The Decision Regarding Offshore Engineering at Acme Machine Works Corporation[1]: A Case-Study Perspective from Optimization Modeling

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Abstract

This case study will focus on the decision process regarding offshore engineering at one Fortune 500 multinational firm just prior to the recent economic downturn. A formal optimization model, that seeks to look beyond the obvious labor cost differential, is built and resolved. The resulting recommendation provides an objective decision support perspective into the outsourcing conundrum faced by many multinationals.

Introduction

Multinational firms recognize that successful business is about bringing the right product to the right market at the right price. The marketing literature contends that those firms that are proactive and aggressive in changing the rules of the market (i.e. 'market driving') rather than reactive and consumer-led (i.e.'market driven') have the best prognosis, especially in times of a soft market (Berghman, *et al*, 2006; Esper *et al*, 2010). The pursuit of greater efficiency of cost control has led many firms to focus on their core competencies, and many believe that outsourcing can assist in such cost containment and, in turn, the quest for a competitive advantage (Quinn and Hilmer, 1994). Firms have been outsourcing manufacturing for decades (Hatonen and Eriksson, 2009). As recent as 2007, Wadhwa and Ravindran contended that most outsourced activities were those not core to the firm's business. Today's outsourcing of engineering design work has reversed that contention for many industries. While it is still more common to offshore the less advanced tasks, the most recent years have witnessed the more advanced tasks (i.e. those closer to the core activities of the firm) being offshored as well (Jensen and Pedersen, 2012). Included in such advanced and high-value tasks are innovation, R&D, and design activities (a.k.a. 'engineering') as well as administrative and technical services (Lewin and Couto, 2007; Manning *et al*, 2008). For many firms, the offshoring of engineering work is simply an extension of their outsourcing strategy, and their overseas manufacturing is often pulling the affiliated engineering offshore with it.

[1] While the model in this paper is built around a real world case situation, the names of the company and the industry have been changed to mask their identity and preserve confidentiality.

Original equipment manufacturers (OEMs) are increasingly becoming outsourcing-focused (Huang and Keskar, 2007). Computer and cell phone manufacturers regularly outsource product design and engineering to China and Taiwan. Manufacturers such as Caterpillar, GE, Honeywell, IBM, and Siemens have all built large engineering facilities offshore or outsource engineering to offshore vendors. The automotive industry (GM and Daimler in particular) have aggressively built technology centers in China and R&D centers in India. While such multinational corporations are making huge investments overseas, they may be neglecting their domestic infrastructure investments and consequently depleting current and future engineering capacity at home. Brown (2009) contends that firms may use the recent recession as the excuse for layoffs of domestic engineers, when the underlying reason is actually a geographic redistribution of the firm's engineering base. Jensen and Pedersen (2012) contend that the drivers behind the decision to offshore may be quite distinct for these more advanced tasks than for the less advanced ones. While most firms claim they need to use local engineers to gain leverage in entering developing markets, the perceived short-term cost savings of outsourcing engineering design is attractive when management can hire multiple engineers overseas for the salary expense of one domestically.

This study adopts the premise of Ng (2008) that simply looking for outsourcing vendors that offer the lowest cost is not 'efficient sourcing' anymore; as this has become as multi-criteria decision. This case study will focus on the decision process regarding offshore engineering at one Fortune 500 multinational firm during the recent economic downturn. A formal optimization model, that seeks to look beyond the obvious labor cost differential, is built and resolved. The resulting recommendation provides an objective decision support perspective into the outsourcing conundrum faced by many multinationals.

Scope of This Case Study

Acme Machine Works Corporation (hereafter 'Acme') designs and manufactures heavy earth moving equipment. This paper focuses on the design effort at the firm's Excavator Development Center (EDC). Within this design center, engineering is split into groups responsible for developing the different Machine systems such as Structural, Hydraulic, and Electrical. Within these groups, there are additional specialized sub-groups, e.g. the Structural Group has engineers responsible for the Cab/Operator Interface, Mechanical Design, and Attachments. This case study will be limited to new product development programs within the Attachments Group. This group is responsible for designing systems such as buckets, augers, grapples, forks, lifters, etc.

Acme has a Product Development Process (PDP) for completing the various new product programs. This PDP consists of distinct stages from developing the scope and budget for the project to launching the product into production. Within this PDP, engineering provides the needed resources to complete the program given the cost, quality and delivery objectives. There are two levels of engineering resources that are required for each program. There are project engineers who are responsible for managing the project within the sub-groups, as well as designers and modelers who are responsible for creating the CAD data and engineering drawings for the systems and components. The demand for project engineers and designers/modelers varies during the different PDP stages. For instance, before a prototype releases, there is an increasing demand for designers/modelers to produce the drawings required for the supplier to

produce the prototype parts. However, this demand typically declines during the testing phase of a program. Demand usually increases again before a production release in order to get the data and drawings to the production supplier. This demand decreases again during the production launch phase. The peak resource demands are met by utilizing contract designers/modelers. In contrast, the demand for project engineers is typically less cyclical. Project engineers are needed to oversee the program throughout the development cycle.

