

Application of Decision Theory and Information Processing in the Selection of Engineering Entities

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The selection of engineering entities often occurs in engineering design processes. Examples of such occurrences are the selection of antifriction bearings, belt drive components, chain drive components and wire rope, to name but a few. This paper reviews the essentials of decision theory and information processing and then goes on to demonstrate their application in developing a quantitative method for wire rope selection. The use of the method is demonstrated in selecting a suitable type and size of wire rope for the hoisting/hauling mechanism of a manual winch. The method should be applicable in other situations in which the need for the selection of wire rope may arise.

Keywords: Decision Theory, Information Processing, Wire Rope Selection.

1. INTRODUCTION

The selection of engineering entities often occurs in engineering design processes. Examples of such occurrences are the selection of antifriction bearings, belt drive components, chain drive components and wire rope. In the selection of wire rope, which shall be the focus of this paper, common practice has been to use wire rope manufacturers catalogues. This can be tedious and time consuming, considering the large amount of data that needs to be accessed and used, as well as the many factors that need to be considered in the selection process.

Engineering design, in general, and the selection of engineering entities, in particular, is largely a decision making process. Prudent decision making should preferably be based on adequate information and therefore the decision making process often involves the processing of available data into information that can be readily used to make the decisions. This paper reviews the essentials of decision theory as well information processing and then goes on to demonstrate their application in developing a quantitative method for wire rope selection. The use of the method is demonstrated in selecting a suitable type and size of wire rope for the hoisting/hauling mechanism of a manual winch.

2. DECISION THEORY

Decision making is one of the most common of human activities. Because the decisions that people make can be either good¹ or bad, there is a need for methods, procedures and rules that can help people to make good decisions. This need has led to the development of decision theory.

Decision theory can be classified into:

- Descriptive decision theory, which is concerned with the ways in which people actually make

decisions and the mechanisms underlying this behaviour, and

- Normative decision theory, which is concerned with the principles that form the basis of rational decision making.

Furthermore, under normative decision theory, decision problems can be classified into decision problems without uncertainty and decision problems with uncertainty (Mendoza and Gutierrez-Pena, 2010).

2.1 Decision Problems without Uncertainty

In a decision problem, the decision-maker is required to select one and only one action from the set of possible actions, $\mathbf{A} = \{a_1, a_2, \dots, a_k\}$. Every action in \mathbf{A} is judged according to the consequence that it will lead to, if selected. Therefore, associated with \mathbf{A} will be the set of consequences, $\mathbf{C} = \{c_1, c_2, \dots, c_k\}$, where c_i is the consequence that is associated with action a_i . If for every action the corresponding consequence is completely known and definite, such that it occurs every time the action is taken, then we have a decision problem without uncertainty.

Under these circumstances, the best action will be that which leads to the most preferred consequence. Therefore, the decision-maker must, in some way, express their preferences among the elements of \mathbf{C} (Mendoza and Gutierrez-Pena, 2010).

2.2 Decision Problems under Uncertainty

Often, once an action has been chosen, there will be a set of possible consequences associated with it. Among these possible consequences, one and only one of them will take place, depending upon the occurrence of some uncertain event. This means that the decision has to be made under uncertainty. This kind of decision problem is mentioned here only for completeness and shall not be elaborated further.

¹ A good decision can be interpreted to mean a decision that has desirable consequences.

2.3 The Analytic Hierarchy Process (AHP)

AHP is a tool that is used in decision making without uncertainty and is designed for situations in which the relative importance of the factors that affect the decision process are quantified to provide a numerical scale for prioritizing the alternatives (Taha, 2008).

In a given decision problem, suppose that the set of possible courses of action is $\mathbf{A} = \{a_1, a_2, a_3, \dots, a_m\}$. Further, suppose that a set of factors $\mathbf{F} = \{f_1, f_2, f_3, \dots, f_n\}$ upon which the decision is to be based has been established and that the intention is to establish a normalized set of weights $\mathbf{W} = \{w_1, w_2, w_3, \dots, w_n\}$ to be used when comparing the relative importance of these factors in the decision making process.

