AN ANALYSIS
ON
EFFECTIVE PHYSICAL PROTECTION SYSTEM DEVELOPMENT
FOR
NUCLEAR MATERIALS AND NUCLEAR FACILITIES IN BANGLADESH

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BANGLADESH

INTRODUCTION

- Nuclear material (NM) is widely used in a lot of legitimate applications like in industry, medicine, agriculture and scientific research.
- But its potential may be misused by the wrong perpetrators to cause a nuclear disaster or to achieve particular anti-state goal in the form of deterrence and violence.
- This is why, it should be highly controlled and accounted since its production to its final disposal along with special attention to its physical protection system (PPS).
- The responsibility of nuclear security and PPS rests entirely with the country since its physical security is subjected to various threats.
- Hence, threat to NM and Nuclear Facilities (NF) is the main factor for the PPS development.

CURRENT ISSUES AND OBLIGATIONS ON PPS FOR NPP – BANGLADESH PERSPECTIVE

- Till date, Bangladesh doesn't have NM in use for industrial purposes as such there is no record of malicious act regarding NM and NF demonstrating a pure case of nuclear security event as per the report of the Criminal Investigation Department.
- The only small nuclear outfit available here is a 3 mega-watt research reactor that uses 19.7% low enriched uranium for research purposes only. For its protection, an average security system is in place that does not fully conform the IAEA guidelines.
- On the other hand, as per crime record, terrorism to non-nuclear targets is a very frequent security event in Bangladesh with the application of sophisticated technologies.
- Hence, addition of this emerging technology might make a significant change in the security situation of Bangladesh.

CURRENT ISSUES AND OBLIGATIONS ON PPS FOR NPP – BANGLADESH PERSPECTIVE

- In such a complex climate of security situation, Bangladesh is going to start its first Nuclear Power Plant (NPP) by 2022.
- Therefore, physical security of the upcoming NPP including its fuel, waste and other industry yields are of a time worthy concern for Bangladesh now.
- Moreover, Bangladesh being a signatory to CPPNM and Convention on Nuclear Safety, it is obligatory to have effective PPS for its NM and NF complying the associated instructions.
- Considering all these issues, development of effective PPS for the NM and NF is a compelling necessity for Bangladesh now.

CURRENT ISSUES AND OBLIGATIONS ON PPS FOR NPP – BANGLADESH PERSPECTIVE

- Unfortunately, Bangladesh has no standard PPS for NM and NF at present.
- The relevant organizations have neither experience on such subject nor institutional practices of nuclear security culture in vogue.
- So far, no study has been carried out comprehensively and deliberately covering the entire spectrum of nuclear security engineering and PPS for Bangladesh.
- On the other hand, PPS being the state's responsibility by law, its engineering aspect specially, the design, development and structural details are normally kept to a security grade not less than SECRET in anywhere of the world due to national security reason.
- As such, there are very less information available publicly in relation to the engineering aspect of effective PPS development and the validation technique.

THREE PREREQUISITES FOR PPS DEVELOPMENT

- Development of Regulatory Framework for Nuclear Security and PPS
- Vulnerability Analysis
- PPS Operation and Maintenance (O&M)

Development of Regulatory Framework

- Consequences of nuclear disaster from an NPP are not only national but international issue also.

- National regulatory framework on nuclear security and PPS should be prepared complying international obligations and regulatory guidelines.

Development of Regulatory Framework

- Basing on IAEA guides, ***eight*** essential national regulatory frameworks are suggested for Bangladesh:
  1) National nuclear *security culture*
  2) Preventive and protective measures against *insider threats*
  3) Development, use and maintenance of the *Design Basis Threat* (DBT)
  4) Nuclear *security policies and procedure* on PPS of NM and NF
  5) Nuclear security systems and *measures for major public events*
  6) Nuclear security systems and *measures for the detection* of NM and radioactive materials (RM) *out of regulatory control*
  7) Security of nuclear information and *security of NM during transport*
  8) NM *accounting and control* for nuclear security purposes at facilities

Development of Regulatory Framework

- Additionally, national legal instruments should also be developed to cover sufficiently:
  - Non-proliferation and safeguard strategy
  - Proper accounting and control system
  - Structural requirements of physical protection architecture
  - National nuclear security infrastructure
  - National nuclear energy law etc.

Vulnerability Analysis

- Vulnerability of NPP in Bangladesh should be analysed and determined as per IAEA Nuclear Security Series 10 through careful threat study and crime record based on national and international intelligence report.

