Title: Freightliner Corporation Service Manual Development

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Author(s): S. Bennett, S. McHenry and C. Nardini

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Abstract: A linear programming model is developed to minimize the labor cost of the development of a technical service manual for a new product line for the Freightliner Corporation. This is achieved by assigning aggregate work hours to various professional groups involved. The model assures participation by all relevant groups, while assuming adequate hours are assigned to complete the project on schedule. Subject to operational goals, cost is minimized.

FREIGHTLINER CORPORATION
SERVICE MANUAL DEVELOPMENT

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by

Sheila Bennett

Stephen McHenry

Carlo Nardini

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Portland State University
Engineering Management Program

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FREIGHTLINER CORPORATION SERVICE MANUAL DEVELOPMENT

EXECUTIVE SUMMARY

Freightliner Corporation is preparing to launch a new product line. Introduction of the new product line is planned for the Spring of 1991. One of the support tools for the new product will be a Service Manual. This project will model this manual. To produce the manual, the following tasks are required:

Develop
Write
Review
Publish

The tasks are to be accomplished through the coordination of the following groups:

Technical Writers
Method Analysts
Service Engineers
Technical Publications
Media Services
Other groups

The organizational ordinal goals are:

1. The manual must be completed in time to support the new vehicles as they are delivered in the field.
2. Every contributing group must complete their assigned tasks.

It is assumed that no overtime cost will be incurred for this project. The objective of the model is to minimize the project's labor cost, while satisfying the organizational goals, subject to labor constraints.

The optimal solution that satisfied goal 1 required a maximum boundary constraint for Technical Writers hours. To satisfy goal 2, minimum boundary constraints were necessary for Technical Writers, Service Engineers, Media Services and Other groups hours. The cost of satisfying goals 1 and 2 is $8,050. The project labor cost is $428,620.

The sensitivity analysis concluded that the binding tasks constraints are Developing and Publishing. The basic variables are the Methods Analysts hours and the Technical Publications hours. Therefore, the work performed by the Methods Analysts and Technical Publications groups to accomplish the Developing and Publishing tasks are most sensitive and need to be monitored closely by management. Sensitivity analysis of time allocated to perform each task was performed with parametric variations. The results are a management tool that provides insight to the effect of major changes in the project schedule. It reveals which groups hours become critical and which task constraints become binding.

This model can be used in conjunction with project scheduling to provide management with the knowledge of whose work in what task is most critical to the scheduled completion of the project.

INTRODUCTION

Freightliner Corporation is preparing to launch a new product line. Introduction of the new product line is planned for the Spring of 1991. One of the support tools for the new product will be a Service Manual. This project will model the production of the manual. The Service Engineering Department is responsible to design, prepare and publish this manual. It must be available at the time of product introduction. To produce the manual, the Service Engineering Department requires input from five groups of personnel:

Technical Writers
Methods Analysts
Technical Publications
Media Services
Other groups

The Other groups, such as Engineering and Service Training, are considered as one entity. The development phase of the project begins October 8, 1990. Manual distribution must be completed by April 30, 1991. Any work related to the manual development that occurred prior to October 8, 1990 was sporadic and is considered external to this model.

MODEL DEVELOPMENT

Goals - The manual development model satisfies the ordinal organizational goals:

1. The project must be completed in time to support the new vehicles as they are delivered in the field.
2. Every designated department must contribute to the project and complete their assigned tasks.

Objective - The objective of the model is to minimize the project's labor cost, while satisfying the organizational goals, subject to labor constraints.

Assumptions - Although Freightliner labor costs are salary, the equivalent hourly rates are used in the objective and constraint equations. Therefore, the following work conditions are assumed:

1. Work performed on this project will occur within the normal work week of 40 hours.
2. No overtime cost will be incurred.

Each of the involved groups participate in various production tasks at different levels. Table 1 is a matrix representing departmental involvement. Specific levels are discussed in the Data Development section.

