) + 3 = 43 \text{ seconds}$$

$$PC = 1 \tag{12.14}$$

where

CT = Cycle time, s; and
PC = Production quantity per cycle.

Sequential Welding Centers

In a sequential welding center, either operator or the machine, but not both, are at work at any point of time during the cycle. For example, the operator would load or unload a workpiece or several workpieces on a manipulator while the welding machine is idle.

Figure 12.10 depicts a typical sequential welding center with a fixed welding manipulator (positioner) and two operators for loading or unloading the parts. After loading or unloading, the welding machine welds all workpieces in sequence until all required welding has been completed. Figure 12.11 presents the accompanying operator-machine chart for this sequence.

The cycle time for a sequential welding center with a fixed manipulator, one welding machine and two operators producing four weldments per cycle can be calculated using the following equation:

$$CT = \text{Max } (L_1, L_2) + W + 2M \tag{12.15}$$

where

L_1 = Average loading and unloading time for Operator 1, s;
L_2 = Average loading and unloading time for Operator 2, s;
W = Average welding time for the welding machine, s; and
M = Manipulation time, s.

The total manipulation time is $2M$ in this example since one manipulation occurs after unloading or loading and another occurs after welding. The Operator Chart in Figure 12.10 illustrates a welding center with a fixed manipulator. If the manipulator does not move the workpieces but only holds them, the manipulation time, M, is zero.

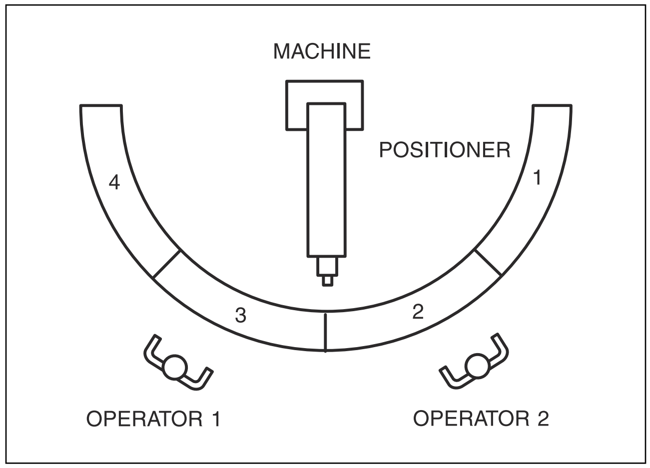


Figure 12.10—A Typical Sequential Welding Center with a Fixed Manipulator (Positioner) and Two Operators

General Formulas for Sequential Welding Centers

The general formulas for sequential welding centers are used to estimate the cycle time for all possible combinations of welding machines and operators. Following are equations that can be used to determine cycle time for sequential operations in various welding centers. The number of weldments produced in a cycle does not affect the calculation of the cycle time.

Single Operator, Single-Machine System. The following expression is used to calculate single-operator, single-machine cycle time for sequential operations.

$$CT = L + W + 2M \tag{12.16}$$

where

CT = Cycle time, s:
L = Average loading and unloading time, s;
W = Average welding time for the welding machine, s; and
M = Manipulation time, s.

Single-Operator, Multiple-Machine System. The following expression is used to calculate the cycle time