- Such an assessment would lead to the DBT for NPP which may be quantified for risk assessment and determination of the consequences.

Threat Assessment of Undesirable Events

- In conducting the threat assessment, each undesirable event should be analysed with parameters like
  - Threat Definition
  - DBT Scenario
  - Baseline Threat
  - Analytical Basis
  - Target Attractiveness and
  - Threat Outlook

DBT Development for NPP in Bangladesh

- In Bangladesh context, considering the threat assessment factors and basing on the current threat pattern, the list of possible and perceivable threats along with its appropriate threat grade has been be identified and categorized with standardized threat variables like High, Medium, Low etc.

- Such a finding yields DBT for NPP in Bangladesh basing on which threat modelling, threat-security interfacing, risk analysis and numerical modelling for PPS development can be done.

Threat Quantification

- Each threat can be quantified reasonably in terms of capability, intent and target values; and put under computational logics for threat modelling.

- This is done to enclose all the threat dimensions under controlled mechanism.

- The output of the threat model can be the input for another computational logic sets to develop an intelligent tool that can design the most effective PPS of a facility.

Threat Quantification

- This tool would act as an effective threat-security interface which can be inputted to the final stage developing another PPS validation program to determine its effectiveness.

- PPS effectiveness can also be re-validated through using other physical means like conducting real time / table top exercises.

Risk Assessments through Intelligent Modelling

- Like other areas, risk assessment involves the process of risk identification, analysis and evaluation in nuclear domain also.
- In this assessment, applicable risk factors can be used as inputs to determine the risk level.
- Essential risk factors are
  - Intent and capability of adversaries
  - NM or RM
  - Vulnerability of the target

Risk Assessments through Intelligent Modelling

- Mathematically this risk level can be determined as the product of the probability of an unsatisfactory outcome (Likelihood) and the loss to the parties affected when the outcome is unsatisfactory.

- This determination can be done by fuzzy logic through intelligent modelling in a form of “IF and THEN” rules which relate input and output variables.

- FIS calculates the level of risk from the combinations of input variables.

