# Technology Evaluation of Robotics Technology in Power Industry

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**Robert Grizzi**, Electric Power Research Institute
**John Lindberg T.,** Electric Power Research Institute

## Abstract

The electric power utilities as important social infrastructures should be operated stably without any failure in supply of electricity. For stable operation, it is necessary to input huge amount of resource and investment throughout power generation, transmission and distribution facilities. Particularly, constant inspection and maintenance of the facilities requires highly skilled manpower and advanced technologies. In spite of endless efforts, the electric power industry is facing serious challenges from social, economic and environmental problems. In this regard, a number of robotic systems have been tested and applied for inspection and maintenance in nuclear power plants and high voltage power transmission lines. The Electric Power Research Institute (EPRI) which conducts research, development and demonstration (RD&D) relating to the generation, delivery and use of electricity for the benefit of the public has also required efficient technology management in providing a blue print of robotics technologies in electric power sector for the future. The organization wants to centralize the R&D capability of robotics technologies which are dispersed by each division in order to prevent duplicated investments and manage its R&D capability effectively. This research is a step towards assessing the current robotics technology being used in the power industry and identifying the technologies that would benefit the industry most by using the Technology Development Envelop (TDE) approach.

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# Project Overview

## Project Background

- Electric Power Research Institute(EPRI) wants to centralize the R&D capability of robotics technologies which are dispersed by each division
- To prevent duplicated investments and manage its R&D capability effectively

## Project Objective

- To evaluate the current robotics technologies and identify the future development strategy in power industry with the Technology Development Envelope (TDE) methodology

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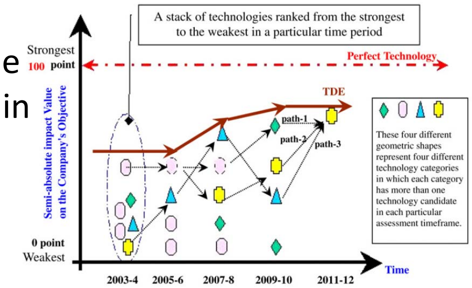
# Introduction of TDE

- "…to link technology to organization strategy so that managers can understand where technologies fit into their organization strategy and where the technologies are going in the future."

- Formed by connecting technologies that have the highest technology value in each period throughout the specified timeframe

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## Six Steps for Formation of TDE

**Step 1:** Develop a forecasting model using Delphi for identifying the trend of emerging technologies.

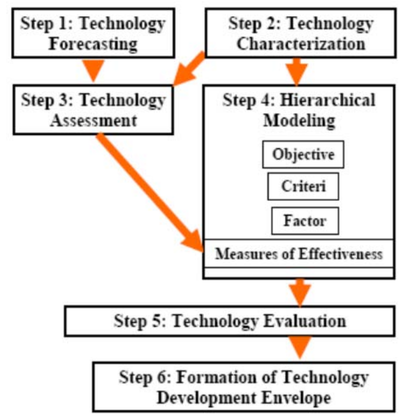
**Step 2:** Identify criteria and technological factors satisfying a company's objective.

**Step 3:** Assess the technological characteristics of each emerging technology along the factors.

**Step 4:** Develop a hierarchical model and determine the relative desirability of measures of effectiveness on the company's objective.

**Step 5:** Evaluate the value of emerging technologies on the company's objective.

**Step 6:** Construct the TDE and technology development paths.

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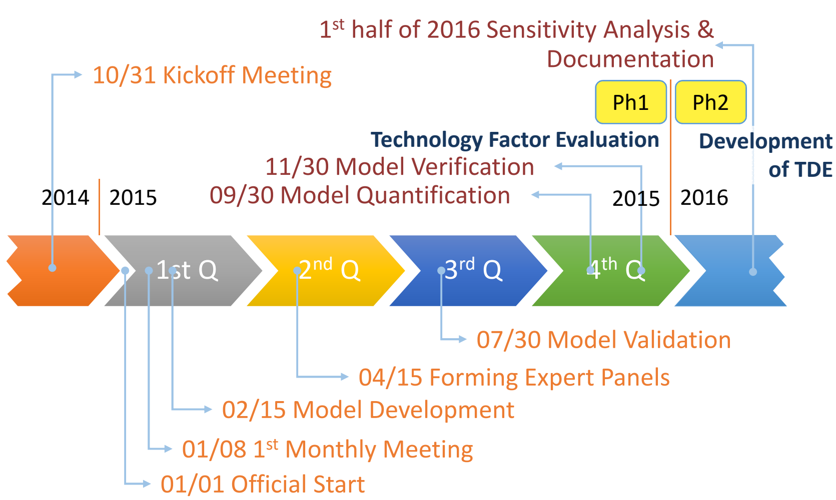
## Project Timeline

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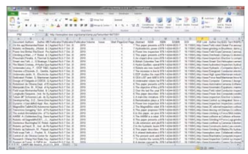
# Expert Identification

**Bibliographic Database**

IEEE Xplore DIGITAL LIBRARY
CARPI 2010
CARPI 2012
CARPI 2014

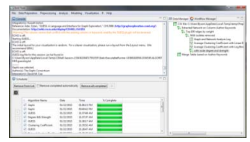
- Title
- Authors
- Affiliations
- Keywords
- Abstracts
- References
- . . .

**Data file**



- CSV
- BibTex
- Refworks
- ISI
- . . .

**Pre-processing**



- Co-Authorship
- Co-Occurrence
- Frequency
- . . .

with Sci2 & MS Excel

**Post-processing**


- Social Network Analysis

With Gephi

**1st Analysis Report**

- Main keywords in CARPI 2010-2014
  - Main usages of Robotic Tech. (RT)
  - Features and functions
  - Challenges
- Proactive People
- Main Reference Source
  - Journals
  - Other conferences
  - Books
  - . . .

