Abstract—Distributed collaborative software development tends to make artifacts and decisions inconsistent and uncertain. We try to solve this problem by providing an information repository to reflect the state of works precisely, by managing the states of artifacts/products made through collaborative work, and the states of decisions made through communications. In this paper, we propose models and a tool to construct the artifact-related part of the information repository, and explain the way to use the repository to resolve inconsistencies caused by concurrent changes of artifacts. We first show the model and the tool to generate the dependency relationships among UML model elements as content of the information repository. Next, we present the model and the method to generate change support workflows from the information repository. These workflows give us the way to efficiently modify the change-related artifacts for each change request. Finally, we define inconsistency patterns that enable us to be aware of the possibility of inconsistency occurrences. By combining this mechanism with version control systems, we can make changes safely. Our models and tool are useful in the maintenance phase to perform changes safely and efficiently.

I. INTRODUCTION

Collaboration is unavoidable in software development because of the increased scale and complexity of projects. However, collaboration is not an easy task, and bad collaboration contributes to project failure. One common problem in a collaborative work is different understandings of the state of shared artifacts, interface definitions, and agreements made through communications. These recognition gaps are more serious in a distributed environment, where geographical distribution of workers can cause convergence delay. J. D. Herbsleb reported that “distributed work items appear to take about two and one-half times as long to complete as similar items where all the work is collocated” [7]. Therefore, in addition to ordinary software development environments (SDEs), additional support for distributed collaborative work is necessary. In [1], [5], we have presented an approach to deal with the instability of the state of distributed collaborative work, which tends to make artifacts and decisions inconsistent and uncertain. This approach proposed technologies for sharing the instability of the state of the distributed collaborative work, and for incremental reinforcement of consistencies and uncertainties (Fig. 1).

Regarding the uncertainty problem, we have proposed a method for decision management support. In a distributed collaborative environment, email is one of the most popular means of communication among workers. However, in email communications, a discussion topic may involve many emails, and one email may contain many topics. Therefore, it is helpful for the participants in deliberations to grasp the progress and the reasoning of the deliberation for each subject. In [3], we have presented a model and a tool for extracting deliberation threads from email communications. This tool helps to reduce the gap in understanding collaborative work among workers, and leads them to reach a decision.

Regarding the inconsistency problem, this paper presents a Change Support Model (CSM) for distributed collaborative work, in which we propose models and a tool to construct the artifact-related part of the information repository, and we explain the way to use the repository to resolve inconsistencies caused by concurrent changes of artifacts. CSM is a combination of model-based approach, process support approach, and awareness support approach, the main collaboration techniques in software engineering [2]. CSM is useful in the maintenance phase to perform changes safely and efficiently.

The information repository contains UML model elements with dependency relationships. We will show a model and a tool to generate the dependency relationships among the UML model elements. Next, we present a method to generate a Change Support Workflow (CSW) for each change request from the information repository. The CSW gives us a way to modify the related artifacts for each change request efficiently. Change workers will perform change activities for each change request by following the generated CSW.
Concerning the inconsistency detection, previous studies have concentrated on detecting code conflicts by using synchronization function of version control system, or by monitoring the behaviors of developers in different workspaces. However, in these works, conflicts are detected after changes have been finished or are being executed, and the awareness of developers is limited to the program elements being accessed concurrently by others. In CSM, we identify patterns of inconsistency existing among concurrently executing CSWs to detect the possibility of inconsistency occurrences earlier. In addition, by using CSWs, CSM can provide change workers with very comprehensive views of shared artifacts.

The rest of this paper is organized as follows. Section 2 provides an overview of our approach to building the CSM and introduces its framework. We present our method and the tool to generate the dependency relationships among UML model elements in Section 3, and develop the method for generating CSWs from these dependency relationships among artifacts in Section 4. Section 5 handles awareness support regarding inconsistencies. Section 6 reports related work, and finally, Section 7 concludes the paper and discusses future work.

II. APPROACH

A. Overview

Distributed collaborative software development tends to make artifacts and decisions inconsistent and uncertain. Our general approach to this problem is to construct an information repository that can reflect the state of work precisely, by managing the states of artifacts/products made through collaborative work and the states of decisions made through communications, and to develop functions that can detect inconsistencies and uncertainties (Fig. 1). In this paper, we apply this approach to the change environment to deal with the inconsistency problem that occurs when several changes of artifacts are made concurrently.

