RT 193: Framework for Analyzing Versioning and Technical Debt

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www.sercuarc.org
• Obsolescence is a complex mix of engineering, economic, and business issues with many associated uncertainties.

• Obsolescence is the inevitable consequences of dependence on COTS components in many Cyber-Physical-Systems (CPS)
  —Long lead time of CPS, tightly-coupled components, shorter upgrade cycle of COTS, no control over COTS evolution, etc.

• “Future Combat System had 153 relevant systems to deal with. If every one updated once a year, that would be a change every other day!”
  ---- Barry Boehm, USC

• “70 percent of electronics are obsolete prior to system fielding, and one component may become obsolete five to ten times during the weapon systems life cycle.” ---- Anthony Haynes, AMRDEC
• **Problem Statement:**
  – COTS components in are increasingly imposing long-term management issues of many CPS systems
    o such as obsolescence, poor reliability, lack of readiness, and inability to be readily maintaining systems in an efficient and effective manner.

• **Motivations:**
  – Obsolescence is the consequence of COTS technical debt that can be possibly captured and managed in early CPS life cycle activities, i.e. COTS acquisition.
  – Increase awareness of COTS technical debt
  – Support early identification, assessment, and management of COTS technical debt
Research Framework

1. Understanding trend in COTS related CPS Obsolescence studies
2. Align existing MPTs
   - Identify gap
3. Taxonomy
   - Meta attributes
   - Simple Model

- Literature Review
- Mapping Framework
- COTS Technical Debt
Literature Review

- Follow Kitchenham’s systematic literature review methodology

- Search Protocol
  - Keywords:
    - (“Technical debt” OR “Obsolescence”) AND
    - (“COTS” OR “NDI” OR “GOTS” OR “Component*”) AND
    - (“cyber physical system” OR “military systems” OR (“embedded systems”))
  - Databases
    - DMSMS; ACM Digital Library, IEEExplore, ScienceDirect, SpringerLink, Scopus, and Web of Science

- Search process
  - Three-round
  - Snowballing

- Results: a collection of 57 literatures included for further analysis
Literature Review Questions

RQ1: Trend in existing MPTs for COTS obsolescence?

RQ2: Types of data used?

RQ3: Sources of COTS obsolescence?

RQ4: Metrics for analyzing COTS obsolescence cost/risk?

RQ5: COTS obsolescence management approaches?

The review process focuses on extracting key information from individual study with regarding to the above review questions.
RQ1: What are the trend in existing MPTs for COTS obsolescence?

• Four categories to characterize current MPTs:
  — Type:
    o Methods
    o Processes
    o Tools
    o Others
  — Sector:
    o Academia
    o Industry
    o Government
    o Others

  — Targeted DoD Phases:
    o Materiel solution analysis
    o Technology maturation and risk reduction
    o Engineering and manufacturing development
    o Production and deployment
    o Operations and support

  — Granularity of obsolescence issue:
    o Component level
    o System level
• Methods
  — Design Refresh; Life Time Buy; Last Time Buy; Substitution; Forecasting Model; VHDl-Based Model; Design Longevity Agreements, etc.

• Processes
  — Open source software products; Software Application programming Interfaces (API) and wrappers; After-market Supplier; Emulation/Cloning; Software Obsolescence Trigger Map

• Tools
  — COCOTS tool for estimating cost associated with COTS evaluation, tailoring, and integration; MOCA (mitigation of obsolescence cost analysis) tool; Total Obsolescence Management Capability Assessment Tool (TOMCAT); Component Information Management System
RQ2: Types of data used?

Five categories of data

- Technology forecasting: 20
  - E.g. High risk COTS/CCA (Circuit Card Assembly), OEM, BOM, contract incentives
- Business Trending (Demand forecasting): 10
  - E.g. regression modelling to forecast business trend based on the obsolescence data and increased functionality of integrated circuits
- Obsolescence data: 9
  - E.g. electronic/sw/media components
- Logistics data: 17
  - E.g. DMSMS
- Others: 19
RQ3: Sources of COTS obsolescence?

