Cost-Aware Business Process Management

Dr. Moe Thandar Wynn
Business Process Management Discipline
Queensland University of Technology, Brisbane, Australia
m.wynn@qut.edu.au
Web: www.yawlfoundation.org/cost
Cost-Aware BPM Research Initiative

- Extend BPM approaches by treating cost as an integral part of process definition, enactment, and analysis
- Research Team:
  - Dr. Moe Thandar Wynn, Prof. Arthur ter Hofstede, Prof. Michael Rosemann, Dr. Chun Ouyang, Dr. Michael Adams, Dr. Jochen De Weerdt, Mr. Keith Low
  - Prof. Zahirul Hoque, Accounting, La Trobe University
  - Prof. Wil van der Aalst and Prof. Hajo A. Reijers, TU/e, The Netherlands
- Supported by an ARC discovery grant (2012-2014)
Why the emphasis on ‘COST’?

- **Cost-effectiveness** – main driver for organisational decisions
- A very close and direct link with BPM/Workflow
  - Versatile [Activities, Resources, Case attributes, Process]
  - Dynamic [and cumulative – in most cases]
  - Applicable at design time and at runtime
- Cost is just another Non-functional Requirement
  - maintainability, usability, reliability, traceability, quality or safety
- Cost is just a number
  - Different cost types/behaviours (opportunity cost, sunk cost, …)
  - Different cost functions (trade-offs, income vs. profits)
- Cost-Aware, Risk-Aware -> X-aware BPM
  - Can be generalised towards “X”
Cost-Aware BPM Research Vision

- Cost Reporting
- Cost Prediction
- Cost-informed log analysis

Process Design

- Cost-informed evaluation of process alternatives
- Cost-informed process visualisation

Process Implementation

- Design of cost-driven business rules
- Design of cost-driven resource allocation rules

Process Enactment

- Enactment of cost-aware workflow processes
- Cost monitoring and escalation

Diagnosis
Cost Reporting
(The Diagnosis Phase)
Management Accounting & BPM

- Capture the real cost of operations
- Multiple techniques and multiple tailored reports used for decision making
- Management accountants do not make adequate use of business process-related data from the WFMS
- Supported by BPM/Workflow technologies
- Capture how the operations are carried out (when and by whom) – ‘event logs’
- BPMS do not support sophisticated costing analysis

Smart Automation = Accurate and Timely Data with less Cost
Overview
Conceptual data model (Cost Model)
Data model (Workflow extensions)

** The cost annotation is derived and stored in an event log
* Durations are derived from the event log, used in calculations, but not stored
XES Cost Extension

- Minimal cost information to be associated with event log
- Can be associated with a process instance or an activity instance
- E.g., $150 AUD (100, CD_A, fixed cost and 50, CD_B, variable cost)

```xml
<xesextension name="Cost" prefix="cost"
  uri="http://www.yawlfoundation.org/yawlschema/xes/cost.xesext">
  <trace>
    <string key="currency"/>
    <float key="total"/>
  </trace>
  <event>
    <string key="currency"/>
    <float key="total"/>
  </event>
  <meta>
    <float key="amount"/>
    <string key="driver"/>
    <string key="type"/>
  </meta>
</xesextension>
```
## Example Cost Drivers

<table>
<thead>
<tr>
<th>Activity</th>
<th>Role</th>
<th>Cost Type</th>
<th>Cost Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyse Defects</td>
<td>Tester</td>
<td>Fixed</td>
<td>$10 per invocation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labour</td>
<td>$25 per (working) hour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>$1 * DefectType</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overhead</td>
<td></td>
</tr>
<tr>
<td>Repair(Complex)</td>
<td>SolverC</td>
<td>Labour</td>
<td>$75 per (working) hour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Materials</td>
<td>5 * DefectType</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>$10 per (total activity duration) hour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overhead</td>
<td></td>
</tr>
<tr>
<td>Archive Repair</td>
<td>System</td>
<td>Fixed</td>
<td>$2 per invocation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Materials</td>
<td>$100 per invocation (if repairsattempt &gt;=5 and defectfixed=false)</td>
</tr>
</tbody>
</table>
Resource Cost Drivers

