A Framework for Life-Cycle Cost Analysis for Future-Proof Systems

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What is Future-Proofing (FP)?

- The etymology of the word originates in the field of electronic storage, where the design of standards and mediums must anticipate future changes in technology, while still maintaining compatibility with older stored data. Hence avoiding obsolescence.

- Does it mean that main purpose of FP is to defy obsolescence?

- The term 'future-proof' indicates a concern for effects of time – the word 'future' implies that thought is given to the time yet to come and the word 'proof' implies a concern about the effects of time on a product.
- It means if future is clear then we know its effect on a product. Which is hardly possible.
- Therefore a time-less design where time doesn't effect the product generally lies in the category of future proof systems.

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- According to Oxford dictionary

"A future-proof product, system, or service is one that is unlikely to become obsolete".

- No physical obsolescence. That is a system **ideally** must not decay, likely in the process of being maintained repeatedly, or (broken and) repaired frequently or because of change in emotions.

- No design obsolescence. That is a system must not outdated and loose its capability or efficiency compared to the other similar design currently available.

- *No requirements* obsolescence That is a system must keep its relevance to the set of new requirements which emerges because of change in circumstances.

- **The main objective of FP design is to avoid obsolescence so that system capability last longer.**

Benefits of FP

- Make people happy for a sustained period.
- Be designed with an aim of increasing pride in workmanship, durability, and the larger concept of quality.
- Instil an attention to FP detail in the creative process, by striving to design products that people will cherish for a long time.
- It strives to alter consumption by reducing the rate of its occurrence.
- FP aims to help alleviate environmental degradation and dependence by offering an alternate paradigm of consumption and obsolescence.
- However, it creates objects that are at odds with the goals of traditional economic growth and the traditional paradigm of technological innovation.

Some FP examples

- Chef knife, coffee cup, dinner plates, pencils etc. are future proof products.
- They are classical time-less design.
- Function in almost all circumstances.
- Functionally would never be obsolete because requirement would not change.
- They are Simple systems which do not generally depend on external factors such as technology.

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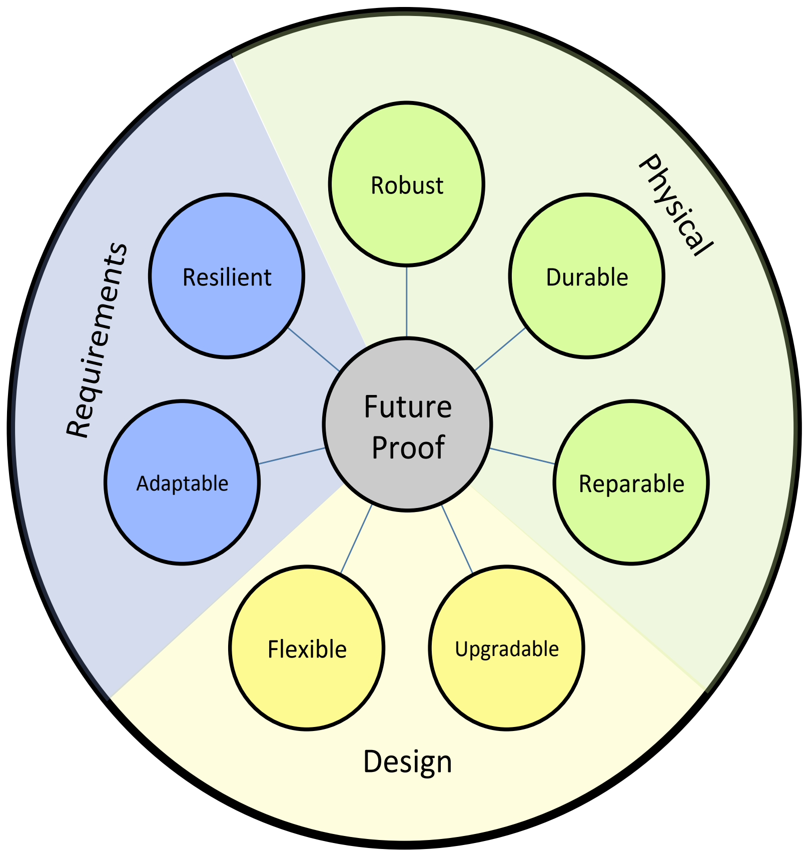
- However innovative systems, depend mainly on technology and cannot be made FP easily.
- They have to evolve with change in future requirements either through external upgrade or through adaptive means.
- Therefore, a FP system should have at least one of the following characteristics:
- **Durable:** contains materials that last long time with reasonable care.
- **Resilient :** Functionally productive even any change in its internal functions.
- **Sustainable:** System remains productive and diverse for long time.
- **Reparable and Maintainable:** FP systems are repairable and maintainable easily.
- **Changeable:** FP systems reduce the likelihood of obsolescence by creating opportunities for change within the system.