Risk Assessments through Intelligent Modelling

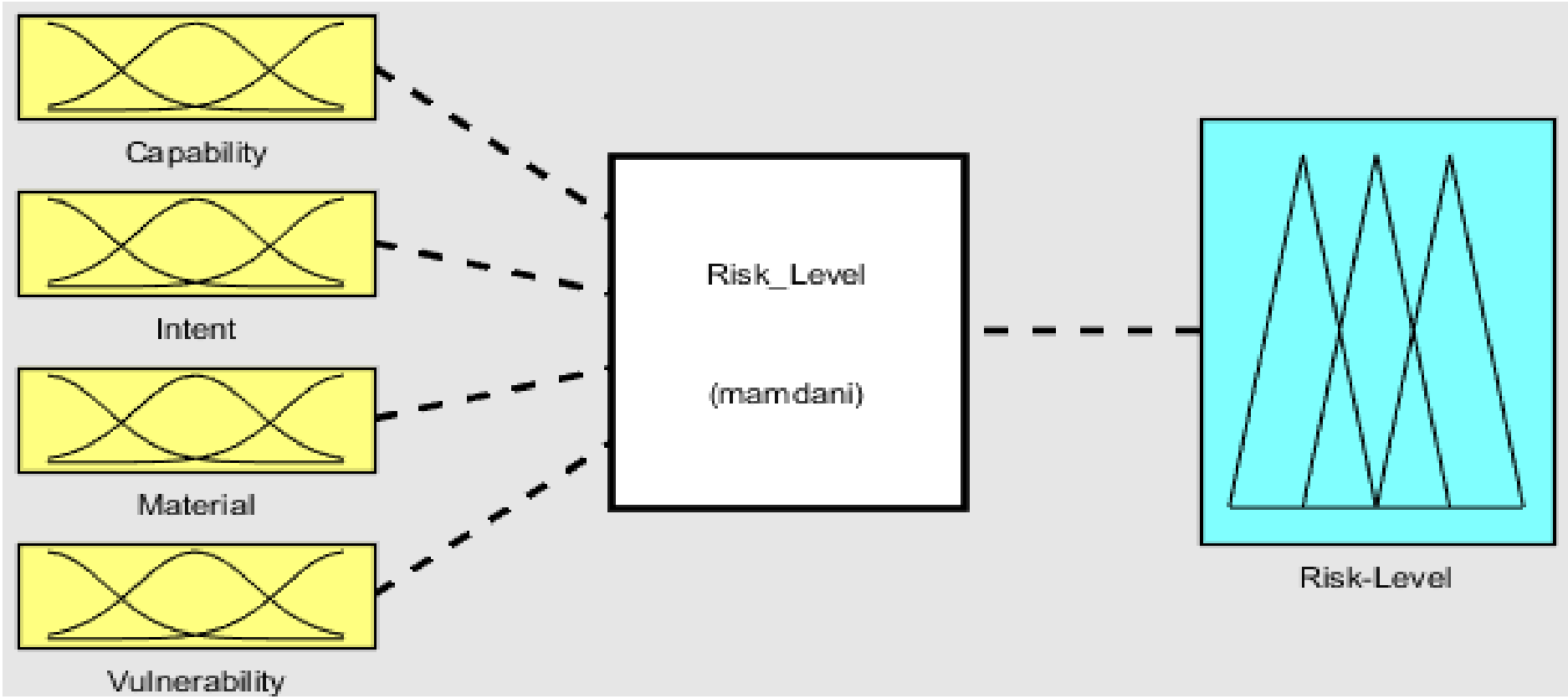


Fig. Architecture for Fuzzy Logic based Risk Model.

Risk Assessments through Intelligent Modelling

- Proposed model was used to analyse the risk level using different assumed values and output based on a hypothetical scenario.
- Operation of the FES was carried out using trapezoidal membership functions for “Low” and “High”, and triangular shaped functions for other variables due to their wide applications and accuracy.
- By using rule viewer, it was observed that the group was a strong organization (e.g. 70% capacity) and their motivation was good to take an act that could increase their profile (e.g. 60% intent).
- Subsequently, the desired RM was tightly controlled, and the target was civilian and highly vulnerable (e.g. 60% vulnerability).
- The combination of factors results 76.5% rating that showed a very high risk for the group deploying an RDD in an annual celebration.

PPS Operation and Maintenance (O&M)

- Like any functional infrastructure, O&M play vital role in PPS performance to achieve the objectives of nuclear security.

- Four essential aspects need to be considered for effective O&M of the PPS.
  1) Development of efficient PPS operator
  2) Facility-specific intelligence organization
  3) State intelligence organization for counter check function
  4) Role of stakeholders for PPS as per threat variance

Effective PPS Development

- Basic functions of PPS are to detect, delay and response to an unwanted intrusion of the motivated adversaries having intention to cause nuclear disaster.
- PPS should be developed as an effective nuclear security infrastructure for the NPP *through any assessable approach either or in mixture of both mathematical and numerical modelling*.
- This would demand the concentration of all-out efforts like
  - Development of integrated engineering solution based on performance evaluation through successive reliability testing,
  - Formulation of necessary regulatory frameworks
  - Introduction of facility-specific administrative measures
- Objective of PPS development is to curve the adversary's initiative at the earliest.

Effective PPS Development

- Three steps to develop effective PPS:
  - Step-1: An Engineering Design Tool (EDT) is developed utilising relevant mathematical formulations in order to generate an estimated PPS design.
  - Step-2: A prototype PPS is designed for a test site representing the NPP utilising the developed EDT and
  - Step-3: Performance of the designed PPS is investigated by developing a Performance Evaluation Tool (PET).

PPS EDT Development

- While developing a PPS, various types and quantities of detection devices and delay components are used in combination to allow sufficient time for the response force to conduct successful neutralization operation.

- These combinations widely vary depending upon the resources. Moreover, the number of all possible combinations might be high enough to be analysed leaving this to be impractical.

- Furthermore, analysis of every combination is time consuming and may not lead to the best possible optimized combination.