GROUP > TASK V	TECH LIT	METH ANAL	SVC ENG	TECH PUB	MEDIA SVC	OTHER
DEVELOP	YES	YES	YES	NO	YES	YES
WRITE	YES	YES	YES	YES	YES	NO
REVISE	YES	YES	YES	YES	NO	YES
PUBLISH	YES	NO	NO	YES	NO	NO

TABLE 1 - Participation Matrix

DATA DEVELOPMENT

Actual data from Freightliner Corp was used to develop the model. Although an action plan has already been developed at Freightliner, it was not used to support or influence this model, but it will be used to check the results of this model. Labor costs are real averages obtained from the Costing Department. Time allocations are derived from experience gained from similar past projects.

Let Aj = Labor cost per hour for each group:

A1 = \$24/hr. Labor cost per hour for the Technical Writers group

A2 = \$30/hr. Labor cost per hour for the Method Analysts group

A3 = \$30/hr. Labor cost per hour for the Service Engineers group

A4 = \$20.5/hr. Labor cost per hour for the Technical Publications group

A5 = \$27.5/hr. Labor cost per hour for the Media Services group

A6 = \$31.0/hr. Labor cost per hour for the other groups

Let Xj = # of hours needed by each group to complete the project:

X1 = # of Technical Writers hours needed to complete the project

X2 = # of Method Analysts hours needed to complete the project

X3 = # of Service Engineers hours needed to complete the project

X4 = # of Technical Publications hours needed to complete the project

X5 = # of Media Services hours needed to complete the project

X6= # of Miscellaneous hours needed to complete the project

Let Di = # hours allocated to perform each function:

D1 = 1214 hrs. Maximum # of hours allocated to perform the function "Develop"

D2 = 9215 hrs. Maximum # of hours allocated to perform the function "Write"

D3 = 4412 hrs. Maximum # of hours allocated to perform the function "Review"

D4 = 3200 hrs. Maximum # of hours allocated to perform the function "Publish"

D5 = 33912 hrs. Maximum # of hours allocated to complete the entire project.

The technological coefficients for the constraints representing the time needed to complete a task are a ratio of a group's time spent in an activity to their time spent on the project. The values are thus unitless. The summation of values in a group's column equals one. Let Cij be defined as these ratios.

GROUP > TASK V	TECH LIT	METH ANAL	SVC ENG	TECH PUB	MEDIA SVC	OTHER
DEVELOP	.08	.45	.21	-	.13	.03
WRITE	.57	.03	.04	.56	.87	-
REVISE	.24	.52	.75	.12	-	.97
PUBLISH	.11	-	-	.32	-	-

TABLE 2 - Technological Coefficients

Minimum and maximum time constraints are necessary to satisfy the organizational goals. These constraints prohibit the model from assigning zero to a variable in order to minimize costs and prohibit the model from allowing the project to be late because a group cannot complete its task on time.

GROUP	LOWER BOUND (hrs)	UPPER BOUND (hrs)
Tech Writers	7065	7728
Method Anal	772	2400
Serv Eng	545	2400
Tech Pub	7485	16560
Media Serv	1099	1800
Other	1075	3024

Table 3

A project duration constraint is needed as a last line of defense for completion on time. Violation of this constraint will make the solution of the model infeasible.

MATHEMATICAL MODEL FORMULATION

$\text{Min } Z = 24X1 + 30X2 + 30X3 + 20.5X4 + 27.5X5 + 31X6$

s.t.

$$\begin{array}{lrrrrrrll}
1) & .08X1 + & .45X2 + & .21X3 & & + .13X5 + & .03X6 & >= 1214 & \\
2) & .57X1 + & .03X2 + & .04X3 + & .56X4 + & .87X5 & & >= 92153 & \text{TASK} \\
3) & .24X1 + & .52X2 + & .75X3 + & .12X4 & & + .97X6 & >= 4412 & \text{CONSTRAINTS} \\
4) & .11X1 & & + & .32X4 & & & >= 3200 & \\
5) & X1 + & X2 + & X3 + & X4 + & X5 + & X6 & <= 33912 & \text{DURATION} \\
6) & X1 & & & & & & >= 7065 & \\
7) & X1 & & & & & & <= 7728 & \\
8) & & X2 & & & & & >= 772 & \\
9) & & & X3 & & & & >= 545 & \text{BOUNDARIES} \\
10) & & & & X4 & & & >= 7485 & \\
11) & & & & & X5 & & >= 1099 & \\
12) & & & & & & X6 & >= 1075 &
\end{array}$$

