

*ARMY RESEARCH LABORATORY*



**Cost and Time Model of a Simulated Painting Facility  
for Tactical Vehicles**

**by James A. Kidd, Jr. and Sandra K. Young**

**ARL-TR-4193**

**August 2007**

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# **Army Research Laboratory**

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**Weapons and Materials Research Directorate, ARL**

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## 1. Introduction

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Simulation is a mathematical description of a system that is based on actual data or reasonable assumptions about the components of the process. The purpose of simulation is to obtain insight into the performance characteristics of the entire system by mathematically imitating the relevant elements of that system. A simulation model is an abstract conceptualization of reality; it does not necessarily need to visually resemble the system that is being represented. The ideal model of a system contains the minimal number of elements and details that is necessary to project or analyze the relevant aspects of the system. Unnecessary details can cause a model to be excessively burdensome and obfuscate the salient elements that must be evaluated. The problem to be solved should be defined clearly, simply, and as quantitatively as is possible with the available information.

Cost and process modeling of manufacturing systems can provide valuable information to system designers prior to actual plant construction. It can also evaluate an existing system and demonstrate the cost of each segment of a process. This information can include guidance regarding optimal end-to-end layout of a production facility, as well as how cost for materials, labor, and energy effects the total cost of production. Various tradeoffs, such as the cost for materials, disposal, labor rate, overhead rate, and energy, can be assessed relevant to their influence on the time required for and the economics of performing each task within the overall process. Because of numerous possible variables, such as inconsistencies in equipment, personnel, and environmental affects, cost and process modeling is not a tool that can prognosticate exact results for any given system.

This report uses external surface area approximations that were calculated from actual measurements, estimates for some cost inputs, and assumed values for input data that were not known. Although grit blasting is often used for large items, in this simulation it is assumed that solvent is used to remove old paint. Also, to include an energy utilization component for the model, a curing oven is used for this simulated facility. The purpose of this report is to mathematically demonstrate an architectural structure that can be adapted to other U.S. Department of Defense materiel and their respective processes. This model represents a simulated painting facility for refurbishing the high-mobility multipurpose wheeled vehicle (HMMWV) and the Stryker combat vehicle; it demonstrates a quantitative approach for evaluating several parameters.

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## 2. Experimental Data and Assumptions

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Generally, experimental data is obtained from the customer and requires a significant amount of detailed information. The type of detail is process dependent. In this example case, surface areas were estimated because exact data was unavailable. The following particular assumptions were made in order to have enough data to construct the cost model:

- The HMMWV has  $\sim 350 \text{ ft}^2$  of external surface area to be painted; the Stryker has an estimated  $700 \text{ ft}^2$  of external surface area to be painted.
- Assume that operator cost = \$25/hr with a 70% overhead rate. An actual overhead rate can vary and is typically different from one production facility to another.
- Assume that while the facility is operating, HMMWVs enter the facility at an average rate of one HMMWV/3 hr and Strykers enter the facility at an average rate of one Stryker/5 hr.
- While the facility is operating, assume that there is a continuous flow of vehicles through the stations. One vehicle at a time is processed by the operator(s) at each station, but all stations operate simultaneously after the facility reaches steady-state conditions.
- Assume that the cumulative driving time between processing stations, excluding time for returning rejected vehicles to station 1, averages 20 min for each vehicle; assume that 15 min are typically required to return rejected vehicles to station 1.
- Consider as part of the overhead expense the cost of fuel for moving the vehicles. The flow of vehicles through the facility is depicted in figure 1.

The tactical-vehicle painting facility presented in figure 1 is comprised of the following processing stations:

- Process 1: removing old paint  
Solvent cost: \$25/gal  
Solvent requirement: 1 gal/300  $\text{ft}^2$   
Time required for one operator: 10 sq  $\text{ft}^2$ /3 min  
Two operators
- Process 1a: disposing of used solvent and removed paint  
Assume that the waste stream is comprised of used solvent + removed paint. Assume that all of the used solvent is collected, that the waste stream volume =  $1.02 (V_{\text{solvent}})$ , and that the disposal cost = \$2/gal.