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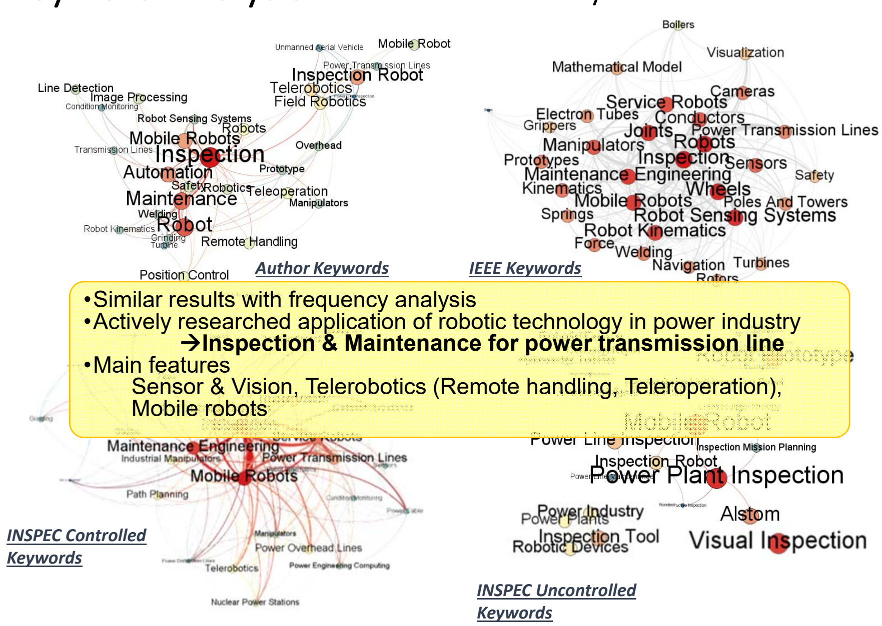
# Keyword Analysis – Social Network Analysis




- Similar results with frequency analysis
- Actively researched application of robotic technology in power industry
  **→Inspection & Maintenance for power transmission line**
- Main features
  Sensor & Vision, Telerobotics (Remote handling, Teleoperation), Mobile robots

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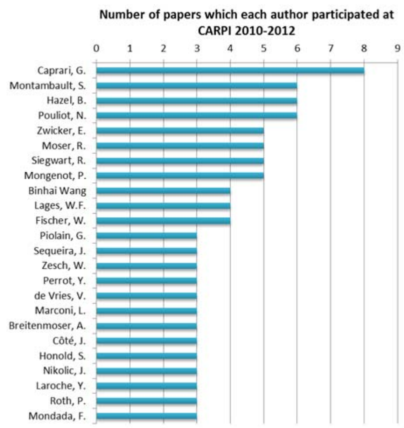
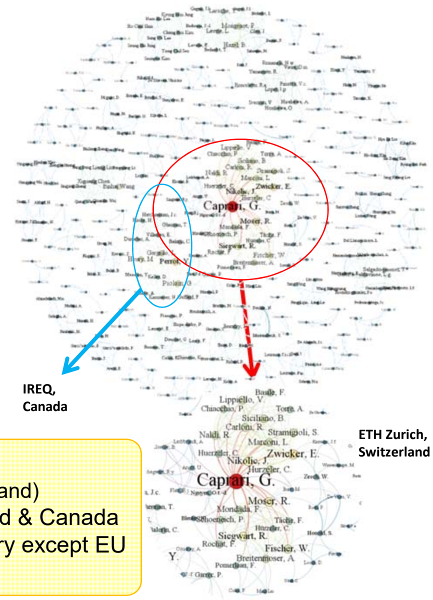
# Co-Authorship Analysis




- Most active player in CAPRI 2010-2012
  - Gilles Caprari (ETH Zürich, Switzerland)
- Most of top rankers belong to Switzerland & Canada
- Rare co-authorship between each country except EU countries

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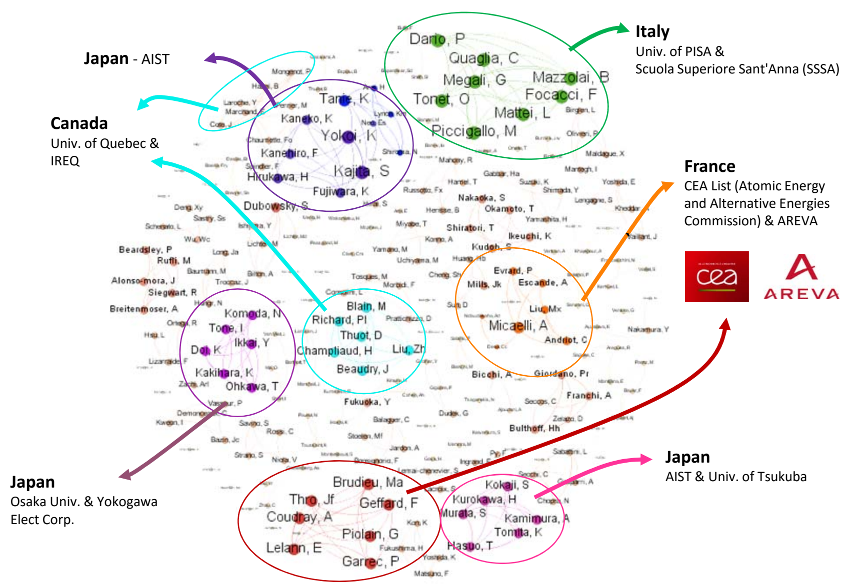
# Robotic Maintenance - Out of US in Robotics Journals