Suppose too that a set of numerical values $\mathbf{B}_i = \{b_{i1}, b_{i2}, b_{i3}, \dots, b_{in}\}$ can be associated with each course of action. If the elements of \mathbf{B}_i are appropriately coded such that they are positive real numbers whose values, in some suitable way, indicate the utility associated with the set of factors \mathbf{F} , we can calculate the utility functions $u(a_i)$, as follows:

$$u(a_i) = \sum_{j=1}^n b_{ij} w_j \quad \text{for } i = 1, 2, 3, \dots, m. \quad (1)$$

The course of action to be preferred will then be the one that returns the highest value of the utility function.

In an attempt to establish the set of normalized weights, \mathbf{W} , an n by n pairwise comparison matrix \mathbf{V} can be formed, in which the element v_{ij} gives the relative importance of f_i as compared with f_j .

If by definition the elements of the pairwise comparison matrix \mathbf{V} are as follows:

$$v_{ij} = \frac{w_i}{w_j}. \quad (2)$$

then it follows that:

$$v_{ji} = \frac{1}{v_{ij}}. \quad (3)$$

The matrix \mathbf{V} is then said to be reciprocal. Moreover, it also follows that:

$$\begin{bmatrix} 1 & v_{12} & \dots & v_{1n} \\ v_{21} & 1 & \dots & v_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ v_{n1} & v_{n2} & \dots & 1 \end{bmatrix} \begin{Bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{Bmatrix} = n \begin{Bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{Bmatrix}. \quad (4)$$

In the above equation, n is the principal eigenvalue, and \mathbf{W} the principal eigenvector of \mathbf{V} .

Furthermore, if the matrix \mathbf{V} is to be consistent, for any i , j and k , the following relationship must hold.

$$v_{ij} = v_{ik} v_{kj}. \quad (5)$$

In practice, the decision maker starts by assigning values of v_{ij} based on their judgment and experience, as a first estimate of \mathbf{V} . Then the matrix \mathbf{V} that is so obtained can be checked for consistency by computing a consistency index. The procedure for doing this can be found in Taha (2008) and Saaty (1990) among others. If the first estimate of \mathbf{V} is found to be too inconsistent, an attempt can be made to improve it and the whole procedure be iterated.

If all the factors are judged to be equally important, as can very well happen in a mechanical design situation, then $v_{ij} = 1$ for all i and all j , and the resulting matrix \mathbf{V} will be consistent.

3. INFORMATION PROCESSING

Though the term *information processing* is a modern one, the activity that it refers to is as old as recorded history. The word information is now a household word, yet information may not be that easy to define. Before we can define information, we will first define the closely related term that is *data*.

We do know that mountains can be distinguished from one another on the basis of their heights and that the heights of mountains are usually given relative to the sea level. Here, the sea level serves as a *basis for comparison* of the heights, and it is known as a *datum*. The word data is the plural of datum.

Data may be defined as bases for comparison or attributes that serve to distinguish. The altitudes of mountains are *numerical data*.

It is quite possible that the peaks of two different mountains can be of exactly the same altitude. In that case, to completely distinguish one mountain from the other, height alone would not be adequate. However, knowledge of other attributes of the mountains, apart from, or in addition to height, could lead to complete distinction. Among such other attributes could be the name and the location of each mountain.

Inasmuch as they can serve to distinguish one mountain from another, the locations too are data and in this case they are *alphabetical data*. Data can be expressed in alphabetic, numeric, alphanumeric and in other convenient codes.

In a given situation, when data are organized in such a manner that they become easier to interpret and to use then they can be referred to as *information*. In their essential nature, data and information cannot be differentiated except in the extent of their usefulness for the purpose at hand. They both serve to distinguish one thing from another. A situation in which we cannot at all distinguish one thing from another is a situation about which we are completely uninformed.

The distinction of any one member of a set of things, from the rest of the members, facilitates selection. Thus, information facilitates selection.

The essence of information processing is to obtain more readily useable information from relatively less useful information.

Whether it is done manually or by use of computer, information processing can be classified into the following four categories of activities:

- Preparation and input of data,
- Processing of data into useful information,
- Storage and retrieval of information,
- Reporting and communication of information.

When these four categories of activities are linked together, they may be regarded as a cycle in which data is processed into information. The term *information processing cycle* (Fig. 1) refers to all the activities involved from the collection of input data to the output of useful information and its delivery to those who need it (Robichaud et. al., 1989).