The mathematical model was run on the computer program Lindo. In order to run the model, Lindo required proper scaling of technological coefficients because the ratio values of Ci,j were extremely small compared to the objective coefficients, Aj, and the RHS values, Di.

Optimal Solution:

$Z = \$428,620$

X1 = 7065 hrs. X2 = 7728 hrs. X3 = 545 hrs.

X4 = 7485 hrs. X5 = 1099 hrs. X6 = 1075 hrs.

MODEL TRIAL RUNS

The model was solved in steps to examine the objective value's fluctuation as the organizational goals were met. Lindo printouts of each trial are in the Appendix. Each printout includes the model, the solution, sensitivity ranges and the optimal tableau.

First, the model was run without boundary contraints for each X variable. The resulting optimal solution was:

Z = $420,570

X1 = 9384 hrs. X2 = 283 hrs. X3 = 1600 hrs.

X4 = 6774 hrs. X5 = 0 X6 = 0

This solution exceeded the upper bound constraint for X1. This would cause the Technical Writers group to run late thereby not satisfying the first organizational goal. X2, X4, X5 and X6 were less than the specified lower bound. This violates the second goal.

For the second run, only an upper bound constraint for X1 was added to the model. This was done to satisfy the first goal. No boundary constraints were put in for variables that were less than the lower bound. The purpose for this was to see what the solution would be with, at least, the first goal satisfied. The second run's optimal solution was:

Z = $423,352

X1 = 7728 hrs. X2 = 117 hrs. X3 = 2154 hrs.

X4 = 7344 hrs. X5 = 699 hrs. X6 = 0

All variables were below their upper bounds, thereby satisfying goal 1. The Z value increased, indicating the cost associated with the fulfillment of goal 1 is \$423,352 - \$420,570 = \$2,782. The value is equal to the increase in X5 multiplied times its Zj-Aj from Step 1. Variables X2, X4, X5, and X6 were less than their lower bounds. For the third trial, a lower boundary constraint was added for X6 since it was below its minimum value by the largest amount. The optimal solution was:

Z = \$424,272

X1 = 7728 hrs. X2 = 943 hrs. X3 = 190 hrs.

X4 = 7344 hrs. X5 = 761 hrs. X6 = 1075 hrs.

The results of this run satisfied goal 1 since all the variables are below their upper bound. Variable X2 was greater than or equal to its lower bound. X3, X4 and X5 dropped below their lower bounds. Again, Z increased by the increase in X6 multiplied times its marginal cost from Step 2. For the fourth run, a lower bound constraint was inserted for X3. The optimal solution was:

Z = \$426,054

X1 = 6667 hrs. X2 = 837 hrs. X3 = 545 hrs.

X4 = 7708 hrs. X5 = 1208 hrs. X6 = 1075 hrs.

Goal 1 remained satisfied in this solution. Goal 2 is violated because X1 is below its lower bound. The objective function value has increased by a surplus of 1061 hours induced in the X1 upper bound constraint multiplied times its dual price from Step 3. Boundary constraints were added to the model twice more before an optimal solution that met both of the organizational goals was reached. The objective function value increased as it did in each of the previous steps. The goal satisfying optimal solution was:

Z = \$428,620

X1 = 7065 hrs.   X2 = 798 hrs.   X3 = 545 hrs.

X4 = 7571 hrs.   X5 = 1099 hrs.   X6 = 1075 hrs.

