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시스템즈 엔지니어링 기법을 이용한 원자력발전소 부지 선정 방법에 대한 연구

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NPP Site Selection : A Systems Engineering Approach

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Abstract : Nuclear power plant site selection is a complex process and its successful completion is a critical milestone in the NPP development cycle. Proper siting of NPP will ensure public health and safety, environmental conservation, reduced project failure risks and a smooth NPP development process among other benefits. The objective of this paper is to demonstrate the application of systems engineering to the problem of NPP siting in Kenya. The siting process demonstrated in this paper includes stakeholder need analysis where stakeholders are identified and their needs concerning NPP site are elicited and converted into system functional requirements. A value model is then developed and potential sites iteratively subjected to three types of criteria i.e. exclusionary criteria, avoidance criteria and suitability criteria. This process is used to identify the candidate sites. An additive value model; multiple objectives Decision Analysis (MODA) is then used to calculate candidate solutions values. The site with the highest solution value score is selected. Sensitivity studies using different criterion weight sets (thereby reflecting different viewpoints) can be conducted to assess their effect on the selection of a preferred site and thereby lend additional credibility to the decision process.

Key Words : Stakeholders, Sensitivity analysis, value modeling, siting, Value measures, Global weights, Swing weight.*

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1. Introduction

Nuclear power plant (NPP) development is a complex process1 that consumes massive resources. The dynamism in NPP technologies; aimed at enhancing the atomic energy safety presents risks that must be managed effectively if maximum benefits are to be attained from this line of atomic energy application.

A systems thinking approach can be used to uncover potential NPP sites, critical systems structure such as boundaries, inputs, outputs, process structure and complex interaction of system with environment. Systems thinking combined with engineering principles focus on creating values (Kossiakoff, 2011) for stakeholders and are capable of addressing many of the challenges posed by the growing complexity of the systems. Systems engineering approach is not only concerned with engineering design of the system but also with external factors (INCOSE, 2006) which can significantly constrain the design. These include the identification of customer needs, system operation environment, interfacing systems and logistics support requirements. A systems decision process approach is collaborative, iterative and value based decision process that can be applied during NPP site selection process. It focuses on the needs and objectives of the stakeholders and decision makers concerned with the value being delivered by the system.

Early identification and management of risks is critical if their impacts are to be minimized during NPP development process (INCOSE, 2006). The identification of a suitable NPP site is a major milestone in the process

of establishing a nuclear power plant, at which major risks can be identified and managed. This paper presents in brief a systems engineering methodology for NPP siting in Kenya that would address major NPP development risks such as radiological hazards, construction cost and schedule overruns. The methodology can generally be applied in all nuclear power plant siting undertakings.

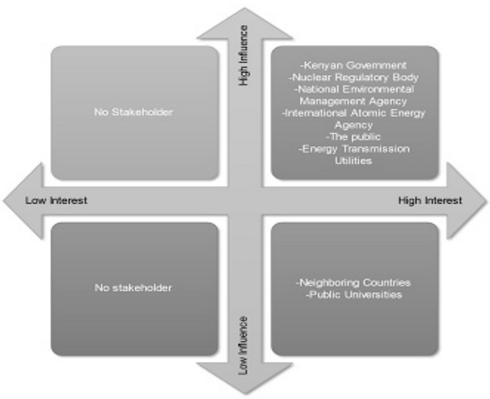
2. Need analysis

2.1 Problem definition

Kenya is seeking to develop a viable nuclear energy program within the next 10 years to meet its growing energy demand which is projected to reach 30,000MW by the year 2030 (LCPDP, 2010). The first NPP is expected to be integrated into the Kenyan grid by the year 2022 (LCPDP, 2010). Nuclear Electricity Board, a body tasked to spearhead this process is expected to ensure that all the 19 infrastructural issues for first NPP development are addressed for ease of licensing. The identification of a suitable site from several existing potential sites is key to ensuring security and protection of the nuclear power plant, which is a key infrastructural issue. Conventional methods of site selection which involve expert judgment and which center on site characteristics only are not sufficient because they exclude public participation; who are key stakeholders of the NPP development process (EPRI, 2002) as per NCR (Nuclear Regulatory Commission) procedures. This paper proposes a methodology of site selection which incorporates systems engineering approach in the identification of a suitable NPP site for Kenya. The application of this methodology will ensure that views of all stakeholders are considered and therefore public acceptance is enhanced. A suitable location will also ensure that economic risks associated with public rejection are minimized and therefore the cost of capital which is greatly influenced by the level of risk is reduced. The method also offers a suitable tool for evaluation of the influence of multiple factors to the site selection decision process. In this methodology, KINGS students with diverse discipline backgrounds represent the various stakeholder groups for the purpose of information gathering.

