Collaborative Process Modeling (CPM)

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Why we need CPM?

Research Objective

to illustrate a methodology for modeling collaborative processes

Collaborative Process Modeling (CPM)
What is CPM?

Collaborative Process

- a process conducted by more than two actors or entities
- endogenous collaborative process includes operations between corresponding entities within a system w.r.t. H/W and S/W
  (e.g., synchronization between processing machines and material handlers, communication/negotiation between control software and traveling agents)
- exogenous collaborative process: cooperation of high-level entities such as departments or enterprises

Modeling Methods

- IDEF3
- Petri-net
- UML
- ARIS
- etc.
A Petri Net (PN) is formally defined as a four-tuple $C = (P, T, I, O)$ where,
- $P$: a finite set of places $p$,
- $T$: a finite set of transitions $t$,
- $I$ & $O$: sets of input and output places of corresponding transition (e.g., $I_t$ is the input place of $t$, $O_t$ is the output place of $t$).

Dynamic behavior of a PN is defined by its marking $\mu$ where,
- $\mu$: a state vector with $\mu_p$ denoting the number of tokens in $p$.

Marked graph is a PN in which each place has exactly one input and one output:
$$p_i \in P, \left| I_{pi} \right| = \left| \{ j \mid p_i \in O(t_j) \} \right| = 1, \left| O_{pi} \right| = \left| \{ j \mid p_i \in I(t_j) \} \right| = 1$$

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Event</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1</td>
<td>Waiting for drawing/part list/mold models</td>
<td>E1</td>
<td>Drawings including mold models and part list are arrived</td>
</tr>
<tr>
<td>O2</td>
<td>Generation of CAM data</td>
<td>E2</td>
<td>Generating CAM data is completed</td>
</tr>
<tr>
<td>O3</td>
<td>Transmission of CAM data and corresponding process info.</td>
<td>E3</td>
<td>CAM data and process info. are arrived</td>
</tr>
<tr>
<td>O4</td>
<td>Detailed production scheduling</td>
<td>E4</td>
<td>Detailed production planning is completed</td>
</tr>
<tr>
<td>O5</td>
<td>Verification of part drawings and production planning</td>
<td>E5</td>
<td>Decision of outside order or self-production</td>
</tr>
<tr>
<td>O6</td>
<td>Production of parts of a mold by a contractor</td>
<td>E6</td>
<td>(always occurring event)</td>
</tr>
<tr>
<td>O7</td>
<td>Detailed production planning</td>
<td>E7</td>
<td>Material and part is deposited and verified</td>
</tr>
<tr>
<td>O8</td>
<td>Delivering process information</td>
<td>E8</td>
<td>Processing operations are distributed</td>
</tr>
<tr>
<td>O9</td>
<td>Distribution of processing operations</td>
<td>E9</td>
<td>Schedule is rearranged or additional works are completed</td>
</tr>
<tr>
<td>O10</td>
<td>Rescheduling</td>
<td>E10</td>
<td>Making parts of a mold is finished or parts produced by a contractor is delivered</td>
</tr>
<tr>
<td>O11</td>
<td>Making parts of a mold</td>
<td>E11</td>
<td>Inspection is done or additional finishing touches are completed</td>
</tr>
<tr>
<td>O12</td>
<td>Inspection of mold parts</td>
<td>E12</td>
<td>Post-processing is finished</td>
</tr>
<tr>
<td>O13</td>
<td>Perform additional works</td>
<td>E13</td>
<td>Parts are assembled into a mold</td>
</tr>
<tr>
<td>O14</td>
<td>Post-processing</td>
<td>E14</td>
<td>Final inspection is completed</td>
</tr>
<tr>
<td>O15</td>
<td>Assembling parts of a mold</td>
<td>E15</td>
<td>Perform additional finishing touches</td>
</tr>
<tr>
<td>O16</td>
<td>Final inspection of a mold</td>
<td>E16</td>
<td></td>
</tr>
<tr>
<td>O17</td>
<td>Perform additional finishing touches</td>
<td>E17</td>
<td></td>
</tr>
<tr>
<td>O18</td>
<td>Finishing up mold production</td>
<td>E18</td>
<td></td>
</tr>
</tbody>
</table>
Collaboration Modeling with UML

Collaboration Modeling with ARIS

ARIS (Architecture of Integrated Information Systems)
- a technique for modeling business processes
- provides the method called Event-driven Process Chain (EPC)

[cf, EPC is used as a component of modeling processes in SAP R/3 (SAP AG), LiveModel/Analyst (Intellicort Inc.), Visio (Vision Cort., MicroSoft Cort.), ARIS (IDS Prof. Sheer GmbH)]
Comparison of Modeling Methods