In essence robustness and FP are two different characteristics of a system. However system can be made FP if system is robust to the requirements at the future time.

Robust to requirements: System doesn't need to change

i.e. it is insensitive to the external system parameter such as requirement.

- In order to design a system with future capability, the system must be adaptable or changeable to the predicted future needs.
- The ability to change can be provided via a single-up front design providing all the expected future system capability or a partial design that allows for easy and cost-effective upgrade.



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FP Projection

- In order to solve the life-cycle cost problem for FP system we define a term **projection function**. This function would help to determine the extent of FP required.
- *(**Projection Function**) A projection function $Prj_{Cf}(\cdot)$ is a dynamical function which projects the future system capability requirement at any instantaneous time t.*

$$Prj_{Cf} : \{C_f(t_f) \rightarrow C_{fp}(t) \,|\, t_{0-} \leq t < t_f\},$$

where C_f is the future system capability, C_{fp} is the projection of future capability, $t-_0$ is the system design and development time and t_f is a future time.

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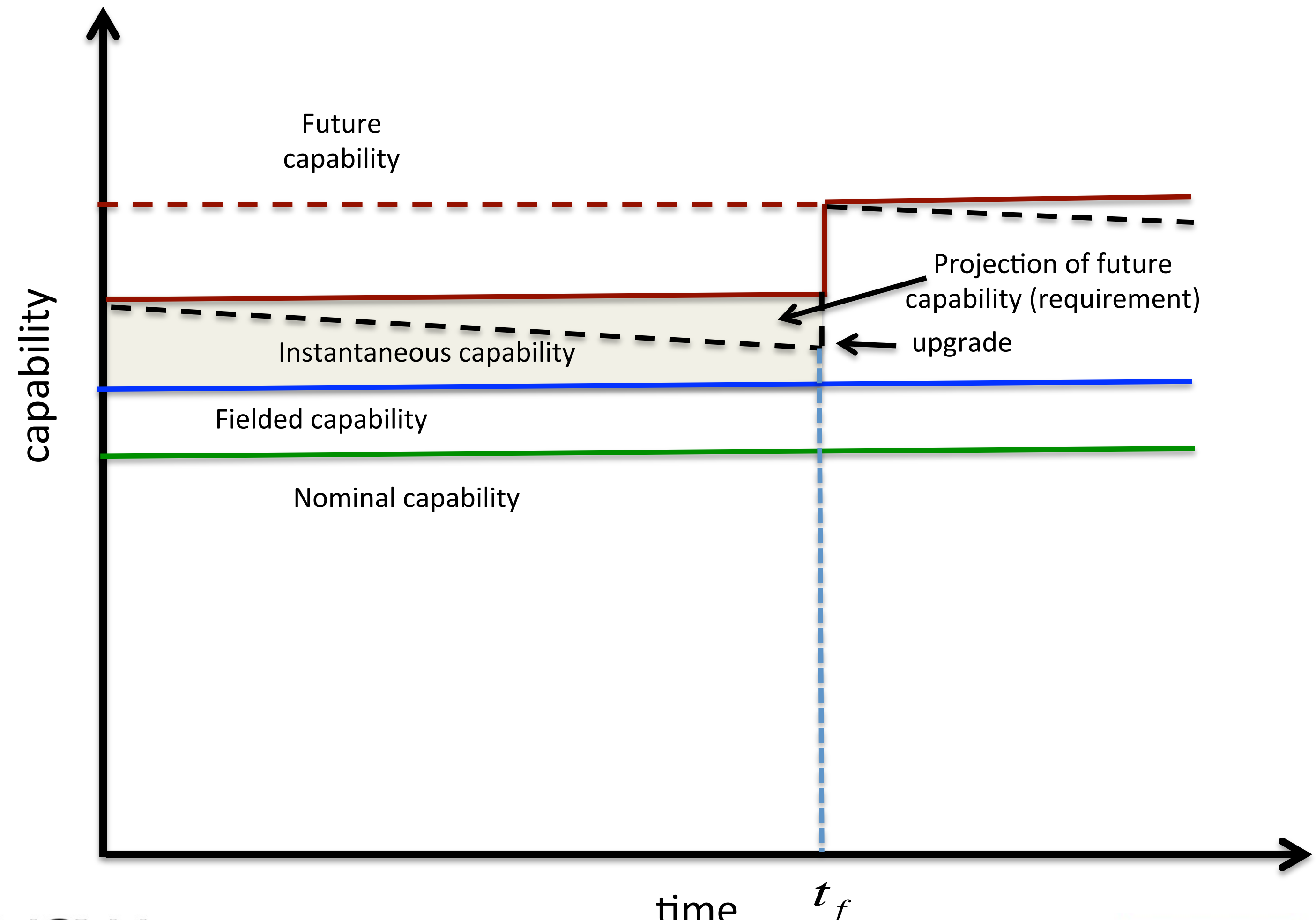
- The increase in the capability from the one to another capability level involves cost, offline time and development resources.