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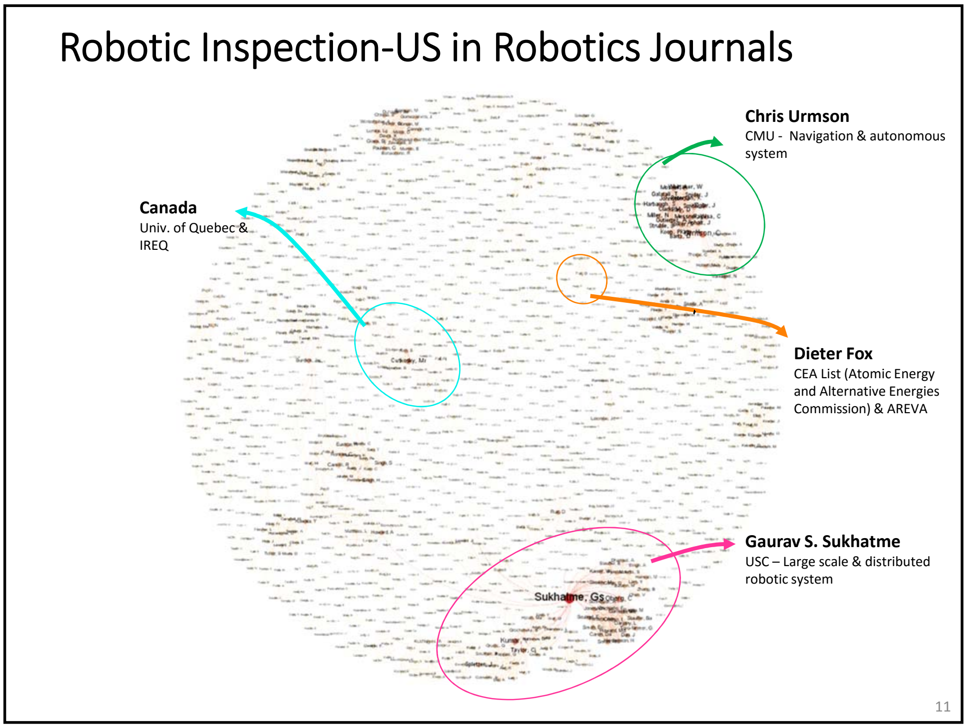
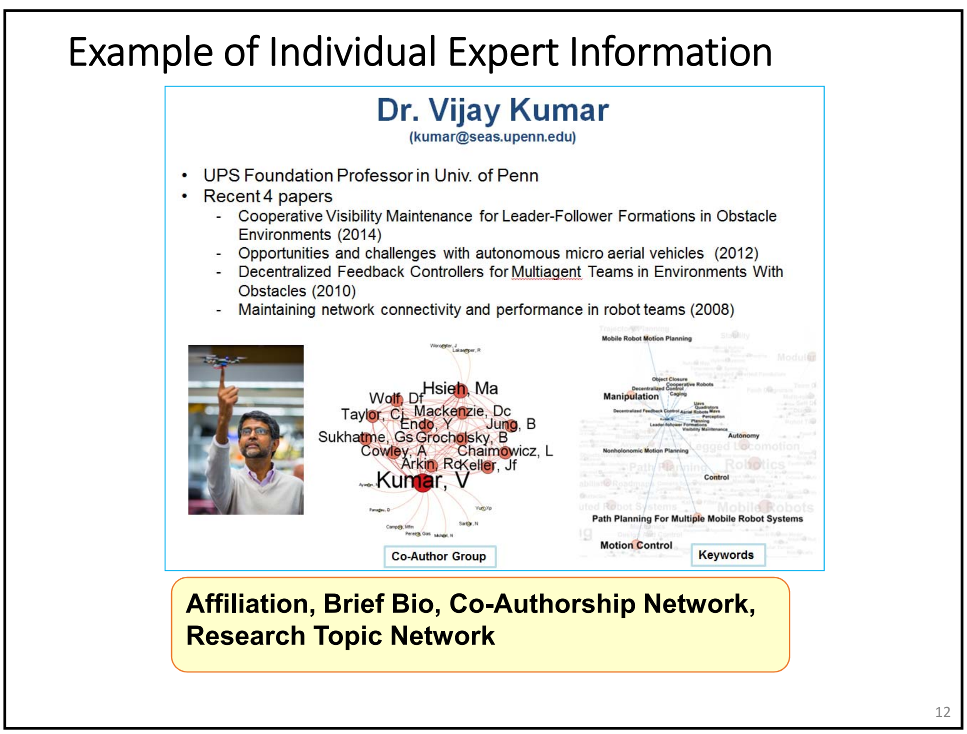

Robotic Inspection-US in Robotics Journals
Chris Urmson
CMU - Navigation & autonomous system
Canada
Univ. of Quebec & IREQ
Dieter Fox
CEA List (Atomic Energy and Alternative Energies Commission) & AREVA
Gaurav S. Sukhatme
USC – Large scale & distributed robotic system
Sukhatme, Gs
11