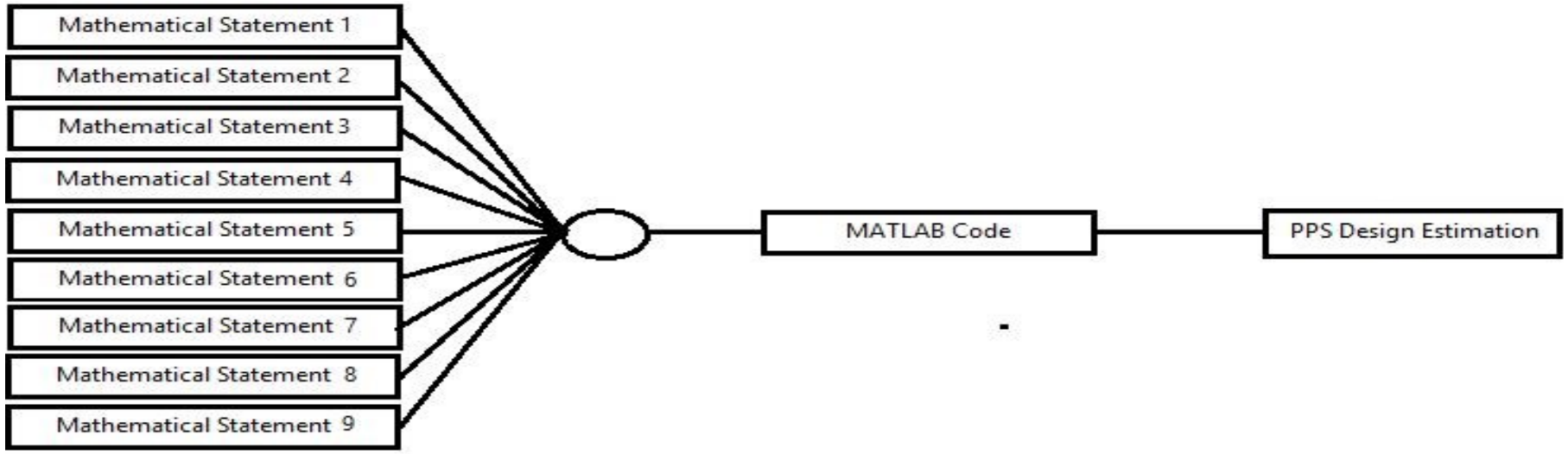
PPS EDT Development

- Therefore, an EDT has been developed by MATLAB code utilizing a set of necessary mathematical statements and formulations that can generate an estimation of PPS design.

- This is an engineering tool since the basic engineering principles like introducing redundant systems to achieve a fail-safe design and preventing the common-mode failure by using the most achievable diversified process are utilized.

PPS EDT Development

- Total ***nine*** mathematical statements are used to develop the EDT
  - Four for delay system design
  - Two for detection system including Line of Detection (LoD) design
  - Three for system reliability calculations for possible interruption to happen with the adversary



Generic Numerical Model for PPS Design Estimation

PPS EDT Development

- Mathematical statements used in this tool include:
  - Relationship between response force arrival time and time remaining for the adversary to reach the target after the sensor activation with a safety factor in the delay system
  - Minimum delay time required between consecutive sectors
  - Algorithm for Critical Detection Point (CDP) prediction
  - Graded delay slope to control the change of protection capability in order to achieve balanced and graded protection
  - Probability of Detection (P_D) for single and multiple detectors
  - Reliability of each detector in a LoD
  - Reliability of each individual LoD
  - Reliability of the total detection network

EDT Features

- Quality features of EDT include
  - Use of deterministic approach instead of probabilistic approach for worst criticality management
  - Introduction of safety factor in delay system design
  - Redundancy at individual detector and LoD level
- These features provide a design margin over the theoretical design capacity to handle any uncertainty.
- EDT is capable to identify and suggest the best possible optimised detector-delay component combinations which meet all possible requirements for an effective PPS.
- The areas of the optimization are *P_D, reliability, common-mode failure, budget, Nuisance Alarm Rate (NAR)* etc.

Proto-type PPS Development

- Using estimated PPS design parameters, *a prototype PPS has been developed* for the test site representing the NPP.
- The prototype PPS consists of external and internal sensors those have the capability to detect any intrusion by the adversaries at the earliest to compensate for and defeat new adversary's capabilities or tactics.
- This is done through *successive well-laid delays or barriers* in order to gain maximum time for first responders to conduct successful neutralization operation against the adversary.
- The test site has been divided into three different area as per the security merit of the various elements of NPP infrastructure i.e. *Vital Area (VA), Protected Area (PA) and Limited Access Area (LAA)*.

Delay Deployment

- This proto-type PPS is a *delay based design* that makes the most convenient selection of CDP to allow more detection area.
- For design purpose, the test site less the VA has been further divided in *four delay sectors* with introduction of incremental delay (linear/step/exponential) from outer perimeter of LAA to perimeter of the VA.
- For this graded delay, the adversary faces more *incremental resistance as he proceeds toward the VA* allowing more time for the response force for possible interruption.
- In addition, it assures *precision finding of the CDP* beyond which successful neutralization is not possible.