- Stores human/non-human resource cost information for single and multiple resources

<table>
<thead>
<tr>
<th>RCD ID</th>
<th>RCD Name</th>
<th>Cost Type</th>
<th>Money</th>
<th>Capacity Unit</th>
<th>Resource(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>James</td>
<td>Labor</td>
<td>AUD 30.00</td>
<td>Hour</td>
<td>• Surgeon</td>
</tr>
<tr>
<td>2</td>
<td>Heart Operation</td>
<td>Variable</td>
<td>AUD 10000.00</td>
<td>Invocation</td>
<td>• Cardiology Operation Team</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Operation Theatre</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Surgical Instrument</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Operation Table</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Blood Circulation Machine</td>
</tr>
</tbody>
</table>

Organizational Model

- Extended with resource capacity value, unit, duration, and limit

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Role (s)</th>
<th>Position (s)</th>
<th>Capability (ies)</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>James</td>
<td>Surgeon</td>
<td>-</td>
<td>Batista Procedure</td>
<td>Value 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unit Hour</td>
</tr>
<tr>
<td>2</td>
<td>Operation Table</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Capacity

- Value
- Unit
- Duration
- Limit
Cost Annotation Example

```
<log xes.version="1.0" xes.features="nested-attributes"
     openxes.version="1.0RC7" xmlns="http://www.xes-standard.org/">
  <trace>
    <string key="concept:name" value="1"/>
    .............
    <event>
      <string key="concept:name" value="Analyze Defect"/>
      <string key="org:resource" value="Tester4"/>
      <string key="lifecycle:transition" value="complete"/>
      <date key="time:timestamp" value="1970-01-02T17:10:00.000+10:00"/>
      <string key="phoneType" value="T3"/>
      <string key="defectType" value="6"/>
      <string key="cost:currency" value="AUD"/>
      <float key="cost:total" value="31.80">
        <string key="d2f4ee27-686c-48ef-a7ac-dcb053408245" value=""/>
        <float key="cost:amount" value="21.00"/>
        <string key="cost:driver" value="d2f4ee27-686c-48ef-a7ac-dcb053408245"/>
        <string key="cost:drive" value="Fixed Cost"/>
      </float>
      <string key="a7edbc32-e038-492a-a2e7-305ee1ed5d3e" value=""/>
      <float key="cost:amount" value="4.20"/>
      <string key="cost:driver" value="a7edbc32-e038-492a-a2e7-305ee1ed5d3e"/>
      <string key="cost:drive" value="Labour"/>
    </event>
    .............
  </trace>
</log>
```
Graphical Resource Cost Reports
Management Accounting Style Cost Reporting
Functional Requirements

- Support for well-known management accounting techniques (ABC, TD-ABC, RCA)
- Support for customisable report templates
- Ability to filter report output
- Support for resource utilisation reports
Management Accounting Style Report Generation

Inputs:
1. Cost-annotated Event Log
2. Cost Model
3. Organizational Model
4. XSLT Template

Plug-ins:
1. Basic Cost Report
2. Enriched (OrgModel) Cost Report
## Management Accounting Style Resource Cost Reports

