Tracking System Evaluation and Performance Measurement: Embraer Case Study

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Report Abstract: The performance of supply chain tracking systems is the cornerstone for the effectiveness of many business operations. But often the managers might ask "How well is my tracking system performing?" or "How much money is the tracking system saving us per year?". This report provides a method to answer these questions through a step-by-step approach. We demonstrate the value of the method through a case study undertaken in Embraer S.A. The results show how the value of a tracking system and its overall performance can be assessed. The analysis of the results provides an insight into the determinants of the value of a tracking system.

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1. Introduction

This report proposes a tracking system audit method which can be used to measure the performance of a tracking system and the value it has for a company. The previous reports of the Aerospace-ID Programme white paper series on the Track and Trace theme [1-4] have revealed the potential of automatic identification (auto-id) technologies for enhancing track and trace effectiveness and proposed a way to assess the performance of a track and trace system in terms of the quality of information that it delivers. The method proposed in this report measures the performance of a tracking system in monetary terms. We demonstrate the use of the method with a case study at Embraer S.A.

1.1. What is a tracking audit method?

A tracking system audit method is a set of well-defined steps that one (hereafter referred to as 'the analyst') has to take in order to estimate the value that a tracking system is/will be delivering to a company and calculate the system's performance in an objective and normalized manner. It should be noted that we define 'tracking system' as an information system that aims at providing information about the ongoing location of products across a supply network [5]. The steps (followed in the method) define the data that should be collected for this purpose, the way that they should be processed and the way that the output metrics shall be calculated. This document presents a tracking system audit method.

1.2. Why audit a tracking system?

Monitoring the performance of the system is crucial as it enables the company to point out shortcomings that need to be addressed. Moreover, delivering a robust return on investment (ROI) study for future tracking systems has always been a difficult challenge for companies. The proposed method can be used to estimate, in monetary terms, the benefits that a tracking system can deliver to a company regarding the improved effectiveness of decisions. In a nutshell, the method can be used to answer the following questions:

- How well is my current tracking system performing?
- What is the value that out current tracking system is delivering per year?
- How much more money would a new/improved system save us per year?
- What exactly should we change in the system to save more money?

From an academic perspective, this paper provides a basis for modelling tracking information, taking into account its intrinsic uncertainty. Moreover, the proposed method provides a way to quantify the value of tracking information for the supply chain decision maker, as a function of its quality; it reveals the critical determinants of a tracking system that make it successful.

1.3. How can the tracking system audit method be used?

From an end user's point of view, the proposed method provides a way to monitor the performance of a tracking system and point out shortcomings that affect its effectiveness. Moreover, the method can provide valuable input to a Return on Investment (ROI) study, regarding the expected benefits that a new/improved system could deliver to the company.

From a solution provider's point of view, the suggested method can be used to point out a customer's special needs with regard to tracking information quality requirements and reveal opportunities for improvement. It can also identify the critical points of a successful tracking system implementation that would meet the customer's information requirements. Finally, as in the case of the end user, the method can provide input to an ROI study by estimating the expected benefits stemming from improved decision making based on tracking information.

2. The Tracking System Audit Method

This section presents the method for evaluating and measuring the performance of a tracking system. We first provide an overview of the method and we then analyze each of the steps required to produce its output.

2.1. Method overview

An overview of the tracking system evaluation and performance measurement method is shown in Figure 2.1. The method's steps follow these three stages:

- Input stage
- Problem analysis and performance assessment
- Output stage

The input stage defines all the steps that should be followed in order to collect the data for the analysis. These include data regarding the configuration of the supply chain, the nature of the decisions to be made and the associated costs. The problem analysis and performance assessment stage is the core of the assessment method, in which the data is processed according to some well defined rules in order to produce the output. Finally, the output stage defines how the system value and performance metrics should be calculated. Section 2.2 describes the aforementioned stages in detail.