Example of Individual Expert Information
Dr. Vijay Kumar
(kumar@seas.upenn.edu)
• UPS Foundation Professor in Univ. of Penn
• Recent 4 papers
- Cooperative Visibility Maintenance for Leader-Follower Formations in Obstacle Environments (2014)
- Opportunities and challenges with autonomous micro aerial vehicles (2012)
- Decentralized Feedback Controllers for Multiagent Teams in Environments With Obstacles (2010)
- Maintaining network connectivity and performance in robot teams (2008)
Hsieh, Ma
Wolf, Df
Taylor, Cj
Mackenzie, Dc
Endo, Y
Jung, B
Sukhatme, Gs
Grocholsky, B
Cowley, A
Chaimowicz, L
Arkin, Rc
Keller, Jf
Kumar, V
Co-Author Group
Mobile Robot Motion Planning
Manipulation
Nonholonomic Motion Planning
Control
Path Planning For Multiple Mobile Robot Systems
Motion Control
Keywords
Affiliation, Brief Bio, Co-Authorship Network, Research Topic Network
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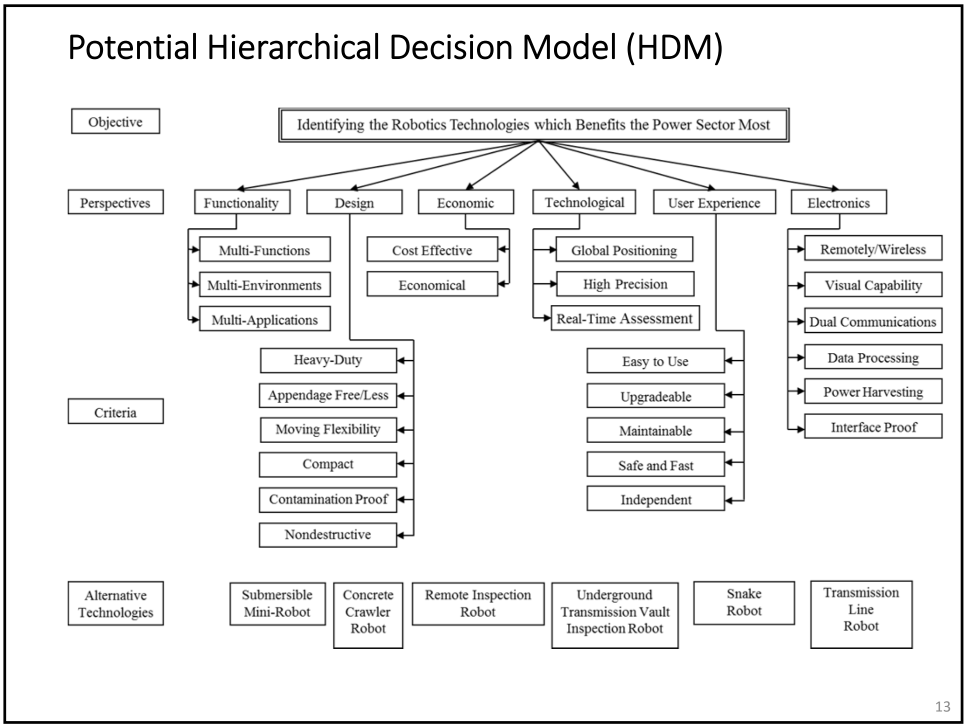
Potential Hierarchical Decision Model (HDM)
Objective
Identifying the Robotics Technologies which Benefits the Power Sector Most
Perspectives
Functionality
Design
Economic
Technological
User Experience
Electronics
Multi-Functions
Multi-Environments
Multi-Applications
Cost Effective
Economical
Global Positioning
High Precision
Real-Time Assessment
Remotely/Wireless
Visual Capability
Dual Communications
Data Processing
Power Harvesting
Interface Proof
Criteria
Heavy-Duty
Appendage Free/Less
Moving Flexibility
Compact
Contamination Proof
Nondestructive
Easy to Use
Upgradeable
Maintainable
Safe and Fast
Independent
Alternative Technologies