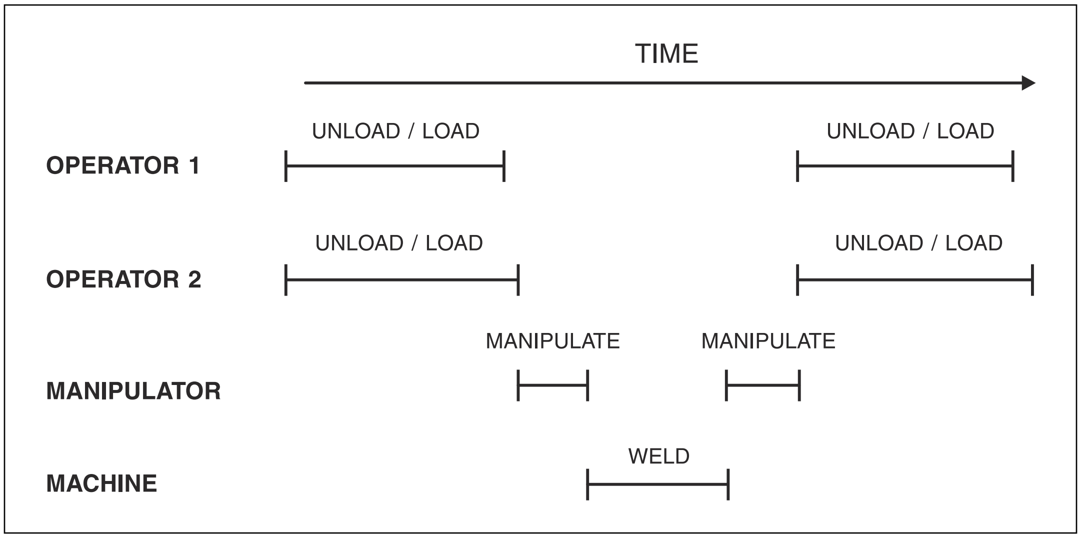


Figure 12.11—Operator-Machine Chart for a Sequential Welding Center with a Fixed Welding Manipulator and Two Operators

for a single-operator, multiple-machine welding center performing sequential operations:

$$CT = L + \text{Max}\,(W_1, W_2, \ldots W_m) + 2M \qquad (12.17)$$

where

CT = Cycle time, s;
L = Average loading and unloading time, s;
W_1 = Average welding time for Machine 1, s;
W_2 = Average welding time for Machine 2, s;
M = Total number of welding machines;
W_m = Average welding time for welding machine m, s;
m = Total number of welding machines; and
M = Average manipulation time, s.

Multiple-Operator, Single-Machine System. The following expression is used to calculate cycle time for a multiple-operator, single-machine welding center performing sequential operations:

$$CT = W + \text{Max}\,(L_1, L_2, \ldots L_n) + 2M \qquad (12.18)$$

where

CT = Cycle time, s;
L_1 = Average loading and unloading time for Operator 1, s;
L_2 = Average loading and unloading time for Operator 2, s;
L_n = Average loading and unloading time for operator n, s;
n = Total number of operators;
W = Average welding time for the welding machine, s; and
M = Manipulation time, s.

Multiple Operator, Multiple Machine System. The following expression is used to calculate cycle time for a multiple-operator, multiple-machine welding center performing sequential operations:

$$CT = \text{Max}\left(L_1,\ L_2, \ldots L_n\right) + \text{Max}\left(W_1,\ W_2, \ldots W_m\right) + 2M \qquad (12.19)$$

where

CT = Cycle time, s;
L_1 = Average loading and unloading time for Operator 1, s;
L_2 = Average loading and unloading time for Operator 2, s;
L_n = Average loading and unloading time for operator n, s;
n = Total number of operators;
W_1 = Welding time for Machine 1, s;
W_2 = Welding time for Machine 2, s;
W_m = Welding time for welding machine m, s;
m = Total number of welding machines; and
M = Average manipulation time, s.

To illustrate the application of Equation 12.19, consider a three-machine welding center in which one operator (e.g., Operator 1) loads and another (e.g., Operator 2) unloads one workpiece per cycle. Once loaded, the workpiece travels to the three welding machines, where all welds are completed in three successive cycles. The three welding machines all work simultaneously, but loading and unloading cannot occur during the welding portion of the cycle. Thus the three welding machines complete all welding on the cycle after the workpiece is loaded. The times for this example are listed below:

L_1 = Loading and unloading for Operator 1 = 18 s;
L_2 = Loading and unloading for Operator 2, = 8 s;
W_1 = Average welding time for Machine 1 = 19 s;
W_2 = Average welding time for Machine 2 = 16 s;
W_3 = Average welding time for Machine 3 = 14 s; and
M = Average manipulation time, s = 3.