- Six categories of COTS sources:
  - S/w and media support tooling: 22
    - E.g. operating system, ERP, database, etc.
  - Electronic components/Mechanical components: 20
    - E.g. EEE (electrical, electronic, mechanical) components, etc.
  - Test equipment: 4
  - Documentation: 2
  - Skills/personnel/training: 1
  - Others: 8
RQ4: Metrics for analyzing COTS obsolescence cost/risk?

- Seven categories of COTS metrics used in existing studies:
  - Multiplicity (e.g. #of COTSs, #of components, etc.): 8 studies
  - Complexity (e.g. system complexity, application complexity, Requalification complexity, etc.): 23
  - Interdependency (e.g. Coupling level and package density, etc.): 20
  - Platform diversity: 11
  - PBS (product breakdown structure): 7
  - OM strategy: 17
  - Financial Metrics (e.g. RO, NPV, etc.): 14
Example 1 - Cost metrics for requalification of air/safety critical components [Romero Rojo et al. 2012]

- The cost metrics represent the non-recurring costs of resolving an obsolescence issue using each of the resolution approaches.
  - during the contracted period within the in-service phase.

<table>
<thead>
<tr>
<th>Obsolescence management approach</th>
<th>Integration level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
</tr>
<tr>
<td>Existing stock</td>
<td>£300</td>
</tr>
<tr>
<td>Life time buy</td>
<td>£2,000</td>
</tr>
<tr>
<td>Cannibalisation</td>
<td>£1,700</td>
</tr>
<tr>
<td>Equivalent</td>
<td>£3,500</td>
</tr>
<tr>
<td>Alternative</td>
<td>£10,100</td>
</tr>
<tr>
<td>Authorised aftermarket</td>
<td>£13,000</td>
</tr>
<tr>
<td>Emulation</td>
<td>£52,100</td>
</tr>
<tr>
<td>Minor redesign</td>
<td>£50,100</td>
</tr>
<tr>
<td>Major redesign</td>
<td>£250,000</td>
</tr>
</tbody>
</table>

Volatility effects dominate increased integration experience

Volatility effects just cancel increased integration experience

Increased integration experience dominates volatility effects

$F_n$ (synchronization, complexity of system, no. planned upgrades, etc.)
**RQ5: COTS obsolescence management approaches?**

- Three categories:
  - **Strategic**
    - Supply-chain: life-time buy and partnering agreement
  - **Proactive**
    - Design: open system architecture, modularity, use of multi-sourced components
    - Planning: obsolescence mgmt. plan, technology roadmap, monitoring tools
  - **Reactive**
    - Some components: last-time buy, cannibalization?
    - Form, fit & function (FFF) replacement (e.g. equivalent-component)
    - Emulation or redesign (e.g. use of state-of-art technology to replicate or redesign the component)

![Bar chart showing the number of studies per category](chart.png)
• Proactive planning at system level is a largely overlooked topic and there is lack of study

• Opportunity: COTS Technical Debt Identification
  — Utilization existing OM MPTs must be strategically coupled and/or replaced with capabilities in the acquisition time, e.g.:
    o Capture interdependencies of COTS components in CPS systems;
    o Identify “technical debt” items associated with COTS decisions;
    o Predict the effects of COTS technical debt items on the system across its system life cycle;
    o Make informed technical decisions associated with COTS usage.
Research Framework

- Literature Review
  - Understanding trend in COTS related CPS Obsolescence studies

- Mapping Framework
  - Align existing MPTs
  - Identify gap

- COTS Technical Debt
  - Taxonomy
  - Meta attributes
  - Simple Model
Mapping Framework

Hybrid Flow of Obsolescence Risk and COTS Technical Debt Management
The Notion of Technical Debt

• Originated in software engineering field, coined by Ward Cunningham in 1992
  — Immature work, compromising in one dimension in order to get benefits in other dimensions
  — Initially concerning "refactoring" at code level (i.e. implementation) in agile software development