<table>
<thead>
<tr>
<th>Criteria</th>
<th>IDEF3</th>
<th>Petri Nets</th>
<th>UML</th>
<th>ARIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model complexity</td>
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<td>Formalism</td>
<td>Not existing or very small (elaboration)</td>
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<td>Not existing or very small (elaboration)</td>
</tr>
<tr>
<td>Representability</td>
<td>Not very large</td>
<td>Very large</td>
<td>Fairly large (restricted to diagrams supported)</td>
<td>Fairly large</td>
</tr>
<tr>
<td>Collaboration Process Modeling</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Dynamics</td>
<td>Limited (temporal relations between entries or objects)</td>
<td>Powerful</td>
<td>Limited (with logical connectors)</td>
<td>Limited (with logical connectors)</td>
</tr>
<tr>
<td>- Collaboration</td>
<td>Not possible</td>
<td>Possible (but models normally become very complex)</td>
<td>Possible but limited (with collaboration diagram)</td>
<td>Possible (with organizational symbols)</td>
</tr>
<tr>
<td>- Multiple actors of a behavior</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Limited (with swimlane)</td>
<td>Possible</td>
</tr>
<tr>
<td>Model verification</td>
<td>Not possible</td>
<td>Powerful (with formalism)</td>
<td>Not possible</td>
<td>Not possible</td>
</tr>
<tr>
<td>Model simulation</td>
<td>Not possible</td>
<td>Possible</td>
<td>Not possible</td>
<td>Possible</td>
</tr>
</tbody>
</table>

Discussion about Modeling Methods

- Representability of collaboration processes
  - ARIS > Petri nets > UML1.x > IDEF3
    - ARIS > UML2.0 > Petri nets > IDEF3
      (ARIS supports Organizational Symbol for indicating multiple actors)

- Complement research on modeling methodologies
  - UML + IDEF
  - IDEF + Petri nets
  - Another Modeling Methods + Petri nets
  - etc.
Collaborative Process Modeling (CPM)

- Types of collaborative processes
  - Normal Process
  - Intra-collaboration Process (cooperation between different groups within the same organization)
  - Inter-collaboration Process (cooperation between different organizations)

CPM is the methodology to model collaborative processes among multiple actors with different affiliations
- based on the UML activity diagram notation
- can be transformed into Marked Graph to take advantage of the analytical power of Petri nets

Characteristics of CPM

- CPM is process-oriented
- CPM elements are based on UML notation, and consist of 8 elements
- CPM is an easy-to-understand process because normal/intra-collaboration/inter-collaboration processes are represented with different symbols
- The processes carried out by corresponding participants can be modeled in a single CPM model, and each participant is explicitly identified in the models,
- CPM models can be transformed into Marked Graph models so that analytical methods of Petri nets can be used
**CPM Elements**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Actor IDs" /></td>
<td>Intra-collaboration process</td>
<td></td>
<td>Horizontal and vertical synchronization</td>
</tr>
<tr>
<td><img src="image2" alt="Actor IDs" /></td>
<td>Inter-collaboration process</td>
<td></td>
<td>Process transition</td>
</tr>
<tr>
<td><img src="image3" alt="Actor ID" /></td>
<td>Normal process</td>
<td></td>
<td>Resource</td>
</tr>
<tr>
<td><img src="image4" alt="Decision" /></td>
<td>Decision</td>
<td></td>
<td>Reference note</td>
</tr>
</tbody>
</table>

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**Representation of Actor_IDs**

- **Company:** \( C = \{c_i \mid i = 1, \ldots, l\}, \quad D^i \subset C, \)
- **Department:** \( D^i = \{d_j \mid d_j \in c_i, i = 1, \ldots, l, j = 1, \ldots, m\}, \quad P^{ij} \subset D^i, \)
- **Individual:** \( P^{ij} = \{p_{kl}^{ij} \mid p_{kl}^{ij} \in d_j^i, i = 1, \ldots, l, j = 1, \ldots, m, k = 1, \ldots, n\}. \)

- **Normal process:** \( c_i(d_j^i(p_{kl}^{ij})) \)
  - e.g., \( <c_i(d_2^1(p_{12}^{13}))> \)
- **Intra-collaboration process:** \( c_i(D^i) \) or \( c_i(d_j^i(P^{ij})) \)
  - e.g., \( <c_i(d_2^1(p_{12}^{13}), p_{12}^{13})>, <c_i(d_2^2(p_{12}^{13}), d_3^1(p_{12}^{13}))> \)
- **Inter-collaboration process:** \( C \)
  - e.g., \( <c_i(d_2^1(p_{12}^{13})), c_2(d_3^2(p_{12}^{13}, p_{12}^{13}))>, <c_i(d_1^3(p_{12}^{13}), d_3^2(p_{12}^{13}), p_{12}^{13})), c_3(d_2^1(p_{12}^{13}, p_{12}^{13}))> \)
Illustrative CPM model (Injection-mold)