Thus, the estimated cycle time can be calculated as follows:

$$CT = \text{Max}(18,\ 8) + \text{Max}(19,\ 16,\ 14) + 2 \times 3 = 43 \text{ seconds} \quad (12.20)$$

where CT denotes cycle time in seconds.

Multiple Welding Centers

Multiple welding centers can be a combination of both simultaneous welding and sequential welding centers. One operator may handle more than one welding center. Workpieces flow between welding centers, and handling may be either manual or mechanized. This category can be divided into two subcategories, depending on whether each center has its own operator or whether a single operator tends multiple welding centers.

Multiple-Operator, Multiple-Welding Center System. In the case of multiple-operator, multiple-machine welding centers, each operator is assumed to work at an individual welding center. Since workpieces flow from one welding center to another, the system is a serial or tandem production line of weld centers, as illustrated in Figure 12.12. Workpiece flow between weld centers may be accomplished manually or by mechanization. It is also assumed that the capacity of the material handling system is greater than that of the welding centers. Thus, the material handling time can be ignored in calculating the cycle time for the system; the slowest welding center dictates the system capacity and cycle time.

The cycle time for a center with multiple operators with multiple welding centers can be calculated as follows:

$$CT = \text{Max}(CT_1,\ CT_2, \ldots CT_k) \quad (12.21)$$

where

CT = Cycle time, s;
CT_1 = Cycle time for Center 1, s;
CT_2 = Cycle time for Center 2, s;
CT_k = Cycle time for welding center k, s; and
k = Total number of welding centers.

The above equation assumes that each welding center produces the same number of weldments during a given cycle. The welding centers can be either simultaneous or sequential; in either case, the cycle times can be computed with the appropriate equation.

Single-Operator, Multiple-Welding-Center System. The general equation for the case of a single-operator, multiple-welding-center system involves the identification of the largest weld center with a single operator and the weld center cycle times. Figure 12.13