Submersible Mini-Robot
Concrete Crawler Robot
Remote Inspection Robot
Underground Transmission Vault Inspection Robot
Snake Robot
Transmission Line Robot
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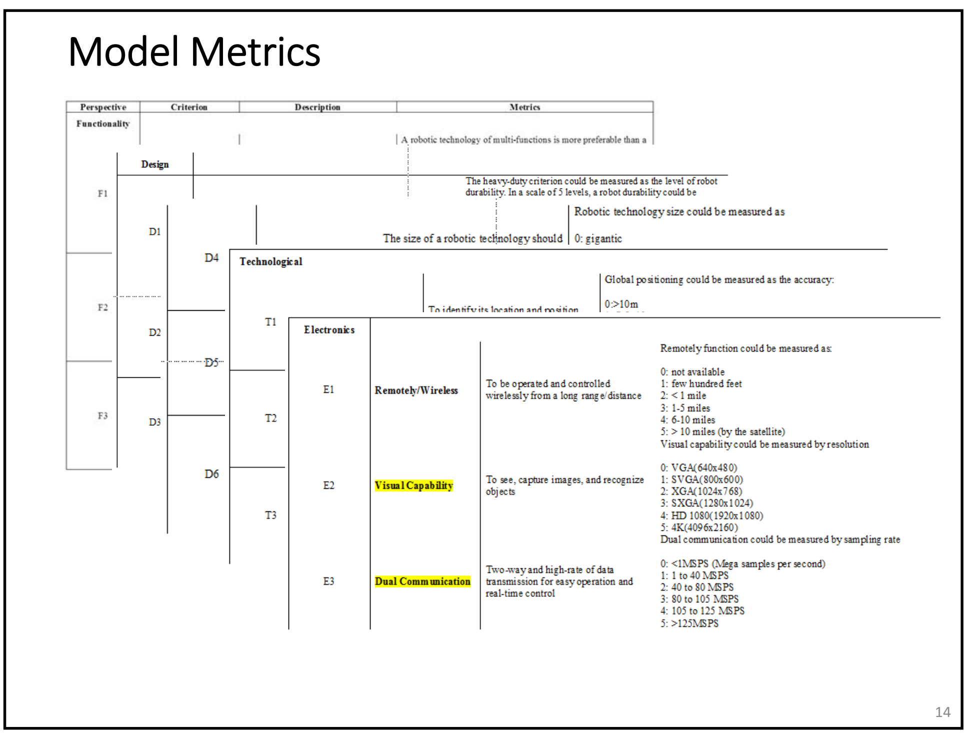
Model Metrics
Perspective
Criterion
Description
Metrics
Functionality
A robotic technology of multi-functions is more preferable than a
Design
The heavy-duty criterion could be measured as the level of robot durability. In a scale of 5 levels, a robot durability could be
F1
D1
Robotic technology size could be measured as
The size of a robotic technology should
0: gigantic
D4
Technological
Global positioning could be measured as the accuracy:
0:>10m
F2
T1
Electronics
D2
D5
Remotely function could be measured as:
0: not available
1: few hundred feet
2: < 1 mile
3: 1-5 miles
4: 6-10 miles
5: > 10 miles (by the satellite)
E1
Remotely/Wireless
To be operated and controlled wirelessly from a long range/distance
F3
D3
T2
Visual capability could be measured by resolution
0: VGA(640x480)
1: SVGA(800x600)
2: XGA(1024x768)
3: SXGA(1280x1024)
4: HD 1080(1920x1080)
5: 4K(4096x2160)
D6
E2
Visual Capability
To see, capture images, and recognize objects
T3
Dual communication could be measured by sampling rate
0: <1MSPS (Mega samples per second)
1: 1 to 40 MSPS
2: 40 to 80 MSPS
3: 80 to 105 MSPS
4: 105 to 125 MSPS
5: >125MSPS
E3
Dual Communication
Two-way and high-rate of data transmission for easy operation and real-time control
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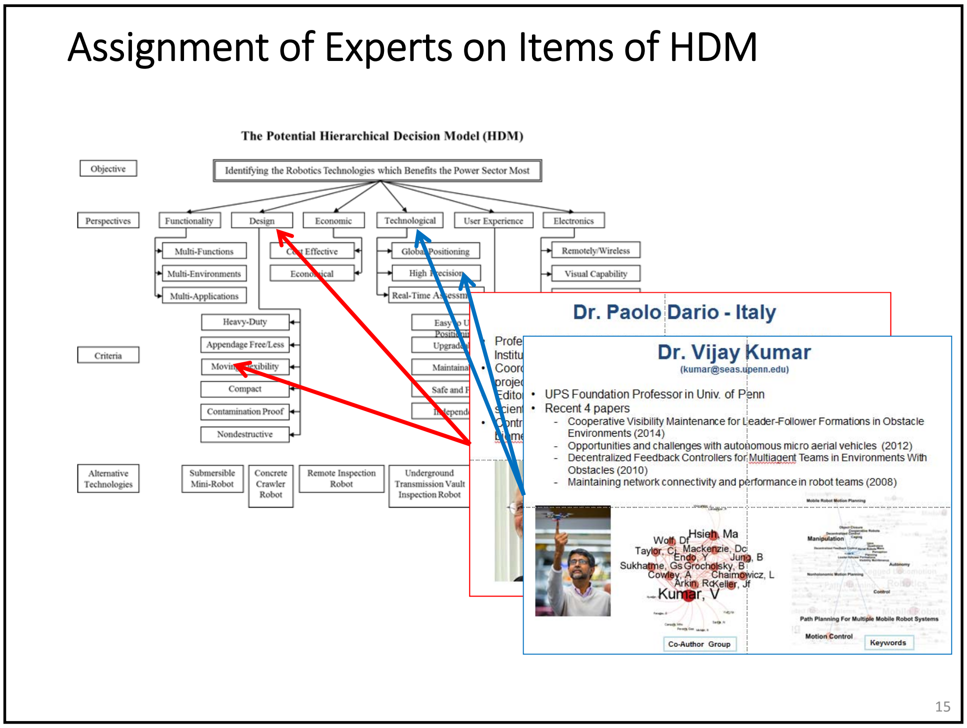
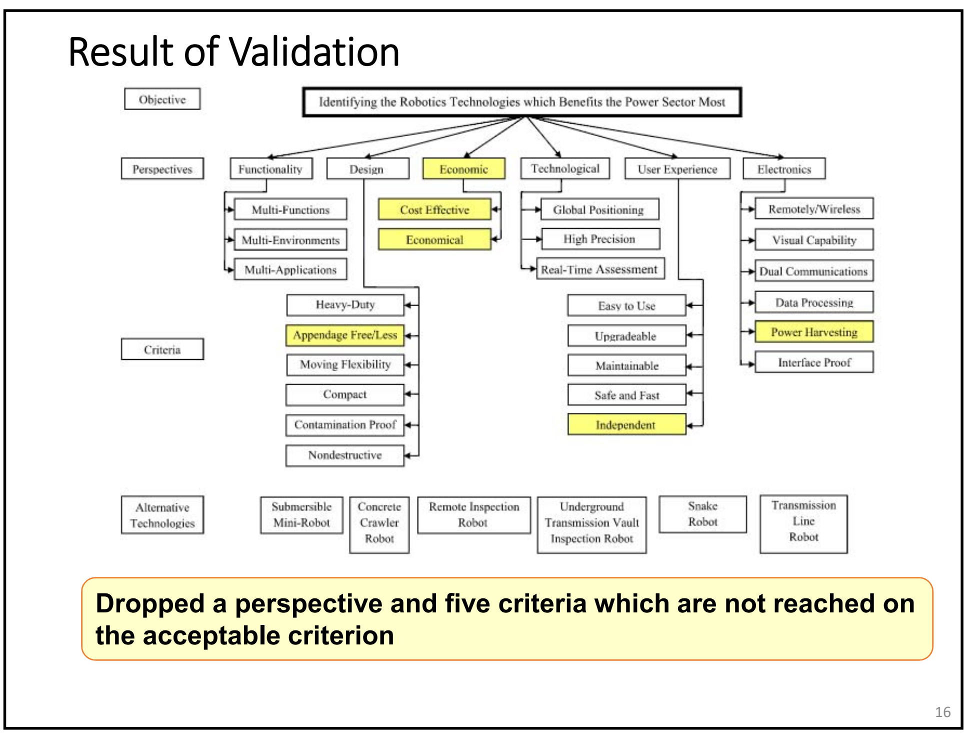