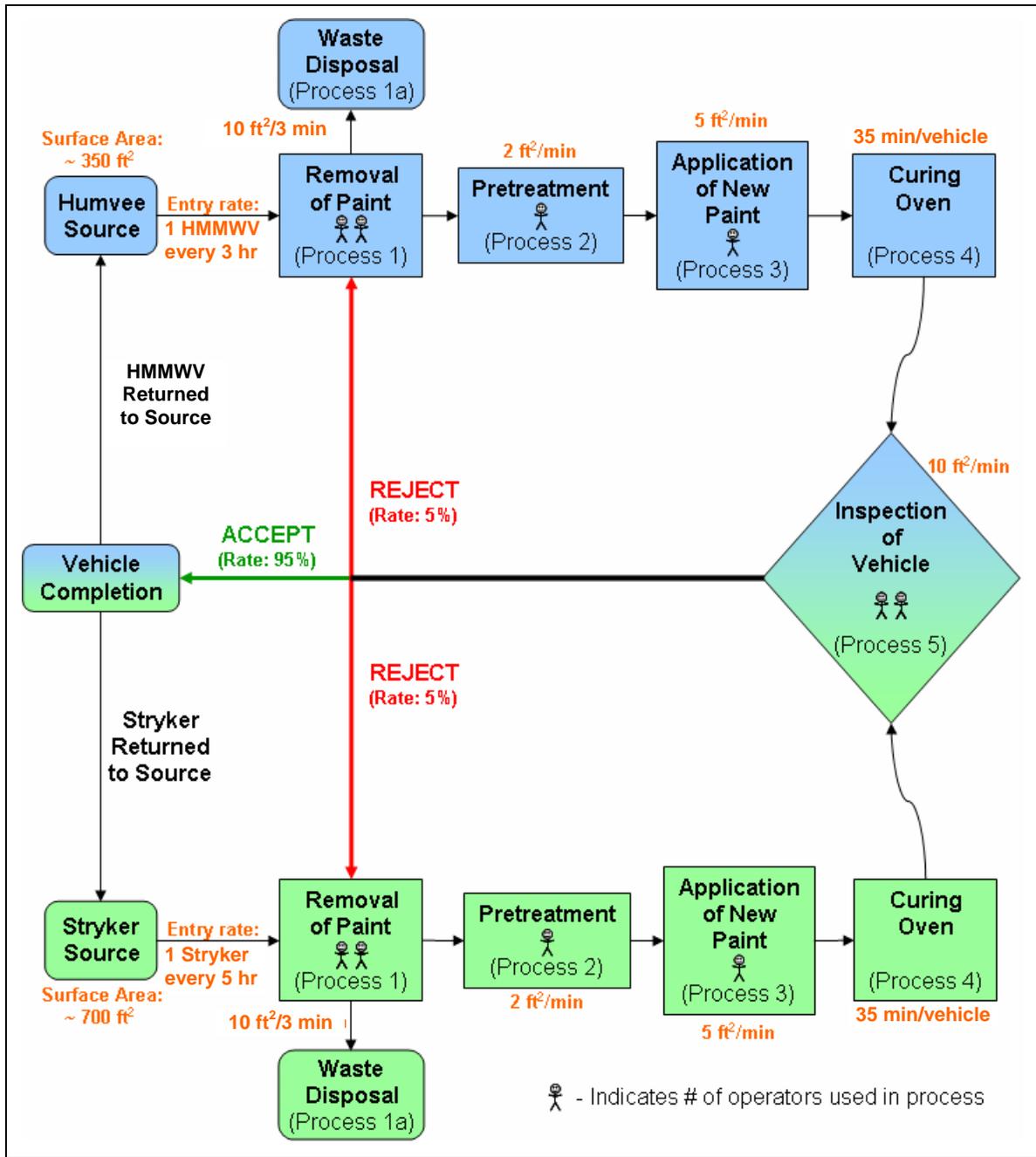


Figure 1. Cost and time model of a simulated painting facility for tactical vehicles.

- Process 2: pretreatment, primer application  
 Primer cost: \$30/gal  
 Primer requirement: 1 gal/250 ft<sup>2</sup>  
 Time required: 10 ft<sup>2</sup>/operator/5 min  
 One operator
- Process 3: new paint application  
 Paint cost: \$50/gal  
 Paint requirement: 1 gal/275 ft<sup>2\*</sup>  
 Time required: 10 ft<sup>2</sup>/2 min  
 One operator
- Process 4: oven, curing paint at elevated temperature  
 Time required: 35 min/vehicle  
 Energy required: 200 kW at \$0.40/kW hr
- Process 5: inspecting finished vehicle  
 Assume that each operator can inspect 10 ft<sup>2</sup>/min  
 Two operators  
 Accepted vehicles = 95%  
 Vehicles rejected and returned to process 1 = 5%

Because this report illustrates an example of a cost-process model, some of the equations and calculations used in this report are simplified. For example, although the model utilizes several different types of operators, all of the employees are paid at the same hourly rate. The report shows representative data that can be generated and the effect of several variables on the overall process. A report for a cost-process model using a software package (such as Arena<sup>†</sup>) would typically provide tabulated data and not show all of the derivations and calculations explained in this report.

### 3. Evaluation Requirements

Estimate values for the following 22 parameters:

1. Thickness of applied topcoat, disregarding waste and volatiles
2. Processing time, HMMWV

\*2006 National Painting Cost Estimator.

†Arena is a trademark of Rockwell Automation.

Costs:

3. Materials
4. Energy
5. Combined materials and energy
6. Labor
7. Labor including overhead
8. Total, HMMWV without overhead
9. Total, HMMWV with overhead
10. Processing time, Stryker

Cost for:

11. Materials
12. Energy
13. Combined materials and energy
14. Labor
15. Labor including overhead
16. Total, Stryker without overhead
17. Total, Stryker with overhead
18. Facility operating cost/hr without overhead
19. Facility operating cost/hr with 70% overhead

Percent increase in cost with 70% overhead for:

20. HMMWV
21. Stryker
22. Facility operating cost/hr

The solutions given in section 4 of this report are referenced (with the parameter number) back to one of the corresponding problem statements just listed.