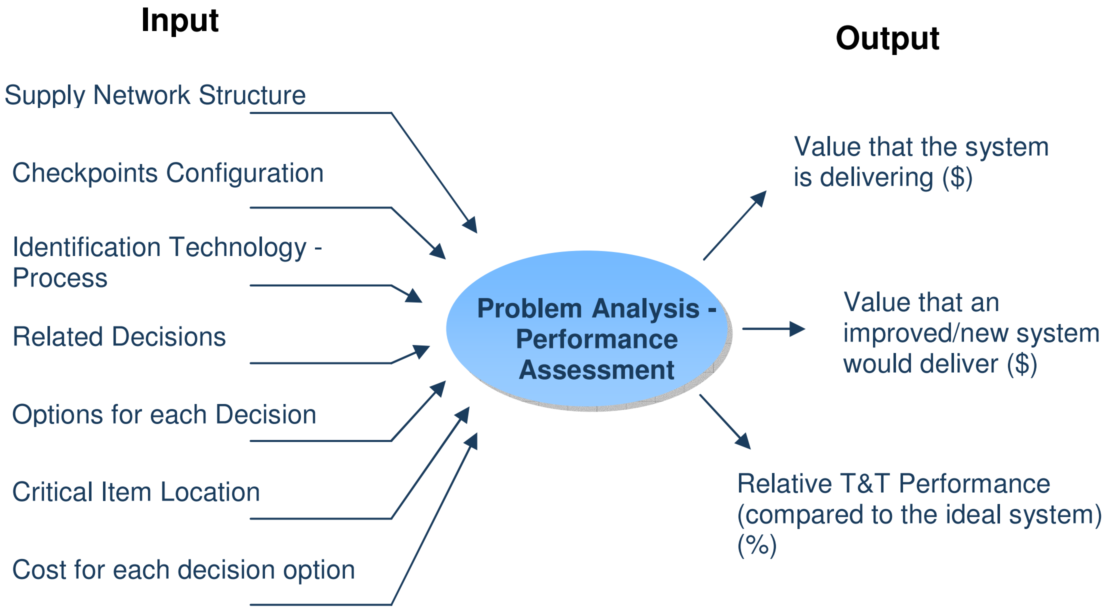

Figure 2.1: Tracking system performance measurement method overview

2.2. The audit method

2.2.1. Data input

2.2.1.1. Step 1: Supply network structure

The aim of the first step is to understand and record the structure of the supply network along with the flows of product in it. The analyst should have a good understanding of the nodes in the network and the way these are interconnected. Moreover, he should identify the possible routes that shipments might follow through the network.

2.2.1.2. Step 2: Checkpoints configuration

The aim of the second step is to identify all checkpoints c_i throughout the supply network. A checkpoint is a point where the location of an item is recorded as it moves across the supply network. This detection creates a detection record, which comprises of the triplet <product ID, location, timestamp> and is then stored in the system. It is important to record any type of checkpoint that would provide with product location information, including manual product scanning and booking into a system and not only checkpoints that use auto-id technologies. The quality of information that a checkpoint generates shall be captured in the next step. The output of this step should be set of locations in the network that have a checkpoint. We say that a tracking system sends an *information signal* y_i for a product with a specific ID if the product was last detected at checkpoint c_i. Figure 2.2 shows an example of checkpoints and the respective information signals across a supply chain.

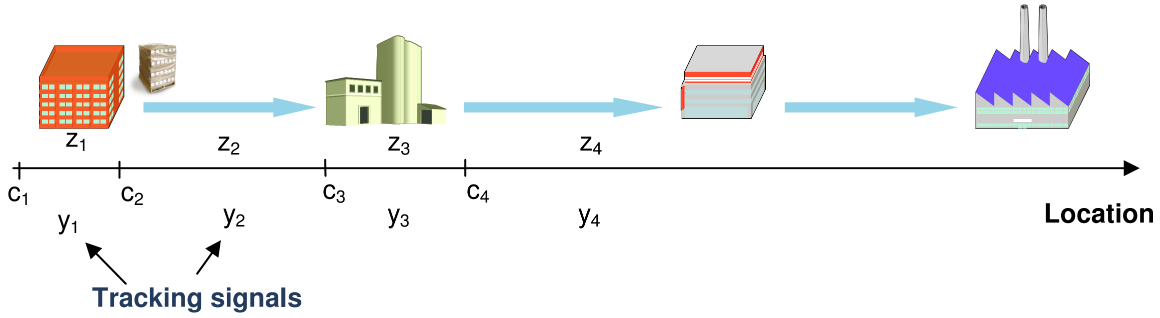

Figure 2.2: Example of checkpoints and information signals in a supply chain

2.2.1.3. Step 3: Product identification process at checkpoints

The aim of this step is to understand the way a product's identity is captured and recorded at each checkpoint. This includes the kind of the automatic identification technology used (if any) together with the associated error rate (percentage of misreads or missed reads). Moreover, the delay between the moment a product arrives at a checkpoint and the moment this is actually reflected by the tracking system should also be recorded. Finally, the analyst should record whether shipments are booked into the tracking system using package aggregation information or not. If so, the accuracy of aggregation information should be recorded. The aforementioned factors affect the quality of tracking information in the system, as analyzed in [2, 3, 6]. The output of this step will be used to determine the accuracy of the tracking system, which will be analyzed in Section 2.2.2.

2.2.1.4. Steps 4 and 5: Related decisions and decision options

Tracking information is used to support business decisions. The analyst should identify the decisions in which tracking information is used. For example, a business decision may be the shipping method, depending on the location of the item and whether it is regarded to be late or not.

For each of the identified decisions, the analyst should identify all available actions a_i that the decision maker should choose from. For example, for the shipping decision, as it will be shown in the case study of Section 3, the available actions might be:

a_1: Send shipment by ship

a_2: Send shipment by air

a_3: Send shipment by air and reschedule production line

2.2.1.5. Step 6: Critical product locations

Each action a_i will lead to a consequence depending on the location of the product in the supply chain. For example, if the decision maker decides to send the shipment by ship while the shipment is still at an early supply chain stage, then a probable consequence will be a delayed production. The aim of this step is to identify the location ranges that lead to the same consequence per action, for all possible actions. For example, assuming that a product should have reached the distribution centre, and we know that it has left the manufacturer, it makes no difference whether it is 3 km or 7 km away from the distribution centre. As long as it still hasn't reached the distribution centre, it is considered 'in transit'. Action a_1 will lead to delayed production for all locations between the manufacturer and the distribution centre. In the same way, action a_2 will lead to minor disruptions in production for all these locations and a_3 will lead to no production disruptions.