Delay Deployment

- PPS EDT provides a convenient and optimized delay component combinations that makes the total delay time greater than the response force arrival time with additional safety factor and most possible precise CDP.
- In this design, 1000 seconds (sec) are considered as the response force arrival time with a safety factor of 2 for fail-safe interruption having 4 delay sectors with a graded slope of 200 sec.
- For these inputs, EDT has provided a set of delay component for each delay sector that offers 205, 399, 639 and 809 sec for sector 1, 2, 3, and 4 respectively and a total delay time of 2052 sec for the adversary.

Sensor/Detector Deployment along LoD

- In this design, *five different types of sensors* with probability of sensing from 0.78 to 0.95, probability of alarm assessment from 0.87 to 0.98, constant probability of alarm transmission of 0.99 and hazard rate from 0.01/year to 0.05/year are considered.
- When an operational time of 06 months and a desired P_D of 0.995 are given as inputs, the *EDT suggests deploying three different LoDs* that provides a *combined P_D of 0.996 and reliability of 65.44%*.

System Redundancy

- To avail a detection system of higher reliability, the *EDT further suggests detector level and LoD level redundancy* i.e. minimum single redundancy for each detector and LoD.

- Through this, the *detection system achieves a reliability over 99.99%* in this detection system design.

Evaluation of Design Effectiveness

- In evaluating the PPS effectiveness, the standard mathematical statements for performance evaluation have been integrated in the MATLAB code in order to develop another computer based '***Performance Evaluation Tool (PET)***'.
- Mathematical statements used to develop the PET include ***Probability of Interruption (PI)*** and ***Probability of Effectiveness (PE)***.
- The PET has generated reliable and efficient evaluation of the performance of the designed PPS considering every probable path of the adversary.
- In validating the correctness of the developed PPS, ***Estimate of Adversary Sequence Interruption (EASI)*** model is taken as reference.

Evaluation of Design Effectiveness

- The value of PI found from the PET is 0.995 considering the probability of communication as a constant of 1 for each detector.
- This is same as the value found from the EASI model as such the designed PPS is considered to be effective.
- *The PET also measures the PE in precision, taking the exact value of Probability of Neutralization (PN) in considerations whereas the EASI model considers the value of PN to be always 1.*
- *Besides, the PET also compares the vulnerability between different adversary paths which is a unique feature in comparison to EASI model.*