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## 4. Calculations

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A summary of the results from most of the calculations can be found in section 5 of this report. As indicated earlier, a software-based cost-process model normally would not produce a report that includes the mathematical derivations required to generate each result.

### 4.1 Coating Thickness

Calculate the thickness (in mil) of a coating when 1 gal of paint covers 275 ft<sup>2</sup>. Assume that zero paint is wasted in the application process and that volatiles are negligible.

$$\frac{7.4805 \text{ gal}}{\text{ft}^3} = 1 \Rightarrow \frac{0.1337 \text{ ft}^3}{\text{gal}} = 1. \quad (1)$$

$$V = At, \quad (2)$$

where V => volume, A => area, and t => thickness.

$$t = \frac{V}{A} = \frac{0.1337 \text{ ft}^3}{275.0 \text{ ft}^2} = 0.0004862 \text{ ft}. \quad (3)$$

$$t = 0.0004862 \text{ ft} \left( \frac{12 \text{ in}}{\text{ft}} \right) \left( \frac{1000 \text{ mil}}{\text{in}} \right) = 5.8344 \text{ mil}. \quad (4)$$

(Equation 4 corresponds with parameter 1.)

Because of application losses and volatiles lost during drying, a measured dry film thickness will be less than this calculated value.

### 4.2 HMMWV Processing

#### 4.2.1 Processing Time

Determine the time required for processing one HMMWV, including the time elapsed between processing stations. The following variable equation is used for calculating the processing time:

$$T_p = S \left( \frac{t_r}{\beta_r} + \frac{t_p}{\beta_p} + \frac{t_a}{\beta_a} + \frac{t_i}{\beta_i} \right) + t_c + t_t. \quad (5)$$

The variables for equation 5 are explained in table 1.

Table 1. Definition of variables for processing-time equation.

Variable	Definition	Units
$T_p$	$\frac{\text{Processing Time}}{\text{Vehicle}}$	$\frac{\text{hr, min}}{\text{Vehicle}}$
$S$	$\frac{\text{Surface area}}{\text{Vehicle}}$	$\frac{\text{ft}^2}{\text{Vehicle}}$
$t_r$	$\frac{\text{time for paint removal}}{\text{Surface area cleaned by one operator}}$	$\frac{\text{min}}{\text{ft}^2 \text{ operator}}$
$\beta_r$	Number of employees at removal station	Operator
$t_p$	$\frac{\text{time for pretreatment}}{\text{Surface area treated by one operator}}$	$\frac{\text{min}}{\text{ft}^2 \text{ operator}}$
$\beta_p$	Number of employees at pretreatment station	Operator
$t_a$	$\frac{\text{time for application of paint}}{\text{Surface area painted by one operator}}$	$\frac{\text{min}}{\text{ft}^2 \text{ operator}}$
$\beta_a$	Number of employees at application station	Operator
$t_i$	$\frac{\text{time for inspection}}{\text{Surface area inspected by one operator}}$	$\frac{\text{min}}{\text{ft}^2 \text{ operator}}$
$\beta_i$	Number of employees at inspection station	Operator
$t_c$	$\frac{\text{curing time}}{\text{Vehicle}}$	$\frac{\text{min}}{\text{Vehicle}}$
$t_t$	$\frac{\text{travel time}}{\text{Vehicle}}$	$\frac{\text{min}}{\text{Vehicle}}$

Parts of this equation are required before labor cost can be subsequently calculated in equations 17, 20, 42, and 45.

$$\text{Time} = \frac{350 \text{ ft}^2}{\text{HMMWV}} \left[ \frac{\text{Removal, 2 operators}}{\frac{3 \text{ min}}{10 \text{ ft}^2 \text{ operator}} \cdot \frac{2 \text{ operators}}{2 \text{ operators}}} + \frac{\text{Pretreatment}}{\frac{5 \text{ min}}{10 \text{ ft}^2 \text{ operator}} \cdot \frac{1 \text{ operator}}{1 \text{ operator}}} + \frac{\text{Application}}{\frac{2 \text{ min}}{10 \text{ ft}^2 \text{ operator}} \cdot \frac{1 \text{ operator}}{1 \text{ operator}}} + \frac{\text{Inspection, 2 operators}}{\frac{\text{min}}{10 \text{ ft}^2 \text{ operator}} \cdot \frac{2 \text{ operator}}{2 \text{ operator}}} \right] + \frac{\text{Oven}}{\frac{35 \text{ min}}{\text{HMMWV}}} + \frac{\text{Transit time between operating stations}}{\frac{20 \text{ min}}{\text{HMMWV}}} \quad (6)$$

$$\text{Time} = \frac{350 \text{ ft}^2}{\text{HMMWV}} \left[ \frac{0.15 \text{ min}}{\text{ft}^2} + \frac{0.5 \text{ min}}{\text{ft}^2} + \frac{0.2 \text{ min}}{\text{ft}^2} + \frac{0.05 \text{ min}}{\text{ft}^2} \right] + \frac{55 \text{ min}}{\text{HMMWV}} \quad (7)$$

$$\text{Time} = \frac{350 \text{ ft}^2}{\text{HMMWV}} \left[ \frac{0.9 \text{ min}}{\text{ft}^2} \right] + \frac{55 \text{ min}}{\text{HMMWV}} \quad (8)$$

$$\text{Time} = (315 + 55) \frac{\text{min}}{\text{HMMWV}} = \frac{370 \text{ min}}{\text{HMMWV}}. \quad (9)$$

$$\text{Time} = \frac{370 \text{ min}}{\text{HMMWV}} \left( \frac{\text{hr}}{60 \text{ min}} \right) = 6.17 \frac{\text{hr}}{\text{HMMWV}}. \quad (10)$$

(Equation 10 corresponds with parameter 2.)

