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USE OF CRYSTAL BALL[®] TO PREDICT PROFITABILITY OF A REVERSE SUPPLY CHAIN

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ABSTRACT

Traditionally, firms have been spending significant time and money in improving their forward supply chains while ignoring their potential reverse supply chains. However, in today's competitive business environment, it is important that firms study the profitability and benefits of implementing a reverse supply chain while considering the uncertainties associated with the supply and composition of used products, disassembly time, recycling/remanufacturing time, and demand for recycled/remanufactured goods. In this paper, we demonstrate how a simulation software package, Crystal Ball[®], can be used to help a firm predict whether investment in a reverse supply chain is profitable with respect to a given product, while considering the aforementioned uncertainties. Crystal Ball[®] is a spreadsheet-based software package designed for predictive modeling, forecasting, Monte Carlo simulation and optimization.

INTRODUCTION

The growing population in this world of finite resources and disposal capacities has been continuously increasing its level of consumption [1]. This is fuelled by the growing desire of consumers to acquire the latest technology, both at home and in the workplace, along with the rapid technological development of new products. As a result, the world now faces a serious environmental problem: used products which are discarded prematurely. To tackle this problem, many an original equipment manufacturer (OEM) today is obligated by the local government to engage in a reverse supply chain, which is a series of activities required to collect a used product from a consumer and reprocess it (used product) to either recover its left-over market value or dispose it of [2 – 4]. Moreover, many third-party companies collect used products solely to make profit. These companies select only those used products for which revenues from recycle or resale of the products' components are expected to be higher than the costs involved in collection and reprocessing of used products and in disposal of waste [5, 6]. To this end, in this paper, we propose a cost-benefit function and demonstrate how Crystal Ball[®] can be used to predict the profitability with respect to a given used product [7].

METHODOLOGY

In this section, first, the nomenclature used in formulating the cost-benefit function is given. Then, the cost-benefit function is formulated. Finally, using a numerical example, we demonstrate how Crystal Ball[®] can be used to predict the profitability with respect to a given used product.

Nomenclature

C_{df} disposal cost factor (cost per unit weight);

C_{dx}	disposal cost of product x ;
C_r	reprocessing cost per unit time;
C_{rf}	recycling revenue factor (revenue per unit weight);
C_{rpx}	total reprocessing cost of used product x ;
CC_x	collection cost of used product x ;
D_{xy}	disposal cost index of component y in used product x (0 = lowest, 10 = highest);
E_{xk}	sub-assembly k in used product x ;
m_{xy}	probability of missing component y in used product x ;
M_x	number of sub-assemblies in used product x ;
N_{xy}	multiplicity of component y in used product x ;
p_{xy}	probability of breakage of component y in used product x ;
P_{xy}	component y in used product x ;
PRC_{xy}	% of recyclable contents by weight in component y of used product x ;
R_{rcx}	total recycling revenue of used product x ;
R_{rsx}	total resale revenue of used product x ;
R_{rsxy}	resale value of component y in used product x ;
RC_{xy}	recycling revenue index of component y in used product x (0 = lowest, 10 = highest);
$Root_x$	root node of used product x ;
$T(E_{xk})$	time to disassemble sub-assembly k in used product x ;
$T(Root_x)$	time to disassemble $Root_x$;
W_{xy}	weight of component y in used product x ;
x	used product type;
X_{xy}	variable signifying selection of component y to be retrieved from used product x for reuse ($X_{xy}= 1$ for reuse, 0 for recycle);
y	component type;
Z	overall profit.

Cost-Benefit Function

The cost-benefit function for used product x consists of five terms: the total resale revenue (R_{rsx}), total recycling revenue (R_{rcx}), total reprocessing cost (C_{rpx}), total disposal cost (C_{dx}) and the collection cost. It can be written as:

$$Z = R_{rsx} + R_{rcx} - C_{rpx} - C_{dx} - CC_x \quad (1)$$

The terms in the function are described as follows:

Total resale revenue: R_{rsx} is influenced by the resale value of individual components of the used product (R_{rsxy}), the number of components (N_{xy}), the probability of breakage (p_{xy}) and the probability of missing components (m_{xy}). The revenue equation can be written as follows:

$$R_{rsx} = \sum_{j \in P_{xy} \in (Root_x)} \{ R_{rsxy} \cdot N_{xy} \cdot (1 - p_{xy} - m_{xy}) \cdot X_{xy} \} \quad (2)$$