With ever increasing competition and a desire to reduce development costs, Acme has started outsourcing engineering design work to India. The labor cost difference alone is often used as the compelling reason for sending engineering work to India. Many companies have jumped at the chance to reduce development costs based on wages alone, without examining the additional economic factors that could impact the decision. The model created here will explore the effect of adding fixed costs into the decision process.

Specifically, this project will seek to optimize the collective domestic and offshore professional labor utilization in Acme Machine Works' Attachment Engineering department. This cost minimization model will determine the labor cost for the fiscal year, utilizing direct as well as contract resources (offshore as well as in-house) and the associated fixed costs, while maintaining the current staffing levels. It will provide the total number of domestic and offshore contract resources given labor requirements for six new product programs. It will decide which programs should be sent offshore and which should be retained domestically. In addition, this model will determine if there are any unused labor hours each month.

The linear optimization model uses Mixed Integer Linear Programming (MILP), containing binary variables as well as continuous variables. Included in this model are labor costs for the three resource types, fixed costs associated with doing a new product program offshore, binary switch variables to insure that any specific program is done either entirely domestically or entirely offshore, binary switch variables for fixed costs, and monthly labor hours required to accomplish the six new product programs. There are also variables that reflect the number of individual resource types (domestic, offshore, and in-house contractors). The model is optimized via the Simplex algorithm, as implemented in the commercial software *Lindo*.

Literature Review

The EDC model developed in this case study draws upon and synthesizes aspects of numerous prior works. Dasci and Verter (2001) present a model that minimizes the overall cost of satisfying demand. They developed an optimization model in a manufacturing setting with different plant location possibilities. The model in this paper seeks to minimize total engineering product development costs, with a choice of where to produce the design (domestic or offshore). Both models contain binary decision variables that control where to produce, and both have fixed costs associated with that decision as well as operating costs in the objective function. One difference is the set of monthly demand variables included in the EDC model versus the single time period employed in the Dasci and Verter model.

Thompson (1996) used multiple distinct time periods for optimal staff scheduling. Both the Thompson and the EDC models have similar assumptions regarding the employee resources.

The first is that all employees have identical skills. The second is that the desired staff size has been predetermined for each time period. Thompson utilized these ideal staff sizes to drive demand, while the EDC model uses the predetermined program hours required for each month as the demand.

Pinker and Larson (2003) suggest that "as a result of changes in the labor market, managers now have many choices in crafting a staffing strategy that flexibly matches labor supply to demand." They use three sources of labor in their model (fixed, over-time, and contingent) to determine how many full-time and contingent workers are required. This approach is similar to the EDC model, except overtime is not included. Both models include fixed costs for the contingent resources. One of their conclusions was that "increased contingent labor flexibility does not always decrease regular worker staffing levels." Consequently, constraints will be put into the EDC model to keep staffing levels from decreasing due to the offshore outsourcing.

In another case study, Kennedy and Whittaker (2002), find that "organizations are very complex and changes can have effects that are unexpected and even counter-intuitive." They illustrate the potential pitfalls of entering into a strategic partnership with an engineering consulting firm. They discuss high turnover, corporate knowledge drain, hidden overheads, and temporary workers, any of which can compromise the promise of savings. The EDC model includes hidden overheads such as the cost of accommodating the offshore employees working domestically, as Acme is using an internship program which brings workers from India to the U.S. for training. Once trained, they can take knowledge back with them and teach others that will be working on the engineering programs offshore. Some of these costs, such as training and travel, have been included in the EDC model. Kennedy and Whittaker conclude that "the decision driver for entering into the arrangements seems to be primarily ideological and is initiated by a directive from upper management with little or no accompanying economic rationale. The possibility of negotiated lower hourly rates provides some justification, but the complexity of modern organizations makes it very difficult to predict or even analyze the outcome of operational changes."

Schniederjans and Zuckweiler (2004) demonstrate the use of a risk factor when dealing with outsourcing. In their case study of Goodyear Corporation, a change of one tenth of one percent in currency valuation between the dollar and the peso resulted in a change to the solution of their model. Without having a risk factor in the model, the decision to outsource production to Mexico would not have been the optimal solution. This illustrates that "very small changes in a single parameter can result in totally different solutions." The sensitivity analysis done with the EDC model of our study will examine the effect of the fixed cost being adjusted. This analysis will show whether the optimal recommendation would remain intact if these costs were not taken into account.

Sehgal, *et al* (2010) recognize that there is far more than mere labor cost involved in the decision to outsource engineering, as they identify and discuss five critical factors for a successful offshore engineering initiative. Lynn and Salzman (2009) examine the potential consequences for multinational corporations and their home countries of the recent pattern of offshoring advanced engineering and dispersing core activities.