The ultimate cost of satisfying both goals was the Z value difference between the last trial and first trial:

\$428,620 - \$420,570 = \$8050

SENSITIVITY ANALYSIS

In the current optimal solution, two of the task constraints are binding. The development task constraint (row 2) is binding with the Methods Analysts group (X2) as its basic variable. The publishing task constraint (row 5) is binding with the Technical Publications group (X4) its basic variable. All other group variables are basic in their respective minimum value constraints. The total project duration constraint (row 6) is non-binding as is the maximum value constraint on the Literature group (row 8). Table 4 is a summary of the individual sensitivities of the RHS values.

Increases in RHS values represent raising the minimum time required to complete a task (rows 2 through 5) or the minimum time a group must dedicate to its assignments (rows 7 and 9 through 13). This type of change is indicative of an expanded program or perhaps an underestimation of the scope of some or all of the individual job packets within the project. An increase could also indicate that one of the groups is going to need more time to finish its tasks.

The RHS values for the binding task constraints can increase substantially before the basis changes. In fact, by increasing the RHS for development beyond its 584% upper limit or by increasing the publishing constraint RHS beyond its increase limit of 158%, the solution becomes infeasible because the project will be late. Conversely, as the binding task constraints decrease beyond their minimums, the constraints become non-binding (surplus). Their basic variables move to their minimums.

ROW	CONST	BASIC VARIABLE	ORIGINAL RHS	MAX RHS	RHS % INCR	RESULT	MIN RHS	RHS % DECR	RESULT
2	Develop	X2 (Methods)	1,214	8,305	580	Infeasible in row 6	1,202	0.99	Surplus
3	Write	surplus	9,215	9,269	0.59	Binding on X5	0	100	
4	Review	surplus	4,412	4,471	1.3	Binding on X6	0	100	
5	Publish	X4 (Publ)	3,200	8,243	160	Infeasible in row 13	3,172	0.88	Surplus
6	Total	slack	33,912	INF	–		18,154	46	Infeasible on X6
7	Min Lit	X1 (Lit)	7,065	7,213	2.1	Const 2 non-binding	6,920	2.0	Const 3 binding on X5
8	Max Lit	slack	7,728	INF	–		7,065	9.3	Min Lit (orig RHS)
9	Min Methods	surplus	772	798	3.4	Const 2 non-binding	0	100	
10	Min Svc Eng	X3 (Svc Eng)	545	601	10	Const 2 non-binding	429	21	Const 4 binding on X6
11	Min Publ	surplus	7,485	7,571	1.2	Const 4 non-binding	0	100	
12	Min Media	X5 (Media)	1,099	1,190	8.3	Const 2 non-binding	1,036	5.7	Const 3 binding on X5
13	Min Others	X6 (Others)	1,075	1,469	37	Const 2 non-binding	1,012	5.9	Const 4 binding on X6

NOTE: RESULT column shows basis change as value goes just past limit.

Table 4 – RHS ranges on optimal solution

The two non-binding task constraints provide further insight. Increasing the RHS of these constraints has the effect of pushing them toward becoming binding. For the writing constraint, the Media Services group will become its basic variable when its RHS exceeds its maximum. This is important information since the upper limit on this RHS is only .59% above its current value. It will be critical to make sure the Media Services group completes its writing tasks on time. Similarly, the Others group (X6) moves in as the basic variable for the review task. When the external review process commences, it will be important to keep tabs on its progress. Fortunately, the monitoring of the external reviews will not be too cumbersome because only two of these groups reviewing the literature have final approval authority. The rest of the other groups make only recommendations which can be incorporated or discarded.

The upper limit sensitivity of the constraints on minimum values for the various groups is a reflection of the upper limit sensitivity of the binding task constraints. As the RHS of the Publishing group constraint (row 11) passes its upper limit, the publishing constraint becomes non-binding. For all other group constraints, the development constraints become non-binding as they pass their upper limits. This makes sense since the development constraint is less sensitive to RHS increases than is the publishing constraint.

