Using Quality Function Deployment Factors for Strategic Transportation Planning

Erick C. Jones and Dejing Kong
University of Nebraska - Lincoln
Lincoln, NE

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The automated identification technology, Radio Frequency Identification (RFID), provides the potential to reduce costs in the transportation operations. Local Department of Transportation (DOT) offices have to carefully consider technologies such as RFID when considering their use for operation such as Right of Way (ROW) property control. ROW operations require strategic planning in that inventory and access rights can be contestable in a myriad of situations. This research investigates the comprehensive impacts of using RFID systems for ROW inventory tracking. We utilize the Quality Function Deployment (QFD) as a means to integrating strategic shareholders needs and their impact on the measurement of the systems usefulness with respect to the RFID systems reliability performance. Multiple RFID systems reliability performances were measured in the harsh ROW environments. We introduced a model that takes both the shareholder requirements and the RFID reliability to demonstrate a multiple decision approach based upon Analytic Hierarchy Process (AHP) to which system provide the best value for improving operational effectiveness.

Keywords
RFID, QFD, AHP, Multiple Decision Approach

1. Introduction

The Department of Transportation (DOT) in the southwest region of the United States manages approximately 1.1 million acres of land that provide Right-of-Way (ROW) for approximately 80,000 center miles of state-maintained roads. Management of the ROW involves managing and inventorying a large number of facilities within the state, including utility (e.g., gas (liquid or natural), energy, sewer, telecommunications, water) assets, roadway infrastructure (e.g., pavements, bridges, traffic signs), and outdoor advertising facilities. It is a challenge to manage these utilities effectively because a significant proportion of assets are underground.

To address the limitations of underground markers, pioneering researchers and the utility industry have been exploring the use of radio frequency identification (RFID) technology in utility asset management. RFID technology provides the capability to store a unique identification (ID) number and some basic attribute information. This data can be retrieved wirelessly when the markers detect a radio signal from a remote reader. RFID technology has the potential to offer the DOT a unique opportunity to help optimize the management of utility installations within a state's ROW.

This research evaluates six different RFID systems and provides multiple attributes analysis. The six different types of RFID systems are: active Dash7 system (AD7), three different passive non-standard systems (PNS1,

PNS2 and PNS3), and two different passive Gen 2 systems (PG21 and PG22). Dash7 is a type of active tag that works on the frequency of 433 MHZ.

This study formulates a multiple decision-making analysis of implementing an RFID system that will be used in ROW. The best plan of action is to utilize quality based Analytic Hierarchy Process (AHP) analysis. The goal of the decision criteria is to find the best system based on a comprehensive consideration.

2. Background

There are several methods of identifying items that use RFID. A standard RFID system always consists of the tag, the reader, and middleware software. Tags often consist of a microchip with an internally attached coiled antenna. Some include batteries, expandable memory, and sensors. A reader is an interrogating device that has internal and often times external antennas that send and receive signals [1].

There are several decision-making analysis tools. The analysis which will be presented in this article is Quality based Analytic Hierarchy Process (QAHP). Analytic Hierarchy Process (AHP), since its invention, has been a tool at the hands of decision makers and researchers; and it is one of the most widely used multiple criteria decision-making tools. Many outstanding works have been published based on AHP: they include applications of AHP in different fields such as planning, selecting a best alternative, resource allocation, resolving conflict, optimization, etc., and numerical extensions of AHP [2, 3]. Bibliographic review of the multiple criteria decision-making tools carried out by Steuer [4] is also important.

3. Quality based Analytic Hierarchy Process (QAHP) Approach

In this article, the QFD has been developed based on the meetings and the experts' directions. The AHP analysis is utilized to provide the acceptable decision of the problem. The scores used in AHP analysis are obtained from QFD. It is easier than collecting data for AHP through interview again, and utilizing QAHP can save time and money. After performing the analysis, the consistency analysis is utilized to prove the results.

Since the decision is made from AHP, the pairwise scores need to be determined. In this approach, the pairwise scores are from the QFD development. The scores in the QFD should be normalized as the pairwise scores' scale in the AHP, and then the AHP can be utilized to do decision-making analysis in this case.

When the problem is stated, there must be several factors that influence the problem. Hierarchical structure can be built based on these factors. Some of these factors influence the objective directly while some of these factors have influence on the objective through affecting the direct factors. The direct factors as subattributes for the objective are supposed to be in the one lower level than the objective. The factors as sub-subattributes should be in the one lower level than the direct factors. The pairwise comparison of the attributes in the same level can be justified. The weight modulus of these can be calculated, and decision will be made according to the calculation.