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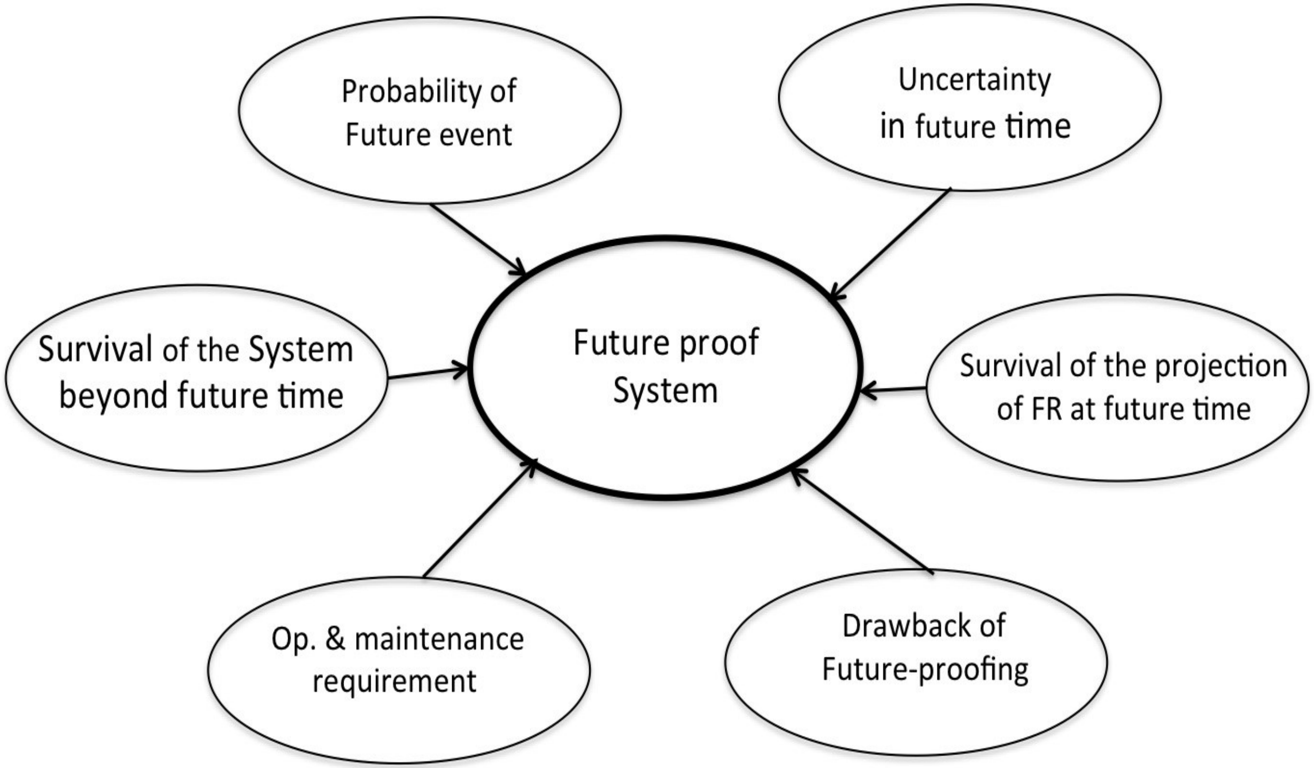
FP dynamics