The above definition will define a set of critical product locations along the supply chain. We will call these payoff relevant states z_i, as all locations within a state lead to the same payoff per action, for all actions. In the example illustrated in Figure 2.2, the payoff relevant states can be the location ranges defined by the checkpoints, although this is not always the case.

Based on historical data, the analyst should record the chance that a product is in any of the identified payoff relevant states at the time of the decision. We will call this the *prior distribution* over the payoff relevant states. The sum of the recorded probabilities for all states should add up to one.

2.2.1.6. Step 7: Costs per decision option

The final step of the input stage aims at recording the costs for all combinations of the actions and payoff relevant states identified at steps 4–6. The output of this step should be a matrix with a number of columns equal to the number of possible actions a_i for the decision in question and a number of rows equal to the number of the payoff relevant states z_i. Each cell should have the cost that the company would incur, should the decision maker choose the respective action while the product is at the respective payoff relevant state. For example, if the product is a state z_1 and the decision maker chooses to ship it by sea, then the production will be severely delayed, which will result at an estimated cost of $100,000.

2.2.2. Data analysis

The evaluation of the system will be based on the expected costs of two cases: the case where the decision maker has no information available (and therefore makes his decision based on historical information) and the case where the decision maker has access to tracking information provided by the tracking system in question. Figure 2.3 shows a

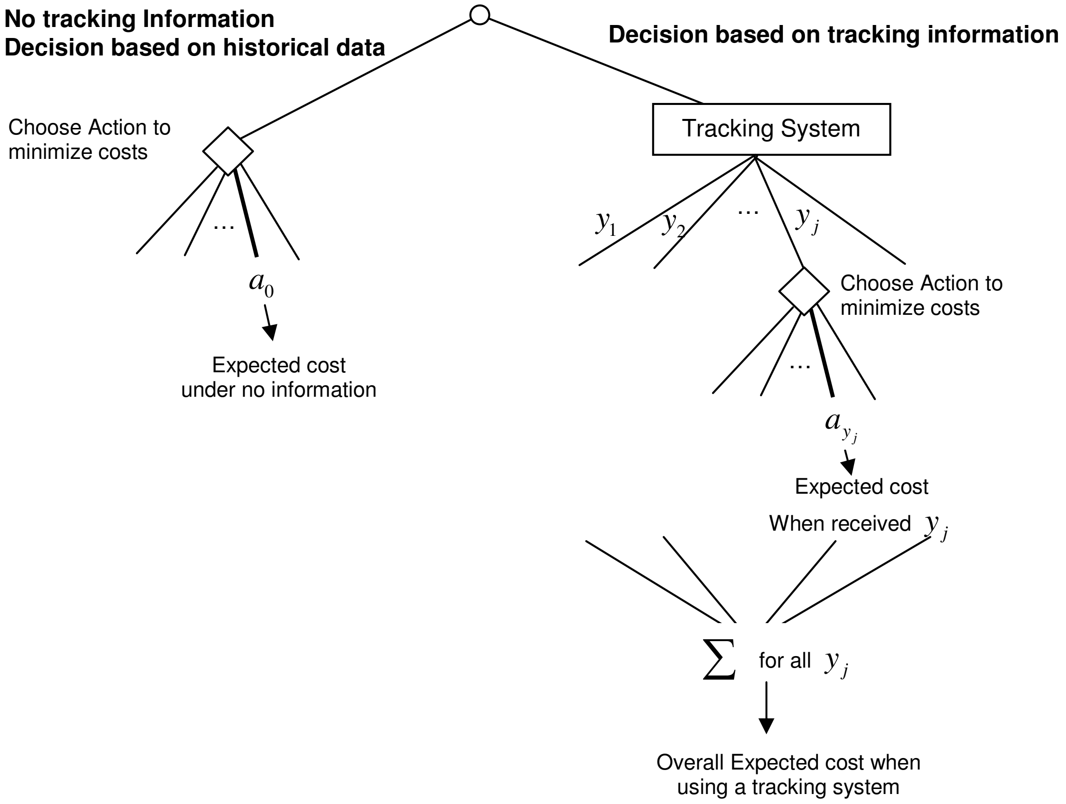

Figure 2.3: Calculation of expected costs in the cases of using historical information and tracking information for decision making

conceptual representation of the calculation of the expected costs for the cases of making a decision using historical information and using tracking information. In the next sub-sections we describe these calculations in detail.

2.2.2.1. Expected cost based on historical information

When no tracking information is available, the decision maker will choose his action based on historical information. Under rational reasoning, he will choose the action a_0 that maximizes his expected payoff (or minimizes his expected cost[1]).

$$a_0 = \arg\max_a \sum_i \text{cost}(z_i, a)\text{chance}(z_i) \qquad (2.1)$$

where $\text{cost}(z_i, a)$ is the cost per payoff relevant state per action (resulting from step 7) and $\text{chance}(z_i)$ is the chance that the product is at state z_i based on historical data (resulting from step 6). The expected cost based on historical information $\text{ExpectedCost}^{\text{H}}$ will be

$$\text{ExpectedCost}^{\text{H}} = \sum_i \text{cost}(z_i, a_0)\text{chance}(z_i) \qquad (2.2)$$

The example presented in Section 3 demonstrates the above calculation with actual numbers.