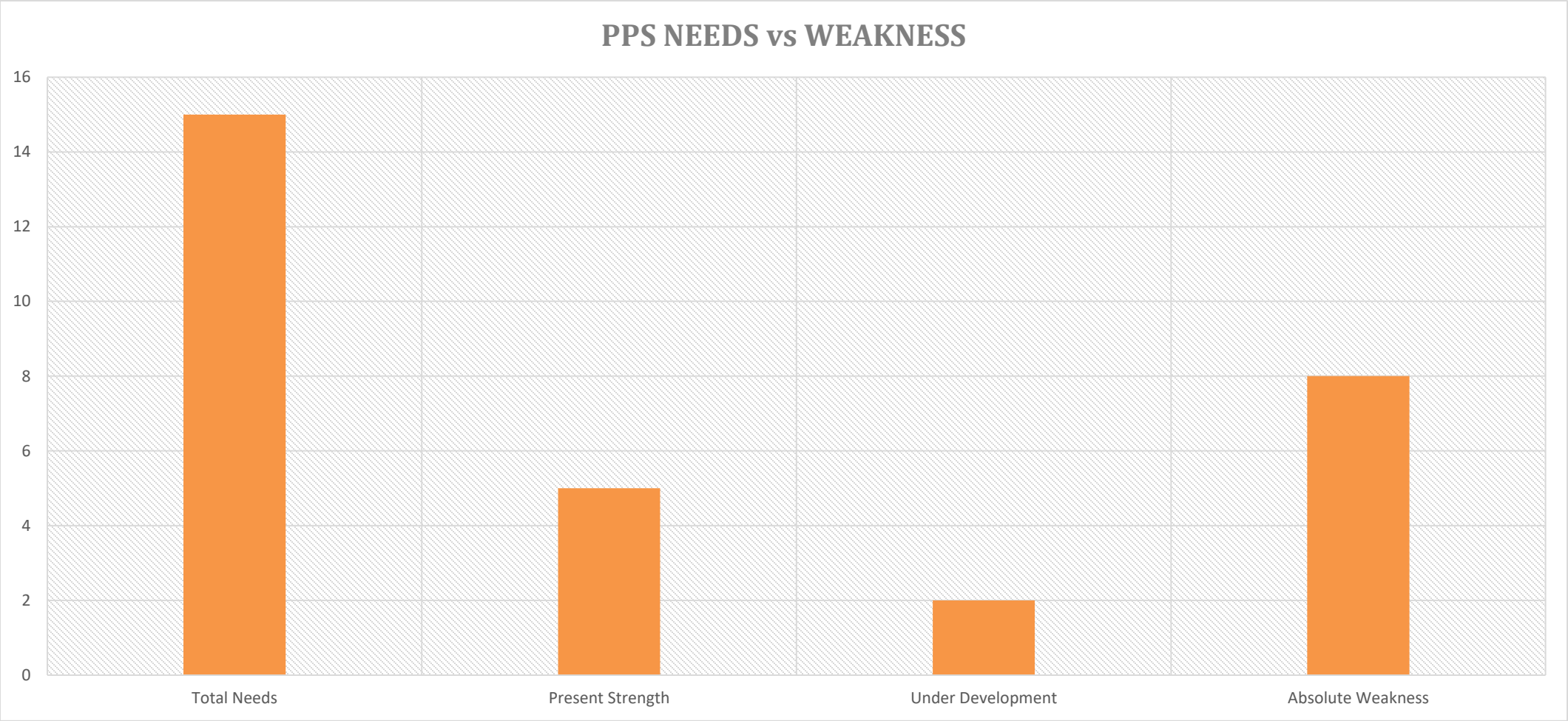
PPS Preparedness of Bangladesh

- In Bangladesh context, a comprehensive analysis is done on the requirements, essential to develop an effective PPS for its NPP.
- This analysis also conforms with the IAEA Milestones Approach for National Nuclear Power Infrastructure Development.
- Subsequently, the gap between the actual requirements for the PPS and the existing security system in place are analysed to deduce the findings as an actionable set of recommendations for the government.

PPS Preparedness of Bangladesh

Ser	Total Needs	Strength		Absolute Weakness
		Present Strength	Under Development	
1	PPS Regulatory Frameworks	x	√	-
2	Guidance by IAEA	√	-	-
3	DBT Development for NPP	√	-	-
4	Risk Modelling for NPP	x	-	√
5	PPS Design Tools for NPP	x	-	√
6	PPS Validation Tools for NPP	x	-	√
7	PPS Operator for NPP	√	-	-
8	Trained Human Resource	x	√	-
9	Institutional Experience	x	-	√
10	Institutional Capacity	x	-	√
11	Legal Organization	√	-	-
12	Site Protective Force	x	-	√
13	PPS Response Force	x	-	√
14	Facility-specific Intelligence Organization	x	-	√
15	State Intelligence Organization	√	-	-
		5	2	8

PPS Preparedness of Bangladesh



PPS Needs vs. Absolute Weakness - Bangladesh Perspective

PPS Preparedness of Bangladesh

- Findings on PPS Preparedness
  - identified present strength = 33.33%
  - identified development initiatives = 13.34 %
  - identified absolute weakness = 53.33 %

- Therefore, the identified weakness clearly reflects
  - the planned PPS is 46.67 % effective and
  - overall protection capability of Bangladesh is in a transitional state towards a full grown and matured system due to development initiatives under process

Future Works

This study recommends further works on the development of PPS for NPP following another deterministic approach to revalidate the developed PPS.

Conclusion

- In this study, the prerequisites in developing the PPS for NPP in Bangladesh has been analysed.
- A generic numerical model for PPS design estimation is also developed.
- Using the developed numerical model, a prototype PPS is developed for a test site representing the NPP.

Conclusion

- Subsequently, a computer based performance evaluation model is also developed in validating the correctness of the developed PPS.
- This tool can generate reliable and efficient evaluation of the performance of the designed PPS taking into consideration of every probable path of adversary.
- Considering Bangladesh perspective, a comprehensive weakness analysis has also been done (53.33%) to identify the gap and the national preparedness for the overall state-level nuclear security capability.

Thanks

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