Assume $f_1, f_2, ..., f_q$ are the factors, and $w_1, w_2, ..., w_q$ are weight modulus. The linear equation can be

$$= \quad + \quad + \cdots + \quad , \quad h \quad \geq 0 \qquad (1)$$

$$\sum \quad = 1 \qquad (2)$$

which are the functions to make a comprehensive decision.

The results of pairwise comparisons can be put into a matrix $\mathbf{A}_{n \times n}$, and the element in this matrix is a_{ij}.

$$\times \quad = \quad \begin{matrix} & \cdots & \\ \vdots & \ddots & \vdots \\ & \cdots & \end{matrix} \qquad (3)$$

where

n = the total number of the attributes in the level;

$a_{ij} = a_i/a_j$;

i = index for the rows of the matrix;

j = index for the columns of the matrix.

The general approach of the AHP is to decompose the problem and to make pairwise comparisons of all elements (attributes, alternatives, etc.) on a given level with respect to the related elements in the level just above. The degree of preference or intensity of the decision maker in the choice for each pairwise comparison is quantified on a scale of 1 to 9 [5], and these quantities are placed in a matrix of comparisons. The suggested numbers to express degrees of preference between the two elements a_i and a_j are shown in Table 1.

Table 1: Trans-Quantitative Scores

a_{ij}	1 2	3	4 5 6	7	8 9
the importance of a_i/a_j	fair	weakly strong	strong	obviously strong	absolutely strong

Even numbers (2, 4, 6, and 8) can be used to represent compromises among the preferences suggested above.

In the next step, a matrix of comparisons for all elements is constructed with preference numbers obtained as above. For inverse comparisons such as a_j to a_i, the reciprocal of the preference number for a_i to a_j (above) is used.

To estimate the elements a_{ij} (= a_i/a_j) in the matrix $\mathbf{A}_{n\times n}$, we must get a_i and a_j. Since defined the range of a_{ij} is the integer from 1 to 9 as identified by Saaty, the raw scores should be normalized if they are out of the range. Assume the range of the raw data is [c, d]. The normalized score a_i is

$$= \begin{cases} 9 - \dfrac{(\quad)\times(\quad')}{(\quad)}, & \text{if the attribute i is positively in\ luenced} \\[2mm] 9 - \dfrac{(\quad)\times(\quad')}{(\quad)}, & \text{if the attribute i is negatively in\ luenced} \end{cases} \qquad (4)$$

where

a_i = the normalized score of attribute i;

a'_i = the raw score of attribute i;

d = the upper limit of the raw scores;

c = the lower limit of the raw scores.

The vector (**W**) for the weight modulus w_i is

$$= \quad \rightarrow\infty \quad = [\quad \cdots \quad] \qquad (5)$$

where

$$= \frac{'}{'};$$

$$' = \quad ;$$

$||W_k'||$ = the sum of the n components of AW_{k-1};

$W_0 = [1/n\ 1/n\ \ldots\ 1/n]^{\mathrm{T}}$;

$k = 1, 2, 3, \dots$;

n = the total number of the attributes in the level.

W can be calculated only if the sequence of $\{\mathbf{W}_k\}$ is convergent.

If we have $\mathbf{W} = [w_1 \ \dots \ w_n]^T$, the matrix whose entries are w_i/w_j is a consistent matrix which is our consistent estimate of the matrix **A**. If a_{ij} represents the importance of criterion i over criterion j and a_{jk} represents the importance of criterion j over criterion k, then a_{ik}, the importance of criterion i over criterion k, must equal $a_{ij}a_{jk}$, for the judgments to be consistent. The matrix **A** needs not to be consistent; i.e., $\mathbf{A_1}$ may be preferred to $\mathbf{A_2}$ and $\mathbf{A_2}$ to $\mathbf{A_3}$, but $\mathbf{A_3}$ is preferred to $\mathbf{A_1}$. We need to measure the error due to inconsistency. A necessary and sufficient condition for **A** to be consistent is that $\lambda_{max} = n$. $\lambda_{max} \geq n$ always holds. As a measure of deviation from consistency we use the consistency index (*CI*): [6]

$$= (\quad - \quad)/(\quad - 1) \tag{6}$$

where λ_{max} is the maximum characteristic root of the matrix **A**, and n is the total number of attributes in the level.