Participants in Exemplary Model

<table>
<thead>
<tr>
<th>Company/Department</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C_1)</td>
<td>Part production company</td>
</tr>
<tr>
<td>(d_1)</td>
<td>strategic planning team</td>
</tr>
<tr>
<td>(d_2)</td>
<td>part design team</td>
</tr>
<tr>
<td>(d_3)</td>
<td>part production team</td>
</tr>
<tr>
<td>(d_4)</td>
<td>marketing team</td>
</tr>
<tr>
<td>(C_2)</td>
<td>Mold design company</td>
</tr>
<tr>
<td>(d_1)</td>
<td>marketing/technology team</td>
</tr>
<tr>
<td>(d_2)</td>
<td>mold design team</td>
</tr>
<tr>
<td>(d_3)</td>
<td>purchasing/procurement team</td>
</tr>
<tr>
<td>(C_3)</td>
<td>Mold production company</td>
</tr>
<tr>
<td>(d_1)</td>
<td>marketing/strategy team</td>
</tr>
<tr>
<td>(d_2)</td>
<td>mold production &amp; management team</td>
</tr>
<tr>
<td>(d_3)</td>
<td>quality management team</td>
</tr>
<tr>
<td>(C_4)</td>
<td>Engineering Service Company</td>
</tr>
<tr>
<td>(d_1)</td>
<td>engineering service team 1</td>
</tr>
</tbody>
</table>
**Model Transformation**

**STEP 1**
Remove reference notes from the CPM model, since they are not defined as MGBB.

**STEP 2**
Choose a level of detail for Marked Graph models. Company, Department, and Individual levels are available for the transformation.

**STEP 3**
Replace the CPM elements with MGBB to generate Marked Graph models.

**STEP 4**
Complete the transformation by adding an “ending mark” between the transition(s) of the MGBB indicating the first process and the place(s) of the MGBB meaning the last process.

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<table>
<thead>
<tr>
<th>Symbol</th>
<th>Marked Graph Building Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>intra-collaboration process</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td>inter-collaboration process</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td>normal process</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td>synchronization</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td>decision</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td>process transition</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td>resource</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
<tr>
<td>ending mark (additional)</td>
<td><img src="image" alt="Symbol" /></td>
</tr>
</tbody>
</table>

Input for extension
Output for extension
Model Transformation (cont’d)

Refer to the another files such as “CSCWD2005_Ryu_Final.ppt” and “CPM–A collaborative process modeling for cooperative manufacturers.pdf”

A Novel Method of Modeling Collaborative Processes in Manufacturing

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(kwang-yeol.ryu@insead.edu)

May 25, 2005

Technology and Operations Management Area
INSEAD
Contents

- **Introduction**
- **Pervasive Process Modeling Techniques**
  - Illustrative process modeling by using IDEF3, Petri Nets, UML, (ARIS)
  - Comparison of pervasive process modeling methods
- **Collaborative Process Modeling (CPM)**
  - Definition and necessity of CPM
  - CPM elements
  - Illustrative CPM
  - CPM model transformation (rule and results)
- **Concluding Remarks**

Introduction

- **Environmental conditions are changing competitively**
  - ever-changing customer demands
  - globalization/distribution of manufacturing industry
  - enhanced social pressures as well as regional, governmental and environmental regulations

→ **Manufacturing industry of today**
  - higher need for collaboration
    - endogenous collaboration → **Manufacturing System**
      - operations between entities within a system
      - e.g., synchronization between machines, communication between software agents, etc.
    - exogenous collaboration → **Supply Chain Management**
      - cooperation of high-level entities such as between companies or enterprises
**Introduction (cont’d)**

- How can we define collaboration between entities?
  - define the **PROCESS of collaborative works** by using a process modeling technique

- **Pervasive process modeling techniques**
  - IDEF3
  - Petri Nets (PN)
  - UML
  - ARIS
  - etc.

- **Collaborative Process Modeling (CPM)**

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**Illustrative Model for Process Modeling**

- Manufacturing processes of a mold company

![Diagram showing process modeling techniques and steps]

- Market analysis & concept design
- UML (ARIS)
- IDEF3
- PN
- Verification of mold design
- Trial injection molding
- Mass production of parts

*INSEAD*
Mold Design

IDEF3

Waiting for drawing/part list/mold models
Generation of CAM data
Transmission of CAM data and corresponding process info.
Detailed production scheduling
Verification of part drawings and production planning
Production of parts of a mold by a contractor
Detailed production planning
Delivering process information
Distribution of processing operations
Rescheduling
Making parts of a mold
Inspection of mold parts
Perform additional works
Post-processing
Assembling parts of a mold
Final inspection of a mold
Perform additional finishing touches
Finishing up mold production