2.2.2.2. Expected cost based on tracking information

When tracking information is available, the decision maker will make his decision based on the information signal he receives. In order to calculate the expected cost the analyst should take the following three steps:

- Estimate the tracking system's accuracy
- Calculate the expected cost for each information signal
- Calculate the overall expected cost

Estimating the system's accuracy

The tracking system is not perfect, mainly because of problems during the product identification process which introduces errors in the detection records. Taking into account the characteristics of the identification process captured by step 3 of the input stage, the analyst should construct a matrix for all payoff relevant states and all information signals. The

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[1] Costs should be recorded as negative payoffs, for example -$1000

ji-th cell should contain the answer to the question "Given that the product is at state z_i ,what is the chance that the system will indicate signal y_j ?". In mathematical terms, this is the conditional probability of the system indicating signal y_j ,given that the product is at state z_i, $p(y_j|z_i)$. Kelepouris et al in [3] describe how this probability should be estimated. Table 3.3: (in Section 3) is an example describing the tracking system's accuracy in the case of Embraer.

Up to this point, the analyst should have recorded the prior distribution over the states $p(z_i) = \text{chance}(z_i)$ and the conditional distribution over the information signals $p(y_j \mid z_i)$. Combining these two, the analyst can calculate the likelihood that the decision maker will receive each information signal y_j

$$p(y_j) = \sum_i p(y_j \mid z_i) p(z_i) \tag{2.3}$$

Finally, using Bayes rule, the analyst can calculate the accuracy of the system in the form "Given that the tracking system indicates signal y_j, what is the chance that the product is at state z_i?". This will result in a second matrix, whose *ji*-th element will be the answer to the above question. This element is called the *conditional distribution over the states* and can be calculated as shown in (2.4).

$$p(z_i \mid y_j) = \frac{p(y_j \mid z_i) p(z_i)}{p(y_j)} \tag{2.4}$$

Table 3.4: on page 16 shows the conditional distribution over the payoff relevant states for the example of the Embraer case.

Expected payoff per information signal

When the decision maker receives information signal y_j (as a response to a tracking query), he will choose action a_{y_j} that maximizes his expected payoff (minimizing his expected costs). The chance of the product being at a state z_i, given that information signal y_j was received, will be given by the posterior distribution matrix resulting from (2.4). Following the above, the decision maker will choose action a_{y_j}

$$a_{y_j} = \arg\max_a \sum_i \text{cost}(z_i, a)\text{chance}(z_i \text{ given } y_j) = \arg\max_a \sum_i \text{cost}(z_i, a) p(z_i \mid y_j) \tag{2.5}$$

Therefore, when the decision maker receives information signal y_j, his expected payoff will be

$$\text{ExpectedPayoff}^{y_j} = \sum_i \text{cost}(z_i, a_{y_j}) p(z_i \mid y_j) \tag{2.6}$$

Overall expected payoff

Having calculated the expected payoff per information signal, the overall expected payoff will result by summing the expected payoffs for all information signals y_j , weighted by the likelihood $p(y_j)$ of receiving each of them. The overall expected payoff using the information provided by the tracking system will then be

$$\text{ExpectedPayoff}^{\text{TS}} = \sum_j p(y_j)\text{ExpectedPayoff}^{y_j} = \sum_j p(y_j) \sum_i \text{cost}(z_i, a_{y_j}) p(z_i \mid y_j) \quad (2.7)$$

2.2.3. Audit output stage

In this final stage of the audit, the analyst should use the results of the analysis stage to calculate the metrics that will reflect the value of the tracking system for the decision maker and the performance of the system.

2.2.3.1. Output 1: Value of the tracking system

The *gross value of the tracking system information* will result from the difference of expected payoffs in the case of decision using only historical information and the case where the decision maker uses tracking information.

$$\text{Gross Value of Information} = \text{ExpectedPayoff}^{\text{TS}} - \text{ExpectedPayoff}^{\text{H}} \quad (2.8)$$

Information comes at a cost. In the case of tracking information, this cost includes the cost of system infrastructure, administrative cost (for example phone calls to locate items in the supply chain etc.) and others. Let $C(I)$ denote the cost of information per decision instance. In that case the *net value of tracking information* for the decision maker will be

$$\text{Net Value of Information} = \text{ExpectedPayoff}^{\text{TS}} - \text{ExpectedPayoff}^{\text{H}} - C(I) \quad (2.9)$$

2.2.3.2. Output 2: Value of improved system

An improved tracking system would include better identification technologies at the checkpoints and possibly more checkpoints across the supply network. Both the above would provide more accurate and timely information to the decision maker. The change in information quality will be reflected by the revised posterior distribution matrix $p'(z_i \mid y_j)$ according to the new system specifications. Following that, the analyst should use the revised posterior distribution to calculate the new estimated value of information as described by (2.5)–(2.9). Section 3.2.2 demonstrates the impact of improved tracking information accuracy on the value of a tracking system.

2.2.3.3. Output 3: Relative tracking system performance

The final metric that the audit method produces is a measure of relative performance for the tracking system. In order to do that, we compare the value of the information that the system is delivering to the value of *perfect information.*

Perfect information occurs when the information system provides categorical direct messages that identify precisely and unequivocally the state that the item is in [7]. Under perfect information the number of information signals is the same with the number of the payoff relevant z_i states, and the posterior probability that a product is in a state z_i given the signal y_j is one, $p(z_i \mid y_j) = 1$. As a consequence, the posterior distribution matrix that reflects the perfect information accuracy, is an n×n matrix (n being the number of states), with all elements equal to zero expect for the ones in the main diagonal that are equal to 1 or 100%.