Probability of
Future event
Uncertainty
in future time
Survival of the System
beyond future time
Future proof
System
Survival of the projection
of FR at future time
Op. & maintenance
requirement
Drawback of
Future-proofing

- **Survival of the system beyond the future time.**
  - System Life.
  - System Reliability.

- **Probability of occurrence of future event**
  - Probability density function for future event.
  - Historical data.
  - Subject matter expert (SME).
  - $E[C_f] = p_{Cf}(\cdot)C_f$

- **Uncertainty in time of the future event**
  - Lower bound on the future time such that $E[t_f] > c$
  - Probability p_{tf}

- **Operational and maintenance requirements of future proofing elements**
  - Maintenance requirement for Cf(t).
  - Operational requirement for Cf(t).

- **Drawback of future-proofing element.**
  - Integration issues of the future capability projection with original system.
  - Effect on the reliability of overall systems.
  - The original system may degrade faster due to FP elements.

- **Survival of future-proofing elements.**
  - Degradation of FP elements.
  - Remaining capability of FP elements at the future time.

Methodology

- Future-proof design is an optional design choice which addresses several -ilities in the system such as changeability, adaptability, flexibility maintainability etc. And commitment to these -ilities requires additional cost.
- Therefore, delivering a financially viable system by appropriately selecting the –ilities is one of the main objectives of the system engineer.
- We use life-cycle cost estimation and analysis to find the optimum value of the FP projection.

Life-Cycle Cost of FP Systems

- As presented previously there are many factors which may contribute to the future proofing dynamics and thus significantly change the life cycle cost of the system.

- Since future proofing affect the system cost, designers face a challenge to select an appropriate future capability projection in the system that is cost effective.
- In the absence of a proper analysis tool, a decision made by the designer for the future proofing may be flawed in the context of the whole system cost.

- Therefore, such a decision is required to be analysed rigorously and must be based on a systematic framework.