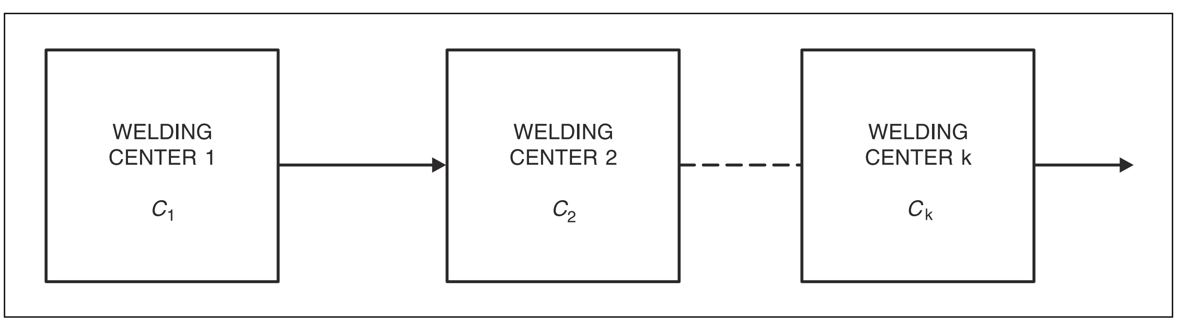


Figure 12.12—Multiple Operators with Multiple Centers

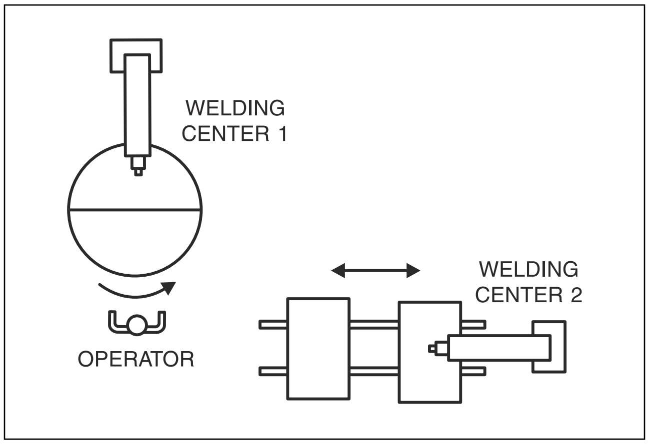


Figure 12.13—Single Operator, Two Welding Centers

illustrates a typical two-welding-center system incorporating one simultaneous welding center, Center 1, and one sequential welding center, Center 2. Workpieces flow from Center 1 to Center 2, as illustrated in Figure 12.13, although the direction of flow does not affect the calculation of the estimated cycle time.

The notations defined in Equation (12.21) are used to analyze this system, where CT_1 represents the cycle time for Center 1. The values of CT_1 and CT_2 are calculated, assuming the operator can allocate all of his or her time to each center. In this case, CT_1 is determined using the Equation (12.7) for a single simultaneous center, while CT_2 is determined from Equation (12.16) for a sequential center.

Also, it is assumed that O_1 denotes the total operator time consumed loading and unloading for Center 1, and O_2 is the total operator time consumed loading and unloading for Center 2. The term O_1 is the value of L in Equation (12.7), whereas O_2 is the value of L in Equation (12.16).

To identify the time constraints, all the activities performed in a welding center must be coordinated to avoid waiting time between activities, which would constitute a time constraint. The operator-machine chart presented in Figure 12.14 depicts a case in which the operator becomes the cycle time constraint. That is, $O_1 + O_2 > CT_1$ and $O_1 + O_2 > CT_2$. In this case, the single operator requires more time than the cycle time required for a system with two operators. It should be noted that the cycle time is $O_1 + O_2$.

In the following example, the operator-machine chart presented in Figure 12.15 depicts the case in which Weld Center 1 is the cycle-time constraint, that is, $CT_1 > O_1 + O_2$ and $CT_1 > CT_2$, where CT_1 represents the cycle time in seconds; O_1 represents the total operator time consumed at Center 1 in seconds; O_2 represents the total operator time consumed at Center 2 in seconds, and CT_2 represents the cycle time for Welding Center 2 in seconds. In this case, if O_1 is greater than CT_1 and O_2, the time consumed by Operator 2 in seconds, the operator would be the cycle-time constraint.

The operator-machine chart presented in Figure 12.16 depicts the case in which Welding Center 2 is the

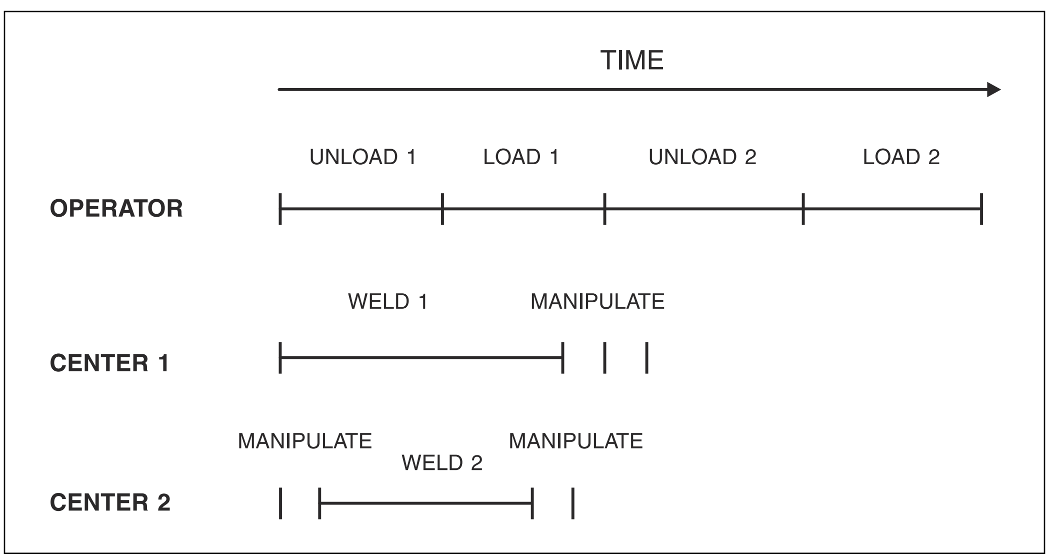


Figure 12.14—Operator-Machine Chart Indicating the Operator as the Time Constraint