While the previous research cited above has provided components and direction for the model presented in this paper, none of them cover all of the requirements needed for the EDC model. Specifically, how to handle sending either an entire program, or none of the program, offshore has not been incorporated into any of these previous models. This paper will ensure that each program is able to retain its integrity or 'wholeness' either domestically or offshore.

Assumptions

Several assumptions need to be made explicit regarding the various resources available. The first is that all three of the resource types have the same productivity and skills. This also leads to the assumption that if work is sent offshore to be completed, it is done correctly with no quality or re-work issues. This is a rather large assumption for this model.

Since Acme began to send work offshore in fiscal year 2005, there has been a learning curve to be addressed. There are associated costs with starting up this relationship. These hidden overhead costs will be presented as fixed costs. There is an on-site coordinator responsible for communicating Acme's requirements back to India. Extensive training needs to be provided for learning the systems and standards. Communication costs will also be included in these fixed costs. These costs include travel, conference calls, data transfer, and managers preparing the statement of work for these programs. Table 1 shows the fixed costs recognized by this model.

Table 1: Annual Fixed Cost Calculation

		Manager	**Rep**	**Offshore**
Hourly Rates		\$92.30	\$50.36	\$35.00
Description		**# People**	**Hours/Yr**	**Cost**
On-Site Coordinator		1	2000	\$70,000.00
Project Mgr		1	500	\$46,150.00
Training:	Orientation	3	80	\$8,400.00
	Orientation Trainer	1	80	\$7,384.00
	BOM	1	80	\$2,800.00
	BOM Trainer	1	80	\$7,384.00
	Welcome Meeting	3	1	\$105.00
	Mgr Support	3	1	\$276.90
	Lunches	3	10 @ \$10	\$300.00
	Dept. Lunches	5	5 @ \$10	\$250.00
Conference Calls:	Phone Bill	\$.06/min	150	\$540.00
	Mgr Support	3	50	\$13,845.00
Travel:	Plane			\$5,000.00
	Hotel		10 @ \$130	\$1,300.00
	Meals		10 @ \$30	\$300.00
Data Transfer:	Rep Support	1	50	\$2,518.00
Statement of Work:	Mgr Support	3	8	\$2,215.20
			Total Cost	\$161,384.10

The hourly rates shown are fully burdened, standard rates used by Acme for accounting purposes. Engineers and designers at EDC belong to the United Steel Workers Union (USW). The pay rate for them ($50.36) includes the average union wage, benefits, and overhead. The offshore rate is higher in this calculation than the standard offshore rate. This is because a higher contract pay scale is used for offshore representatives that are working at EDC. No additional overhead costs were included due to the offshore representatives working at EDC. Overhead cost estimates could have been made to include office space, computer usage, additional CAD software licenses required, electricity costs, etc. The project manager is responsible for all offshore outsourcing. Only 500 hours of his time were used because he also oversees the outsourcing for the Hydraulic, Electrical, and Technical Development Groups (2000 hrs/yr X .25). The 2000 hours represents 40 hours per week for 50 weeks. The training figures show the cost effects for the various training classes, meetings, as well as paid lunches. It is assumed there will need to be three hours of conference calls per week for fifty weeks (150 hrs). In addition, three managers attend weekly hour-long conference calls to track offshore program progress. The travel costs shown in Table 1 represent one trip for an Acme employee to India to facilitate training and the communication of expectations. The costs were based on actual costs incurred on a previous benchmarking trip to India. In order to design products offshore, Internet data transfer is critical. The data transfer costs are only shown for one USW represented employee to spend one hour per week on data transfer. The costs associated with setting up the computer systems, as well as the actual transaction costs for each transfer, were not included in this calculation. A statement of work needs to be developed in order to communicate the requirements to the offshore resources. For fixed cost purposes, it was assumed that twenty-four hours would be used for managers to create the statement of work.

One element that will not be included is the costs associated with selecting the company in India. There were several trips to India by Acme executives to vet the possible companies. The costs of preparing the contract will also not be included. The fixed cost amortization is assumed to be over the first year of the contract (fiscal year 2005).

The pay rate for the three different resources is assumed to be constant over the entire year, and no overtime shall be used for these programs. For purposes of the fixed cost calculation of the previous Table 1, the manager's labor rate is also needed. The following rates are fully burdened. They include salary, benefits, as well as overhead.

Table 2: Labor Rates

	$/Hour
International Manager	$92.30
USW Represented	$50.36
In-house Contractor	$37.67
Offshore Resource	$25.00

For planning purposes, overtime is used only for unplanned events to keep the programs on schedule. These events may include attrition, loss of resources due to sickness or injury, or program scope creep. Scope creep is often due to not knowing the full requirements of a program during the planning phase.