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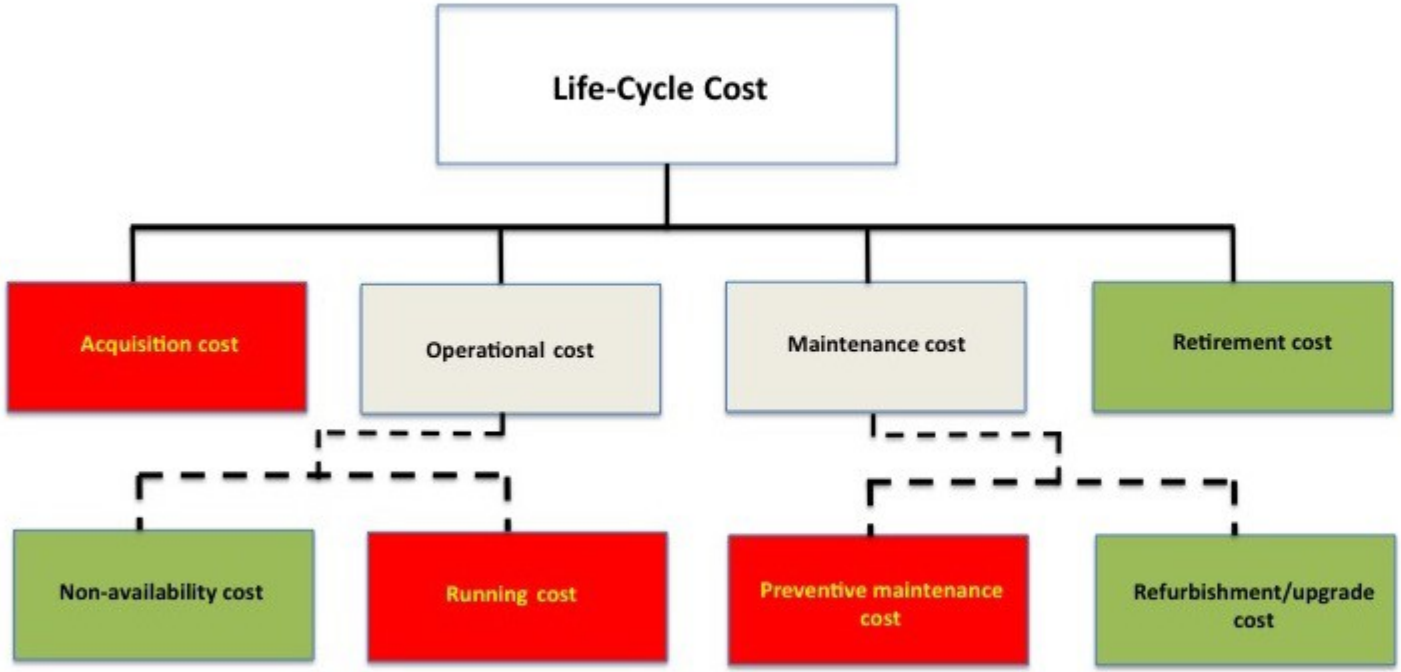
Generic LCC model

- A generic model for a life-cycle cost analysis mathematically can be written as follows:

  - $L_{CC} = C_{Acq} + \sum C_M(t) + \sum C_O(t) + C_{ret}$, (11)

  - where
  - C_{Acq}= Cost of acquisition i.e. cost of planning, research and development.
  - C_M= Cost of maintenance, repair and refurbishment.
  - C_O= Cost of operation and unavailability.
  - C_{ret}= Cost of retirement.

- Here we considers four major costs elements.



Life-Cycle Cost architecture model. Red box indicates where cost is likely to increase and green box indicates where cost is likely to decrease by incorporating robustness and futureproofing in the system

Life Cycle Cost

- The life cycle cost of a system can be obtained by determining the individual cost of the system's main cost elements.
- The framework presented here integrates the general method of LCCA with future-proofing cost analysis.
- In this model, we keep the system cost without FP as a separate element wherever possible.
- This allows for the future-proof cost analysis to be integrated with existing LCCA method.

Cost of Acquisition

Cost of the research and development, design, construction, production and deployment.

- Future-proof planning and analysis cost.
- Cost of future capability projection.

$$C_{Acq} = C_{in} + C_{C_{fp}} + C_{sfp}$$

Cost of Future Projection will be a function of the selected projection.

$$C_{C_{fp}} = f_{cp}(c_p, Prj_{Cf}(\cdot)),$$

Cost of Maintenance

- Cost of maintenance of the system without future capability is C_{M_s} and $c_{mf}(t)$ is the per unit cost of future capability maintenance requirement $M_{Cf}(t)$ at time t.

$$C_M = \alpha_f C_{M_s} + \int_0^{t_f} T_i(t) c_{m_f}(t) M_{C_f}(t) dt,$$

- where $\alpha_f \geq 1$ is a factor by which the maintenance cost of the system with capability is increased due to the presence of projection of future capability
  - Specialised maintenance requirement
  - Larger maintenance line requirement.