• Evolved to span across all life cycle phases
  — a metaphor reflecting technical compromises that can yield short-term benefit but may hurt the long-term health of a software system

• Technical Debt Quadrants [Martin Fowler, 2009]

Technical Debt Quadrants

<table>
<thead>
<tr>
<th></th>
<th>Reckless</th>
<th>Prudent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deliberate</td>
<td>&quot;What's Layering?&quot;</td>
<td>&quot;We must ship now and deal with the consequences&quot;</td>
</tr>
<tr>
<td>Accidental</td>
<td>&quot;We don't have time for design&quot;</td>
<td>&quot;Now we know how we should have done it&quot;</td>
</tr>
</tbody>
</table>
What Constitutes Technical Debt?

• Technical Debt Landscape (Ozkaya, Nord, Kruchten, 2012)
  —Differentiate visible elements from invisible elements

  —Propose to limit debt to the invisible elements
  ○ Four colors in a backlog
Some Existing Taxonomies on Technical Debt

- **Rubin’s Taxonomy**
  - Context: within Agile team
    - Naïve technical debt
    - Unavoidable technical debt
    - Strategic technical debt

- **Clark’s Taxonomy**
  - Context: Riot Games (League of Legends)
    - Local debt
    - MacGyver debt
    - Foundational debt
    - Data debt

- **Bavani’s Taxonomy**
  - Context: distributed teams & agile testing
    - Degree of awareness of technical debt across distributed teams
    - Degree of alignment in managing technical debt across distributed teams

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*Tradeoff can be an alternate approach to lessen the impact of technical issues or debt*
Research Framework

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- Meta attributes
- Simple Model
# Technical Debt as A Metaphor for Predicting COTS Obsolescence

<table>
<thead>
<tr>
<th>COTS Benefits</th>
<th>COTS Implications</th>
<th>COTS “Technical Debt”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available now, earlier payback</td>
<td>Licensing and procurement delays</td>
<td>N/A</td>
</tr>
<tr>
<td>Avoids expensive development &amp; maintenance</td>
<td>Up front license fees</td>
<td>N/A</td>
</tr>
<tr>
<td>Predictable license costs &amp; performance</td>
<td>Recurring maintenance fees</td>
<td>Yes. Incurred COTS upgrading cost and system re-evaluation/re-testing cost</td>
</tr>
<tr>
<td>Rich in functionality</td>
<td>Reliability often unknown/ inadequate; Unnecessary features compromise usability, security, performance</td>
<td>Yes. Incurred cost to take care of functional/non-functional requirement mismatch and additional verification &amp; validation</td>
</tr>
<tr>
<td>Broadly used, mature technology</td>
<td>Functionality, efficiency constraints</td>
<td>Yes. Incurred cost to tailor to specific CPS context; increased limitation over system evolution</td>
</tr>
<tr>
<td>Frequent upgrades often anticipate organization’s needs</td>
<td>No control over upgrades/maintenance</td>
<td>Yes. Increased obsolescence risk due to life cycle mismatch between CPS system and COTS components</td>
</tr>
<tr>
<td>Dedicated support organization</td>
<td>Dependency on vendor</td>
<td>Yes. Increased obsolescence risk due to documentation and support dependency</td>
</tr>
<tr>
<td>Hardware/software independence</td>
<td>Integration not always trivial; incompatibilities among different COTS</td>
<td>Yes. Incurred cost to evaluate and enhance COTS interoperability in COTS-intensive CPS.</td>
</tr>
<tr>
<td>Tracks technology trends</td>
<td>Synchronizing multiple-vendor upgrades</td>
<td>Yes. Increased obsolescence risk due to life cycle mismatch between CPS system and COTS components</td>
</tr>
</tbody>
</table>
# COTS TD Taxonomy in CPS Context