Drawings including mold models and part list are arrived
Generating CAM data is completed
CAM data and process info. are arrived
Detailed production planning is completed
Decision of outside order or self-production (always occurring event)
Material and part is deposited and verified
Processing operations are distributed
Schedule is rearranged or additional works are completed
Making parts of a mold is finished or parts produced by a contractor are delivered
Inspection is done or additional finishing touches are completed
Post-processing is finished
Parts are assembled into a mold
Final inspection is completed
Finishing up mold production
**Comparison of Methods**

- **CPM**

<table>
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<tr>
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<th>IDEF3</th>
<th>PN</th>
<th>UML</th>
<th>ARI S</th>
</tr>
</thead>
<tbody>
<tr>
<td>General characteristic</td>
<td></td>
<td></td>
<td></td>
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<td>Powerful</td>
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<tr>
<td>Model verification</td>
<td>Impossible</td>
<td>Powerful (with formalism)</td>
<td>Impossible</td>
<td>Impossible</td>
</tr>
<tr>
<td>Model simulation</td>
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<td>Possible</td>
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<td>Possible</td>
</tr>
</tbody>
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Collaborative Process Modeling (CPM)

What is CPM?
- CPM is a visual modeling method to clearly define collaborative process existing in the domain considered
- main characteristics
  - CPM is process-oriented (support object-oriented message modeling)
  - CPM elements are based on UML notation, 8 elements are available
  - CPM uses different notations according to process types
    - process types: normal/inter-collaboration/intra-collaboration process
  - participants of a process can be explicitly identified
  - CPM model can be transformed into Marked Graph model

Why we need CPM?
- not enough to clearly illustrate collaborative processes with pervasive process modeling techniques
- can utilize benefit of both CPM and PN through model transformation
  - CPM: powerful expressiveness, understandability, readability, etc.
  - PN: analysis and verification of model

Collaborative Process Modeling (CPM) (cont’d)

CPM elements

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<th>Symbol</th>
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<tbody>
<tr>
<td>![Actor_IDs]</td>
<td>Intra-collaboration process</td>
<td></td>
<td>Horizontal and vertical synchronization</td>
</tr>
<tr>
<td>![Actor_IDs]</td>
<td>Inter-collaboration process</td>
<td>→↑</td>
<td>Process transition</td>
</tr>
<tr>
<td>![Actor_ID]</td>
<td>Normal process</td>
<td>![Resource]</td>
<td>Resource</td>
</tr>
<tr>
<td>![Decision]</td>
<td>Decision</td>
<td>![Reference note]</td>
<td>Reference note</td>
</tr>
</tbody>
</table>
Collaborative Process Modeling (CPM) (cont’d)

- Component of Actor_ID(s) of a process
  - Company
    - \( C = \{c_i | i = 1, \ldots, n\} \), \( D^i \subset C \)
  - Department
    - \( D^i = \{d^i_j | d^i_j \in c_i, j = 1, \ldots, m\} \), \( P^i \subset D^i \)
  - Individual
    - \( P^i = \{p^i_k | p^i_k \in d^i_j, k = 1, \ldots, l\} \)
- Illustrative use of Actor_ID(s)
  - Normal process
    - \( c_i(d^i_j(p^i_k)) \) - e.g., \( <c_i(d^i_j(p^i_k))> \)
  - Inter-collaboration
    - \( c_i(D^i) \) or \( c_i(d^i_j(P^i)) \) - e.g., \( <c_i(d^i_j(p^i_k)), d^i_j(p^i_k)> \), \( <c_i(d^i_j(p^i_k), p^i_k)> \)
  - Intra-collaboration
    - \( C - c_i(d^i_j(p^i_k)), c_i(d^i_j(p^i_k), p^i_k)> \), \( <c_i(d^i_j(p^i_k), d^i_j(p^i_k), p^i_k)> \)

Illustrative CPM

- CPM for collaboration of mold companies
  - part design \( \rightarrow \) mold design \( \rightarrow \) mold production
Model Transformation

- Transformation procedure

## Marked Graph Building Block (MGBB)

<table>
<thead>
<tr>
<th>Symbol</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Normal process</td>
<td>![Normal process Diagram]</td>
</tr>
<tr>
<td>Intra-collaboration process</td>
<td>![Intra-collaboration process Diagram]</td>
</tr>
<tr>
<td>Inter-collaboration process</td>
<td>![Inter-collaboration process Diagram]</td>
</tr>
</tbody>
</table>
Marked Graph Building Block (MGBB) (cont’d)

Synchronization

Decision

Process transition

Resource

Ending mark (additional)

Transformation Rules

Rule 1) delete reference notes
Rule 2) choose a level of detail of the Marked Graph model to be transformed
   ✓ C_{level} – company level
   ✓ T_{level} – department level
   ✓ I_{level} – individual level
Rule 3) transform CPM elements into PN by using MGBB defined