Let $I\uparrow$ denote perfect information. Similarly to the non-perfect information case, once the decision maker receives an information signal $y_j\uparrow$ he will choose action $a_{y_j\uparrow}$ that maximizes his expected payoff

$$a_{y_j\uparrow} \equiv \arg\max_a \sum_i \mathrm{cost}(z_i, a)\, p(z_i \mid y_j\uparrow) = \arg\max_a \mathrm{cost}(z_j, a) \tag{2.10}$$

The expected payoff under perfect information, following the same logic as in (2.7), will be

$$\mathrm{ExpectedPayoff}^{\mathrm{PI}} = \sum_j p(y_j\uparrow) \sum_i \mathrm{cost}(z_i, a_{y_j\uparrow}) \tag{2.11}$$

and the value of perfect information (assuming that perfect information always comes at no cost) will be

$$\text{Net Value of Perfect Information} = \mathrm{ExpectedPayoff}^{\mathrm{PI}} - \mathrm{ExpectedPayoff}^{\mathrm{H}} \tag{2.12}$$

Finally, we define a tracking system performance measure as the ratio of the value of information that the tracking system is delivering over the value of the perfect information for the same decision problem.

$$\text{Tracking System Performance} = \frac{\text{Net value of tracking information}}{\text{Net value of perfect information}} \tag{2.13}$$

Replacing recursively from (2.9) and (2.12) we can get a metric that reflects the performance of the tracking system in a 0 to 100 scale.

2.3. Summary

This section described in detail the tracking system audit method. The proposed method consists of three stages that the analyst has to go through in order to evaluate a tracking system. The first stage includes all the data gathering steps regarding the configuration of the supply network, the tracking system and the related decisions that information is used for. The second stage includes the data analysis, during which the analyst should calculate the expected payoffs (or expected costs) for the cases where the decision is based on historical tracking data or using tracking information. In the third stage the analyst should use the analysis results to calculate the value that the system is delivering to the decision maker (value of information) and an overall tracking performance metric, compared to the case of a perfect tracking system.

The next section demonstrates the use of the method in the context of a case study undertaken at Embraer S.A. The results show how the method can be used to monitor a tracking system's performance and drive improvements.

3. Case Study at Embraer S.A.

In this section we present the way the tracking audit method was applied in the case of the tracking application that Embraer uses to track inbound logistics. We analyze how the value of tracking information at Embraer was estimated and discuss the results of the study. It should be noted that all cost numbers in this report are fictitious, yet credible; these are used to demonstrate the use of the method in a realistic context.

3.1. The context of the study

The study focused on the inbound logistics operations at Embraer. Embraer is an aircraft manufacturer. The headquarters and factory are in Brazil. A large number of aircraft components are shipped from the US to Brazil. The components take the following route before reaching Embraer's factory in Brazil: the original equipment manufacturers (OEMs) in the US receive an order from Embraer, which is acknowledged by the OEMs and the material is prepared. A freight forwarder is then notified to pick the material and bring it to his distribution centre, where multiple orders may be consolidated into a shipment which is then shipped to Brazil. After being cleared in the customs, the material is picked up by a logistics provider and it is finally delivered at Embraer facilities.

Embraer needs to monitor the progress of shipments across the supply chain, since the time that these arrive at the factory directly affects the effectiveness of production and delivery times. Depending on the shipment progress, the logistics managers need to choose between different shipment options and take any necessary action regarding production scheduling in order to minimize costs and deliver aircrafts with minimum delays. The decision problem analyzed in the next sub-section provides more details on the above.

3.2. Applying the method

We shall demonstrate the use of the proposed method by applying it step-by-step in the Embraer case study.

3.2.1. Data input

Step 1: Supply network structure

As described in this section's introduction, the supply chain in question consisted of four partners. The OEMs, the freight forwarder, the customs and the Embraer factory. The material shipments flow in a linear supply chain until they reach the end of the chain, at Embraer facilities, as shown in Figure 2.2.

Step 2: Checkpoint configuration

Embraer's logistics managers have access to shipment tracking information through a number of different channels. A business message is sent to Embraer when a shipment is picked up by the freight forwarder. Also, Embraer is notified when a shipment is received at the freight forwarder and when it is shipped to Brazil. The aforementioned messages are either automatically communicated to Embraer's information systems or, in some cases, involve human action to resolve the location of a shipment (phone calls, fax, etc). According to the above, the location of the four checkpoints in Embraer's supply chain is depicted in Figure 2.2. This configuration of checkpoints creates a set of possible information signals that the logistics manager may receive when searching for a shipment.

y_1: Shipment with OEM and ready to ship

y_2: Shipment picked up, on the way to freight forwarder

y_3: Shipment arrived at freight forwarder

y_4: Shipment shipped to Brazil

The set of possible information signals is also shown in Figure 2.2.