Cost of Future Upgrade

- A future proof design must facilitate the future upgrade to meet the future capability.
- Inclusion of future elements at design time may significantly reduce the cost of upgrade at time t_f.
- The cost of future upgrade can be written as given below.

$$C_{up} = T_i(t_f) F_{C^f}(C_f(t), C_{fp}(\cdot), t_f)$$

Where $T_i(t_f)$ is discount factor.

Cost of Operation

- If C_{O_s} is the operational cost of the system without FP and c_{o_f} is the per unit cost of the future projection operational requirement $O_{C_R}(C_f, t)$

$$C_O = \beta_f C_{O_s} + \int_0^{t_f} T_i(t) c_{o_f} O_{C_R}(C_f, t) dt,$$

- where β_f is a factor by which operational cost of the fielded system capability is increased as a result of the future projection.
  – Increased fuel requirements
  – Increased in human resource requirements etc.

Cost of Unavailability

- Any major upgrade, such as incorporating future capability in the system, requires all or a part of a system to be unavailable for a period of time.
- This period may be significant and thus may be costly.
- A future-proof system may help to alleviate the cost of the system by reducing the upgrade time.
- The cost of unavailability is generally inversely proportional to the $Prj_{Cf}(\cdot)$

$$C_u = T_i(t_f)c_u k_u(1 - C_{fp}(\cdot))$$

Cost of Retirement

- Introduction of future projection increases the life of the system.
- We consider the resale value of the system with and without future proofing at time t_f in the model.
- The resale value can be determined by analysing the remaining capability of the system at the time of retirement.
- A function $f_{ret}(\cdot)$ can be obtained which determines the cost of the retirement by considering the capability of the system at t_f. Hence we can write:

$$C_{ret} = T_i(t_f) f_{ret}(C(t), C_{fp}(\cdot), t_f).$$

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Total Life Cycle Cost

- The total life cycle cost (LCC) can be written as a sum of the individual cost as given below:

$$LCC = C_{Acq} + C_{C_{fp}} + C_M + C_O + C_{up} + C_u.$$

- The LCCA model contains several nonlinear and linear functions (such as $f_{cp}(c_p, Prj_{Cf}(\cdot)), f_{ret}(C, t_f, Prj_{Cf}(\cdot))$ etc.).

- These functions can be evaluated by carefully considering the cost of each factor for the given future capability projections.

- In order to find the closed form of these functions, curve fitting technique can be used which will help to simplify the analysis.

- Hence the objective would be to select the best FP projection so that whole life cycle cost is minimised.

Prj*Cf (Cf(t),RT,t0,tf) → min[LCC].