<table>
<thead>
<tr>
<th>Process</th>
<th>C_{level}</th>
<th>T_{level}</th>
<th>I_{level}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Process</td>
<td>[ P0 ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intra-collaboration</td>
<td>[ P0 ]</td>
<td>[ P1 ]</td>
<td>[ P2 ]</td>
</tr>
<tr>
<td>Inter-collaboration</td>
<td>[ P1 ]</td>
<td>[ P2 ]</td>
<td>[ P3 ]</td>
</tr>
</tbody>
</table>

Rule 4) complete transformation by adding an “ending mark”
(a) Object-oriented message flow diagram

(b) Meaning of diagram (a)
Concluding Remarks

- Characteristics of CPM modeling is as easy as IDEF3
- CPM models are well understandable (high representability as UML)
- Actors involved in collaborative process are readily recognizable
  - This supports the design of efficient schedules and workflows by identifying in advance collaboration opportunities
- Analysis of models is available through model transformation

Application of CPM
- e-mfg. pilot project, 2004, KITECH
  - Collaborative activities were modeled and defined as a business template, which is a group of relevant standard documents corresponding to a collaborative process
  - The business template was implemented as a web-based hub system
  - Hub system is being utilized for helping online collaboration of Korean mold companies

Business Template

The 40th International Conference on Computers & Industrial Engineering

Extended Collaboration Process Modeling Method
Enabling Model Verification

July 27th, 2010

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Sunhwa Lee
1. Introduction

To cope with the rapidly changing market environment, a new management strategy named “collaboration” came to appear. To promote effective communication, various modeling methods are being used. There are frequently-used methodologies, IDEF3, Petri-Nets, and UML, but they have limitations in modeling the collaborative process. People began to discuss about the necessity of modeling methodologies to clearly represent the collaboration.

“Collaboration”: appearance of new management strategy

To cope with the rapidly changing market environment, a new management strategy named “collaboration” came to appear.
### 2. Review of process modeling methods

<table>
<thead>
<tr>
<th>Criteria</th>
<th>IDEF3</th>
<th>UML</th>
<th>BPMN</th>
<th>ARIS</th>
<th>Petri-Nets</th>
<th>CPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model simplicity</td>
<td>Very simple (but not available for very complex models)</td>
<td>Simple</td>
<td>Fairly simple</td>
<td>Simple</td>
<td>Fairly simple, but complex when a model size becomes large</td>
<td>Fairly simple</td>
</tr>
<tr>
<td>Understandability</td>
<td>Very easy</td>
<td>Easy</td>
<td>Fairly easy</td>
<td>Easy</td>
<td>Mostly difficult</td>
<td>Fairly easy</td>
</tr>
<tr>
<td>Standardization</td>
<td>Very strong</td>
<td>Fairly strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Very weak (many versions)</td>
<td>Strong</td>
</tr>
<tr>
<td>Data flow</td>
<td>Impossible</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
<td>Improbable</td>
<td>Limited</td>
</tr>
<tr>
<td>Representability</td>
<td>Not very strong</td>
<td>Fairly strong (restricted to diagrams supported)</td>
<td>Strong</td>
<td>Fairly strong</td>
<td>Very strong</td>
<td>Strong</td>
</tr>
<tr>
<td>Dynamics</td>
<td>Impossible (Static)</td>
<td>Impossible (Static)</td>
<td>Limited (through BPEL)</td>
<td>Impossible (Static)</td>
<td>Powerful (with tokens)</td>
<td>Impossible (Static)</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Impossible</td>
<td>Limited (with collaboration diagram)</td>
<td>Possible (through BPEL)</td>
<td>Possible (with organizational symbols)</td>
<td>Possible (but models normally become very complex)</td>
<td>Possible</td>
</tr>
<tr>
<td>Model verification</td>
<td>Not directly (via Petri-Nets transformation)</td>
<td>Not directly (via Petri-Nets transformation for certain diagrams)</td>
<td>Possible (through BPEL)</td>
<td>Not directly (via Petri-Nets transformation)</td>
<td>Powerful (with formalism)</td>
<td>Not directly (via Petri-Nets transformation)</td>
</tr>
<tr>
<td>Model simulation</td>
<td>Not directly (via WITNESS or Petri-Nets transformation)</td>
<td>Not directly (via WITNESS or Petri-Nets transformation)</td>
<td>Possible (through BPEL)</td>
<td>Not directly (via WITNESS etc)</td>
<td>Possible</td>
<td>Not directly (via Petri-Nets transformation)</td>
</tr>
<tr>
<td>Real-time monitoring</td>
<td>Impossible</td>
<td>Impossible</td>
<td>Possible (through BPEL)</td>
<td>Impossible</td>
<td>Possible</td>
<td>Impossible</td>
</tr>
</tbody>
</table>