This model will only explore requirements for new product programs. For efficiency, an entire program will be completed either domestically or in India. This model will not allow part of a project to be done at EDC, while another part of it is sent offshore. The staff size for working on these new product programs domestically is predetermined and no layoffs or firings will happen during the year. The current staff size of seventeen USW represented employees will not diminish. If this were not a requirement, it is likely that because of the reduced labor cost, all of the programs would be done offshore. One could argue that developing new products is a core competency at Acme Machine Works Corporation. Core competencies are specific skills the company has or must have to create unique value for customers. Large programs at Acme tend to be for new models of excavator attachments that certainly create value for customers. For purposes of this model, all programs that require 700 or more hours during any month will be considered a core competency and be done domestically. While the domestic resource pool size is predetermined, it can grow throughout the year to meet peak demand, as long as the number of people at the beginning of the fiscal year does not decrease. This increase can happen by additional hiring of in-house contractors or temporarily transferring a person from another group to help during the peak demand periods.

The fiscal year starts in November and runs through October. There are twelve distinct periods (months) utilized by Acme for program planning at the beginning of the year. Although the months have nearly the same hours available to work, Acme has developed a planning model for available productive hours by month. This planning tool incorporates holidays, vacations, absences, organizational meetings, as well as other non-productive time to come up with productive resource hours available to work on the various programs at EDC. There is a holiday shut down at Christmas that is also accounted for. A total of 1731 hours will be used to represent the total yearly hours available. They will be allocated each month per Table 3.

Table 3: Fiscal Year - Available Productive Hours per Employee

Fiscal Month	Paid Hrs W/O O.T.	Non-Program Hours						Program Hours
		Holidays	Vacation	Absence	Org Mtgs	Indirect	Total	
NOV	176.0	24.0	13.3	3.5	1.5	2.0	44.3	132
DEC	184.0	56.0	18.9	3.1	1.5	2.0	81.5	103
JAN	168.0	8.0	7.2	4.4	1.5	2.0	23.1	145
FEB	160.0	0.0	5.9	4.0	1.5	2.0	13.4	147
MAR	184.0	8.0	8.5	4.4	1.5	2.0	24.4	160
APR	168.0	0.0	10.1	4.4	1.5	2.0	18.0	150
MAY	176.0	8.0	12.1	3.5	1.5	2.0	27.1	149
JUN	176.0	0.0	14.3	3.1	1.5	2.0	20.9	155
JUL	168.0	8.0	21.3	3.0	1.5	2.0	35.8	132
AUG	184.0	0.0	16.0	3.1	1.5	2.0	22.6	161
SEP	176.0	8.0	10.6	4.0	1.5	2.0	26.1	150
OCT	168.0	0.0	12.8	3.5	1.5	2.0	19.8	148
Total	**2088.0**	**120.0**	**151.0**	**44.0**	**18.0**	**24.0**	**357.0**	**1731.0**

The same total of 1731 hours will be used for offshore resources as well. However, they will be distributed equally each month. This was done to simulate a constant availability of these

resources. Moreover, other people can fill in for these resources during vacations and absences; the offshore resources are not subject to holiday shutdowns and the identical vacation schedule.

Each new product program at EDC has unique hourly requirements. Table 4 details the hours that will be used in this model by each of six programs ('A' through 'F'). Programs that require 700 hours or more in any month will be done at EDC; based on this requirement, Program A, B, and C will not be included in the program variables that can possibly be sent offshore.

Table 4: Exterior Body New Product Program Requirements (Hours/Month)

Program	Total Hrs	Nov-04	Dec-04	Jan-05	Feb-05	Mar-05	Apr-05	May-05	Jun-05	Jul-05	Aug-05	Sep-05	Oct-05
A	13545	1,064	896	1,064	1,120	1,128	1,428	1,344	1,137	1,120	1,196	1,008	1,040
B	12066	1,634	1,280	1,400	1,160	880	756	756	840	800	920	840	800
C	5278	670	600	700	700	451	341	341	359	322	378	341	60
D	2539	70	56	60	120	138	131	52	350	318	365	450	429
E	2007	60	80	60	96	111	106	60	257	234	269	345	329
F	1739	43	16	40	120	138	131	42	247	224	258	236	224

Acme managers allocate the total number of hours needed per month between project engineers and designers/modelers. Depending on the scope and schedule of the program, additional resources may need to be dedicated to a specific program. However, people can work on a program for a period of time and then work on another program during the year to supply this flexibility of needed resources. Because of this shifting of resources, Acme utilizes a "Full Time Equivalent" (FTE) approach to resource planning. When budgeting, managers can allocate a percentage of an FTE to a particular program rather than budget for one person when there is not enough demand. For example, Program 'F' in December only requires 16 hours for the entire month. Using the 103 available hours from Table 3 for December, the requirement would only be 0.16 FTE. Therefore, this model will use <u>continuous</u> valued variables to represent FTE people rather than counting integers. The number of Full Time Equivalents is to be no less than 17 throughout the year. Non-negativity is also assumed for all of the variables.