Assignment of Experts on Items of HDM
The Potential Hierarchical Decision Model (HDM)
Objective
Identifying the Robotics Technologies which Benefits the Power Sector Most
Perspectives
Functionality
Design
Economic
Technological
User Experience
Electronics
Multi-Functions
Multi-Environments
Multi-Applications
Cost Effective
Economical
Global Positioning
High Precision
Remotely/Wireless
Visual Capability
Criteria
Heavy-Duty
Appendage Free/Less
Compact
Contamination Proof
Nondestructive
Alternative Technologies
Submersible Mini-Robot
Concrete Crawler Robot
Remote Inspection Robot
Underground Transmission Vault Inspection Robot
Dr. Paolo Dario - Italy
Dr. Vijay Kumar
(kumar@seas.upenn.edu)
UPS Foundation Professor in Univ. of Penn
Recent 4 papers
Cooperative Visibility Maintenance for Leader-Follower Formations in Obstacle Environments (2014)
Opportunities and challenges with autonomous micro aerial vehicles (2012)
Decentralized Feedback Controllers for Multiagent Teams in Environments With Obstacles (2010)
Maintaining network connectivity and performance in robot teams (2008)
Kumar, V
Co-Author Group
Keywords
15


Result of Validation
Objective
Identifying the Robotics Technologies which Benefits the Power Sector Most
Perspectives
Functionality
Design
Economic
Technological
User Experience
Electronics
Multi-Functions
Multi-Environments
Multi-Applications
Cost Effective
Economical
Global Positioning
High Precision
Real-Time Assessment
Remotely/Wireless
Visual Capability
Dual Communications
Data Processing
Power Harvesting
Interface Proof
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Heavy-Duty
Appendage Free/Less
Moving Flexibility
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Nondestructive
Easy to Use
Upgradeable
Maintainable
Safe and Fast
Independent
Alternative Technologies
Submersible Mini-Robot
Concrete Crawler Robot
Remote Inspection Robot
Underground Transmission Vault Inspection Robot
Snake Robot
Transmission Line Robot
Dropped a perspective and five criteria which are not reached on the acceptable criterion
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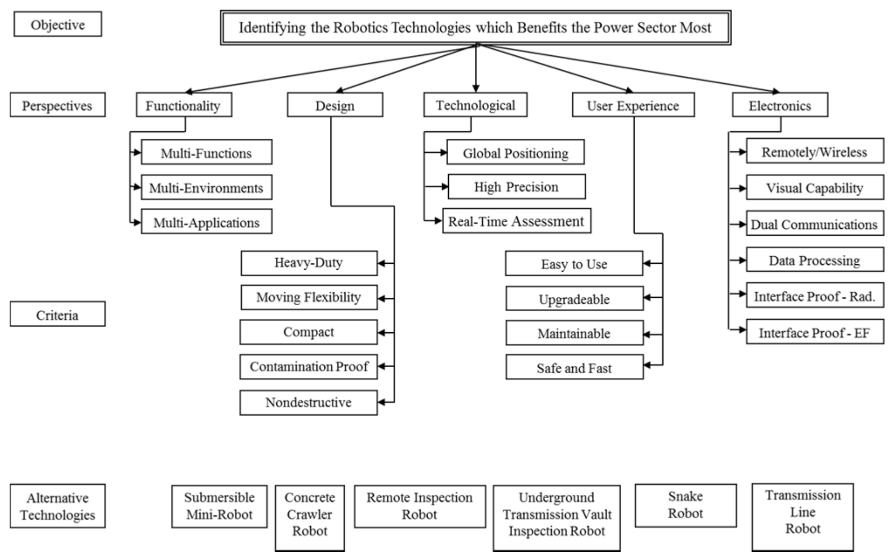
# New Validated Model

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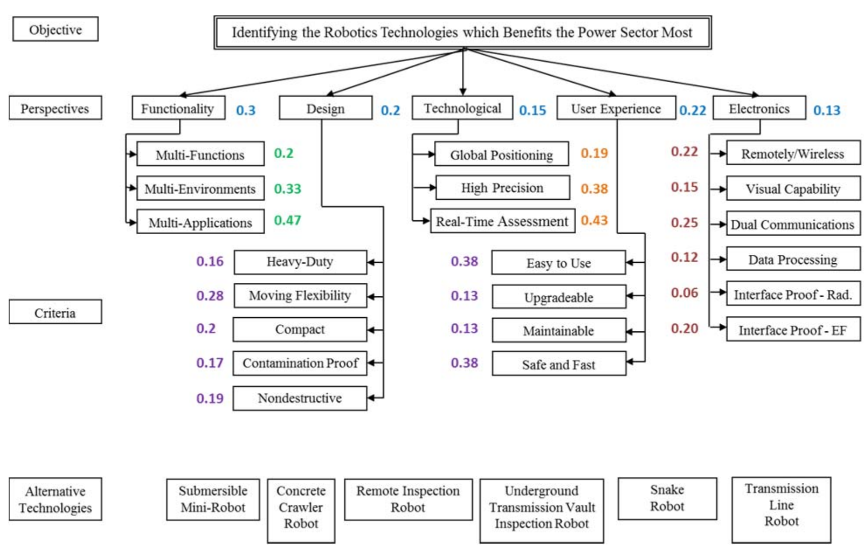
# Model Quantification

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# Model Quantification – Global Weights

| Perspectives | | Criteria | | Global Weights |
|---|---|---|---|---|
| (P1) Functionality | 0.30 | (F1) Multi-Function | 0.20 | **0.06** |
| | | (F2) Multi-Environment | 0.33 | **0.10** |
| | | (F3) Multi-Applications | 0.47 | **0.14** |
| (P2) Design | 0.20 | (D1) Heavy-Duty | 0.16 | **0.03** |
| | | (D2) Moving Flexibility | 0.28 | **0.06** |
| | | (D3) Size | 0.20 | **0.04** |
| | | (D4) Contamination Proof | 0.17 | **0.03** |
| | | (D5) Nondestructive | 0.19 | **0.04** |
| (P3) Technological | 0.15 | (T1) Global Positioning | 0.19 | **0.03** |
| | | (T2) High Precision | 0.38 | **0.06** |
| | | (T3) Real-time Assessment | 0.43 | **0.06** |
| (P4) User Experience | 0.22 | (U1) Easy to Use | 0.38 | **0.08** |
| | | (U2) Upgradable | 0.13 | **0.03** |
| | | (U3) Maintainable | 0.13 | **0.03** |
| | | (U4) Safe and Fast | 0.38 | **0.08** |
| (P5) Electronics | 0.13 | (E1) Remotely/Wireless | 0.22 | **0.03** |
| | | (E2) Visual Capability | 0.15 | **0.02** |
| | | (E3) Dual Communication | 0.25 | **0.03** |
| | | (E4) Data Processing | 0.12 | **0.02** |
| | | (E5) Interference Proof - Radiation | 0.06 | **0.01** |
| | | (E6) Interference Proof – Electromagnetic Field | 0.20 | **0.03** |

To get Technology Value, each Global Weight will be multiplied by the Desirability Score of each Technology Alternative.