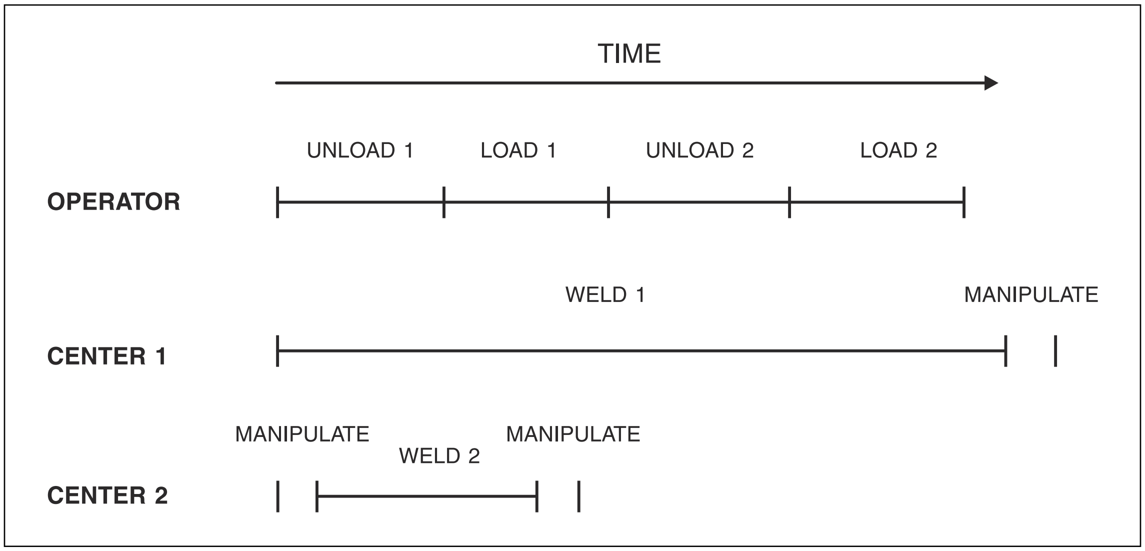


Figure 12.15—Operator-Machine Chart Indicating Welding Center 1 as the Cycle-Time Constraint