The Conceptual Model

An overview of the model's design is offered by the following conceptual statements:

Minimize Costs (depicted as $\Sigma X_{ip} + \Sigma X_{ipt} + F_i X_{ifc} + \Sigma C_r H_{ipt}$)
subject to
$X_{dp} + X_{op} = 1$ (mutually exclusive requirement for Programs to be done domestically or offshore)
$X_{dpt} + X_{opt} = 1$ (mutually exclusive requirement for each Program for all time periods *t*)
$\Sigma X_{ipt} - 12X_{ip} = 0$ (insures that if any $X_{ipt} = 1$ then $X_{ip} = 1$)
$\Sigma H_{ipt} + M_p X_{ip} \leq 0$
$HE_{pt} \geq Y_{pt}$
$HM_{pt} \geq Y_{pt}$
$HE_{pt} + HM_{pt} - H_{ipt} = 0$
$P_{ipt} - C_{ht}(\Sigma C_r H_{ipt}) = 0$
X_{ip} , $X_{ipt,}$, X_{ofc} are binary {0,1} and all variables are non-negative

where i = where design is produced (domestic or offshore);
p = engineering program designation;
t = time period (months of fiscal year 2005);
r = resource (represented, offshore, and in-house contractor);
o = engineering program done offshore;
d = engineering program done domestically;
X_{ip} = Binary decision variable for sending entire program p to i or not;
X_{ipt} = Binary decision variable for ensuring entire program p is sent to i or not;
F_i = Fixed Costs incurred by producing design at i;
X_{ifc} = Binary decision variable for fixed cost at location i;
C_r = Hourly labor cost for resource r;
H_{ipt} = Hour worked at i on program p during time period t;
M_p = Number greater than the hours for program p could ever be;
HE_{pt} = Project engineer hour requirements for program p during time period t;
HM_{pt} = Designer/Modeler hour requirements for program p during time period t;
Y_{pt} = Hour requirements for program p during time period t;
P_{ipt} = Full Time Equivalent at location i for program p during time period t;
C_{ht} = Coefficient for Full Time Equivalent per hour for time period t

The Operational Model: Variable Description

There are a total of 343 variables included in the EDC model. Seventy nine of them are binary variables with the first 78 of these associated with a specific program, at a specific location and in a specific month. A value of one indicates that the program will be done at the designated location and during the designated month; otherwise it will not be done there & then. The first character of all binary variables is an X. The second character of such variables signifies where the program will be done (O for offshore and D for domestic). The third character of the binary variables signifies the program designation (D = Program D, E = Program E, and F = Program F). If there is a fourth character in the binary variables, it signifies the month of the fiscal year (1 = November, 2004, 2 = December, 2004, 3 = January, 2005, etc.). For example, XDD6 is a binary variable for executing program D domestically in April 2005. When there is no fourth character, the binary variable signifies the entire program, without regard to month. The variable XOFC is the remaining binary variable in the model. This stands for a binary offshore variable where the 'FC' signifies Fixed Cost. This variable will be used to trigger the fixed cost associated with doing a program offshore.

The remaining 264 are continuous valued variables. Included in this set are the following:

- 96 variables for figuring labor cost (hours worked each month for each program for offshore, direct, and in-house contractors);
- 144 program requirement variables (6 programs X 12 monthly hour requirements for each of project engineers and designers/modelers); and
- 24 variables for Full Time Equivalents (12 months for each of offshore and domestic).

For the continuous variables, the following notation applies: The first character is either an H or a P. The H designates hours and P represents Full Time Equivalents (People). The second character can be a D, O, E, M, or P. As with the binary variables, the D is for domestic and the

O is for offshore. The E signifies a project engineer working on one of the core competency programs (Program A, B, or C). The M signifies a designer/modeler working on one of the core competency programs. The P stands for program. This is used for program hour requirements. The third character designates the program (A = Program A, B = Program B, etc.) or a T signifies the total FTEs required. The final character in the continuous variables signifies the fiscal month. Like the binary variables, 1 is November 2004, 2 is December 2004, etc. This notation convention holds for all of the continuous variables except $HECC_i$ and $HMCC_i$ (where *i* = month). Here the third and fourth characters signify the core competency (CC) programs. Therefore, HMCC12 is the hours worked for domestic designers/modelers working on programs A, B, or C in October, 2005.

The Operational Model: Objective Function Description

The goal of this model is to minimize the aggregate cost in dollars of all programs undertaken. The cost is determined by adding all of the hours worked each month multiplied by the cost per hour. This is done for both possible locations. Because of the policy constraint not to send any programs with 700 or more hours required in any month offshore, programs A, B, and C have the hours removed from consideration to send offshore. However, the costs and resource requirements are accounted for in this model.

The 78 program-related binary values are also entered into the objective function in order to set their default value to zero. However, there are constraints in the model that cause half of them to be reset to one. Consequently, the objective function value will overstate cost by at least 39 dollars. When any program(s) is/are sent offshore, the objective function value will be further increased due to the activation of the fixed cost trigger variable.