Changes are inevitable during software development and after delivery. In a distributed collaborative environment, change implementation is difficult because software artifacts with very complex relationships are created based on the collaboration of many workers. Also, lack of awareness of concurrent work of workers contributes to (potential) inconsistencies on artifacts (See Fig. 2). Supporting change workers to work safely and efficiently is the objective of the CSM.

When a change worker makes a change on an artifact, called change root, the artifacts connected to this artifact by dependency relationships may be affected. Dependency is a relationship between two artifacts in which a change to one artifact may affect the other. By repeating the process, we can see that a change initiated from a change root can spread to many artifacts, which in turn can reach the change root by dependency relationships. In the example shown in Fig. 2 from a change request (CR) on artifact 1 (CR1), Worker 1 (W1) may have to implement changes on artifacts 3, 4, 6, and 7. Similarly, from CR2 on artifact 2, Worker 2 (W2) may have to implement changes on artifacts 2, 4, 5, 7, and 8. Because the two workers work independently, they may not have sufficient information about each other’s activities. Therefore, if these change requests are implemented concurrently, inconsistency may happen on shared artifacts 7 and 8. To implement changes efficiently, we will formalize change implementations on related artifacts for each change request in the system by a special workflow, Change Support Workflow (CSW). A CSW is a sequence of activities defined to carry out a change request. Activities in a CSW take care of creating new artifacts or modifying exiting ones. To implement changes safely, a mechanism to handle inconsistency is indispensable in CSM.

1) Dependency Generation: To generate a CSW for a change request, we need to identify the impacted artifacts based on dependency relationships among artifacts.

We classify relationships among software artifacts into two groups (Fig. 3). The first is intra-relationships that are relationships among model elements in the same diagram. The second is inter-relationships that connect related model elements in different diagrams or in different phases together. Based on these classifications, we name dependency relationships in the inter-relationship group “inter-dependency” and dependency relationships in intra-relationship group “intra-dependency”. Examples of intra-dependency relationships are generalization, association (aggregation, composition), and usage dependency (call, instantiation, send, parameter). Examples of inter-dependency relationships are trace, refinement and derivation. In this paper, we will pay attention to automatic generation of inter-dependencies among UML model elements, named Basic Dependency Relationships (BDRs).

- Define BDR types by analyzing dependency relationships defined in UML 1.5.
- Develop a BDR Generation Engine to generate BDRs among UML model elements. This engine operates based on a set of rules for identifying BDRs among UML model elements. It receives UML model elements in UML diagrams and process information (phase names and phase orders), and returns the UML model elements.
with BDRs attached.

2) CSW construction: Based on dependency relationships among software artifacts and change requests. By tracing dependency relationships, we can identify data elements (software artifact impacted by a change request) and the control flow (change order of impacted software artifacts) of a CSW.

3) Inconsistency Awareness: Consider the following points:
   - Establish agreements on using CSWs among workers. Every worker will work based on a CSW.
   - Inform workers about (potential) inconsistencies, and support them in inconsistency resolution by collecting and analyzing information of CSWs in the system.

B. CSM Framework

Fig. 4 describes the conceptual framework of the system with the following main components:

- **Dependency Repository**: is a part of Information Repository. This repository contains UML model elements linked by dependency relationships.
- **CSW Repository**: is a part of Information Repository. It contains information of CSWs executed in local workspaces of workers.
- **Version Control System**: manages changes to software artifacts.
- **Dependency Generator**: generates dependency relationships among software artifacts in Version Control System and stores them in Dependency Repository.
- **CSW Generator**: generates CSWs based on change requests and information in Dependency Repository, and stores them in CSW Repository.
- **Inconsistency Awareness**: notifies workers of the possibility of inconsistency based on collected information of CSWs at clients, and information in Dependency Repository and CSW Repository.

The main processing flow of the system is as follows:
1) Generate dependency relationships by using Dependency Generator component (1.1, 1.2).
2) Generate a CSW for each change request from workers using CSW Generator component (2.1, 2.2, 2.3).
3) Notify the workers of the possibility of inconsistency in the newly generated CSWs and executing CSWs in the system using Inconsistency Awareness component (3.1a or 3.2b, 3.2a and 3.2b, 3.3).