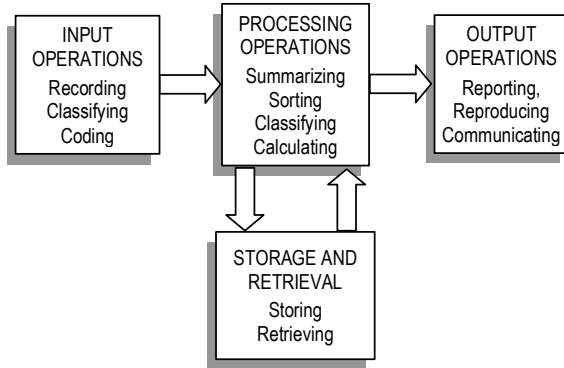


Figure 1. The Information Processing Cycle

4. WIRE ROPE SELECTION FOR MANUAL WINCH APPLICATION

A winch is a mechanical device for hoisting or hauling. Essentially, it consists of a rotating drum around which a cable is wound so that rotation of the drum can produce a drawing force at the end of the cable. When the winch is manually powered then it is known as a manual winch.

Fundamentally, we need to select a suitable flexible hauling/hoisting appliance for our purpose, which may not necessarily be wire rope. The processing of information in the selection process can begin with the categorization (sorting) of such appliances as given in Table 1 (Oduori and Mbuya, 2009).

Based on experience, from among the community of flexible hoisting/hauling appliances, wire rope types 6×19 , 6×37 , and their variants are the more commonly used in such applications as on manual winches. In the selection process, then, a quantitative screening of rope types 6×19 , 6×37 , and their variants, shall be carried out in order to determine the suitable rope type for our particular application.

Suppose that we have the set of requirements $\mathbf{R} = \{r_1, r_2, r_3, \dots, r_n\}$, that are to be met by the type of rope that we select. Further suppose that we can assign weights $\mathbf{W} = \{w_1, w_2, w_3, \dots, w_n\}$, which represent the relative importance that we attach to each requirement. Given that there are m candidate types of ropes to be screened, suppose that, for each type of rope, we have the set of n attributes or properties,

$\mathbf{P} = \{p_1, p_2, p_3, \dots, p_n\}$, each of which should in some way, and to some extent, satisfy a corresponding requirement, and each of whose value may be appropriately coded $b_{i1}, b_{i2}, b_{i3}, \dots, b_{in}$, for $i = 1, 2, 3, \dots, m$ (for all rope types). We should then be able to calculate indices of merit $u(a_i)$, for each type of rope, as follows:

$$u(a_i) = \sum_{j=1}^n b_{ij} c_j \quad (6)$$

Having found at least one type of rope to be suitable, in the next stage of selection, we will scrutinize the attributes of each of the ropes within the selected types, vis-à-vis each requirement upon the rope in order to finally select a suitable rope.

Table 1. Taxonomy of the Community of Flexible Hoisting or Hauling Appliances

Families of flexible hoisting/hauling appliances	<ul style="list-style-type: none"> • Chains • Natural Fibre Ropes • Synthetic Fibre Ropes • Wire Ropes
Classes (say of the wire rope family)	<ul style="list-style-type: none"> • Construction Ropes • Excavator Ropes • General Engineering Ropes • Oil-well Applications Ropes • Shipping Applications Ropes, etc.
Subclasses (say the hoisting/hauling subclass of the general engineering ropes class)	<ul style="list-style-type: none"> • 6×19 • 6×37 • 8×19, etc.
Attributes (say of the 6×19 type of wire rope)	Diameter, breaking load, unit mass, etc.

4.1 Wire Rope Selection Criteria and Property Ratings

Several factors have to be considered in the selection of a suitable wire rope for a given application. The following factors usually need to be considered in most applications:

- Resistance to breaking,
- Resistance to bending fatigue,
- Resistance to abrasion,
- Resistance to crushing,
- Resistance to corrosion,
- Cost of the rope.

Resistance to Breaking

Wire rope standards publications and manufacturers' catalogs usually give three fields of data, namely, rope nominal diameter, d_r , the corresponding breaking load, W_b , and the corresponding linear density or unit mass (mass per unit length), ρ_l , for each rope entry. A

nominal specific breaking stress of wire rope may be defined as follows (Oduori and Mbuya, 2009):

$$\sigma_{bs} = \frac{4W_b}{\pi d_r^2} \div \frac{4\rho_l}{\pi d_r^2} = \frac{W_b}{\rho_l} \quad (7)$$

where σ_{bs} is the specific breaking stress of the rope, and is seen to be independent of the diameter of the rope. A large value of σ_{bs} implies a strong light rope.