<table>
<thead>
<tr>
<th>Resource Name</th>
<th>Used Capacity (Hr)</th>
<th>Allocated Capacity (Hr)</th>
<th>Idle Capacity (Hr)</th>
<th>Cost per Unit</th>
<th>Idle Cost</th>
<th>Cost per Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tester1</td>
<td>58.68</td>
<td>65</td>
<td>6.32</td>
<td>AUD 25.00</td>
<td>AUD 158.00</td>
<td>5.11</td>
</tr>
<tr>
<td>Tester2</td>
<td>64.58</td>
<td>65</td>
<td>0.42</td>
<td>AUD 25.00</td>
<td>AUD 10.50</td>
<td>3.40</td>
</tr>
<tr>
<td>Tester3</td>
<td>65.73</td>
<td>70</td>
<td>4.27</td>
<td>AUD 25.00</td>
<td>AUD 106.75</td>
<td>3.57</td>
</tr>
<tr>
<td>Tester4</td>
<td>65.92</td>
<td>80</td>
<td>14.08</td>
<td>AUD 25.00</td>
<td>AUD 352.00</td>
<td>9.49</td>
</tr>
<tr>
<td>Tester5</td>
<td>71.15</td>
<td>75</td>
<td>3.85</td>
<td>AUD 25.00</td>
<td>AUD 96.25</td>
<td>1.95</td>
</tr>
<tr>
<td>Tester6</td>
<td>67.23</td>
<td>70</td>
<td>2.77</td>
<td>AUD 25.00</td>
<td>AUD 69.25</td>
<td>6.92</td>
</tr>
<tr>
<td>SolverS1</td>
<td>40.12</td>
<td>50</td>
<td>9.88</td>
<td>AUD 65.00</td>
<td>AUD 642.20</td>
<td>45.44</td>
</tr>
<tr>
<td>SolverS2</td>
<td>60.35</td>
<td>75</td>
<td>14.65</td>
<td>AUD 65.00</td>
<td>AUD 952.25</td>
<td></td>
</tr>
<tr>
<td>SolverS3</td>
<td>86.97</td>
<td>100</td>
<td>13.03</td>
<td>AUD 65.00</td>
<td>AUD 846.95</td>
<td></td>
</tr>
<tr>
<td>SolverC1</td>
<td>100.32</td>
<td>150</td>
<td>49.68</td>
<td>AUD 75.00</td>
<td>AUD 3,726.00</td>
<td></td>
</tr>
<tr>
<td>SolverC2</td>
<td>96.92</td>
<td>165</td>
<td>68.08</td>
<td>AUD 75.00</td>
<td>AUD 5,106.00</td>
<td></td>
</tr>
<tr>
<td>SolverC3</td>
<td>193.63</td>
<td>200</td>
<td>6.37</td>
<td>AUD 75.00</td>
<td>AUD 477.75</td>
<td></td>
</tr>
</tbody>
</table>

Total: 971.60 Hr 1165 Hr 193.40 AUD

This report is generated from the event log, cost model, and organisational model that is associated with the event log: cpnToolsSimulationLog.mxml.gz
Outcomes

- Generic data format for a cost model
  - literature & interviews
- A data format for the cost extension in event log
  - an XES extension for the cost perspective
- Prototype implementation
  - sample management accounting reports & interviews

Cost-Informed Process Execution
(Implementation and Enactment Phases)
Conceptual Framework: Cost-Informed Execution

Data Input

- Executable Process Model/s
- Cost Model/Cost Profile
- Historical Data
- Context Data
  - instance/case attributes
  - process context (e.g. resourcing specification)
  - social context (e.g. organisational data)
  - external/environment (e.g. weather, regulations)

Cost Optimisation Goals

Process
- Design-time process selection
- Run-time process selection

Activity
- Control Flow branching
- Activity selection

Resource
- Push and Pull resource assignments
- Workitem ordering

Actions

Cost-informed Support

System Decisions
- Process variant selection
- Branching
- Activity selection
- Resource assignment of Workitems
- Workitem ordering

System Supported User Decisions
- Process variant selection
- Activity selection
- Workitem selection
- Workitem ordering
Functional Requirements

- Association of cost data and cost-based (branching and resource allocation) rules with a process/workflow
- Runtime calculation of the cost of execution of each process instance and its activity instances
- Logging and analysis of cost data
- Support for cost-informed decisions (system and user)
Resource/WorkItem Lifecycle (cost-informed)
YAWL workflow environment (cost-informed)
Example: Home Loan Application Process

Activity – XOR split

Process variants selection

Resource – cheapest

(Activity) Roles Abbreviations
LO Loan Officer
LC Loan Consultant
LP Loan Processor
LM Loan Manager
MI Mortgage Insurer
MU Mortgage Underwriter
PV Property Valuer
UA Underwriting Assistant

(YAWL) Symbols
start condition
end condition
atomic task
composite task
XOR-split task
XOR-join task
XOR-split task
XOR-join task
Cost Model

• **Role-based (variable)** cost rate of a resource
  – An employee in a certain role has a salary of $50 per hour.