The collective objective function appears as:

MINIMIZE
50.36HDD1 + 50.36HDD2 + 50.36HDD3 + 50.36HDD4 + 50.36HDD5 + 50.36HDD6 + 50.36HDD7 +
50.36HDD8 + 50.36HDD9 + 50.36HDD10 + 50.36HDD11 + 50.36HDD12 +
50.36HDE1 + 50.36HDE2 + 50.36HDE3 + 50.36HDE4 + 50.36HDE5 + 50.36HDE6 + 50.36HDE7 +
50.36HDE8 + 50.36HDE9 + 50.36HDE10 + 50.36HDE11 + 50.36HDE12 +
50.36HDF1 + 50.36HDF2 + 50.36HDF3 + 50.36HDF4 + 50.36HDF5 + 50.36HDF6 + 50.36HDF7 +
50.36HDF8 + 50.36HDF9 + 50.36HDF10 + 50.36HDF11 + 50.36HDF12 +
25HOD1 + 25HOD2 + 25HOD3 + 25HOD4 + 25HOD5 + 25HOD6 + 25HOD7 + 25HOD8 + 25HOD9 +
25HOD10 + 25HOD11 + 25HOD12 +
25HOE1 + 25HOE2 + 25HOE3 + 25HOE4 + 25HOE5 + 25HOE6 + 25HOE7 + 25HOE8 + 25HOE9 +
25HOE10 + 25HOE11 + 25HOE12 +
25HOF1 + 25HOF2 + 25HOF3 + 25HOF4 + 25HOF5 + 25HOF6 + 25HOF7 + 25HOF8 + 25HOF9 +
25HOF10 + 25HOF11 + 25HOF12 +
50.36HECC1 + 50.36HECC2 + 50.36HECC3 + 50.36HECC4 + 50.36HECC5 + 50.36HECC6 +
50.36HECC7 + 50.36HECC8 + 50.36HECC9 + 50.36HECC10 + 50.36HECC11 + 50.36HECC12 +
37.67HMCC1 + 37.67HMCC2 + 37.67HMCC3 + 37.67HMCC4 + 37.67HMCC5 + 37.67HMCC6 +
37.67HMCC7 + 37.67HMCC8 + 37.67HMCC9 + 37.67HMCC10 + 37.67HMCC11 + 37.67HMCC12
+
XDD + XOD + XDE + XOE + XDF + XOF + XDD1 + XOD1 + XDE1 + XOE1 + XDF1 + XOF1 +
XDD2 + XOD2 + XDE2 + XOE2 + XDF2 + XOF2 + XDD3 + XOD3 + XDE3 + XOE3 + XDF3 +

XOF3 + XDD4 + XOD4 +XDE4 + XOE4 + XDF4 + XOF4 + XDD5 + XOD5 + XDE5 + XOE5 + XDF5 + XOF5 + XDD6 + XOD6 + XDE6 + XOE6 + XDF6 + XOF6 + XDD7 + XOD7 + XDE7 + XOE7 + XDF7 + XOF7 + XDD8 + XOD8 + XDE8 + XOE8 + XDF8 + XOF8 + XDD9 + XOD9 + XDE9 + XOE9 + XDF9 + XOF9 + XDD10 + XOD10 + XDE10 + XOE10 + XDF10 + XOF10 + XDD11 + XOD11 + XDE11 + XOE11 + XDF11 + XOF11 + XDD12 + XOD12 + XDE12 + XOE12 + XDF12 + XOF12 + 161384.1XOFC

The Operational Model: Constraint Development

For this mixed integer linear programming model, there are 292 constraints that are bundled into the following eleven groupings.

Mutually Exclusive Binary Variables: This group of 39 constraints ensures that a program cannot be done domestically and offshore, as they are mutually exclusive. Representative of this set of constraints is that for program D in April: XDD6 + XOD6 = 1

Binary Trigger Variables: This group of 6 constraints ensures that each of programs D, E, and F has to be done completely either domestically or offshore. If any of the variables for each month are equal to 1 then the variable for the whole program equals 1. Representative of this set of constraints is that for program D offshore: XOD1 + XOD2 + XOD3 + XOD4 + XOD5 + XOD6 + XOD7 + XOD8 + XOD9 + XOD10 + XOD11 + XOD12 - 12XOD = 0

Binary Fixed Cost Trigger: This constraint triggers the binary fixed cost variable if any of the programs (D, E, or F) are executed offshore. XOD + XOE + XOF - 3XOFC <= 0

Binary Hour Trigger Variables: The final group of 6 binary constraints links the hour requirements to the binary variables. If there are any hours worked on a particular program during any month, the binary variable has to become a 1. This then interacts with the earlier constraints to force the whole program to be done together. Representative of this set of constraints is that for hours offshore for program D: HOD1 + HOD2 + HOD3 + HOD4 + HOD5 + HOD6 + HOD7 + HOD8 + HOD9 + HOD10 + HOD11 + HOD12 - 2600XOD <= 0

Program Requirements Per Month: The next group of 144 constraints enforces the requirement to complete each program. The monthly hours from Table 4 above have been disaggregated into the component requirements for project engineers as well as designers/modelers for each of the six programs. These requirements are also allocated for each month. Representative of this set is the pair of requirements for program C in month the tenth month: HEC10 = 145 and HMC10 = 233.