#### 4.2.2 Materials and Energy Cost

Determine the materials and energy cost (without operator expense and without cost for reprocessing rejected vehicles) for an HMMWV.

The following is the variable equation used for calculating the materials and energy cost:

$$C = S \left[ R_s C_s + (1 + \Delta V)(R_s)(C_w) + R_{pr} C_{pr} + R_p C_p \right] + \frac{t_c (P_c)(E_c)(CF)}{\text{vehicle}}. \quad (11)$$

The variables for equation 11 are explained in table 2.

Table 2. Definition of variables for materials and energy equation.

Variable	Definition	Units
C	$\frac{\text{Cost}}{\text{Vehicle}}$	$\frac{\$}{\text{Vehicle}}$
S	$\frac{\text{Surface area}}{\text{Vehicle}}$	$\frac{\text{ft}^2}{\text{Vehicle}}$
R <sub>s</sub>	$\frac{\text{Solvent Required}}{\text{Surface area}}$	$\frac{\text{gal}}{\text{ft}^2}$
C <sub>s</sub>	$\frac{\text{Cost of Solvent}}{\text{Volume}}$	$\frac{\$}{\text{gal}}$
ΔV	Coefficient of Volumetric increase in waste stream from removed paint	Dimensionless
C <sub>v</sub>	$\frac{\text{Cost for disposal of waste stream}}{\text{Volume}}$	$\frac{\$}{\text{gal}}$
R <sub>pr</sub>	$\frac{\text{Primer Required}}{\text{Surface area}}$	$\frac{\text{gal}}{\text{ft}^2}$
C <sub>pr</sub>	$\frac{\text{Cost of Primer}}{\text{Volume}}$	$\frac{\$}{\text{gal}}$
R <sub>p</sub>	$\frac{\text{Paint Required}}{\text{Surface area}}$	$\frac{\text{gal}}{\text{ft}^2}$
C <sub>p</sub>	$\frac{\text{Cost of Paint}}{\text{volume}}$	$\frac{\$}{\text{gal}}$
t <sub>c</sub>	Time for Curing	min
P <sub>c</sub>	Power for Curing oven	kW
E <sub>c</sub>	$\frac{\text{Cost}}{\text{Energy}}$	$\frac{\$}{\text{kWh}}$
CF	Conversion Factor	$\frac{\text{hr}}{\text{min}}$

$$\text{Cost} = \frac{350 \text{ ft}^2}{\text{HMMWV}} \left[ \begin{array}{l} \text{Removal} \qquad \qquad \qquad \text{Waste stream} \qquad \qquad \qquad \text{Pretreatment} \\ \left( \frac{\text{gal}}{300 \text{ ft}^2} \right) \left( \frac{\$25}{\text{gal}} \right) + (1.02) \left( \frac{\text{gal}}{300 \text{ ft}^2} \right) \left( \frac{\$2}{\text{gal}} \right) + \left( \frac{\text{gal}}{250 \text{ ft}^2} \right) \left( \frac{\$30}{\text{gal}} \right) \\ \text{Application} \\ + \left( \frac{\text{gal}}{275 \text{ ft}^2} \right) \left( \frac{\$50}{\text{gal}} \right) \\ \text{Energy} \\ + \frac{35 \text{ min} (200 \text{ kW}) \left( \frac{\$0.40}{\text{kW hr}} \right) \left( \frac{\text{hr}}{60 \text{ min}} \right)}{\text{HMMWV}} \end{array} \right] \quad (12)$$

$$\text{Cost} = \frac{350 \text{ ft}^2}{\text{HMMWV}} \left[ \frac{\$0.0833}{\text{ft}^2} + \frac{\$0.0068}{\text{ft}^2} + \frac{\$0.12}{\text{ft}^2} + \frac{\$0.1818}{\text{ft}^2} \right] + \frac{\$46.67}{\text{HMMWV}} \quad (13)$$

$$\text{Cost} = \frac{350 \text{ ft}^2}{\text{HMMWV}} \left[ \frac{\$0.3919}{\text{ft}^2} \right] + \frac{\$46.67}{\text{HMMWV}} \quad (14)$$

$$\text{Cost} = \frac{\$}{\text{HMMWV}} (137.17 + 46.67) \quad (15)$$

$$\text{Cost} = \frac{\$183.84}{\text{HMMWV}} \quad (16)$$

(In equation 15, 137.17 corresponds with parameter 3 and 46.67 corresponds with parameter 4. Equation 16 corresponds with parameter 5.)

#### 4.2.3 Cost for Labor Without Overhead

Assume that all of the processing stations, except the curing oven, require operator interaction.