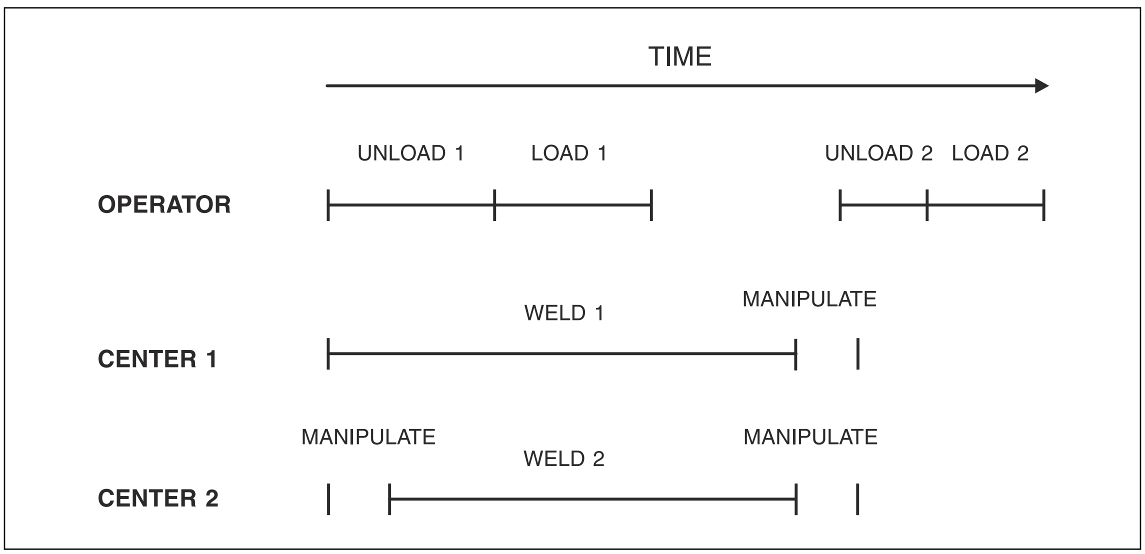


Figure 12.16—Operator-Machine Chart Indicating Welding Center 2 as the Cycle-Time Constraint

cycle time constraint, that is, $CT_2 > O_1 + O_2$ and $C_1 < C_2$, where CT_2 represented the cycle time of Machine 2 in seconds; O_1 represents the total operator time consumed at Center 1 in seconds; and O_2 represents the total operator time consumed at Center 2 in seconds.

The following equation is employed to estimate the cycle time for a weld manufacturing center consisting of one operator and two welding centers:

$$CT = \text{Max}\,(O_1 + O_2,\ CT_1,\ CT_2) \tag{12.22}$$

where

CT = Cycle time, s;
O_1 = Total operator time consumed at Center 1, s;
O_2 = Total operator time consumed at Center 2, s;
CT_1 = Cycle time for Center 1; and
CT_2 = Cycle time for Center 2.

In general, for one operator tending k welding centers, the cycle time is the maximum of the total operator time compared to the individual center cycle times, assuming a dedicated operator. This expression is written as follows:

$$CT = \text{Max}\,(O_1 + O_2 + \ldots + O_k,\ CT_1,\ CT_2, \ldots,\ CT_k) \quad (12.23)$$

where

CT = Cycle time, s;
O_1 = Total operator time at Center 1, s;
O_2 = Total operator time at Center 2, s;
O_k = Total operator time at welding center k, s;
k = Total number of welding centers
CT_1 = Cycle time for Center 1, s;
CT_2 = Cycle time for Center 2, s; and
CT_k = Cycle time for welding center k, s.

ECONOMICS OF RESISTANCE SPOT WELDING

Many of the principles of cost estimating presented in previous sections for other welding processes hold true for resistance spot welding. Although some repetition is inevitable, this section specifically addresses calculating costs for resistance spot welding.

The five main factors involved in the manufacturing cost of a weldment using resistance spot welding machines are the following:

1. Set-up or line changeover costs,
2. Direct labor cost,
3. Direct material cost,
4. Cost of small tools and fixtures, and
5. Overhead or indirect costs.

COST MODEL

The costs of consumables such as electrodes are important considerations; however, the viewpoint assumed in this model is that these costs are included in overhead costs when estimating the total cost to produce a weldment. Methods for estimating the costs of consumables appear in a subsection below.

Overhead and indirect costs represent a major portion of weldment costs, and the method for allocating indirect costs affects price competitiveness and resource management decisions. Many companies assign unique overhead rates to various cost centers. For example, welding operations may have a different overhead rate than forming or stamping operations. This cost model assumes that the overhead rate for welding operations is the same for each welding machine or welding work center.