• **Fixed** cost rate for an activity
  – A mortgage insurance processing fee is $50 per loan application. (Regardless of who carries out the activity)

• **Fixed** cost rate of a resource for a given activity
  – A property valuer charges $300 to conduct a property valuation activity.

• **Case-based (variable)** cost rate
  – A mortgage broker service charges a commission of 0.5% of the loan amount.
Realisation in YAWL (Design and Runtime)
Future Work

- Link to Worklets for cost-based selection
- Evaluations within an organisational setting
Cost-Informed Log Analysis
(The Diagnosis Phase)
Cost-Informed Log Analysis

Event Log

Cost Structure

Trade-offs
(defined as cost functions)

Alternative Execution Scenarios

Trade-offs types:
• Time
• Cost
• Quality
Overall Approach
Definition 1 (Abstract Event Log). $L = (C, A, T, case, task, art, dur, prop, \prec)$ is an abstract event log where:

- $C$ is a set of cases,
- $A$ is a set of activities (an activity is an instance or an instantiation of a task),
- $T$ is a set of tasks,
- $I$ is a set of property names,
- the sets $C$, $A$, and $T$ are pairwise disjoint and finite,
- $case \in A \rightarrow C$ is a function mapping activities to cases,
- $task \in A \rightarrow T$ is a function mapping activities to tasks,
- $art \in C \rightarrow TS$ is a function specifying the arrival time of cases,
- $dur \in A \rightarrow Dur$ is a function mapping activities to durations,
- $prop \in (C \cup A \times I) \rightarrow Val$ is a function mapping cases and activities to their invariable properties,
- $\prec \subseteq A \times A$ defines a partial order on activities within cases:
  - $\forall a_1, a_2 \in A \ a_1 \prec a_2 \Rightarrow case(a_1) = case(a_2)$ (activities of different cases are unordered),
  - $\forall a \in A \ a \nprec a$ (irreflexive),
  - $\forall a_1, a_2 \in A \ a_1 \prec a_2 \Rightarrow a_2 \nprec a_1$ (asymmetric), and
  - $\forall a_1, a_2, a_3 \in A \ (a_1 \prec a_2 \land a_2 \prec a_3) \Rightarrow a_1 \prec a_3$ (transitive).
Definition 2 (Binding, Concrete Event Log). Let $L = (\mathcal{C}, \mathcal{A}, \mathcal{T}, \text{case}, \text{task}, \text{art}, \text{dur}, \text{prop}, \prec)$ be an abstract event log. $B = (\mathcal{R}, \text{res}, \text{st}, \text{et})$ is a binding for $L$ where:

- $\mathcal{R}$ is a set of resources,
- $\text{res} \in \mathcal{A} \rightarrow \mathcal{P}(\mathcal{R})$ is a function mapping each activity onto a set of resources,
- $\text{st} \in \mathcal{A} \rightarrow TS$ assigns a start time to each activity and $\text{et} \in \mathcal{A} \rightarrow TS$ assigns an end time to each activity such that:
  
  - $\forall a \in \mathcal{A} \; \text{st}(a) \geq \text{art}(\text{case}(a))$,
  - $\forall a \in \mathcal{A} \; \text{st}(a) + \text{dur}(a) = \text{et}(a)$, and
  - $\forall a_1, a_2 \in \mathcal{A} \; a_1 \prec a_2 \Rightarrow \text{et}(a_1) \leq \text{st}(a_2)$.