Ratings of specific strength of the candidate types of rope for manual winch application, based on data from Japanese Industrial Standards, JIS G 3525, 1981, were derived by Oduori and Mbuya (2009).

Resistance to Bending Fatigue

As a rope moves over sheaves, drums and rollers, it is subjected to cyclic bending stresses. The magnitude of variation of the cyclic stresses may be expressed as follows:

$$\sigma_f = \pm E \frac{d_r}{D_d} \quad (8)$$

where E is the effective wire rope modulus of elasticity, d_r is the nominal diameter of the wire rope, and D_d is the nominal diameter of the drum or sheave on which the rope moves.

Evidently, the smaller the ratio d_r/D_d the smaller the magnitude of variation of bending stress and the longer will be the fatigue life of the rope, all other things being equal. Some wire rope data tables give the lower limiting values for the inverse ratio D_d/d_r for various types of rope. The smaller the limiting value of this inverse ratio, the higher the resistance to bending fatigue of the particular type of rope, since the rope can withstand higher variation in bending stress.

Oduori and Mbuya (2009) derived ratings of resistance to bending fatigue for the candidate types of rope, based on data from U.S. Army Corps of Engineers (1998) and Shigley and Mischke (1989).

Resistance to Abrasion

When wire rope is loaded, it stretches much like a coil spring. When bent over a sheave or drum, its load-induced stretch causes it to rub against the drum groove, leading to abrasion of both the rope and the groove. Abrasion also occurs whenever a rope rubs against itself, and internally as wires and strands move relative to each other. Abrasion weakens the rope simply by wearing away material from inside and outside wires.

Generally speaking, *wire ropes with larger diameter outer wires and lang lay construction are more resistant to abrasion than those of regular lay and outer wires of small diameter*. Thus, for the lack of a better, more direct measure of abrasion resistance, the number of outer wires per strand, may be used as a basis for rating the abrasion resistance of various types of ropes (Elsevier, 2004).

Oduori and Mbuya (2009), derived the ratings of resistance to abrasion based on the number of outer wires per strand.

Resistance to Crushing

Crushing is the effect of external pressure on a rope and it results in distortion of the rope cross-section, the strand cross-section, the core cross-section or all three of these. Crushing resistance therefore, is the ability of the rope to withstand or resist external pressure, and is generally used to express comparison among ropes.

When a rope is damaged through crushing, the wires, the strands and the core are prevented from moving and adjusting normally in operation. As a rule of thumb, regardless of the type of rope, *ropes with independent wire rope core (IWRC) and ropes of regular lay are more crush resistant than those with fiber core and those of lang lay*.

Resistance to Corrosion

The importance of corrosion as a design factor depends upon the environment in which the wire rope will function during its service life. Some of the possible causes of corrosion are the following:

- Submersion into fresh water, which may contain some corrosive substances,
- Exposure to a damp atmosphere, either periodically or continually,
- Exposure to airborne corrosive substances, such as acids and salts.

Galvanized carbon steel, stainless steel and Kevlar ropes have been used for their corrosion resistance. When administered carefully, lubrication may alleviate corrosion.

Cost of Rope

The cost and availability of candidate ropes should be taken into account early in the process of selecting wire rope. Some factors that contribute to the cost of wire rope are the following:

- The material of which the rope is made,
- The type of rope ó certain rope constructions may be either expensive or not readily available,
- The size (diameter) of the rope ó large rope diameters may not be readily available.

Oduori and Mbuya (2009) derived ratings of cost of candidate types of rope, based on data from U.S. Army Corps of Engineers (1998). Since lower cost is generally preferable, the ratings of economy were calculated as the reciprocals of the relative cost indices.

4.2 Selection of a Suitable Type of Rope

As discussed in the preceding section, some wire rope properties were processed and coded into quantitative ratings that can be used in the screening of the candidate types of rope. The factors to be used in this quantitative screening will be the following:

- Resistance to breaking ó attribute b_{fl} ,

- Resistance to bending fatigue ó attribute b_{i2} ,
- Resistance to abrasion ó attribute b_{i3} ,
- Cost of the rope ó attribute b_{i4} .