### 3. Procedure of research

Colored Petri-Nets (CPN) → c-IDEF* → IDEF3 → IDEF0 → CPM

Collaborative process modeling
4. Collaborative process modeling methodology
4-1. Definition of CPM

- CPM (Collaborative process modeling)
  - CPM is the methodology to model collaborative processes among multiple actors with different affiliations.
  - Characteristics
    - CPM is process-oriented.
    - CPM elements are based on UML notation, and consist of 8 elements.
    - Models in CPM are easy-to-understand because normal/intra-/inter-collaboration processes are represented with different symbols.
    - The processes carried out by corresponding participants can be modeled in a single CPM model, and each participant is explicitly identified in the models.
    - CPM models can be transformed into marked graph so that analytical methods of Petri-Nets can be used.


4-2. Elements of CPM

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Actor_ID]</td>
<td>Normal process</td>
<td>![Horizontal/vertical synchronization]</td>
<td>Horizontal/vertical synchronization</td>
</tr>
<tr>
<td>![Actor_IDs]</td>
<td>Intra-collaboration process</td>
<td>![Process transition]</td>
<td>Process transition</td>
</tr>
<tr>
<td>![Actor_IDs]</td>
<td>Inter-collaboration process</td>
<td>![Resource]</td>
<td>Resource</td>
</tr>
<tr>
<td>![Decision]</td>
<td>Decision</td>
<td>![Reference note]</td>
<td>Reference note</td>
</tr>
</tbody>
</table>

4. Collaborative process modeling methodology

4-3. Illustrative CPM model of collaborative works


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4. Collaborative process modeling methodology

4-4. IDEF*

- IDEF* : a methodology which combines the features of IDEF0 & IDEF3
  - IDEF0 (Function modeling method)
    - The IDEF0 is designed to model the functions of an organization or a system
    - It can express the functional data clearly by using ICOM (input, output, control, mechanism) concept
  - IDEF3 (Process modeling method)
    - IDEF3 is based upon the concept of direct capture of descriptions of the precedence and causality relations between situations and events in a form that is natural to domain experts in an environment

Illustrative example of IDEF0
Illustrative example of IDEF3
4. Collaborative process modeling methodology

4-5. Process notation and diagrams of IDEF*

Control flow

Input

Process

Mechanisms

Output

Process Owner/ Organization Cell

Control

Authority


Colored Petri-Nets (CPN)

- CPN : High-level Petri-Nets
- CPN is a graphical oriented language for design, specification, simulation, verification of systems
- If more than two tokens in a place, tokens discriminate by color
- Weakness : difficult to understand of models
- Strength : it is efficiently used to make a modeling in complex system

<table>
<thead>
<tr>
<th>CPN</th>
<th>PN</th>
</tr>
</thead>
<tbody>
<tr>
<td>(p_{123})</td>
<td>({p_1, p_2, p_3})</td>
</tr>
<tr>
<td>(p'_{123})</td>
<td>({p'_1, p'_2, p'_3})</td>
</tr>
<tr>
<td>(t_{12})</td>
<td>({t_1, t_2})</td>
</tr>
</tbody>
</table>

Illustrative example of Petri-Nets

Illustrative example of Colored Petri Nets
4. Collaborative process modeling methodology

4-7. Definition of c-IDEF*

- **c-IDEF* (IDEF* + CPN)**
  - c-IDEF* is a modeling methodology that can express the dynamic collaborative process through the token of Colored Petri-Nets based on IDEF*
  - **Characteristics**
    - Possible to represent time-oriented processes and information regarding each functional activity
    - It can express the **collaboration process with the color token**
    - As it is based on IDEF0 and IDEF3, it can make the hierarchical expression
    - By adopting the **Petri-Nets token**, it can make the **dynamic expression** and divide the before-and-after of the process


4. Collaborative process modeling methodology

4-8. Process notation and exemplary model of c-IDEF*

5. exCPM (extended CPM)  
5-1. Definition of exCPM

- **exCPM**
  
  - exCPM is an improved CPM methodology that uses the advantages of CPM and c-IDEF* in a mixed way in order to clearly represent collaborative processes

- **Characteristics**
  
  - Process-oriented modeling methodology
  - Based on the components of CPM, and composed of 10 components
  - Uses separate symbols for the normal/intra-/inter-collaborations to facilitate the intuitive comprehension of models
  - Clearly expresses complex and multiple actors with the **color tokens**
  - Adopts the token of Petri-Nets to enable the dynamic expression and the real-time monitoring of the process
  - Clearly represents the **collaborative data and flow** with ICOM elements
5. exCPM (extended CPM)