Total recycling revenue: R_{rcx} is influenced by the percentage of recyclable contents in each component (PRC_{xy}), the weight of the components (W_{xy}), the recycling revenue index (RC_{xy}) which is a number in the range (1-10) representing the degree of benefit generated by recycling component of type y (the higher the value the more profitable it is to recycle), the number of components (N_{xy}), the probability of breakage (p_{xy}) and the probability of missing components (m_{xy}). The recycling revenue equation can be written as follows:

$$R_{rcx} = \sum_{j \in P_{xy} \in (Root_x)} \{ PRC_{xy} \cdot W_{xy} \cdot RC_{xy} (N_{xy} (1 - m_{xy}) - N_{xy} (1 - p_{xy} - m_{xy}) X_{xy}) \} * C_{rf} \quad (3)$$

Total reprocessing cost: C_{rpx} can be calculated from the disassembly time of the root node of the used product ($T(Root_x)$), the disassembly time of each sub-assembly in the used product ($T(E_{xk})$) and the reprocessing cost per unit time (C_r). The total reprocessing cost equation can be written as follows:

$$C_{rpx} = \left\{ T(Root_x) + \sum_{k=1}^{M_x} T(E_{xk}) \right\} \cdot C_r \quad (4)$$

Total disposal cost: C_{dx} can be calculated from the disposal cost index (D_{xy}) which is a number in the range (1-10) representing the degree of difficulty in disposing component y of used product x (the higher the number, the more difficult it is to dispose), the percentage of recyclable contents in each component (PRC_{xy}), the weight of the components (W_{xy}), the number of components (N_{xy}), the probability of breakage (p_{xy}), the probability of missing components (m_{xy}) and the disposal cost factor (C_{df}). The disposal cost equation can be written as follows:

$$C_{dx} = \sum_{j \in P_{xy} \in (Root_x)} \{ D_{xy} \cdot W_{xy} \cdot (1 - PRC_{xy}) \cdot (N_{xy} (1 - m_{xy}) - N_{xy} (1 - p_{xy} - m_{xy}) \cdot X_{xy}) \} \cdot C_{df} \quad (5)$$

Collection cost: CC_x is the average cost of collecting used product x from the consumers.

Use of Crystal Ball®

Two used products (1 and 2) are considered in this numerical example (see Figures 1 and 2).