$(L, B)$ is a concrete event log.
Definition 6 (Cost Structure). Let $\mathcal{R}$ be a set of resources and $\mathcal{T}$ a set of tasks. $CS = (\text{costs}^{\text{case}}, \text{costs}^{\text{act}}, \text{costs}^{\text{res}}, h, \text{can})$ is a cost structure over $\mathcal{R}$ and $\mathcal{T}$ where:

- $\text{can} \in \mathcal{T} \rightarrow \mathcal{P}(\mathcal{P}(\mathcal{R}))$ such that $\text{can}(t)$ is a set of sets of resources for task $t \in \mathcal{T}$. Any $R \in \text{can}(t)$ is a set of resources that can be used to execute task $t$,
- $\text{costs}^{\text{case}} \in (\mathcal{D} \times \mathcal{V}) \rightarrow \text{Costs}$ such that $\text{costs}^{\text{case}}(d, v)$ are the costs of a case having duration $d \in \mathcal{D}$ and invariable properties $v \in \mathcal{V}$,
- $\text{costs}^{\text{act}} \in (\mathcal{T} \times \mathcal{P}(\mathcal{R}) \times \mathcal{D} \times \mathcal{V}) \rightarrow \text{Costs}$ such that $\text{costs}^{\text{act}}(t, rs, d, v)$ are the costs of executing task $t \in \mathcal{T}$ by resources $rs \subseteq \mathcal{R}$ having duration $d \in \mathcal{D}$ and invariable properties $v \in \mathcal{V}$,
- $\text{costs}^{\text{res}} \in (\mathcal{R} \times \mathcal{D} \times \mathcal{U}) \rightarrow \text{Costs}$ such that $\text{costs}^{\text{res}}(r, d, u)$ are the costs of using resource $r \in \mathcal{R}$ for $d \in \mathcal{D}$ time units and having a utilisation of $u \in \mathcal{U}$,
- $h \in \mathcal{D} \setminus \{0\}$ is the horizon used to compute utilisation.
Example Cost Functions

Cost Function for a case (SLA violation penalties):

<table>
<thead>
<tr>
<th>Duration</th>
<th>Gold</th>
<th>Silver</th>
<th>Bronze</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>10</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>20~29</td>
<td>50</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>&gt;=30</td>
<td>100</td>
<td>80</td>
<td>60</td>
</tr>
</tbody>
</table>

Cost Function for activities (quality)

<table>
<thead>
<tr>
<th>Task</th>
<th>Inexperienced</th>
<th>Experienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Z</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>

Inexperienced Resource = R1, R3, R5, R7
Experienced Resource = R2, R4, R6

Cost Function for resources:

Resource Utilisation:

\[ f(x) = 30x^2 - 20x + 5 \]
Cost of An Event Log

Cost = Cost of Cases + Cost of Activities + Cost of Involved Resources

Overall Log Execution Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Case Execution Cost</td>
<td>264.00</td>
</tr>
<tr>
<td>Total Resource Execution Cost</td>
<td>377.98</td>
</tr>
<tr>
<td>Total Activity Execution Cost</td>
<td>382.00</td>
</tr>
<tr>
<td>Overall Log Execution Cost</td>
<td>1023.98</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Case Execution Cost</td>
<td>264.00</td>
</tr>
<tr>
<td>Total Activity Execution Cost</td>
<td>384.00</td>
</tr>
<tr>
<td>Total Resource Execution Cost</td>
<td>493.50</td>
</tr>
<tr>
<td>Overall Log Execution Cost</td>
<td>1141.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Resource Execution Cost</td>
<td>228.73</td>
</tr>
<tr>
<td>Total Case Execution Cost</td>
<td>264.00</td>
</tr>
<tr>
<td>Total Activity Execution Cost</td>
<td>388.00</td>
</tr>
<tr>
<td>Overall Log Execution Cost</td>
<td>880.73</td>
</tr>
</tbody>
</table>
Cost Driven Improvement

- Overall resource utilisations were increased
- Overall case durations are shorter
Ongoing Work

- Compute cost and generate alternative execution scenarios by manipulating the variable part of the event log
  - Safe: A resource only works on one workitem at a certain time
  - Valid: A resource has the permission to do a task
- A first step towards comparing different execution scenarios and reasoning the possible cost inefficiencies
- Explore efficient scenario generation techniques
  - Brute Force, Simulated Annealing, Genetic Algorithms, others??
Thanks! Questions?

Dr Moe Thandar Wynn
Email: m.wynn@qut.edu.au

This presentation contains slides created by other members of the research team.