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# Description of Desirability Curve

- A desirability curve presents the preference on the technological metric of each factor. (Gerdsri, 2007)
- Development of a desirability curve*
  - Step 1: Identify the best and worst desirable limiting metrics that each factor can take on.
  - Step 2: Verify the measures of effectiveness whose desirability value is linearly proportional to their numerical value between the two limits.
  - Step 3: Develop a semi-absolute scale by assigning 0 point to the worst and 100 points to the best desirable limiting metrics under each factor.
  - Step 4: Calculate the relative desirability of the intermediate values between the two limits.
  - Step 5: The relative desirability values of metrics under each factor can be graphically presented as a desirability curve by arranging the range of metrics value on the horizontal axis (X- axis) and the desirability value on the vertical axis (Y-axis).

Source: Gerdsri, N. (2010), "Strategic evaluation of technology", in Daim, T., Gerdsri, N. and Basoglu, N. (Eds.),*Technology Assessment: Forecasting Future Adoption of Emerging Technologies*, Erich Schmidt Verlag GmbH & Co., Berlin, Germany.

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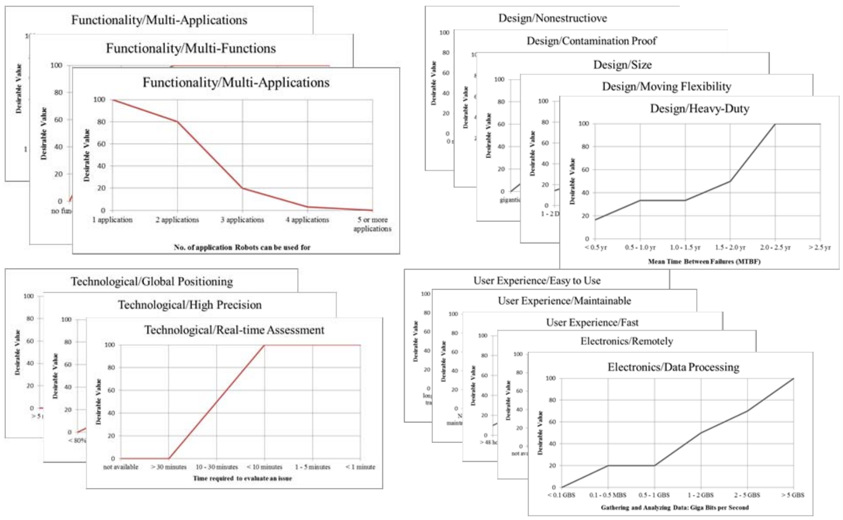
# Desirability Curves

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# Calculation of Technology Value

| Perspectives | Criteria | Global Weight | Robotic Systems: Submersible Mini-Robot: Tech Metrics | Desirability Values | Tech Values | Transmission Line Robot: Tech Metrics | Desirability Values | Tech Values |
|---|---|---|---|---|---|---|---|---|
| Functionality | **Multi-Functions** | **0.06** | 2 (Locomotive-ability, imaging) | 100 | 6.00 | 3 (Locomotive-ability, imaging, sensing) | 100 | 6.00 |
| | **Multi-Environments** | **0.10** | 1 (Underwater) | 100 | 9.90 | 1 (On the transmission line) | 100 | 9.90 |
| | **Multi-Appications** | **0.14** | 2 (Inspection, Monitoring) | 80 | 11.28 | 2 (Inspection, Monitoring) | 80 | 11.28 |
| Design | **Heavy-Duty** | **0.03** | - | 17 | 0.54 | 4 (MTBF 2.0-2.5yr) | 100 | 3.20 |
| | **Moving Flexibility** | **0.06** | 3 (4-5 DOF) | 71 | 3.98 | 2 (3-4 DOF) | 43 | 2.41 |
| | **Compact** | **0.04** | 3 (Small) | 100 | 4.00 | 2 (Medium) | 67 | 2.68 |
| | **Contamination Proof** | **0.03** | 0* (<0.5hr) | 0 | 0.00 | 5 (>3.0hr) | 100 | 3.40 |
| | **Nondestructive** | **0.04** | 0 (No function) | 0 | 0.00 | 0 (No function) | 0 | 0.00 |
| Technological | **Global Positioning** | **0.03** | - (Unavailable) | 0 | 0.00 | 4 (0-2.5m) | 0 | 0.00 |
| | **High Precision** | **0.06** | 4 (95-99%) | 100 | 5.70 | 4 (95-99%) | 100 | 5.70 |
| | **Real-Time Assessment** | **0.06** | 0 (Unavailable) | 0 | 0.00 | 5 (Spontaneous) | 100 | 6.45 |
| User Experience | **Easy to Use** | **0.08** | 4 (one-time training) | 83 | 6.94 | 3 (few training required) | 67 | 5.60 |
| | **Upgradeable** | **0.03** | 0 (Impossible) | 100 | 2.86 | | 100 | 2.86 |
| | **Maintainable** | **0.03** | 4 (< 6 hrs) | 50 | 1.43 | 3 (<12 hrs)) | 25 | 0.72 |
| | **Fast** | **0.08** | - (Unavailable) | 10 | 0.84 | - (Unavailable) | 10 | 0.84 |
| Electronics | **Remotely/Wireless** | **0.03** | 1 ( <x00 ft.) | 100 | 2.86 | 5 (>10 miles) | 100 | 2.86 |
| | **Visual Capability** | **0.02** | 0* (VGA) | 5 | 0.10 | 0* (VGA) | 5 | 0.10 |
| | **Dual Communications** | **0.03** | 0 (<1 MSPS) | 0 | 0.00 | 1 (1 to 40 MSPS) | 50 | 1.63 |
| | **Data Processing** | **0.02** | - | 0 | 0.00 | 2 (500Mb/sec to 1 Gb/sec) | 20 | 0.31 |
| | **Interface Proof** | **0.03** | 0 (<2.7 µSv/h avg ) | 0 | 0.00 | - | 0 | 0.00 |
| **Tech Level** | | | | | **56.42** | | | **65.92** |