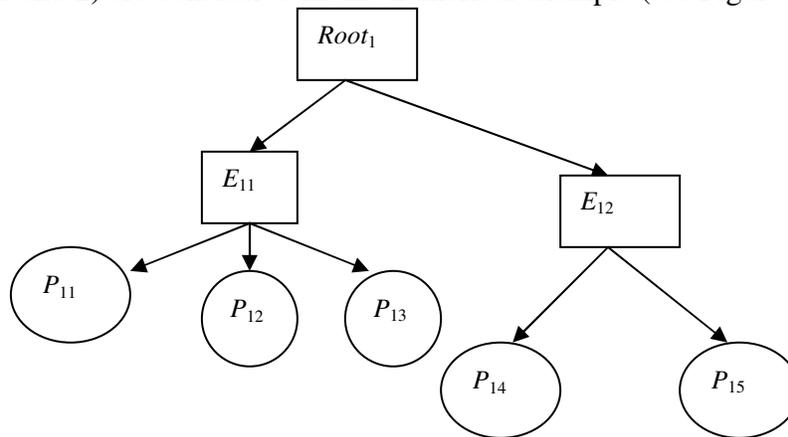


Figure 1. Structure of Used Product 1

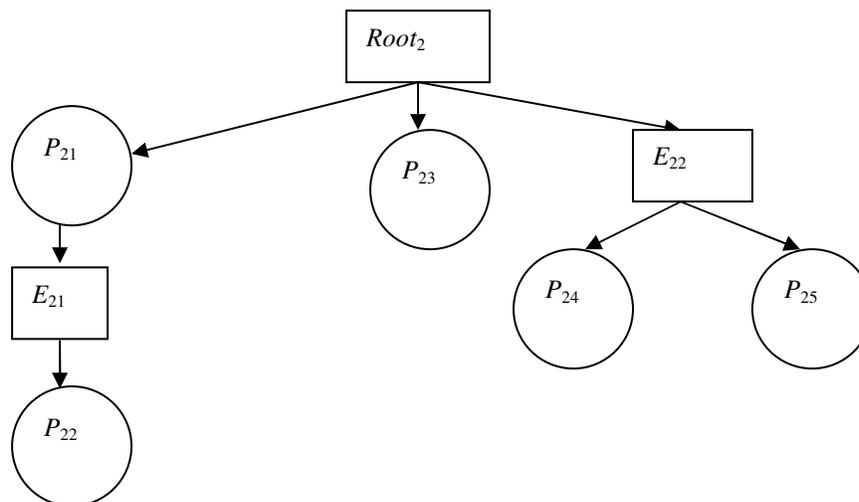


Figure 2. Structure of Used Product 2

The data required to implement the model for the products are shown in Tables 1 and 2, respectively. Notice that the resale value (R_{rsxy}) of each component is assumed to be triangularly distributed ((a, b, c) where a is the pessimistic estimate, b is the most likely estimate, and c is the optimistic estimate) and the % of recyclable components by weight (PRC_{xy}) is assumed to be normally distributed ((m, s) where m is the mean and s is the standard deviation).

Table 1. Data for Used Product 1

Part	R_{rs1y}	N_{1y}	W_{1y}	R_{c1y}	PRC_{1y}	D_{1y}	p_{1y}	m_{1y}	X
P_{11}	(8, 10, 12)	4	3	7	(0.75, 0.02)	3	0.02	0	0
P_{12}	(1, 2, 3)	2	2.5	9	(0.60, 0.01)	2	0.05	0	1
P_{13}	(2, 3.75, 5)	1	5	5	(0.50, 0.03)	6	0	0.5	1
P_{14}	(3, 5, 7)	5	7	3	(0.70, 0.05)	1	0.1	0.3	0
P_{15}	(1, 3, 6)	6	4	6	(0.40, 0.02)	7	0.4	0.02	1

Table 2. Data for Used Product 2

Part	R_{rs2y}	N_{2y}	W_{2y}	R_{c2y}	PRC_{2y}	D_{2y}	p_{2y}	m_{2y}	X
P_{21}	(1, 2.5, 4)	7	4	5	(0.40, 0.02)	2	0	0.05	1
P_{22}	(3, 5, 6)	9	1	6	(0.35, 0.01)	6	0	0.1	1
P_{23}	(2, 3, 5)	1	3	2	(0.70, 0.03)	8	0.1	0	1
P_{24}	(0.1, 0.5, 3)	2	4.5	8	(0.80, 0.05)	5	0.15	0.2	1
P_{25}	(1, 2, 4)	2	5	7	(0.25, 0.02)	7	0.1	0.25	0

Also, $CC_1 = 25$, $CC_2 = 40$, $C_{rf} = 0.5$, $C_r = 0.8/\text{min}$, $C_{df} = 0.25/\text{lb}$, $T(\text{Root}_1) = 6\text{min}$, $T(\text{Root}_2) = 4\text{ min}$, $T(E_{11}) = 3\text{ min}$, $T(E_{12}) = 5\text{ min}$, $T(E_{21}) = 2\text{ min}$, and $T(E_{22}) = 4\text{ min}$.

Figure 3 shows the simulation output (distribution of overall profit) of Crystal Ball[®] for a run of 1000 trials for Product 1. Figure 4 shows the probability (90.66%) of achieving an overall profit of at least \$30 (a randomly selected threshold) for Product 1.

Similarly, Figure 5 shows the simulation output (distribution of overall profit) of Crystal Ball[®] for a run of 1000 trials for Product 2. Figure 6 shows the probability (0.08%) of achieving an overall profit of at least \$30 for Product 2.

Evidently, Product 1 is more economical than Product 2.