Saaty also defined a random index *RI* shown in Table 2.

Table 2: Random Index

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

When the ratio *CR=CI/RI<0.1*, it passes the consistency test. Otherwise it fails, which means the results from the process cannot be accepted.

The weighted evaluation for each attribute in the lower level can be obtained by multiplying the matrix of evaluation ratings by the vector of attributes weights in the higher level. Expressed in conventional mathematical notation, the weights are

$$= \Sigma \qquad \cdot \tag{7}$$

where

g_j = the weight modulus evaluated for the attributes j in the lower level;

w_i = the weight modulus evaluated for the attributes i in the higher level;

g_{ij} = the evaluation ratings for the attributes j in the lower level to the attribute i in the higher level;

h = the total number of attributes in the higher level.

The vector (**G**) for the attributes in the lower level composed by the weight modulus (g_j) is $\mathbf{G} = [g_1 \ g_2 \ \dots \ g_m]$, where m is the total number of attributes in the lower level.

In the multiple cases, the consistency index for the lower level (CI_L) can be achieved from the consistency index for the matrix of the attributes in the lower level to the attribute i in the higher level (CI_{Li}) and the weight modulus of the attribute i in the higher level (w_i).

$$= \Sigma \qquad \cdot \tag{8}$$

where

CI_L = the consistency index for the lower level;

CI_{Li} = the consistency index for the matrix of the attributes in the lower level to the attribute i in the higher level;

w_i = the weight modulus of the attribute I in the higher level;

i = index of the attributes in the higher level;

h = the total number of attributes in the higher level.

The consistency ratio (*CR*) of the AHP will be the sum of all consistency ratios for every level.

$$= \Sigma \qquad\qquad (9)$$

where

CR = the consistency ratio for the AHP;

CR_l = the consistency ratio for level l except level I since there is only one objective in Level I;

l = index for the levels;

L = the total number of levels in the AHP.

4. A Case Study in Transportation Utilizing QAHP

In this case, QAHP is utilized to make multiple decisions which RFID system is the best selection to be implemented in ROW project.

4.1 Quality Function Deployment

Stakeholder requirements were gathered in a kick off session. The stakeholder requirements for the Department of Transportation in Right of Way Project were focused around using RFID readers for data collection and facilities management.

As shown in Figure 1, the most significant technical factor which may influence the implementation of RFID systems in ROW was Physical Limitation. For all uses of RFID system in transportation, it was necessary to overcome the physical limitations. The second important technical factor was Read Distance. And the lowest factor (0.12) was from Manufacturing Cost.

Figure 1: Quality Function Deployment for all Stakeholders
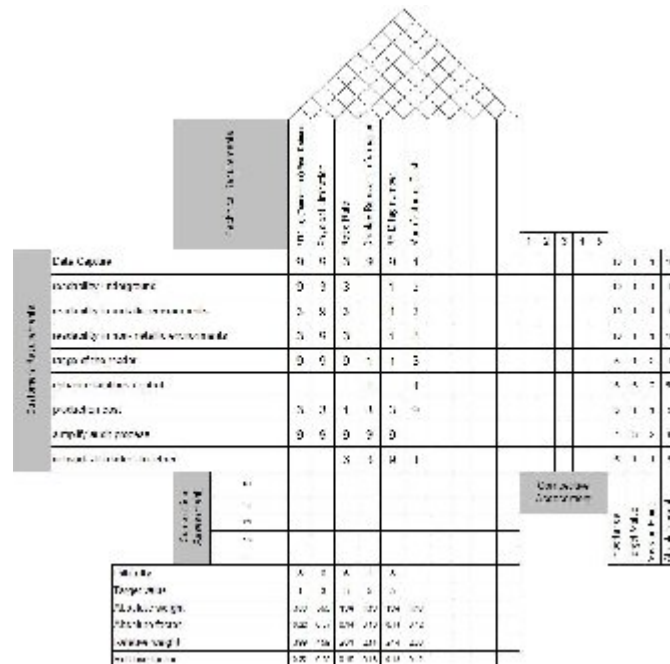
4.2 Quality based Analytic Hierarchy Process