The following is the total time with two operators (2 op), with values for removal and inspection from equation 7:

$$\text{Time}_{2 \text{ op}} = 350 \text{ ft}^2 \left( \frac{\text{Removal}}{\text{ft}^2} \left( \frac{0.15 \text{ min}}{\text{ft}^2} \right) + \frac{\text{Inspection}}{\text{ft}^2} \left( \frac{0.05 \text{ min}}{\text{ft}^2} \right) \right) \quad (17)$$

$$\text{Time}_{2 \text{ op}} = 350 \text{ ft}^2 \left( \frac{0.2 \text{ min}}{\text{ft}^2} \right) \quad (18)$$

$$\text{Time}_{2 \text{ op}} = 70 \text{ min} \left( \frac{\text{hr}}{60 \text{ min}} \right) = 1.167 \text{ hr} \quad (19)$$

The following is the time with one operator (1 op), with values for pretreatment, application, and driving from equations 6 and 7:

$$\text{Time}_{1\text{ op}} = 350 \text{ ft}^2 \left( \overset{\text{Pretreatment}}{\frac{0.5 \text{ min}}{\text{ft}^2}} + \overset{\text{Application}}{\frac{0.2 \text{ min}}{\text{ft}^2}} \right) + \overset{\text{Driving between stations}}{20 \text{ min}} . \quad (20)$$

$$\text{Time}_{1\text{ op}} = 350 \text{ ft}^2 \left( \frac{0.7 \text{ min}}{\text{ft}^2} \right) + 20 \text{ min} = (245 + 20) \text{ min} \left( \frac{\text{hr}}{60 \text{ min}} \right) = 4.42 \text{ hr} . \quad (21)$$

Without overhead (value for hour from equation 19),

$$\text{Labor cost}_{2\text{ op}} = 2 \text{ op} \left( \frac{\$25.00}{\text{hr operator}} \right) (1.167 \text{ hr}) = \$58.35 . \quad (22)$$

Without overhead (value for hour from equation 21),

$$\text{Labor cost}_{1\text{ op}} = 1 \text{ op} \left( \frac{\$25.00}{\text{hr operator}} \right) (4.42 \text{ hr}) = \$110.50 . \quad (23)$$

Without overhead,

$$\frac{\text{Total operator cost}}{\text{HMMWV}} = \$(58.35 + 110.50) = \$168.85 . \quad (24)$$

(Equation 24 corresponds with parameter 6.)

#### 4.2.4 Cost for Labor With Overhead

Recall that the given overhead rate = 70% (value for hour from equation 19).

$$\text{Labor cost}_{2\text{ op}} = 1.7 (2 \text{ op}) \left( \frac{\$25.00}{\text{hr operator}} \right) (1.167 \text{ hr}) = \$99.20 . \quad (25)$$

With overhead (value for hour from equation 21),

$$\text{Labor cost}_{1\text{ op}} = 1.7 (1 \text{ op}) \left( \frac{\$25.00}{\text{hr operator}} \right) (4.42 \text{ hr}) = \$187.85 . \quad (26)$$

With overhead,

$$\frac{\text{Total operator cost}}{\text{HMMWV}} = \$(99.20 + 187.85) = \$287.05 . \quad (27)$$

(Equation 27 corresponds with parameter 7.)

#### 4.2.5 Total Cost for HMMWV Without Overhead

In the following, value for materials and energy is from equation 16 and operator value is from equation 24:

$$\frac{\text{Cost}}{\text{HMMWV}} = \begin{matrix} \text{Materials} \\ \text{and energy} \end{matrix} + \begin{matrix} \text{Operator} \end{matrix} = \$(183.84 + 168.85) = \$352.69 . \quad (28)$$

This value does not allow for a 5% reprocessing of HMMWV => 1 of 20 HMMWV must be processed twice. Therefore, the cost for 20 acceptable HMMWVs is 21 (\$352.69) = \$7,406.49. Then the average cost per HMMWV is

$$\frac{\$7,406.49}{20} = \$370.32 \quad (29)$$

or

$$1.05 (\$352.69) = \$370.32. \quad (30)$$

This value should be increased by the cost of returning the rejected HMMWV to station 1.

$$\frac{\text{Total cost}}{\text{HMMWV}} = \$370.32 + 1 \text{ op} \left( \frac{\$25.00}{\text{hr operator}} \right) 15 \text{ min} \left( \frac{\text{hr}}{60 \text{ min}} \right). \quad (31)$$

$$\frac{\text{Total cost}}{\text{HMMWV}} = \$(370.32 + 6.25) = \$376.57 . \quad (32)$$

(Equation 32 corresponds with parameter 8.)