2.2 Stakeholder identification

A group of experts with knowledge in nuclear power plant development cycle stages were identified and tasked to identify stakeholders. Identified stakeholders were classified based on their interest and their power of influence to the success of the NPP development project as shown in the figure below.



[Figure 1] NPP Siting Stakeholders,

During needs elicitation, main focus is placed on stakeholders with high interest and high influence

2.3 Stakeholder needs elicitation

In identifying stakeholder' s needs, the following different techniques are used on different stakeholders to as discussed below :

2.3.1 The Public

To gather information from the public, Conferences are held in the candidate regions with a theme of NPP siting. A total of three conferences are held, one in each of the three regions of interest. For the sake of result validity with an average attendance of 700 participants per conference and with 20 technical experts will assumed in order to gain good population representation. During the conferences, technical papers are presented on siting requirements. The attendees are grouped in a total of 10 groups with each having 2 technical experts to receive and record needs as pertains NPP siting within their respective regions. This method is suitable due to the large size of target group.

2.3.2 Nuclear Regulatory Body, Energy Transmission Utility and National Environmental Management Agency.

Focus groups are used to gather information from the above institutions. Two technical representatives from each institution, are invited in a discussion to present their organization's needs as pertains to NPP siting. Two staffs of Nuclear Electricity Board carry out the facilitation of this exercise. Questions are prepared in advance to guide the discussion.

2.3.3 International Atomic Energy Agency

IAEA technical staffs are invited to present their organization's needs as well as provide training on technical aspects of NPP siting. IAEA publications on siting are also reviewed to obtain technical information on siting on areas not covered during the training.

2.4 Stakeholder Needs Summary

Sample Stakeholder needs are summarized in table 1 below.

<Table 1> NPP siting value hierarchy

Stakeholder	Needs
Kenyan Government	That facilitate emergency planning
	Minimum population transfer.
	Away from social amenities
	Adequate Security
Nuclear Regulatory Body	Adequate security ensure security
The media	Timely news.
National Environmental Management Authority	Minimum destruction to environment
	Away from water catchment areas.
	Minimum earth movement
Energy Transmission Utilities	Near electrical grid
	Near electric load centers
	Accessible.

3. Functional and requirements analysis

Records of needs obtained from stakeholders were massive with multiple repetitions. The first step in functional analysis involved the categorization of the stakeholder needs to reduce on the amount of data and eliminate repetitions. Affinity diagramming was used for this task as described below

3.1 Affinity diagramming

Affinity diagramming is a group process used to generate ideas and provide new groupings of the ideas for a specific purpose. A total of 20 members from Nuclear Electricity board participated in this exercise which took a period of 6 days. During the exercise, ideas which had already been generated from stakeholders were categorized under various groups with Similar stakeholder needs being grouped together.

3.2 Generation of system Functions

From stakeholder need groupings obtained through affinity diagramming, NPP site system functions were derived. For each category of needs, one function of the site as a system was identified that would enable the site to meet all the needs under that category. An example of system function generated is the need to ensure public safety.

3.3 Objective Functions

Objective functions were then derived from system functions. This involved what the NPP site intended to achieve. An example is maximizing public safety.

System functions and objective functions generated are presented in column 1 and 2 respectively of table 2 below.