The cost model used in this section to estimate manufacturing costs exclusive of general and administrative expenses is as follows:[6]

$$TMC = \frac{SETC}{LOT} + \frac{CT}{PC \times 3600}\left[NO\left(L + LOVH\right) + \left(NWC \times WCOVH\right)\right] + DMC + ST \quad (12.24)$$

where

TMC = Total manufacturing costs of a weldment, $;
$SETC$ = Total set-up or changeover costs, including overhead, $;
LOT = Lot size or mean number of weldments produced per setup;
CT = Cycle time or mean time between production of weldments, s;
PC = Production quantities per cycle;
NO = Total number of operators;
L = Labor rate per person per hour, $;
$LOVH$ = Labor overhead rate per hour, $;
NWC = Total number of welding work centers;
$WOCVH$ = Welding work center overhead rate per work center per hour, $;
DMC = Direct material cost per weldment, $; and
ST = Cost of small tools and fixtures per weldment, $.

The cost model stated in Equation (12.24) utilizes a method for allocating overhead that is compatible with the accounting methods for many companies to illustrate the computation of a cost estimate. Two overhead rates are defined—one for labor ($LOVH$) and one for work centers ($WCOVH$). A company that only uses one of these rates can assign a value of zero to the other.

To determine overhead rates, all indirect or fixed costs in a time period such as a year are assigned to one of two cost pools, i.e., a labor pool and a work center pool. Each pool has its own cost driver—direct labor hours for the direct labor pool and assignable work center hours for the work center pool. Work center hours are assignable when the work center is scheduled

6. Munusamy, A., G. Clark, and T. Miller, 1996, *Resistance Spot Welding Cost Model,* Working Paper, Columbus, Ohio: The Ohio State University, Department of Industrial, Welding, and Systems Engineering.

to produce a particular weldment. To calculate the overhead rates, the total costs in each pool are divided by the total of the pool's cost driver for the past year.

The use of only one overhead rate can significantly affect the cost estimate. For example, a manufacturer uses one overhead rate, *LOVH*, for direct labor hours. Two weldments, A and B, are produced in the welding manufacturing center. Three operators produce A, and one operator tends the welding work center producing B. Assuming that the cycle times (*CT*) and total production quantities per cycle (*PC*) are the same for Weldments A and B, Weldment A bears three times the indirect cost as compared to B because B requires three operators.

In another example, Weldments C and D are produced by spot welding work centers. In this case, only the work center overhead rate, *WCOVH*, is used. One operator tends the work center producing C, and another operator tends two work centers, producing D. If the cycle times and the production quantities produced per cycle are the same, Weldment D has twice the overhead cost of weldment C because D requires two work centers.

Estimating Spot Welding Machine Cycle Time

Several different cycle times are important when calculating spot welding product costs. They are defined as follows:

Spot welding system cycle time (*CT* in the above model)—Time interval between the production of one or more weldments by the spot welding system. Some spot welding systems produce two or more weldments in a given cycle (*PC* 2);

Welding center cycle time—Time interval between the production of one or more weldments by a welding center. If the spot welding system has a single machine, the spot welding system's cycle time and the welding center's cycle times are identical;

Welding machine cycle time—Time required by a single welding machine to complete all spot welds assigned to that welding machine. This time includes the welding times and the times required to move welding heads or electrodes to their proper positions;

Machine cycle time—Time interval between the production of a set of spot welds by a welding machine. A welding machine may perform multiple machine cycles during its welding machine cycle. This occurs when a welding machine produces a group of spot welds and then proceeds to the production of another group; and

Spot weld cycle time—Time required to produce a group of spot welds once the welding machine has moved the electrodes to their proper positions. The spot weld cycle time includes the time to apply contact pressure, perform the welds, and apply heat treatment.

Each cycle time defined above has an associated cycle that consists of the activities performed during the cycle time. For example, a spot weld cycle consists of the activities accomplished during the spot cycle time. These are presented in Table 12.21.