#### 4.2.6 Total Cost for HMMWV With Overhead

In the following, value for materials and energy is from equation 16 and operator value is from equation 27:

$$\frac{\text{Cost}}{\text{HMMWV}} = \begin{matrix} \text{Materials} \\ \text{and energy} \end{matrix} + \begin{matrix} \text{Operator} \end{matrix} = \$(183.84 + 287.05) = \$470.89 . \quad (33)$$

This value does not allow for a 5% reprocessing of HMMWV => 1 of 20 HMMWV must be processed twice. Therefore, the cost for 20 acceptable HMMWVs is 21(\$470.89) = \$9,888.69. Then the average cost per HMMWV is

$$\frac{\$9,888.69}{20} = \$494.43 \quad (34)$$

or

$$1.05(\$470.89) = \$494.43. \quad (35)$$

With the return cost from equation 32,

$$\frac{\text{Total cost}}{\text{HMMWV}} = \$(494.43 + 6.25) = \$500.68. \quad (36)$$

(Equation 36 corresponds to parameter 9.)

### 4.3 Stryker Processing

#### 4.3.1 Processing Time

Determine the time required for completing one Stryker, including the elapsed time between processing stations. Assume that this driving time is the same for HMMWVs and Strykers.

In the following, values for time are from equation 8.

$$\text{Time} = \frac{700 \text{ ft}^2}{\text{Stryker}} \left[ \frac{0.9 \text{ min}}{\text{ft}^2} \right] + \frac{55 \text{ min}}{\text{Stryker}}. \quad (37)$$

$$\text{Time} = (630 + 55) \frac{\text{min}}{\text{Stryker}} = \frac{685 \text{ min}}{\text{Stryker}}. \quad (38)$$

$$\text{Time} = \frac{685 \text{ min}}{\text{Stryker}} \left( \frac{\text{hr}}{60 \text{ min}} \right) = 11.42 \frac{\text{hr}}{\text{Stryker}}. \quad (39)$$

(Equation 39 corresponds to parameter 10.)

#### 4.3.2 Cost for Materials and Energy

Determine the materials and energy cost for a Stryker without operator expense and without the cost for rejected vehicles. Assume that the energy cost for the curing oven is the same for HMMWVs and Strykers.

In the following, value for materials and energy are from equation 14:

$$\text{Cost} = \frac{700 \text{ ft}^2}{\text{Stryker}} \left[ \frac{\text{Materials } \$0.3919}{\text{ft}^2} \right] + \frac{\text{Energy } \$46.67}{\text{Stryker}}. \quad (40)$$

$$\text{Cost} = \frac{\$(274.33 + 46.67)}{\text{Stryker}} = \frac{\$321}{\text{Stryker}}. \quad (41)$$

(In equation 41, 274.33 corresponds with parameter 11 and 46.67 corresponds with parameter 12. Equation 41 corresponds with parameter 13.)

### 4.3.3 Cost for Labor Without Overhead

Assume that all of the processing stations, except the curing oven, require operator interaction.

The following is the time<sub>2 op</sub>, with values for removal and inspection from equation 7:

$$\text{Time}_{2 \text{ op}} = 700 \text{ ft}^2 \left( \frac{\text{Removal}}{\text{ft}^2} \frac{0.15 \text{ min}}{\text{ft}^2} + \frac{\text{Inspection}}{\text{ft}^2} \frac{0.05 \text{ min}}{\text{ft}^2} \right). \quad (42)$$

$$\text{Time}_{2 \text{ op}} = 700 \text{ ft}^2 \left( \frac{0.2 \text{ min}}{\text{ft}^2} \right). \quad (43)$$

$$\text{Time}_{2 \text{ op}} = 140 \text{ min} \left( \frac{\text{hr}}{60 \text{ min}} \right) = 2.33 \text{ hr}. \quad (44)$$

The following is the time<sub>1 op</sub> with values for pretreatment, application, and driving from equation 7:

$$\text{Time}_{1 \text{ op}} = 700 \text{ ft}^2 \left( \frac{\text{Pretreatment}}{\text{ft}^2} \frac{0.5 \text{ min}}{\text{ft}^2} + \frac{\text{Application}}{\text{ft}^2} \frac{0.2 \text{ min}}{\text{ft}^2} + \frac{\text{Driving between stations}}{\text{ft}^2} \right) + 20 \text{ min}. \quad (45)$$

$$\text{Time}_{1 \text{ op}} = 700 \text{ ft}^2 \left( \frac{0.7 \text{ min}}{\text{ft}^2} \right) + 20 \text{ min} = (490 + 20) \text{ min} = 510 \text{ min}. \quad (46)$$

$$\text{Time}_{1 \text{ op}} = 510 \text{ min} \left( \frac{\text{hr}}{60 \text{ min}} \right) = 8.50 \text{ hr}. \quad (47)$$

Without overhead (value for time from equation 44),

$$\text{Labor cost}_{2 \text{ op}} = 2 \text{ op} \left( \frac{\$25.00}{\text{hr operator}} \right) (2.33 \text{ hr}) = \$116.50. \quad (48)$$

Without overhead (value for time from equation 47),

$$\text{Labor cost}_{1 \text{ op}} = 1 \text{ op} \left( \frac{\$25.00}{\text{hr operator}} \right) (8.50 \text{ hr}) = \$212.50. \quad (49)$$

Without overhead,

$$\frac{\text{Total operator cost}}{\text{Stryker}} = \$(116.50 + 212.50) = \$329.00. \quad (50)$$

(Equation 50 corresponds with parameter 14.)