<Table 2> NPP siting value hierarchy

	Objectives		Attributes
NPP SITING	Public Health & Safety	Maximize public health and safety	Proximity from large population centres
			Wind Speed & Air Dispersion Conditions
			Proximity from the active fault line
			Proximity from flight paths & hazardous area
			Seismic & topography profiles
	Environmental Protection	Maximize environ-mental protection	No. of protected species
			Proximity to important ecological areas
			Air quality index
			Proximity to important heritage areas
	Social-Economic Consideration	Minimize no. of people to be relocated	No. of households to be relocated
			Population Distribution & Density
	Construction Cost (Economic and Technical Aspects)	Minimize construction cost	Proximity to demanding area
			Proximity from the power grid
			Proximity from large quantities of water source for cooling
			No. of transportation modes

4. Value modeling

Value modeling provided the siting team with an initial methodology for evaluating candidate sites.

Value measures were obtained from objective functions derived above. Value measures are measurable attributes of a system whose level of measure provides an indication of how well a system is meeting its objective functions. For example the number of household to be relocated was identified as an appropriate measure to identify the site that would minimize people to be relocated.

4.1 Quantitative/Qualitative Value Model

Value measures were modeled both qualitatively and quantitatively. A team of experts from Nuclear Electricity board undertook this task. To generate qualitative model, Value models that addressed majority of stakeholders' needs were classified as very important and of high measure while those which addressed few stakeholder needs were classified as less important and of low value measure. Expert judgment was also applied during classification process. For quantitative modeling, weights were allocated to value measures based on their capability to support the system functions. The highest weight of 100% was assigned to the very important and high valued value measure. Expert judgment was also applied in assigning weights. In this way, it was possible to identify key stakeholder values regarding the systems decision problem and therefore obtain a priority list based on swing weight matrix value. The Table 3 below shows swing weight matrix which reflects the qualitative and quantitative value model while table 4 shows the value hierarchy structure.

<Table 3> swing weighting matrix for determining measure weight

	Level of importance of the value measure		
	Very Important	Important	Less Important
HIgh	Distance from cooling water-source (100) Distancefrompowergrid (95)	Distance from fault lines (41)	
MedIum	Wind speed (90) Population density (85)	No of transport modes (78)	No of protected species (30)
Low	No. of household to be relocated (65)	Distance from flight paths (63)	

<Table 4> Global weight of the value measures

Value Measures (x)	Swing Weight	Measures Global Weight
Distance from cooling water source(km)	100	0.154
Distance from power grid (km)	95	0.147
Wind speed	90	0.139
Population density	85	0.131
No of transport mode	78	0.121
No of households to be relocated	65	0.100
Distance from flight paths (km)	63	0.097
Distance from fault lines (km)	41	0.063
No. of protected species	30	0.046
Total	647	1.00

Measure weight for value measures,

$$(wi) = \frac{f_i}{\sum_{i=1}^{m} f_i}$$

where, f_i = the non-normalized swing weight assigned to the value measure, i = 1 to n for the number of value measures and is the corresponding weight.

5. Solution Design

A screening process was undertaken by experts from different disciplines including geologists, electrical engineers, Surveyors, nuclear scientists and meteorologists from Nuclear electricity board.

5.1 Screening Criteria Definition

- Exclusionary Criteria : Included regulatory, institutional, facility design, and/or environmental constraints that were used to eliminate infeasible areas (EPRI, 2002).
- Avoidance Criteria : Constraints applied to screen out feasible but not favorable areas e.g. distance from water bodies (EPRI, 2002).
- Site Specific suitability Criteria : Constraints developed to eliminate sites which are unsuitable e.g. topographical features (EPRI, 2002).

Table 5 below provides a summary of sample criteria used in site screening process

<Table 5> NPP siting value hierarchy

CRITERIA	SAMPLE CONSTRAINTS
Exclusionary Criteria	Site suitability Regulations as prescribed by Kenya Nuclear Regulatory Board
	Regulations as prescribed by the Kenya Environmental Management Authority
	Constitutional acts and laws defining protected zones such as national parks and water catchment areas.
Avoidance Criteria	Avoid sites with population density of more than 50 persons per square kilometer
	Avoid areas that are within a distance of 20km from an airport.
Site specific Criteria	Kilometers of transmission lines
	Geological characteristics
	Size of population to be affected
	hectares of wetlands

5.2 Regions of interest

Regions of interest for NPP siting were identified. The selection was based on information available from published reports, public records, public and private agencies and individual knowledge of selection team about the regions.

5.3 Candidate Areas

Within the regions of interest identified above, candidate areas were selected using exclusion and avoidance criteria developed above.