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## Calculation of Technology Value

| Perspectives | Criteria | Global Weight | Robotic Systems: Concrete Crawler Robot – Tech Metrics | Desirability Values | Tech Values | Robotic Systems: Snake Robot – Tech Metrics | Desirability Values | Tech Values |
|---|---|---|---|---|---|---|---|---|
| Functionality | **Multi-Functions** | **0.06** | 4 (Locomotive-ability, crawling, sensing, imaging) | 100 | 6.00 | 2 (Locomotive-ability, imaging) | 100 | 6.00 |
| | **Multi-Environments** | **0.10** | 1 (high reach areas) | 100 | 9.90 | 4 (Underground, tight or narrow pipes, high reach areas, variety of terrains) | 0 | 0.00 |
| | **Multi-Appications** | **0.14** | 3 (Inspection, Monitoring, Maintenance) | 20 | 2.82 | 2 (Inspection, Monitoring) | 80 | 11.28 |
| Design | **Heavy-Duty** | **0.03** | 3 (MTBF 1.5-2.0yr) | 50 | 1.60 | 3 (MTBF 1.5-2.0yr) | 50 | 1.60 |
| | **Moving Flexibility** | **0.06** | 1 (2-3 DOF) | 29 | 1.62 | 5 (Infinite DOF) | 100 | 5.60 |
| | **Compact** | **0.04** | 2 (Medium) | 67 | 2.68 | 3 (Small) | 100 | 4.00 |
| | **Contamination Proof** | **0.03** | 5 (>3.0hr) | 100 | 3.40 | 1 (0.5 - 1.0 hr) | 25 | 0.85 |
| | **Nondestructive** | **0.04** | ? | 0 | 0.00 | 0 (No function) | 0 | 0.00 |
| Technological | **Global Positioning** | **0.03** | ? | 0 | 0.00 | ? | 0 | 0.00 |
| | **High Precision** | **0.06** | 4 (95-99%) | 100 | 5.70 | ? | 0 | 0.00 |
| | **Real-Time Assessment** | **0.06** | 5 (Spontaneous) | 100 | 6.45 | 5 (Spontaneous) | 100 | 6.45 |
| User Experience | **Easy to Use** | **0.08** | 3 (few training required) | 67 | 5.60 | 4 (one-time training) | 83 | 6.94 |
| | **Upgradeable** | **0.03** | 5 (0 - 25%) | 0 | 0.00 | ? | 100 | 2.86 |
| | **Maintainable** | **0.03** | 3 (<12 hrs) | 25 | 0.72 | 4 (< 6 hrs) | 50 | 1.43 |
| | **Fast** | **0.08** | - (Unavailable) | 10 | 0.84 | - (Unavailable) | 10 | 0.84 |
| Electronics | **Remotely/Wireless** | **0.03** | 2* (<1 mile) | 100 | 2.86 | 2* (<1 mile) | 100 | 2.86 |
| | **Visual Capability** | **0.02** | - | 5 | 0.10 | 0 (Analog NTSC) | 5 | 0.10 |
| | **Dual Communications** | **0.03** | 1 (1 to 40 MSPS) | 50 | 1.63 | 0 (<1 MSPS) | 0 | 0.00 |
| | **Data Processing** | **0.02** | 2 (500Mb/sec to 1 Gb/sec) | 20 | 0.31 | 0 (<100Mb/sec) | 0 | 0.00 |
| | **Interface Proof** | **0.03** | 0 (<2.7 µSv/h avg ) | 0 | 0.00 | 0 (<2.7 µSv/h avg ) | 0 | 0.00 |
| **Tech Level** | | | | | **52.22** | | | **50.80** |

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## Conclusions

- Functionality has been identified as the most important perspective.
- Transmission Line Robot was rated as the most valuable technology in this case
- This presentation demonstrated how we can integrate the following concepts
  - Hierarchical Decision Modeling
  - Technology Value
  - Bibliometric Analysis
  - Social Network Analysis

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# References


Daim, T., Gerdsri, N., Kockan, I. and Kocaoglu, D. (2011), “Technology Development Envelope Approach for The Adoption of Future Powertrain Technologies: A Case Study on Ford Otosan Roadmapping Model”, *Journal of Transportation Systems Engineering and Information Technology*, Vol. 11 No. 2, pp. 58–69.

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Gerdsri, N. and Kocaoglu, D.F. (2003), “An analytical approach to building a technology development envelope (TDE) for roadmapping of emerging technologies: a case study of emerging electronic cooling technologies for computer servers”, *PICMET ’03: Portland International Conference on Management of Engineering and Technology Technology Management for Reshaping the World*, 2003., pp. 380–389.


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Kockan, I., Daim, T.U. and Gerdsri, N. (2010), “Roadmapping future powertrain technologies: a case study of Ford Otosan”, *International Journal of Technology, Policy and Management*, Vol. 10 No. 1/2, p. 157.

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Allan, J.-F. (2012), “Robotics for distribution power lines: Overview of the last decade”, *2012 2nd International Conference on Applied Robotics for the Power Industry (CARPI)*, IEEE, pp. 96–101.



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