#### 4.3.4 Cost for Labor With Overhead

Recall that overhead rate = 70% (value for time from equation 44).

$$\text{Labor cost}_{2\text{ op}} = 1.7 (2 \text{ op}) \left( \frac{\$25.00}{\text{hr operator}} \right) (2.33 \text{ hr}) = \$198.05 . \quad (51)$$

In the following, value for time is from equation 47:

$$\text{Labor cost}_{1\text{ op}} = 1.7 (1 \text{ op}) \left( \frac{\$25.00}{\text{hr operator}} \right) (8.50 \text{ hr}) = \$361.25 . \quad (52)$$

$$\frac{\text{Total operator cost}}{\text{Stryker}} = \$ (198.05 + 361.25) = \$559.30 . \quad (53)$$

(Equation 53 corresponds with parameter 15.)

#### 4.3.5 Total Cost for Stryker Without Overhead

In the following, value for materials and energy are from equation 41 and value for operator is from equation 50:

$$\frac{\text{Cost}}{\text{Stryker}} = \$ \left( \begin{array}{c} \text{Materials} \\ \text{and energy} \end{array} + \begin{array}{c} \text{Operator} \end{array} \right) = \$650.00 . \quad (54)$$

This value does not allow for a 5% reprocessing of Strykers. With the additional expense for reprocessing,

$$\frac{\text{Total cost}}{\text{Stryker}} = 1.05(\$650.00) = \$682.50 . \quad (55)$$

With the return cost from equation 32,

$$\frac{\text{Total cost}}{\text{Stryker}} = \$ (682.50 + 6.25) = \$688.75 . \quad (56)$$

(Equation 56 corresponds with parameter 16.)

#### 4.3.6 Total Cost for Stryker With Overhead

In the following, value for materials and energy is from equation 41 and operator value is from equation 53:

$$\frac{\text{Cost}}{\text{Stryker}} = \$ \left( \begin{array}{c} \text{Materials} \\ \text{and energy} \end{array} + \begin{array}{c} \text{Operator} \end{array} \right) = \$ (321.00 + 559.30) = \$880.30 . \quad (57)$$

This value does not allow for a 5% reprocessing of Strykers. With the additional expense for reprocessing,

$$\frac{\text{Total cost}}{\text{Stryker}} = 1.05 (\$880.30) = \$924.32. \quad (58)$$

With the return cost from equation 32,

$$\frac{\text{Total cost}}{\text{Stryker}} = \$ (924.32 + 6.25) = \$930.57. \quad (59)$$

(Equation 59 corresponds with parameter 17.)

#### 4.4 Facility Operating Cost

##### 4.4.1 Facility Without Overhead Operating Cost

Determine the facility operating cost per hour based on the required completion time for each type of vehicle.

The processing times for HMMWV and Stryker are from equations 10 and 39, respectively.

In the following, values for the costs of HMMWV and Stryker are from equations 32 and 56, respectively.

$$\text{Facility operating cost} = \left( \frac{\text{HMMWV}}{6.17 \text{ hr}} \right) \left( \frac{\$376.57}{\text{HMMWV}} \right) + \left( \frac{\text{Stryker}}{11.42 \text{ hr}} \right) \left( \frac{\$688.75}{\text{Stryker}} \right). \quad (60)$$

$$\text{Facility operating cost} = (61.03 + 60.31) \left( \frac{\$}{\text{hr}} \right). \quad (61)$$

$$\text{Facility operating cost} = \frac{\$121.34}{\text{hr}}. \quad (62)$$

(Equation 62 corresponds with parameter 18.)

##### 4.4.2 Facility With Overhead Operating Cost

Determine the facility operating cost per hour based on the required completion time for each type of vehicle.

The processing times for HMMWV and Stryker are from equations 10 and 39, respectively.

In the following, values for the costs of HMMWV and Stryker are from equations 36 and 59, respectively.

$$\text{Facility operating cost} = \left( \frac{\text{HMMWV}}{6.17 \text{ hr}} \right) \left( \frac{\$500.68}{\text{HMMWV}} \right) + \left( \frac{\text{Stryker}}{11.42 \text{ hr}} \right) \left( \frac{\$930.57}{\text{Stryker}} \right). \quad (63)$$

$$\text{Facility operating cost} = (81.15 + 81.49) \left( \frac{\$}{\text{hr}} \right). \quad (64)$$

$$\text{Facility operating cost} = \frac{\$162.64}{\text{hr}}. \quad (65)$$

(Equation 65 corresponds with parameter 19.)

#### 4.5 Overall Increase in Cost From Overhead

The 70% overhead rate increases the total cost values by the following percentages:

from equations 36 and 32,

$$\text{HMMWV: } \frac{\$(500.68 - 376.57)}{\$376.57} (100) = 32.96\%, \quad (66)$$

from equations 59 and 56,

$$\text{Stryker: } \frac{\$(930.57 - 688.75)}{\$688.75} (100) = 35.11\%, \quad (67)$$

and from equations 65 and 62,

$$\text{Facility operating cost: } \frac{\$(162.64 - 121.34)}{\$121.34} (100) = 34.04\%. \quad (68)$$

(Equation 66 corresponds with parameter 20, equation 67 corresponds with parameter 21, and equation 68 corresponds with parameter 22.)