5.4 Potential sites

Candidate areas identified above were subjected to exclusion criteria and more stringent avoidance criteria to identify potential sites.

5.5 Candidate sites

Potential sites were subjected to suitability criteria to obtain candidate sites.

5.6 Preferred Sites

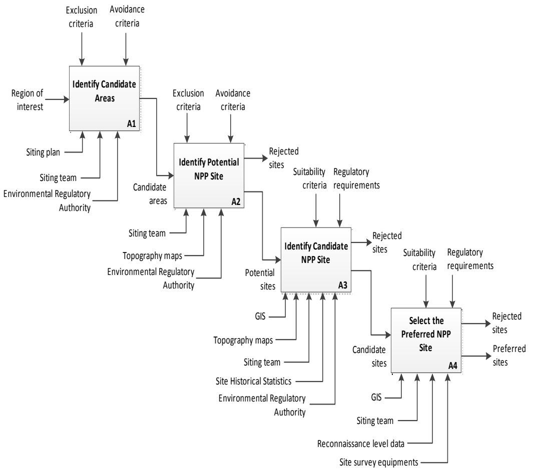
Reconnaissance level data was collected and a detailed investigation done on candidate sites. Trade-off analysis was also done to identify preferred sites for NPP development.

The table below shows site classification summary

<Table 6> NPP siting value hierarchy

NAME	DESCRIPTION
Regions of Interest	3 out of 8 provinces of Kenya having sufficient water bodies.
Candidate Areas	Districts within the 3 regions of interest that emerged out of first screening involving the application of less stringent exclusionary and avoidance criteria
Potential Sites	Sites within candidates areas which emerge out of second stage screening involving the application of more stringent exclusionary and avoidance criteria
Candidate Sites	Sites within potential sites which arise from third screening involving the application of site specific suitability criteria
Preferred Sites	Sites within candidate sites which arise from final screening involving the application of site suitability criteria based on collected reconnaissance data

The Figure 2 below is an IDEF0 level 1 diagram provides a summary of the site selection process employed.



[Figure 2] IDEF0 level 1

5. Decision Making

Value measures identified in table 1 above have varying units in their measurement scales. Value functions were used to convert candidate solutions scores on the value measures to standard units. Value functions are generated based on the views of stakeholders. Value measures scores for the candidate solutions were obtained through expert opinion methodology. Experts who participated in the screening process and who came from different disciplines allocated weights based on actual sites data obtained from reconnaissance and relevant institutions such as meteorological departments. Questionnaires were prepared beforehand and experts were required to allocate weights ranging between 0% and 100% where 100 represented most suitable site as determined against a given solution value after which average weights were computed. Table 6 below provides a sample score levels for the various siting options. An additive value model (MODA) was used to calculate candidate solutions values (Parnell, 2011). The mathematical expression for the additive value model used to compute the total value for competing solutions is given by

$$V_x = \sum_{i=1}^{n} w_i v_i (x_i)$$

where, v_x is the total value of a candidate solution i = 1 to n for the number of value measure x_i is the score of the candidate solution on the ithvaluemeasure w_i is the normalised swing weight

<Table 6> Value Matrix for Decision Tree

Candidate Sites	Site A	Site B	Site C	Weight (wi)
A	65	70	40	0.154
B	78	30	63	0.147
C	40	35	25	0.139
D	80	40	47	0.131
E	50	60	44	0.121
F	85	50	45	0.100
G	70	45	32	0.097
H	35	45	50	0.063
I	68	72	46	0.046
Solution value	64	48	44	

A : Distance from cooling water source
B : Distance from power grid (km)
C : Wind speed (km/h)
D : Population density
E : No of transport modes
F : No of households to be relocated

G : Distance from flight paths
H : Distance from fault lines (km)
I : No of protected species

6. CONCLUSION

From the analysis above, the site with the highest solution value score was selected. Sensitivity studies using different criterion weight sets (thereby reflecting different viewpoints) can be conducted to assess their effect on the selection of a preferred site and thereby lend additional credibility to the decision process.

This process of criterion weighting and composite suitability scoring can be applied at both site screening and site selection stages, although a GIS application is required for the former because of the volume of information and data that is involved.

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