Step 3: Product identification process

Shipments are identified using barcode technology, both at the OEMs and at the freight forwarder. However, the OEMs and the freight forwarder use different identification scheme and therefore stick different labels to shipments. This creates an additional burden and error source for Embraer when it comes to shipment tracking. The correct tracking number and scheme should be used to track a shipment at different stages of the supply chain. The matching process from one scheme to the other may also cause information inaccuracies. Moreover, the delays taking place during shipment identification (due to manual scanning) also cause information inaccuracies [2, 3]. Finally different pieces of material may be consolidated into one or more shipments. This aggregation information is also used to track shipments. As a consequence, the accuracy of the tracking system is subject to the quality of the aggregation information. All the above sources of possible inaccuracies result in the tracking system accuracy matrix, presented in the next sub-section.

Steps 4 and 5: Related decisions and decision options

The logistics managers need to plan the delivery of incoming material at Embraer, given a production schedule. It is clear that order delivery delays must be kept to a minimum, as they directly affect production and may cause production delays that result in significant penalties for the company. The decision that this analysis focused on was a *shipping method and scheduling* decision.

At the time that a shipment should have reached the freight forwarder, the logistics manager needs to choose one of the following options regarding its shipment method and whether any contingency action should be taken regarding production schedule

a_1 : Send shipment by sea

a_2 : Send shipment by air

a_3 : Send shipment by air and reschedule production

Depending on the location of the shipment at the time of decision, the manager will take one of the above actions.

Step 6: Critical item locations

In this step we need to identify the location ranges across the supply chain, for which each action leads to the same consequence. Due to the nature of the decision we studied, the decision consequence would change depending on whether the shipment is very late, is fairly late or on schedule. The discussion with the managers revealed that the critical location ranges are those shown in Figure 2.2. That is, if the shipment is still with the supplier (state z_1) then it is considered very late. A shipment on the way to the freight forwarder (state z_2) is consider late, whereas if a shipment is already with the forwarder (state z_3) or has already left his premises (state z_4), it is considered on schedule. As analyzed in section 2.2.1.5, for example, for all locations between the OEMs and the freight forwarder, each action leads to the same consequence (per action): a_1 will lead to some delay in production, a_2 will save the lost time and will cause no production problems and a_3 will save the lost time and will cause unnecessary production rescheduling. It should be noted that in this case the set of payoff relevant states z_i happen to be the same with the set of information signals. However, this is not always the case.

Based on historical data, the analysis and discussion with managers showed that at the time of decision, a shipment could be at any of the aforementioned states with the following chances: $p(z_1) = 5\%, p(z_2) = 40\%, p(z_3) = 40\%, p(z_4) = 15\%$. This information shall be used in the analysis stage to estimate the expected payoff of the decision using historical information.

Step 7: Cost per decision option

For each combination of payoff relevant state and action taken, we evaluate the cost of the consequence that the action will lead to. For example, if the shipment is still with the supplier and the manager decides to send it by sea, the shipment will be extremely late resulting in a cost of approximately $100.000. Table 3.1 shows the costs per action per shipment state.

		Action		
		a_1	a_2	a_3
Shipment Location	z_1	–$100100	–$71700	–$51700
	z_2	–$60100	–$11700	–$61700
	z_3	–$100	–$3400	–$56700
	z_4	–$100	–$3400	–$71700

Table 3.1: Costs per action per shipment location

3.2.2. Data analysis

Expected payoff using historical information

The logistics manager will choose the action that will minimize the expected cost, according to the expected shipment location, based on historical information. Table 3.2: describes the calculations for the expected cost per action using historical information, as defined by (2.1). Using the numbers of costs and prior distribution over the states z_i obtained from the previous stage, the optimum action, when using only historical information, is action a_2; the expected cost for the logistics manager in that case is $\text{ExpectedCost}^{\text{H}} = -\$10135$.

Action / State	a_1	a_2	a_3
z_1	5% ×(–$100100)	5% × (–$71700)	5% × (–$51700)
z_2	40% × (-$60100)	40% × (–$11700)	40% × (–$61700
z_3	40% × ($100)	40% × (–$3400)	40% × (–$56700)
z_4	15% × ($100)	15% × (–$3400)	15% × (–$71700)
Expected Cost	+ –$29100	**–$10135**	–$60700

Table 3.2: Calculation of expected cost per action using historical information

Tracking system accuracy

Based on information collected in step 3 of the input stage, a matrix that reflects the accuracy of the tracking system at the time of decision was constructed. Table 3.3: contains the results of this analysis. Each cell of the matrix answers the question “When the shipment is at state z_i, what is the chance of the system indicating signal y_j?”. For example the second column in Table 3.3: indicates that when the shipment is at state z_2 the system will indicate signal y_2 in 97% of the cases. However there will be a 3% possibility of the system indicating signal y_1, possibly because of processing delays at checkpoint c_2. It should be noted that each column of the matrix in question should add up to 100%.

		Actual State			
	P(y|z)	z_1	z_2	z_3	z_4
Information Signal	y_1	100%	3%	0%	0%
	y_2	0%	97%	5%	0%
	y_3	0%	0%	95%	10%
	y_4	0%	0%	0%	90%

Table 3.3: Conditional probability over the tracking information signals

Using (2.3) we can calculate the likelihood of receiving each information signal:

$$p(y_1) = 7\%,\ p(y_2) = 40\%,\ p(y_3) = 39\%,\ p(y_4) = 14\% \tag{3.1}$$

Finally, using Bayes rule and taking as input the historical information, Table 3.3: and (3.1) we can populate the matrix of posterior distribution over the states, given an information signal, shown in Table 3.4:.