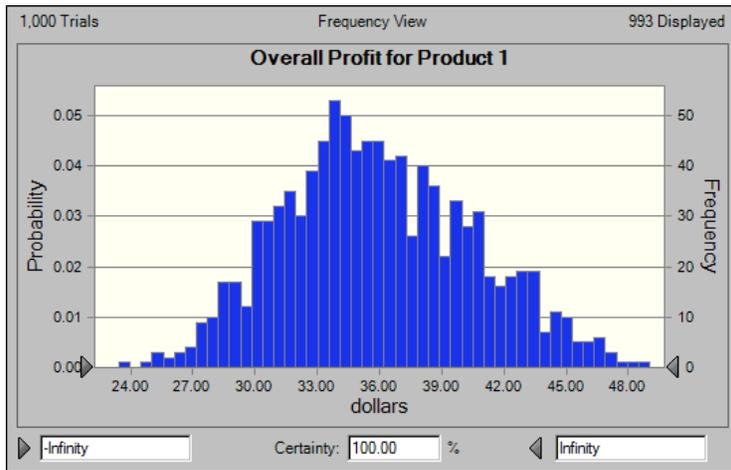


Figure 3. Distribution of Overall Profit for Used Product 1

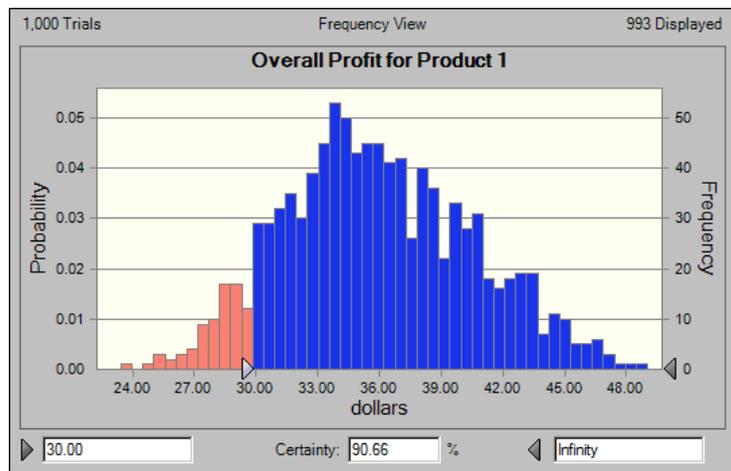


Figure 4. Probability (Overall Profit \geq \$30) for Used Product 1

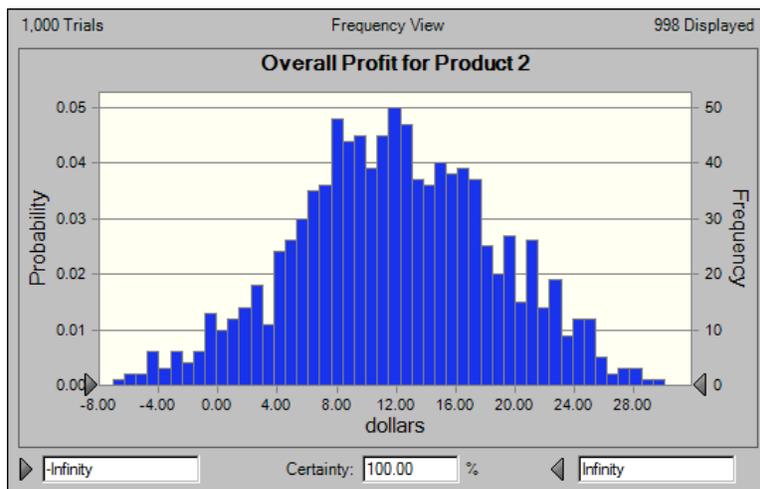


Figure 5. Distribution of Overall Profit for Used Product 2

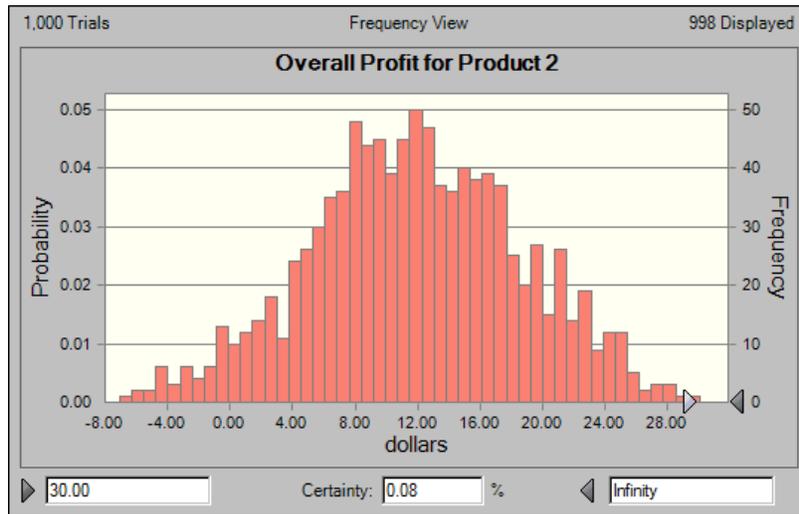


Figure 6. Probability (Overall Profit \geq \$30) for Used Product 2

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