In the absence of strong reasons to compel the assignment of different weights to the different attributes, based on relevant and reliable data, a weight of unity may be assigned to all the attributes and equation (6) reduces to the following equation, which will be used to screen the candidate types of rope:

$$u(a_i) = \sum_{j=1}^n b_{ij}c_j . \quad (9)$$

Moreover, we may examine the standard deviation among the values of the attributes of each type of rope, in order to gain insight into the variability within these values for each type of rope. In this context, the type of rope with less variability within the values assigned to its attributes should be preferred. A Microsoft Excel® worksheet was used for the screening of wire rope types and the results are given in **Table 2**.

Based on our screening, two types of rope, namely, **6 by 19 Seale** and **6 by 26 Warrington Seale**, appear to be the most suitable, and about equally suitable for our specific application. These two are the only types that shall be further considered in the selection process.

Table 2. Screening of the Types of Wire Rope

Types of Wire Rope	6 by 19S	6 by 19	6 by 25Fi	6 by 26WS	6 by 31WS	6 by 36WS	6 by 41WS
Specific Strength Rating	0.8996	0.9682	0.8996	0.9003	0.9055	0.9055	0.9055
Bending Fatigue Rating	0.7647	0.7647	1.0000	0.8667	1.0000	1.1304	1.3000
Abrasion Resistance Rating	1.3333	1.0000	1.0000	1.2000	1.0000	0.8571	0.7500
Relative Cost Rating	1.0753	1.0753	1.0753	1.0753	0.9259	0.9259	0.9259
Sum of Ratings	4.0729	3.8082	3.9749	4.0422	3.8315	3.8190	3.8815
Standard Deviation of Ratings	0.2456	0.1327	0.0721	0.1559	0.0494	0.1206	0.2334

4.3 Selection of a Suitable Wire Rope

So far, it has been possible to select suitable types of rope, without using the specifications of the winch on which the rope is to be used. This was done by using only the characteristics of the types of rope.

To proceed farther, we now have to consider the load that the wire rope will be subjected to when in use. Suppose that, in our specifications, the load capacity of our winch is 2.5 metric tons (2 500 kg). Then our safe working load will be as follows:

$$W_{sw} = 2500 \times 9.8 = 24500 \text{ N}$$

Moreover, we will use a design factor of safety, denoted f_s , which is defined such that:

$$f_s = \frac{W_d}{W_{sw}} . \quad (10)$$

where W_d is the design load and should be less than the rope's breaking load.

Recommended minimum factors of safety for wire rope in some common applications are given in Shigley and Mischke (1989) and in Black and Adams (1981). For a manual winch designed to be used for haulage/hoisting operations, a factor of safety of 6 would be appropriate. Thus:

$$W_d = f_s W_{sw} = \frac{6 \times 24500}{1000} = 147 \text{ kN} . \quad (11)$$

Equation (11) will be used to determine the diameters of ropes that can sustain the design load.

Oduori and Mbuya, (2009) derived equations relating wire rope diameter and rope breaking load through regression analyses of wire rope data from JIS G 3525, 1981 and found that wire rope breaking load is, to a very close approximation, proportional to the square of the rope diameter, with the constant of proportionality being a characteristic of the rope type rather than the particular rope.

The regression equations together with the relevant breaking load data were used to determine the suitable diameters of the candidate ropes (**Table 3**). Six wire ropes that could all be used for the application at hand were identified. There is still a need to finally screen the six ropes so as to end up with one that will be most suitable. The final screening of these ropes may be based on the following factors.

- **Rope diameter:** A smaller rope diameter is desirable because it costs less (U.S. Army Corps of Engineers, 1998). Moreover, a larger rope diameter will require a larger rope drum diameter too. In the present case we have only two rope diameters to deal with, i.e. 16 mm and 18 mm. If we assign a rating of unity to the reciprocal of 16 mm then the corresponding rating for the 18 mm diameter will be 0.8889.
- **Specific strength:** Ratings of specific strength were derived by Oduori and Mbuya (2009), based on data from JIS G 3525, 1981.
- **Percent reserve strength:** Abrasion and fatigue reduce rope strength. The term reserve strength defines the combined strength of only the rope's inner wires, which tend to be less affected by abrasion and fatigue. Ratings of reserve strength were derived by Oduori and Mbuya (2009), based on data from Elsevier (2004) and US Army Corps of Engineers (1998).