<table>
<thead>
<tr>
<th>COTS TD Category</th>
<th>Description</th>
<th>Analogy to existing work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>The degree of functionality mismatch between COTS capabilities and system needs.</td>
<td>Local TD; Data TD</td>
</tr>
<tr>
<td>Performance</td>
<td>The degree of mismatches between COTS capabilities and system needs, w.r.t. quality/extra-functional properties such as: (1) Reliability – mainly of hardware; (2) Safety assurance – of software and hardware; (3) Performance in terms of e.g. bandwidth, processing capability, memory etc.</td>
<td>MacGyver TD; Data TD</td>
</tr>
<tr>
<td>Interoperability</td>
<td>The degree of interface/ assumption mismatches among various interdependent COTS components, as well as among COTS and system custom components.</td>
<td>MacGyver TD; Data TD</td>
</tr>
<tr>
<td>Configuration Version</td>
<td>CPS configuration version planning needs to address solution availability plan. Greater tendency of COTS version upgrade/refresh may lead to more obsolete COTS.</td>
<td>Unavoidable TD; Local TD; MacGyver TD; Foundational TD; Data TD</td>
</tr>
<tr>
<td>Documentation &amp; Support</td>
<td>Lack of documentation and vendor support will seriously impact on issue resolution related to obsolete COTS.</td>
<td>Unavoidable; Data TD</td>
</tr>
<tr>
<td>System Evolution Limitations</td>
<td>Requirements imposed by COTS may place great limitation on system evolution.</td>
<td>Unavoidable TD; Foundational TD; Data TD</td>
</tr>
<tr>
<td>Organic</td>
<td>People-centric perspective of TD focusing on organizational decision-making, behaviors, and practices associated with those personnel responsible for introductions of new technologies &amp; systems and/or the sustainment of existing systems</td>
<td>Local TD; Naïve TD; Strategic TD</td>
</tr>
</tbody>
</table>
## Attributes For Representing A COTS TD Item

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>A unique identifier for the COTS TD item.</td>
</tr>
<tr>
<td>Name</td>
<td>The name of a specific COTS TD item</td>
</tr>
<tr>
<td>Location</td>
<td>The location of the identified COTS TD item, e.g. the name of the COTS(s) with which it is associated.</td>
</tr>
<tr>
<td>Accountable Party</td>
<td>The party responsible to repay the COTS TD item, e.g. COTS vendor, integration team, program office, specific organization. This identifies the “accountable” debt-holder for the liability. The Accountable Party is identified at the start of a new design/development/modernization effort, and can assign TD “tracking” and “maintenance of TD visibility” within its span of authority/control.</td>
</tr>
<tr>
<td>Type</td>
<td>The COTS TD type that the COTS TD item is classified into.</td>
</tr>
<tr>
<td>Description</td>
<td>General information on the COTS TD item.</td>
</tr>
<tr>
<td>Open date/time</td>
<td>The specific date/time when the COTS TD is identified.</td>
</tr>
<tr>
<td>Principle</td>
<td>The estimated cost of repaying the COTS TD item.</td>
</tr>
<tr>
<td>Interest amount</td>
<td>The estimated extra cost of tolerating the COTS TD item.</td>
</tr>
<tr>
<td>Interest probability</td>
<td>The probability that the interest for the COTS TD item needs to be repaid.</td>
</tr>
<tr>
<td>Contagion</td>
<td>The degree of spreading of the COTS TD item through the interfaces with other system components, if this TD is allowed to continue to exist.</td>
</tr>
<tr>
<td>Context</td>
<td>A certain implementation context of a specific COTS TD item</td>
</tr>
<tr>
<td>Propagation rule</td>
<td>How the COTS TD item impacts the related parts of the CPS system</td>
</tr>
<tr>
<td>Intentionality</td>
<td>Is the COTS TD item Intentionally or unintentionally incurred?</td>
</tr>
</tbody>
</table>
### COTS TD Management Activities