Reducing the RHS values represents lowering the minimum time required to complete a task or the minimum time a group must dedicate to its assignments. This can occur in the task constraints if a decision is made somewhere to "crunch" the timeline for product introduction. It can also occur if the scope of the project has been overestimated. The binding task constraints were mentioned earlier in this regard - they go non-binding. The non-binding constraint RHS values can decrease to zero.

Reducing the RHS values of the minimum value constraints that are currently at their minimums (rows 7, 10, 12 and 13) is worthy of careful inspection. When any one of these constraints passes below its minimum limit, one of the two surplus task constraints becomes binding. When looking at increases in the RHS, it was seen that when the non-binding task constraints became binding, a given group's minimum value became its basic variable. The same task constraints are associated with the same group minimum constraints in this part of the analysis. When the minimum limit on the Literature group value is passed, the writing constraint becomes binding with the Media Services group value its basic variable. Not surprisingly, when the Media Services minimum limit is passed, the same thing happens. For the Service Engineering group minimum value constraint, the review constraint becomes binding with X6 (Other's group) its basic variable. What all of this is saying is it will still be important to keep an eye on the progress of the groups linked to the currently non-binding task constraints. It provides additional information in as much as they should be watched if it is seen that the Literature group or Service Engineering group duties have been underestimated.

What if a new option, for example a new engine or suspension, is added to the design package? Such a change will require coverage in the Service Manual. Typically, the program schedule will not be pushed out. This being the case, the RHS values for the task constraints will all increase by some value based on the percentage increase in time required to complete the various tasks involved.

This is a classic parametric change in RHS parameters. To handle this on a percentage basis, the current largest task constraint (writing) RHS will be used as a unitary benchmark. A dummy constraint is added to the model with negative coefficients in the task constraints. The dummy constraint is set at zero and then varied to some value representing the increase in writing time corresponding to the change in the design package. Figure 1 illustrates an example of a 15% increase in the four tasks. The RHS parametrics feature of Lindo outputs information about basis changes as the RHS parameters are varied. The graph shows how the objective function value is affected by the change. Even if the program schedule were pushed out or crunched, a parametric analysis like this would be very useful.

Since this model is based on goal programming, the sensitivity of the objective function coefficients doesn't provide much information. The iterative process of satisfying goals gives the necessary information about the objective function. These effects were discussed previously in the Model Trial Runs section of this report.

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EMGT543

   MIN    24 X1 + 30 X2 + 30 X3 + 20.5 X4 + 27.5 X5 + 31 X6
   SUBJECT TO
        2)  8 X1 + 45 X2 + 21 X3 + 13 X5 + 3 X6 - 13.2 D >=  121400
        3)  57 X1 + 3 X2 + 4 X3 + 56 X4 + 87 X5 - 100 D >=  921500
        4)  24 X1 + 52 X2 + 75 X3 + 12 X4 + 97 X6 - 47.9 D >=  441200
        5)  11 X1 + 32 X4 - 34.7 D >=  320000
        6)  X1 + X2 + X3 + X4 + X5 + X6 <=  33912
        7)  X1 >=  7065
        8)  X1 <=  7728
        9)  X2 >=  772
       10)  X3 >=  545
       11)  X4 >=  7485
       12)  X5 >=  1099
       13)  X6 >=  1075
       14)  D =   0
  END
  !VARY RHS ON CONST 2-5 TO REFLECT A 15% INCREASE IN TASK PACKAGES
  PARA 14 1382.25
     VAR          VAR       PIVOT     RHS      DUAL PRICE      OBJ
     OUT           IN        ROW      VAL     BEFORE PIVOT     VAL