## 5. Results and Discussion

This financial analysis considered operating expenses of materials, labor, overhead, and energy. Table 3 provides a summary of the economic analysis. The numbers in parentheses are references to the parameters in section 3 and 4 of this report (evaluation requirement and calculations).

Although the value for the external surface area of the Stryker was double that of the HMMWV, the quantities calculated for the six parameters involving Stryker time and cost were less than 2× the corresponding result for the HMMWV. This difference was because the time and energy required for process 4 (the curing oven) were not dependent on the surface area of the tactical vehicle. Also, the driving time and labor cost for driving between stations and returning rejected vehicles to station 1 was equal for both types of vehicles (it was not area dependent).

Table 3. Summary of economic parameters for vehicles listed in section 3 of this report.

Parameter, Units	Tactical Vehicle	
	HMMWV	Stryker
External surface area, ft <sup>2</sup>	350	700
Processing time, hr	6.17 (2)	11.42 (10)
Materials and energy, \$	183.84 (5)	321.00 (13)
Labor, \$	168.85 (6)	329.00 (14)
Labor with overhead, \$	287.05 (7)	559.30 (15)
Total cost without overhead, \$	376.57 (8)	688.75 (16)
Total cost with overhead, \$	500.68 (9)	930.57 (17)
Increase in total cost from overhead, %	32.96 (20)	35.11 (21)

For this, model labor cost was applied when an operator(s) was working on a vehicle. In a different scenario, the total operator and facility costs would increase because workers (such as the inspectors) would be paid for the time they were waiting for the next vehicle to arrive at their station—inspectors would have time available to perform administrative or other duties. Because the time between arrivals for each type of vehicle was less than the processing time, queues would form at some processing stations. The overhead cost of 70% included electrical energy not used for the curing ovens. As indicated in the introduction of this report, the model assumed that not more than one vehicle was processed within each station. Table 4 summarizes the operating costs for the facility.

Table 4. Summary of facility operating costs.

<b>Without Overhead</b>	121.34 \$/hr
<b>With Overhead</b>	162.64 \$/hr
<b>Increase From Overhead</b>	34.04%

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## 6. Cost-Sensitivity Analysis

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To illustrate the effect a price change of several variables has on the final cost of the product, the initial cost for materials (solvent, pretreatment, and paint), electrical energy, waste disposal, labor without overhead, and labor with overhead were separately increased by 5% while the price for all other variables was held constant. In most applications, the price fluctuations for input variables would not be identical. However, comparing the relative effect of each variable on the final price for the output product would be inconsistent if each variable was changed by different coefficients. The results of this analysis are summarized in table 5.

Table 5. Cost-sensitivity analysis with a 5% increase in baseline price.

Parameter		1.05 (Baseline)	Total Cost Without Overhead ( $\Delta$ %)		Total Cost With Overhead ( $\Delta$ %)	
			HMMWV	Stryker	HMMWV	Stryker
Materials	Solvent	\$26.25 gal	\$383.66 (1.88)	\$702.93 (2.06)	\$507.77 (1.42)	\$944.75 (1.52)
	Pretreatment	\$31.50 gal				
	Paint	\$52.50 gal				
Electrical energy		\$0.42 kW hr	\$397.02 (0.65)	\$691.20 (0.36)	\$503.13 (0.49)	\$933.01 (0.26)
Disposal of waste stream		\$2.10 gal	\$376.68 (0.03)	\$688.97 (0.03)	\$500.79 (0.02)	\$930.78 (0.02)
Labor		\$26.25 hr	\$385.75 (2.44)	\$706.32 (2.55)	\$516.05 (3.07)	\$960.23 (3.19)

All of these parameter increases are reasonable, considering today’s economic environment. The cost of chemicals can fluctuate with the price of oil and natural gas—petroleum is used to make many chemicals through the cracking process that is used to produce gasoline. Energy costs are also subject to variation because of the delivery cost of oil and natural gas and the level of demand. Environmental regulations change with time and become more stringent, causing costs to increase. Typically, labor costs increase on a yearly basis with cost-of-living and performance-based increases. Here, it is interesting to notice that with a 5% increase in any one of these four parameters, the overall impact to cost is fairly minor. The parameter impacted the most by the overall cost was an increase in labor costs.

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## 7. Conclusion

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The economics of this model do not consider the following: purchasing costs for land, taxes, capital investment for construction and equipment, associated depreciation of buildings and machinery, and return on investment. Nor does it consider the cost of transporting the tactical vehicles from the source/field to the painting facility and returning them to the source/field. Depending on where the tactical unit is located relative to the painting facility, the expense for transportation could be substantial.

For this scenario, the overhead rate of 70% that was applied to labor cost increases the overall operating cost by ~34%.

For this model with the specified set of input values, the final production cost for painting HMMWV and Stryker combat vehicles is affected hierarchically by the price of labor, materials, energy, and waste disposal.

Although the manufacturing process and specific values can vary, the mathematical techniques that are demonstrated in this report have broad applicability for similar manufacturing scenarios and are transferable to other materiel systems, such as aviation, artillery, ammunition, explosives, small arms, and logistical support for the soldier.

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