Since QFD can be utilized to determine which factor is the most important and most effective one to be improved to achieve the objective. The factors in the QFD are all the attributes which should be paid more attention to. It is possible to use the data from QFD to AHP to get the most effective decision which RFID system is the best one to be implemented. There are four levels in the Quality based Analytic Hierarchy Process (QAHP). Level I is the objective, Level II is the Customers Requirements, Level III is the Technical Requirements, and Level IV is the Alternatives, which are shown in Figure 2.
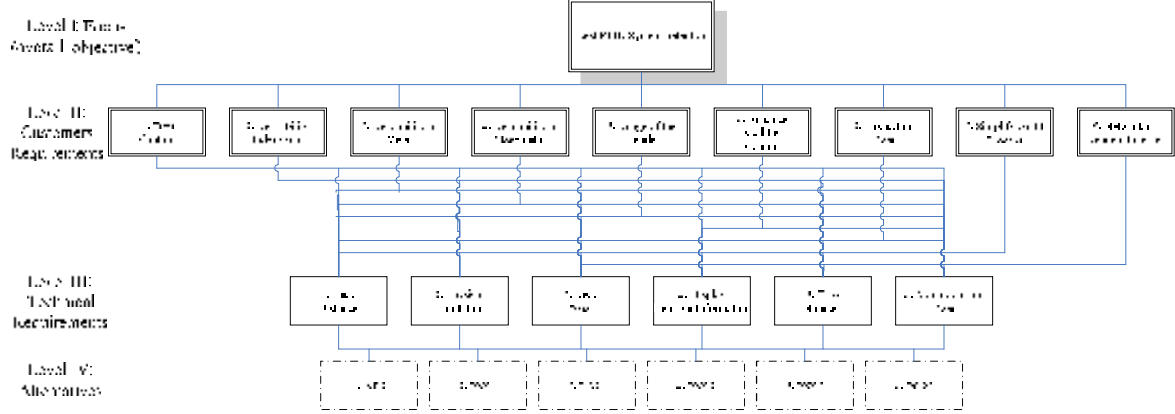

Figure 2: Structure of QAHP

The raw scores a_i' used for Level II are the absolute weights (AW_i) of each customer requirement in QFD, where i is the index for the customer requirements. For Example, AW_3 is the absolute weight of Readability in Metal (Customer Requirement 3), and it is 10 shown in Figure 1. From Equation 4, the matrix in form of Equation 3 can be calculated. Since the element in the matrix must be an integer from 1 to 9 or the reciprocal of the integer, the element larger than 1 should be rounded to the nearest integer, and the element in the symmetrical position will be the reciprocal of the integer.

In the same way, the matrix of the technical requirements to each customer requirement can be achieved while the raw scores utilized are the relationship scores (CT_{ij}) in QFD, where i is the index for the customer requirements and j is the index for the technical requirements. For example, CT_{12} is the relationship scores between Physical Limitation (Technical Requirement 2) and Data Capture (Customer Requirement 1), and it is 9 as shown in Figure 1. The matrix of the alternatives to each technical requirement also can be calculated, and the raw scores will be the performances of each alternative shown in Table 3 which have been graded based on the previous experiments and their costs.

Table 3: Performance of the Alternatives

	AD7	PNS1	PG21	PNS2	PNS3	PG22
Read Distance	10	8	6	4	4	3
Physical Limitation	10	9.25	6.31	4	4	3
Read Rate	10	8.67	5.67	3.67	3.67	2.67
Display information	10	10	10	10	10	10
Tag Number	10	10	10	10	10	10
Cost	105379	58280	9175	10600	6460	6910

Using the process shown above to achieve the AHP results, the weight modulus of each attribute are shown in Table 4 and Table 5.

Table 4: the Weight Modulus of Technical Requirements

Technical Requirements	Customers' Requirements									Weight Modulus of Technical Requirements
	1	2	3	4	5	6	7	8	9	
	0.0893	0.0893	0.0893	0.0893	0.0893	0.2951	0.0856	0.0867	0.0861	
1	0.2250	0.4737	0.1579	0.1579	0.2813	0.0000	0.1364	0.2000	0.0000	0.1447
2	0.2250	0.1579	0.4737	0.4737	0.2813	0.0000	0.1364	0.2000	0.0000	0.1729
3	0.0750	0.1579	0.1579	0.1579	0.2813	0.0000	0.0455	0.2000	0.1875	0.1115
4	0.2250	0.0000	0.0000	0.0000	0.0313	0.5000	0.1364	0.2000	0.1875	0.2156
5	0.2250	0.0526	0.0526	0.0526	0.0313	0.0000	0.1364	0.2000	0.5625	0.1144
6	0.0250	0.1579	0.1579	0.1579	0.0938	0.5000	0.4091	0.0000	0.0625	0.2408