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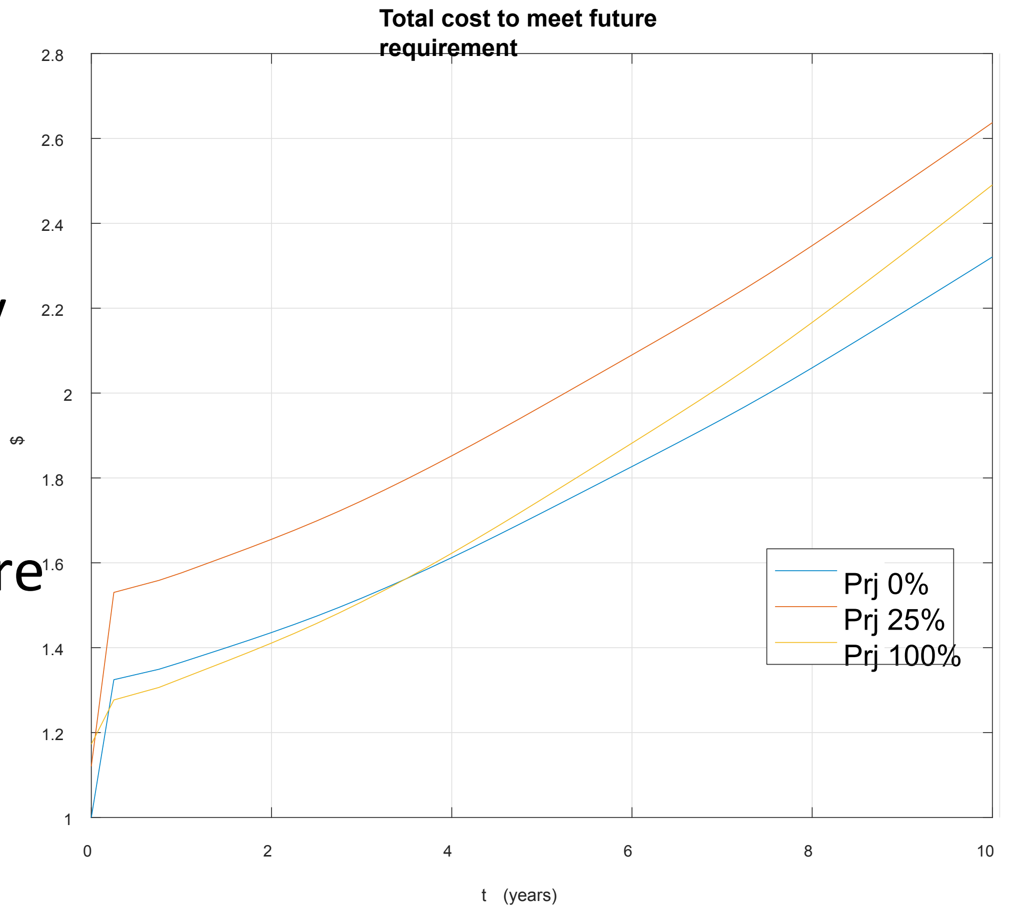
Example

- Let us assume that a business is planning to buy a truck to deliver certain goods.
- The current load delivery requirement is 3 tonne truck. It is expected that business will grow over the years and is expected that the load requirement will increase to 4.5 tonne in some future time.

Option no	Future capability projection $Prj_{Cf}(\cdot)$	Option details
1	0 %	buy 3.5 tonne truck now and upgrade to 5 tonne truck in future.
2	25 %	buy 3.5 tonne truck with capability to increase to 5 tonne with extra trailer and engine overhaul in future.
3	100 %	buy 5.5 tonne truck now.

Result

- The analysis shows that option 2 is not feasible for the future requirement.
- Interestingly, decision on option 1 and 3 dynamically related with the future time.
- Option 3 is feasible if requirement appears before 3.5 years.
- If requirement appears after 3.5 years then option 1 is the cost effective option.



Results implication

- It is quite obvious that the decision for FP is significantly depend upon the future time which is uncertain.
- Hence the FP decision is dynamically related with the uncertain future time.
- Therefore, the estimation of uncertain time should be the prime focus of the analysis.
- The option 3 contains 100 % FP i.e. robust to the future requirements. However, if option 1 is desirable then system doesn't have to be future proof as this option contains 0% future projection.
- In this example, option 2 seems to be infeasible. However, if this option would be suitable for certain application then it means system can only be made future proof by making it changeable and upgradable at the future time.

Conclusion

- The framework for future proofing cost analysis developed in this paper can be used for a variety of applications where a cost of the system is the main factor in future-proofing decision.
- This framework can also be used for multi attribute decision analysis where attributes can be transformed into an equivalent cost model.
- It has been seen that FP decision is dynamic in nature and needs rigorous analysis using stochastic dynamic models.

Thank you!

Questions?

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