Table 3. Determination of Rope Diameters Suited to the Design Load

Type or Rope	Grade of Rope	Lay of Rope	Bright or Galvanized	Design Load, kN	Calculated Rope Diameter, mm	Standard Rope Diameter, mm	Breaking Load, kN
6 by 19S	G	Ordinary	Galvanized	147	17.3064	18	158.9
6 by 19S	A	Ordinary/Lang	Bright/Galv.	147	16.415	18	176.5
6 by 19S	B	Ordinary/Lang	Bright	147	15.9407	16	148.1
6 by 26WS	G	Ordinary	Galvanized	147	17.3064	18	158.9
6 by 26WS	A	Ordinary/Lang	Bright/Galv.	147	16.415	18	176.5
6 by 26WS	B	Ordinary/Lang	Bright	147	15.9407	16	148.1

Table 4. The Screening of Candidate Ropes

Wire Rope	6 by 19S Grade G	6 by 19S Grade A	6 by 19S Grade B	6 by 26WS Grade G	6 by 26WS Grade A	6 by 26WS Grade B
Diameter Rating	0.8889	0.8889	1.0000	0.8889	0.8889	1.0000
Strength Rating	0.8996	1.0000	1.0651	0.9063	0.9994	1.0653
Reserve Strength Rating	0.7442	0.7442	0.7442	0.8372	0.8372	0.8372
Sum of Ratings	2.5327	2.6331	2.8093	2.6264	2.7255	2.9025
Standard Deviation of Ratings	0.0868	0.1283	0.1696	0.0336	0.0828	0.1175

The results of wire rope screening are given in **Table 4**. The **6 by 26WS**, Grade B Rope should be the most suitable for the application at hand.

The following factors, have not been considered yet because they are difficult to quantify:

- **Corrosion resistance:** In corrosive environments, ropes should either be galvanized or made of stainless steel. In non-corrosive environments, lubrication can provide some protection against corrosion.
- **Resistance to crushing:** Ropes with IWRC and regular lay ropes are more crush-resistant than fiber core and lang lay ropes. Fibre cores are not suitable for operations at temperatures greater than 82°C (Elsevier, 2004). On the other hand, ropes with fibre cores are more flexible and retain lubricant better.
- **Rope lay:** Regular lay ropes are easier to handle and are not prone to untwisting in applications with suspended loads. On the other hand, lang lay ropes exhibit better flexibility and fatigue resistance but they are less resistant to crushing under heavy loads.

Thus, a 6 by 26WS, Grade B, Right Regular lay rope of 16 mm diameter, with a fibre core was selected.

5. CONCLUSION

Decision theory and information processing have been shown to be applicable in the selection of wire rope for manual winch application. Further research should demonstrate and strengthen their wider applicability in the selection of engineering entities.

REFERENCES

[1] Black, P. H and O. E. Adams Jr.: *Machine Design*, 3rd Edition. McGraw-Hill International, 1981.

- [2] Elsevier Ltd: Wire Rope, *Encyclopedia of Materials Science and Technology*, 2004. <http://www1.elsevier.com/emsat/pdf/200134.pdf>.
- [3] Japanese Standards Association: *JIS Handbook, Ferrous Materials and Metallurgy*, 1981.
- [4] Mendoza, M and E. Gutierrez-Pena: Decision Theory, International Encyclopedia of Education, 3rd Edition, 2010. <http://allman.rhon.itam.mx/~mendoza/decisiontheory.pdf>
- [5] Oduori, M. and T. Mbuya: Wire Rope Selection for Manual Winch Application, Journal of Engineering, Design and Technology, Vol. 7, No. 2, 2009.
- [6] Robichaud, B., Eugene, J. M. and Alix-Marie H.: *Introduction to Information Processing*, 4th Edition, McGraw-Hill Book Company, 1989.
- [7] Saaty, T. L.: How to Make a Decision: The Analytic Hierarchy Process, European Journal of Operational Research, 48, 1990, 9-26.
- [8] Shigley, J. E. and C. R. Mischke: *Mechanical Engineering Design*, 5th Edition. McGraw-Hill International, 1989.
- [9] Taha, H. A.: *Operations Research-An Introduction*, 8th Edition, Prentice-Hall of India, 2008.
- [10] U.S. Army Corps of Engineers: *Wire Rope Selection Criteria for Gate Operating Devices*, 1998. http://www.gisceu.com/epdf_files/U2.pdf