Core Competency Program Hours – Project Engineer: The next set of 12 constraints add programs A, B, and C hours together to come up with how many "core competency" hours are required to be done by project engineers for any specific month. Representative of these 12 monthly constraints is that for the tenth month: HEA10 + HEB10 + HEC10 - HECC10 = 0

Core Competency Program Hours – Designer/Modeler: In parallel fashion**,** these 12 constraints add programs A, B, and C hours together to come up with how many "core

competency" hours are required to be done by designers/modelers. Representative of these 12 monthly constraints is that for the tenth month: HMA10 + HMB10 + HMC10 - HMCC10 = 0

Program D Hours, Program E Hours, and Program F Hours: The hours for programs D, E, and F are determined for each month in subsequent groups of 12 (36 total). The hours for project engineers are added to the designer/modeler hour requirements. These hours are either done domestically or offshore. Representative of this group of constraints is the following subset for the second month:
HED2+HMD2-HOD2-HDD2=0 and HEE2+HME2-HOE2-HDE2=0 and HEF2+HMF2-HOF2-HDF2=0

FTE per Month: This set of 12 constraints converts the hours into Full Time Equivalents. The available productive hours differ from month to month (see Table 3). The coefficients used for these constraints are generated as '1/available hours'. Representative of these constraints is that for the fifth month:
PDT5 - .00625HDD5 - .00625HDE5 - .00625HDF5 - .00625HECC5 -.00625HMCC5 = 0

Minimum Staff Size: This group of 12 constraints ensures there are no less than 17 FTE for any month. The constraint for the seventh month appears as: PDT7 >= 17

Offshore FTE per Month: The last set of 12 constraints calculates the Full Time Equivalents for offshore resources. The coefficient for this constraint was figured by taking the 1731 available hours per year and dividing that by twelve and taking the inverse of that number. Thus, the coefficient becomes 0.0069324 (=1/144.25) for each month. The specific relationship among variables for the seventh month is:
POT7-.0069324HOD7-.0069324HOE7-.0069324HOF7= 0

In sum, the mixed integer linear programming model is built with 343 variables and 292 constraints.

Solution - Original Model

Using the 'Branch and Bound' supplement to the Simplex algorithm to enforce the binary requirement, the optimal recommendation was found after 205 iterations. To minimize labor costs for fiscal year 2005, the Attachment Engineering Department at EDC should be to **keep all six engineering programs in-house**. The total labor cost of this plan would be $1,653,581 (1653620 – 39 @1 for the binary values included in the objective function). This is the minimum labor expense possible that will meet the six program requirements and will satisfy the assumptions made above. Table 5 below details the month-by-month resource requirements necessary to deliver all of the required work at minimal cost.

Surprisingly, this recommendation is <u>not</u> consistent with the direction that Acme took in 2005. Prior to the construction of this model, Acme had already contracted work for program D to be done in India as a result of a directive from the President of the Excavator Group. Given the results of this model, such a decision was evidently influenced by factors other than cost efficiency.

Table 5: EDC Results: Original Model			
	$161,384.10 Fixed Cost		
Fiscal Month	**Domestic FTE**	**Offshore FTE**	**Surplus Domestic FTE**
NOV	26.823076	0.000000	9.823075
DEC	28.902193	0.000000	11.902192
JAN	22.925629	0.000000	5.925629
FEB	22.558748	0.000000	5.558748
MAR	17.787500	0.000000	0.787500
APR	19.287630	0.000000	2.287630
MAY	17.415045	0.000000	0.415045
JUN	20.581879	0.000000	3.581879
JUL	22.861351	0.000000	5.861351
AUG	21.030447	0.000000	4.030446
SEP	21.467739	0.000000	4.467739
OCT	19.439890	0.000000	2.439889
Total Cost	**$1,653,581.00**		

Sensitivity Analysis

Due to the use of the 'Branch and Bound' approach to Integer Linear Programming, the automated post-optimality analysis of 'shadow prices' and range analysis is simply not forthcoming. Thus, any insight regarding the cause and effect of specific parameters on the recommendation must come from a deliberate approach of 'revise and resubmit' with respect to the chosen parameter(s).

Because of the large amount of fixed cost assumed for this model, and the fact that the hourly labor costs are already negotiated for the year, the sensitivity analysis will focus on changes in the fixed cost parameter. There were already labor contracts with the USW in place for the following year. Also, the contract for the company in India had already been negotiated. With the $161,384.10 fixed cost, the model revealed the optimum recommendation to be to execute all six programs at EDC. However, how might the recommendation change if the fixed cost were substantially less or even nil? Would such a reduction in burden change where a specific program should be done?