<table>
<thead>
<tr>
<th>TDM Activity</th>
<th>Description/Example</th>
<th>Techniques</th>
<th>Example metrics</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD identification</td>
<td>Detects TD caused by intentional or unintentional technical decisions</td>
<td>Static code analysis; dependency analysis; checklist</td>
<td>Violations of coding rules, lack of tests; static code metrics,</td>
</tr>
<tr>
<td>TD measurement</td>
<td>Quantifies the benefit and cost of known TD in a system through estimation techniques</td>
<td>Expert Estimation; estimation models; cost categorization; solution comparison</td>
<td>code metrics; operational metrics; ROI; Cost-benefit ratio; Real options</td>
</tr>
<tr>
<td>TD prioritization</td>
<td>Ranks identified TD items according to predefined rules, which is to be repaid first, and which can be tolerated until later releases.</td>
<td>Cost benefit analysis; High remediation cost first; Portfolio approach; High interest first</td>
<td>Portfolio approach considering TD items along with other new functionalities and bugs as risk and investment opportunities.</td>
</tr>
<tr>
<td>TD prevention</td>
<td>Aims to prevent certain TD from being incurred.</td>
<td>Development process improvement; design decision support; lifecycle cost planning; human factor analysis</td>
<td>Improve process to prevent certain type of TD; evaluate and choose candidate solutions with less potential TD</td>
</tr>
<tr>
<td>TD monitoring</td>
<td>Watches the change of cost and benefit of unresolved TD over time</td>
<td>Threshold-based; Planned check; TD propagation tracking; TD plot; TD monitor with quality attribute focus</td>
<td>Define threshold for quality metrics, and issue warnings if threshold is not met.</td>
</tr>
<tr>
<td>TD repayment</td>
<td>Resolves or mitigates TD</td>
<td>Reengineering, rewriting; refactoring; bug fixing; fault tolerant; repackaging; automation</td>
<td>Make changes to the code, design, or architecture of the software system without altering external behavior, in order to improve internal quality.</td>
</tr>
<tr>
<td>TD representation/ documentation</td>
<td>Provides ways to represent and codify TD in a uniform manner to address concerns of particular stakeholder</td>
<td>Various format of representing TD items.</td>
<td>Example TD data fields: ID, Location, Responsible / author, Type, Description, date /Time, principle, interest amount, interest probability, relation to other TD, context, propagation rule, intentionality</td>
</tr>
<tr>
<td>TD communication</td>
<td>Makes identified TD visible to stakeholders so that it can be discussed and further managed.</td>
<td>TD dashboard; backlog; dependency visualization; code metric visualization; TD list; TD propagation visualization</td>
<td>Dashboard or other visualization tool displaying undesirable dependencies, e.g. overly complex dependencies between system components</td>
</tr>
</tbody>
</table>
Hierarchical View of a Simple Technical Debt Model for COTS-Intensive CPS

Technical Debt = $f_S$(changes across entire system, required work, TD management strategy)

Technical Debt = $f_{PU}$(changes across a PU, required work, TD management strategy)

Technical Debt = $f_C$(changes within a component, required work, TD management strategy)
Modeling COTS-intensive CPS

- COTS-intensive CPS
  - A set of physical units, i.e. subsystems, \( \{\text{SS}_i\} \), \( i=1, 2, \ldots, M \)
  - Attributes:
    - Budget, schedule
    - %req’ts covered by COTS
    - Planned upgrade cycle
    - Acquisition cost
    - COTS technical debt

- Dependency matrix
  - Interface requirements among all components

- Multi-Agent Models
  - Each physical unit, \( \text{SS}_i \)
    - A set of hardware and/or software components, \( \{\text{C}_{ij}\} \), \( j=1, 2, \ldots, n_i \)
    - Type: Application, Infrastructure, Network, other
  - Each component, \( \text{C}_{ij} \)
    - Attributes: %req’t’s gap; acquisition cost, upgrade cycle, upgrading cost
    - Type: COTS h/w, COTS s/w, custom h/w, custom s/w, other
Modeling COTS Configuration Version
Technical Debt