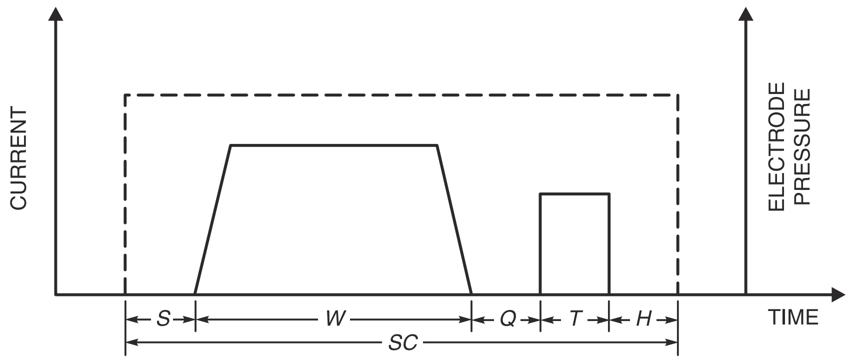
Total cycle time is important to the process of determining the costs of labor, equipment, energy, and consumables. Figure 12.17 depicts a typical resistance spot weld cycle showing squeeze time, weld time, quench time, temper time, hold time, and spot cycle time.

The spot welding cycle time is also important in determining the overall welding machine cycle time and air consumption costs. It may also affect coolant consumption costs. The weld and temper times are important in calculating energy costs.

A machine cycle includes a spot weld cycle *(WMC)*. However, it should be noted that a welding machine

Table 12.21
Symbols and Definitions for a Typical Spot Weld Cycle

Symbol	Operation	Definition
S	Squeeze time	The time for the electrodes to close and develop contact pressure on the workpiece.
W	Weld time	The total time current flows in order to form the weld nugget and accomplish joining. This time interval includes preheat and postheat times.
Q	Quench time	Cooling time in the interval between weld and tempering times.
T	Temper time	Time to heat treat after cooling.
H	Hold time	Time after tempering when the electrodes continue to maintain contact pressure.
SC	Spot weld cycle time	Total time the electrodes contact the workpiece.



Key:
= Current
= Electrode pressure
S = Squeeze time, s
W = Weld time, s
Q = Quench time, s
T = Temperature, s
H = Hold time, s
SC = Spot cycle time, s

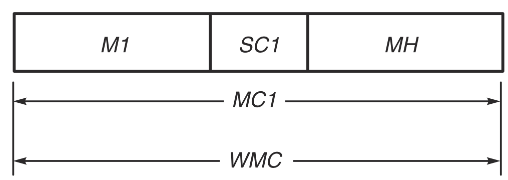
Figure 12.17—Typical Resistance Spot Welding Cycle

that has only a single machine cycle is not limited to one weld. It produces all the spot welds assigned to it in a single spot weld cycle *(SC1)*. Some resistance welding machines produce welds in two spot cycles. They move the electrodes to perform the first spot weld cycle *(SC1)* and then move the electrodes to produce the second spot weld cycle *(SC2)*.

Figure 12.18 depicts the activities for a welding machine with a single machine cycle showing. Figure 12.19 illustrates the activities performed with a welding machine that has two machine cycles.

The activity representation depicted in Figures 12.18 and 12.19 permits considerable flexibility with respect to the number of welding heads used by a welding machine. In Figure 12.19, the welding machine might use the same welding head to accomplish the two spot weld cycles, but the model can also represent multiple heads on a particular spot weld cycle as well as a particular spot weld cycle with its own unique set of heads. The only requirement is that a given spot weld cycle conform to the activity times shown in Figure 12.18.

When the welding machine uses the same welding head or heads to accomplish *SC1* and *SC2*, then *M2* represents the time to move those heads from the *SC1* position to the *SC2* position. When the welding machine uses different heads, *M2* represents the movement of heads involved in *SC1* back to a home position and the movement of heads for *SC2* to its position.



Key:
M1 = Movement of electrodes from home position to the position required for the first weld cycle
SC1 = First spot weld cycle
MH = Movement of electrodes back to home position from the last spot weld cycle position
MC1 = First machine cycle
WMC = Spot weld cycle

Figure 12.18—Spot Welding Machine Activities During a Single Machine Cycle

Resistance Welding Machine Consumable Costs

The cost models for each of the consumable costs for a resistance welding machine are represented in the equations below and include the following factors:

1. Replacement of electrodes,