5-2. Process notation

Inter-collaboration process notation of exCPM

5-3. Elements of exCPM

### Elements of exCPM

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Normal process" /></td>
<td>Normal process</td>
<td><img src="image2.png" alt="Process transition" /></td>
<td>Process transition</td>
</tr>
<tr>
<td><img src="image3.png" alt="Intra-collaboration process" /></td>
<td>Intra-collaboration process</td>
<td><img src="image4.png" alt="Input/control/output" /></td>
<td>Input/control/output</td>
</tr>
<tr>
<td><img src="image5.png" alt="Inter-collaboration process" /></td>
<td>Inter-collaboration process</td>
<td><img src="image6.png" alt="Synchronization" /></td>
<td>Synchronization</td>
</tr>
<tr>
<td><img src="image7.png" alt="Decision" /></td>
<td>Decision</td>
<td><img src="image8.png" alt="State token" /></td>
<td>State token</td>
</tr>
<tr>
<td><img src="image9.png" alt="Resource" /></td>
<td>Resource</td>
<td><img src="image10.png" alt="Color token" /></td>
<td>Color token</td>
</tr>
</tbody>
</table>

### Elements of CPM

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image11.png" alt="Intra-collaboration process" /></td>
<td>Intra-collaboration process</td>
<td><img src="image12.png" alt="Horizontal and vertical synchronization" /></td>
<td>Horizontal and vertical synchronization</td>
</tr>
<tr>
<td><img src="image13.png" alt="Inter-collaboration process" /></td>
<td>Inter-collaboration process</td>
<td><img src="image14.png" alt="Process transition" /></td>
<td>Process transition</td>
</tr>
<tr>
<td><img src="image15.png" alt="Normal process" /></td>
<td>Normal process</td>
<td><img src="image16.png" alt="Resource" /></td>
<td>Resource</td>
</tr>
<tr>
<td><img src="image17.png" alt="Decision" /></td>
<td>Decision</td>
<td><img src="image18.png" alt="Reference note" /></td>
<td>Reference note</td>
</tr>
</tbody>
</table>
### 5. exCPM (extended CPM)

#### 5-4. Comparison of CPM, c-IDEF*, and exCPM

<table>
<thead>
<tr>
<th>Criteria</th>
<th>CPM (Literature)</th>
<th>c-IDEF* (My past work)</th>
<th>exCPM (This research)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understandability of models</td>
<td>Fairly easy</td>
<td>Easy</td>
<td>Fairly easy</td>
</tr>
<tr>
<td>Formalism</td>
<td>Existing</td>
<td>Not existing</td>
<td>Existing</td>
</tr>
<tr>
<td>Model verification</td>
<td>Possible</td>
<td>Impossible</td>
<td>Possible</td>
</tr>
<tr>
<td>Model simulation</td>
<td>Possible</td>
<td>Impossible</td>
<td>Possible</td>
</tr>
<tr>
<td>Discrimination of actor</td>
<td>Difficult</td>
<td>Easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Discrimination of process type</td>
<td>Easy</td>
<td>Difficult</td>
<td>Easy</td>
</tr>
<tr>
<td>Real-time monitoring</td>
<td>Impossible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Data flow</td>
<td>Impossible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
</tbody>
</table>

**Weakness of exCPM**
- if the model size becomes larger, it becomes more difficult to read and understand due to the complexity
- exCPM still remains as a conceptual method, which has not yet been deployed as computer software

---

### 5. exCPM (extended CPM)

#### 5-5. Illustrative exCPM model of collaborative works

![Diagram of exCPM model](image)

**Diagram Description**

- **p1**: Production planning and scheduling
  - **p2**: Purchase request
  - **p3**: Making parts of a mold
  - **p4**: Making parts of a mold (out-sourcing)
  - **p5**: Manage the purchasing list
  - **p6**: Assemble mold parts
  - **p7**: Trial injection

**Company/department**

<table>
<thead>
<tr>
<th>Company</th>
<th>Color token</th>
<th>Company/department</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company A</td>
<td>1</td>
<td>Marketing/strategy team</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Mold production team</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Mold assembly team</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Quality management team</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Purchasing/procurement team</td>
</tr>
<tr>
<td>Company B</td>
<td>6</td>
<td>Mold outsourcing company</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Mold production team</td>
</tr>
<tr>
<td>Company C</td>
<td>8</td>
<td>Trial injection company</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Trial injection team</td>
</tr>
</tbody>
</table>
5. exCPM (extended CPM)
5-6. Transformation procedure of the exCPM model

Transformation rules

Marked graph building block (MGBB)