		Actual State			
	P(z|y)	z_1	z_2	z_3	z_4
Information Signal	y_1	80%	20%	0%	0%
	y_2	0%	95%	5%	0%
	y_3	0%	0%	96%	4%
	y_4	0%	0%	0%	100%

Table 3.4: Posterior distribution over payoff relevant states given information signals

The above table essentially expresses the accuracy of the tracking system by answering the reverse question of that answered by Table 3.3:: “When the system indicates information signal y_j, what is the chance that the shipment is at state z_i?”. Note that each row of Table 3.4: should add up to 100%.

Expected payoff per information signal

When the logistics manager receives an information signal y_j, he will choose the action that maximizes his expected payoff, as analyzed in section 2.2.2.2. This will be based on the posterior distribution, described in Table 3.4:, and the cost per action. For example, the expected costs per action when the manager receives information signal y_1 are shown in Table 3.5.

Action / State	a_1	a_2	a_3
Z_1	80% × (–$100100)	80% × (–$71700)	80% × (–$51700)
Z_2	20% × (–$60100)	20% × (–$11700	20% × (–$61700
Z_3	0% × ($100)	0% × (–$3400)	0% × (–$56700)
Z_4	0% × ($100) +	0% × (–$3400)	0% × (–$71700)
Expected Cost	–$92358	–$60087	**–$53635**

Table 3.5: Expected costs per action when signal y_1 is received

The manager's optimal action when the tracking system indicates information signal y_1 (i.e. shipment is still with OEM) is a_3 (i.e. Send shipment by air and reschedule production). This action has an expected cost of –$53635, which is the lowest expected cost among the available actions (the other actions will lead to even more delay resulting in higher costs). Following a similar analysis we can calculate the manager's optimum action and expected cost for all information signals. The analysis results (including the case of decision under historical information only) are shown in Table 3.6:.

Signal Received	Preferred Action	Expected Cost
No tracking system	a_2: Send by air	–$10135
y_1	a_3: Send by air and reschedule production	–$53635
y_2	a_2: Send by air	–$11293
y_3	a_1: Send by sea	–$100
y_4	a_1: Send by sea	–$100

Table 3.6: Preferred actions and expected payoffs for all information signals

Overall expected payoff

The overall expected payoff when the logistics managers are using the tracking system will result by summing the expected costs per information signal in Table 3.6:, weighted by the likelihood of receiving each information signal as described in (3.1). In the case of the tracking system that Embraer uses, the overall expected payoff per decision instance is

$$\begin{aligned}&\text{ExpectedPayoff}^{\text{TS}} = \\ &= 7\%(\text{-}\$53635)+40\%(\text{-}\$11293)+39\%(\text{-}\$100)+14\%(\text{-}\$100) = -\$7986\end{aligned} \tag{3.2}$$

3.2.3. Audit output stage

Having completed the data analysis stage, we now calculate the value that the tracking system is delivering to Embraer per decision (that is, the money saved by decision) as well as the overall performance metric.

3.2.3.1. Output 1: Value of the tracking system

As defined by (2.8), the gross value of tracking information for Embraer is

$$\begin{aligned}&\text{Gross Value of Information=ExpectedPayoff}^{\text{TS}} - \text{ExpectedPayoff}^{\text{H}} \\ &= -\$7986 - (-\$10135) = \$2139\end{aligned} \tag{3.3}$$

The cost of obtaining tracking information (infrastructure, administrative etc), per decision, was estimated at approximately \$200. Consequently, the net value of tracking information for Embraer is

$$\text{Net Value of Information=ExpectedPayoff}^{\text{TS}} - \text{ExpectedPayoff}^{\text{H}} - C(I) = \$1939 \tag{3.4}$$

The above figure is the money that the tracking system saves for Embraer each time the logistics manager has to make a decision regarding the shipment of materials from the US to Brazil.

3.2.3.2. Output 2: Value of improved system

The calculation of this metric is actually a ‘what if’ scenario exploration, regarding the improved accuracy of the tracking system and a possible reconfiguration of checkpoints across the supply chain. The analyst can adjust the tracking accuracy matrices accordingly in order to reflect the desired accuracy and configuration of the improved system. Then, following the same approach he can calculate the expected value of the new system. For example, in the case of Embraer, it is estimated that if the accuracy of information signal y_1 is increased from 80% to 93%, the gross value of the tracking system will increase from $2139 to approximately $2500 per decision.

3.2.3.3. Output 3: Relative tracking system performance

In order to calculate a relative tracking system performance measure for the Embraer tracking system, we shall compare its value with the value of the perfect tracking system for the same shipment method decision problem.

The perfect tracking system would reflect the actual shipment state with absolute accuracy. Therefore, the matrix describing the posterior distribution over the states given an information signal (Table 3.4:) would be replaced by a matrix with all elements equal to zero expect for the ones in the main diagonal, which would be equal to 100%. This represents that the system indicates unequivocally the state of the shipment.