Table 5: the Weight Modulus of Alternatives

Alternatives	Technical Requirements						Weight Modulus of Alternatives
	1	2	3	4	5	6	
	0.1447	0.1729	0.1115	0.2156	0.1144	0.2408	
AD7	0.2656	0.2396	0.2623	0.1667	0.1667	0.0237	0.1698
PNS1	0.2223	0.2225	0.2363	0.1667	0.1667	0.1102	0.1785
PG21	0.1596	0.1811	0.1585	0.1667	0.1667	0.2165	0.1792
PNS2	0.1243	0.1261	0.1232	0.1667	0.1667	0.2165	0.1607
PNS3	0.1243	0.1261	0.1232	0.1667	0.1667	0.2165	0.1607
PG22	0.1039	0.1047	0.0966	0.1667	0.1667	0.2165	0.1511

The consistency index can be calculated based on Equation 8 and Equation 9. The ratios can be calculated by using *CI* divided by the corresponding *RI*, which are shown in Table 6.

Table 6: the Consistency Analysis

	Level II	Level III	Level IV	SUM
CI	0.0054	0	0.0080	
CR	0.0037	0	0.0064	0.0101

As we can see in Table 6, *CR=0.0101* <0.1. It means that this AHP is consistent and the results can be accepted. PG21 is the best implementation in the project, since it has the highest weight modulus. PNS1 is the second best one, and AD7 is the third best one.

Since the weight modulus of alternatives obtained from above analysis of the best two alternatives have no significant difference, and there is approximate calculation when determining the matrix, it is also needed to do a fuzzy analysis selecting the boundary of the elements to see which decision will be made. The lower boundary can be obtained by approximating the element which is larger than 1 to the nearest integer which is smaller than itself. The upper boundary is obtained by approximating the element which is larger than 1 to the nearest integer

which is larger than itself. The element in the symmetrical position will be the reciprocal of the integer. Following the same procedure shown above, the weight modulus of alternatives is shown in Table 7.

Table 7: the Weight Modulus for Boundary Analysis

Alternatives	AD7	PNS1	PG21	PNS2	PNS3	PG22	*CR*
For the Lower Boundary	0.2110	0.1930	0.1662	0.1465	0.1465	0.1407	0.0113
For the Upper Boundary	0.2055	0.1822	0.1616	0.1689	0.1431	0.1387	0.0300

As shown in Table 7, *CR*s are still smaller than 0.1. So the results can be accepted. The first two best alternatives are AD7 and PNS1 while the third best can be PG21 or PNS2, since the weight modulus of these two alternatives has an overlap. PG22 and PNS3 will be worthless to be implemented. Also, we can see that the weight modulus of PG21 has the smallest range when matrix changed. PG21 has the most stationary performance. AD7, PNS1 and PG21 can be considered to be implemented.

5. Conclusion

There are six RFID systems, which have potential to be implemented in the project. The six RFID systems have different technique parameters. The best alternative can be selected by utilizing Quality based AHP. The stakeholders' requirements, the technical requirements, and performances of the alternatives are considered in this approach.

1. Quality based AHP passes the consistency analysis, and the results can be accepted.
2. PG21 has the largest weight modulus, which means it is the best alternative to be implemented based on QAHP. The second and third best alternatives are PNS1 and AD7 respectively.
3. Based on Fuzzy QAHP, the top two best alternatives are AD7 and PNS1 while PG21 is ranked as the third one but with the most stationary performance.
4. PG21 should be the best alternative based on its most stationary performance and not bad weight modulus.

References:

1.   Jones, E.C. and Chung, C.A., 2008. RFID in Logistics: a Practical Introduction, Taylor &Francis Group, LLC.

2.   Vargas, L., 1990. An overview of analytic hierarchy process: Its application. European Journal of Operational Research, 48(1), 2-8.

3.   Zahedi, F., 1986. The Analytic hierarchy process: A survey of methods and its application. Interfaces, 16(4), 96-108.

4.   Steuer, R.E., 2003. Multiple criteria decision making combined with finance: A categorized bibliographic study. European Journal of Operational Research, 150(3), 496-515.

5.   Saaty, T.L., 1980. The Analytic Hierarchy Process. McGrawHill.

6.   Saaty, T.L., and Vargas, L., 1991. Prediction, projection, and forecasting: Applications of the analytic hierarchy process in economics, finance, politics, games, and sports. Springer