5. exCPM (extended CPM)
5-7. Marked graph building block (MGBB)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Marked graph building block</th>
<th>Symbol</th>
<th>Marked graph building block</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normal process</strong></td>
<td><img src="image1" alt="Normal process" /></td>
<td><img src="image2" alt="Split-type" /></td>
<td><img src="image3" alt="Join-type" /></td>
</tr>
<tr>
<td><img src="image4" alt="P0" /></td>
<td><img src="image5" alt="Input for extension" /> <img src="image6" alt="Output for extension" /></td>
<td><img src="image7" alt="Decision" /></td>
<td><img src="image8" alt="Process transition" /> <img src="image9" alt="Resource" /></td>
</tr>
<tr>
<td><img src="image10" alt="P1" /></td>
<td><img src="image11" alt="Input for extension" /> <img src="image12" alt="Output for extension" /></td>
<td><img src="image13" alt="Decision" /> <img src="image14" alt="Process transition" /> <img src="image15" alt="Resource" /></td>
<td></td>
</tr>
<tr>
<td><img src="image16" alt="P2" /></td>
<td><img src="image17" alt="Input for extension" /> <img src="image18" alt="Output for extension" /></td>
<td><img src="image19" alt="Decision" /> <img src="image20" alt="Process transition" /> <img src="image21" alt="Resource" /></td>
<td></td>
</tr>
<tr>
<td><img src="image22" alt="P3" /></td>
<td><img src="image23" alt="Input for extension" /> <img src="image24" alt="Output for extension" /></td>
<td><img src="image25" alt="Decision" /> <img src="image26" alt="Process transition" /> <img src="image27" alt="Resource" /></td>
<td></td>
</tr>
<tr>
<td><strong>Intra-collaboration process</strong></td>
<td><img src="image28" alt="Intra-collaboration process" /></td>
<td><img src="image29" alt="Decision" /> <img src="image30" alt="Process transition" /> <img src="image31" alt="Resource" /></td>
<td></td>
</tr>
<tr>
<td><strong>Inter-collaboration process</strong></td>
<td><img src="image32" alt="Inter-collaboration process" /></td>
<td><img src="image33" alt="Decision" /> <img src="image34" alt="Process transition" /> <img src="image35" alt="Resource" /></td>
<td></td>
</tr>
</tbody>
</table>

Decision (linked from a place)
Process transition (link places to transitions)
Resource (link to transition)
Ending mark (additional) (start) - link to the first transitions

Intra-collaboration process
Inter-collaboration process
5. exCPM (extended CPM)
5-8. Transformation procedure

Rule 1: Remove Inputs/Outputs/Controls from the exCPM model, since they are not defined as MGBB.

Rule 2: Choose a level of detail for marked graph model (Company, Department, Individual).

Rule 3: Replace the exCPM elements with MGBB to generate marked graph models.

Rule 4: Add an "ending mark" between the transition(s) of the MGBB indicating the first process and the place(s) of the MGBB meaning the last process.

5. exCPM (extended CPM)
5-9. Transformation result (company/department level)
5. exCPM (extended CPM)
5-10. Reachability analysis and verification results_1

- Reachability analysis is a powerful formal method for analyzing concurrent/distributed finite state systems
- If given initial markings are expressed in the Petri-Nets, all reachable marking information will be appeared in the tree
- Tokens will be positioned at next place by fire of transition between markings

\[ P = \{p_i | i = 1, \ldots, Z\} \]
- Set of places

\[ T = \{t_k | k = 1, \ldots, K\} \]
- Set of transitions

\[ M = \{m_n | n = 1, \ldots, N\} \]
- Set of markings; the number of tokens at the each place

Reachability Tree

5. exCPM (extended CPM)
5-11. Reachability analysis and verification results_2

Company Level

Reachability Tree
5. exCPM (extended CPM)
5-12. Reachability analysis and verification results

- Through the Reachability Tree analysis, we can obtain the following results:
  - [Boundedness] According to property of Boundedness, Bounded marking is 1-bounded and indicates Safe in Petri-Nets (Safe in this sentence means that a system do not have overflow).
  - [Liveness] In case that all markings have more than one fireable transition in Reachability Tree, we call it as Liveness. And this Petri-Nets model which work without Deadlock or Blocking state means the Live.
  - [Persistence] all markings can reach the initial markings on Reachability Tree, we said that it is reversible, and Persistence/Consistency.
- This result means, the Petri-Nets model, automatically transformed from the exCPM, is developed well, transformation rules work effectively, the initial exCPM model is proved to be well defined as a consequence.

6. Concluding remarks

Proposed the exCPM to capture and verify collaborative processes
- Compare the existing method to obtain the collaborative feature
- Suggest the exCPM which combines the c-IDEF* and CPM
- Suggest to verification methodology of exCPM (using Petri-Nets)
- exCPM is useful to capture and to verify collaboration

- Collaboration process can be expressed more clearly and validated more efficiently
- exCPM is available for all kinds of collaborative processes

- Development of computer software
Thank You!