The first permutation was to see what the effect would be without any fixed cost. If these costs were ignored, would it make sense to outsource programs to India? The fixed cost coefficient was removed and the model was re-submitted for solution. In this situation, XDD, XOE, and XDF all equal one. This means the optimum decision, without any offshore fixed cost, would be to send program E offshore and do programs D and F domestically. This would result in a $50,897 dollar savings for fiscal year 2005. The model was then revised and re-submitted again with the fixed cost just below this cost savings ($50,895) to confirm that the recommendation would remain the same, which it did.

The final permutation used was to set the fixed cost at $50,900, moreover, just slightly in excess of the dollar savings identified above. This level of fixed cost did cause the optimum recommendation to change back to executing all six programs domestically.

Table 6 below summarizes and compares the results of these permutations based on the assumed value of fixed costs.

Table 6: Comparative EDC Results

	Original Run		**Sensitivity Analysis**					
	$161,384.10 Fixed Cost		**No Fixed Cost**		**$50,895.00 Fixed Cost**		**$50,900.00 Fixed Cost**	
	Location		**Location**		**Location**		**Location**	
Program	**Domestic**	**Offshore**	**Domestic**	**Offshore**	**Domestic**	**Offshore**	**Domestic**	**Offshore**
XDA	**1**		**1**		**1**		**1**	
XOA		**0**		**0**		**0**		**0**
XDB	**1**		**1**		**1**		**1**	
XOB		**0**		**0**		**0**		**0**
XDC	**1**		**1**		**1**		**1**	
XOC		**0**		**0**		**0**		**0**
XDD	**1**		**1**		**1**		**1**	
XOD		**0**		**0**		**0**		**0**
XDE	**1**		**0**		**0**		**1**	
XOE		**0**		**1**		**1**		**0**
XDF	**1**		**1**		**1**		**1**	
XOF		**0**		**0**		**0**		**0**
Fiscal Month	**Domestic FTE**	**Offshore FTE**	**Domestic FTE**	**Offshore FTE**	**Domestic FTE**	**Offshore FTE**	**Domestic FTE**	**Offshore FTE**
NOV	26.823076	0.000000	26.368576	0.415944	26.368576	0.415944	26.823076	0.000000
DEC	28.902193	0.000000	28.117872	0.554592	28.117872	0.554592	28.902193	0.000000
JAN	22.925629	0.000000	22.511808	0.415944	22.511808	0.415944	22.925629	0.000000
FEB	22.558748	0.000000	21.905659	0.66551	21.905659	0.66551	22.558748	0.000000
MAR	17.787500	0.000000	17.093750	0.769496	17.093750	0.769496	17.787500	0.000000
APR	19.287630	0.000000	18.580929	0.734834	18.580929	0.734834	19.287630	0.000000
MAY	17.415045	0.000000	17.012384	0.415944	17.012384	0.415944	17.415045	0.000000
JUN	20.581879	0.000000	18.923716	1.781627	18.923716	1.781627	20.581879	0.000000
JUL	22.861351	0.000000	21.088800	1.622182	21.088800	1.622182	22.861351	0.000000
AUG	21.030447	0.000000	19.359688	1.864816	19.359688	1.864816	21.030447	0.000000
SEP	21.467739	0.000000	19.167624	2.391678	19.167624	2.391678	21.467739	0.000000
OCT	19.439890	0.000000	17.216837	2.28076	17.216837	2.28076	19.439890	0.000000
Total Cost	**$1,653,581.00**		**$1,602,684.00**		**$1,653,578.00**		**$1,653,581.00**	

Conclusions and Directions for Further Research

Given the program requirements for fiscal 2005, the Attachment Group at Acme Machine Works Corporation should conduct all six programs in-house. Even ignoring the fixed cost penalties, it would still only send a very small program (Program E in this case) to India without reducing the staff size at EDC.

This model was constructed without overtime being utilized as a resource for meeting the program demand. Pinker and Larson (2003) explore the use of overtime as a contingent resource. Their approach could be taken with this model to potentially open up more flexibility management.

Another area for future research would be to add inefficiencies into the mix. As stated earlier, there is a learning curve that has to be overcome to efficiently outsource programs offshore. Even among direct and in-house contractors, not everyone has the same skills and abilities. One could add an efficiency factor to this model.

Kennedy and Whittaker (2002) illustrate the high turnover rate in their case study. Within two years of entering into a strategic partnership, their case firm decreased its direct engineering employees from 22 to 1. This affect of losing experience could also be examined in the EDC model.

While hard to quantify, a risk factor associated with outsourcing offshore could be incorporated into this model. Schniederjans and Zuckweiler (2004) mentioned economic, political, as well as cultural risk factors in their research. These could be added to this model in much the same way the fixed cost variable was handled. If a program is outsourced offshore, a trigger variable for the specific risk factor could kick in.

Reflecting on the 'bigger picture' beyond the specifics of this case, we pose the question 'Can multinationals remain close to their customer base, retain and advance their domestic engineering talent, and maintain adequate control over project design if they outsource critical engineering capacity?' As this model has attempted to address, this may be a classic case of perspective; namely perceived short-run advantages versus actual longer term consequences.

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