                                        0        -31.0297     428620
 SLK   3       SLK  12        3     140.425      -31.0297     432977
 SLK   4       SLK   7        4     258.948      -39.4249     437650
 SLK  12       SLK  10        3     500.499      -44.7801     448467
 SLK   8       SLK  12        8     786.435      -45.6506     461520
                                    1382.25      -47.3629    -489739
```

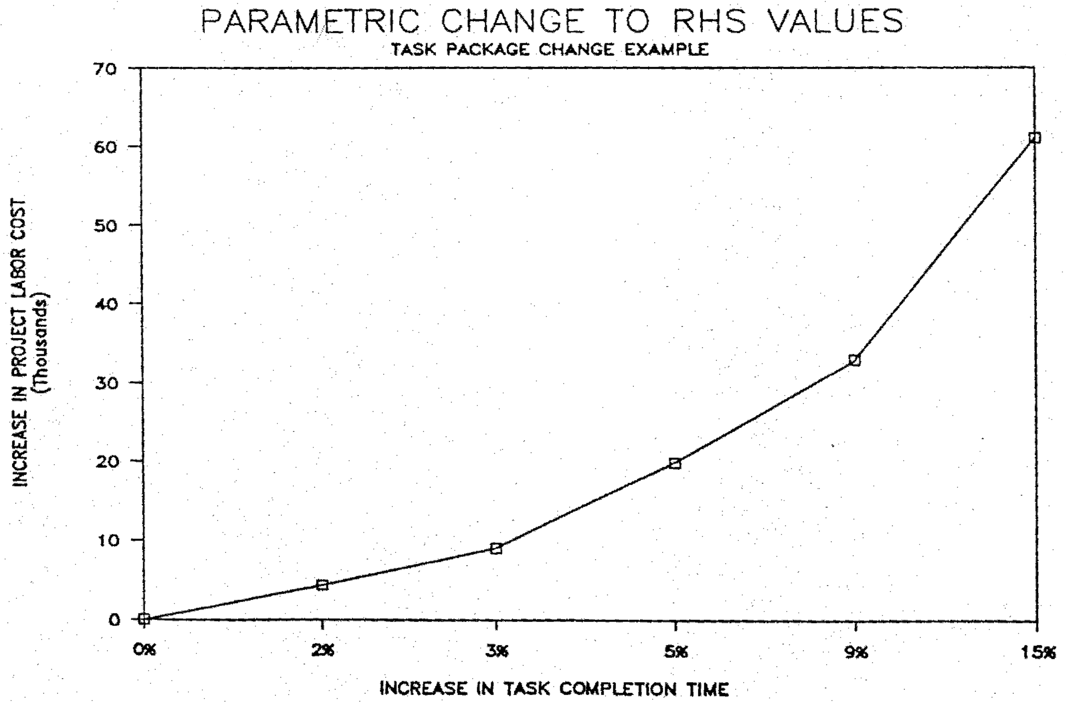

FIGURE 1 - PARAMETRIC VARIATIONS OF RHS

RECOMMENDATIONS AND CONCLUSIONS

This linear programming model is somewhat similar to a project scheduling model. In fact, the project scheduling that is typically undertaken for projects like this should be used hand in hand with the interpretation of this model. A project schedule, e.g. PERT or CPM, will give a manager information about a project's timing. This simple model will give a manager information about WHAT will happen when the schedule is disturbed. In that light, this model can be quite a valuable tool for any multi-task, multi-group project manager. This type of application is apparently a new one. A literature search of classic operations research topics provided no useful background for this project.

The information provided by the optimal solution throughout the iterative boundary insertion process is also valuable. In this particular application, it can be seen that project labor costs increase by less than 2% while satisfying all of the organizational goals. Other applications of this model can be used to assist a manager in what was, until now, a very subjective decision.

This paper does not present a sensitivity analysis of the technological coefficients. Since the values of these coefficients are not written in stone, this type of analysis should be done. Another issue not discussed here is project costs other than labor. Indeed, many of these costs are volatile. Some of them are sensitive to timing. Sensitive costs should be identified and incorporated in the model.

Initially, the potential of this project was unknown to the writers. With the information extrapolated through the model's development and analysis, Freightliner management could be presented with a proposal to include this in its management tool box. Proposal presentations could also be developed for other companies.