- Discrete Event Model
  - COTS change events
    - COTS change:
      - Upgrade cycle: Probabilistic distribution function: e.g. [6month, 12month]
      - Change ratio: random variable \( \{0, 1\} \), larger number indicating greater portion of COTS is changed
  - TD management actions
    - TD Principal Measurement
      - Component level: \( f_C(\text{change ratio, required work, TD reduction strategy}) \)
      - Physical Unit level: \( f_{PU}(\text{changes across a PU, required work, TD reduction strategy}) \)
      - System level: \( f_S(\text{changes across entire system, required work, TD reduction strategy}) \)
    - TD Reduction strategies
      - 0: no work
      - 1: upgrade every version
      - 2: upgrade every other version
      - 3: upgrade until end-of-life
    - TD Dynamic Forecasting
      - \( f(\text{TD principal, probability of TD interest, TD interest amount, } t) \)
COTS Change Propagation and Change Impact Modeling

- COTS Change Impact Analysis
  - Dependency matrix
    - Coupling rate
  - State transition model
    - InService
    - Impacted
    - Obsolete
COCOTS is an effort/cost estimation model for COTS integration, developed at USC
- 3 submodels: COTS assessment, tailoring, integration
- 15 cost drivers: COTS integrator, COTS vendor, system

Extension with 3 additional security drivers
- Required system EAL level
- COTS certified EAL level
- Degree of unused COTS features

COCOTS Risk Analyzer
- Identify COTS integration risk from cost driver inputs
  - A pair of cost drivers with two opposite extreme rating levels, e.g.
    - very high system complexity vs. very low COTS product maturity,
    - very high system complexity vs. very low COTS integrator capability
- Knowledge base of 24 rules

### COTS TD Interest Probability based on COCOTS Model

<table>
<thead>
<tr>
<th>SIZE</th>
<th>AAREN(Application Architectural Engineering)</th>
<th>ACIEF(COTS Integrator Experience with Product)</th>
<th>ACIPC(COTS Integrator Personnel Capability)</th>
<th>AXCIP(Ext Integrator Experience with COTS Integration Processes)</th>
<th>APCON(Integrator Personnel Continuity)</th>
<th>ACPMT(COTS Product Maturity)</th>
<th>ACSEW(COTS Supplier Extension Willingness)</th>
<th>APCPX(COTS Product Interface Complexity)</th>
<th>ACPPS(COTS Supplier Produce Support)</th>
<th>ACPTD(COTS Supplier Provided Training and Documentation)</th>
<th>ACPER(Constraints on COTS Technical Performance)</th>
<th>ASPRT(Application System Portability)</th>
<th>APEAL (Application Evaluated Assurance Level)</th>
<th>ACEAL (COTS Evaluated Assurance Level)</th>
<th>ACPUF (percentage of COTS’ unused features)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
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<td>R</td>
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<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>TD Risk Probability:</td>
<td>&gt;=50%</td>
<td>[40%, 50%)</td>
<td>[20%, 40%)</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Examples of Decision Scenario Simulation

- Scenario 1: Selecting different COTS-based solutions
- Scenario 1: Dynamics of TD aggregation and reduction

*Fn (synchronization, complexity of system, no. planned upgrades, etc.)
Conclusions and Future Directions

• Conclusions
  — Compelling and critical need for a Systems Engineering technical debt metaphor grows
  — The notions of COTS technical debts will help to inform COTS decision making practices in the acquisition process to avoid unaffordable obsolescence issues particularly in the sustainment phase
  — Taxonomy of COTS-related technical debt can support early identification, communication, and assessment of obsolescence risks in CPS system engineering life cycles

• Future directions:
  — Map major obsolescence issues in existing case studies to the proposed COTS TD taxonomy
  — Modelling and Simulation of COTS changes and impact on technical debt aggregation within CPS
  — Align COTS TD management techniques and align with existing acquisition activities
Thank you!