Going through the same calculations as in the case of imperfect information, we find that the expected payoff per decision would be

$$\text{ExpectedPayoff}^{PI} = -\$7320 \qquad (3.5)$$

and the net value of perfect information would be

$$\text{Net Value of Perfect Information= -\$7320-(-\$10135)=\$2815} \qquad (3.6)$$

According to (2.13) the tracking system, performance measure for the system that Embraer is currently using will be

$$\text{Tracking System Performance=}\frac{\text{Net value of tracking information}}{\text{Net value of perfect information}} = \frac{\$1939}{\$2815} = 68\% \qquad (3.7)$$

3.3. Interpretation of the results

Value of tracking information

The audit method estimated a $1939 saving per decision for the Embraer logistics managers. Multiplying this amount by the average shipment decisions per year would give an estimate of annual savings for Embraer based on tracking information. It should be noted that these figures are sensitive in the initial cost estimations, as described in Table 3.1. It is critical that these costs are realistic for the audit method to produce credible results.

Cost of tracking information

As explained earlier, the cost of information includes all costs that the company and the managers need to incur in order to obtain tracking information per one decision instance. These would include the tracking system infrastructure and maintenance costs, which should be split over the number of expected decision instances during the system's lifecycle (or during period that an ROI study is conducted for). It also includes any administrative costs that take place per decision (product scanning, document reconciliation, phone calls, emails, etc.). As it becomes clear from (2.9) and (2.13), the cost of information directly affects the performance of the tracking system. The cheaper the information, the higher the performance of the tracking system, even if it provides the managers with the same level of information accuracy. Auto-ID systems are a way to minimize cost of information, since, although they involve an investment cost, they provide tracking information in an automated manner, minimizing operational and administrative costs. In addition to that, auto-ID based tracking systems can significantly enhance the quality of the provided tracking information, resulting in further increase in the benefits gained.

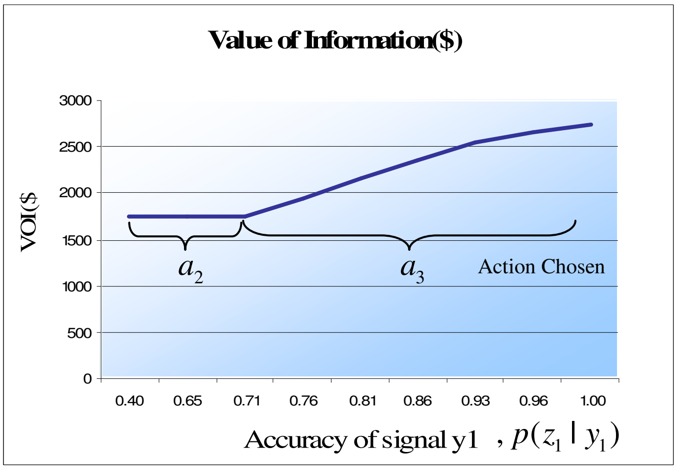

Figure 3.1: Value of information as a function of accuracy of signal y_1

Information accuracy

The description of the data analysis part of the method as well as the presented case study should have made clear that information accuracy is a direct determinant of the information value and system performance. This is also confirmed by well established literature in the field of information theory [7-9].

The aim of the tracking system is to provide information to the logistics manager so that he changes his prior decision to the best option according to the received information signal. The more accurate the signal, the more the manager will trust it and change his decision to the preferred action. Figure 3.1 shows how the value of information behaves as a function of information signal y_1, in the case of the Embraer tracking system. The graph shows that there is a threshold value of the accuracy of signal y_1 , $p(z_1 | y_1) = 0.71$, below which the signal does not add any value to the decision (the value in the graph for $p(z_1 | y_1) < 0.71$, which is approximately $1780, is due to the other information signals y_2-y_4). This is because the decision maker cannot trust it and does not change his prior decision, therefore staying with action a_2. On the contrary, above the threshold, the manager can trust the signal (taking into account the associated costs) and changes his decision by selecting a_3. From that point on, the more accurate the signal, the more the value delivered to the manager. It should be noted that this threshold value depends on the associated costs per decision option.

3.4. Summary

We have demonstrated the use of the proposed audit method in the case of the tracking system that Embraer uses for their inbound logistics supply chain. The study assessed the accuracy of the tracking system. Following that, the value that the system delivers to the managers was estimated and an overall performance measure was calculated for the system in question. The analysis of the results revealed that the accuracy of the system and the cost at which information is obtained are critical factors that affect the value of the tracking system and its overall performance. Auto-id technologies have the potential to improve the tracking system's efficiency and enhance the quality of the provided information.

4. Conclusion and Future Work

The performance of supply chain tracking systems is the cornerstone of the effectiveness for many business operations. In this report we have proposed a method that enables the assessment of the information quality that a tracking system provides, the measurement of the system's performance and the estimation of the value that it delivers to the company, in terms of the money it saves for the company through effective decision making. We have demonstrated the use of the method through a case study at Embraer. The analysis of results have provided useful insights in the determinants of tracking performance and the value gained by the system. Information accuracy and the cost of information seem to play a key role in determining the performance of the system.

The proposed audit method can be used by both tracking system end user companies and solution providers to monitor the performance of a tracking system and estimate its actual value for the company or the customer respectively. The audit results can be used to steer system improvements and investments in key areas, which promise to deliver business value.

The method we have proposed addresses business decisions that refer to the current location of shipments. However, there are many cases in which a manager needs to make a decision based on the location of a shipment at a specific time in the future. Our model needs to be extended to address this class of decisions. Moreover, including time as a variable in the overall assessment process, therefore generating time-dependent results, is another aspect that further work needs to be done. Our research team is currently working towards these directions in order to make the tracking audit method more robust.

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