III. Dependency Generation

In this section, we will define types of BDRs by analyzing dependency relationships of UML, and present a method and a tool for automatic generation of BDRs from UML diagrams created during the software development process [23].

A. Basic Dependency Relationship

UML 1.5 has defined ‘dependency’ as a relationship between two elements in which a change to one element, the Target, may affect or supply information needed by the other element, the Source. Dependency has many varieties that represent different kinds of relationships: Abstraction, Binding, Permission, and Usage. In addition to these varieties, we realize that developers also create some implicit relationships among UML model elements: Copy, relationship among copies of an element but in different diagrams, and Inclusion, the whole-part relationship between an element and its internal members or between a diagram and its elements. By analyzing the ‘dependency’ of UML 1.5 and the dependencies generated implicitly by developers, we propose a set of new generable Basic Dependency Relationships (BDRs) between UML model elements: Exist Together, Information Sharing, Copy, and Concept (see Table I).

1) **Exist Together**: The Source does not exist without the Target. Exist Together is defined from Usage and Inclusion relationships. Usage and Inclusion relationships can be generated automatically by comparing the names of UML model elements or analyzing the whole-part relationship. Therefore, we can generate Exist Together relationships automatically if the names of model elements are comparable or the Inclusion relationship can be analyzed.

2) **Information Sharing**: Information of the Target is a part of information of the Source. Information Sharing has been extracted from Binding, Permission, and Usage. Although Binding and Permission cannot be generated automatically, Usage can be generated automatically if the names of UML model elements are comparable. Therefore, when at least one name in the shared information group is comparable, we can generate Information Sharing relationship automatically.

3) **Copy**: Information of the Target and the Source is the same. This relationship is extracted from the Copy relationship generated implicitly by developers. Copy relationship can be generated automatically among UML diagram elements which are in the same phase, and have the same name and type.

4) **Concept**: The Source and the Target represent the same concept but the Source is more concrete. Concept has been extracted from Abstraction. Abstraction can be generated automatically by comparing the names of UML model elements and using the process information. Therefore, we can generate Concept relationship automatically if process information is given and elements representing the same concept are named similarly.

B. Dependency Generation Model

To generate the dependency relationships automatically, we define a Dependency Generation Model (DGM) consisting of
TABLE I
DEPENDENCY ANALYSIS

| UML 1.5 Dependency | BDR Types       | Automatic Generation Method     |
|--------------------|----------------|---------------------------------|
| Abstraction        | Concept        | Process Information             |
|                    |                | + Name Comparison               |
| Binding            | Information Sharing |                  |
| Permission         | Information Sharing |                  |
| Usage              | Exist Together  | Information Sharing            |
| Copy               | Copy           | Name comparison                |
| Inclusion          | Exist Together  | Inclusion of UML description    |

![Diagram of BDR Generation Model]

Fig. 5. Method for generating BDRs automatically

comparison rules, addition rules, and selection rules. Comparison rules look for pairs of UML model elements that may have some BDRs, based on the similarity in names between UML model elements, and inclusion relationships between a diagram and its components. Addition rules identify BDR candidates that may be set to a pair of UML model elements. Regarding the information about phase, diagram, type and name of UML model elements, selection rules will choose one BDR from the BDR candidates found by addition rules to attach to the selected pair. Based on DGM, BDR Generation Engine accepts as input a group of UML diagrams and their process information (phase names and phase orders). Outputs will be these UML diagrams with newly added BDRs (see Fig. 5).

1) **Comparison rules:** Find pairs of UML elements to which BDRs may be attached. A BDR may exist between two UML model elements if they satisfy one of the following conditions:

- **Contained:** The name of the Target is included in the name of the Source, for example “Elevator” and “ElevatorControl”.
- **Similar:** The name of the Target is similar to the name of the Source, for example “FloorLampInterface” and “FloorLampInterfaces”.
- **TypeSim:** The type of the Target is similar to the name of the Source, for example “FloorLampInterface” and “FloorLampInterfaces”.
- **SimType:** The name of the Target is similar to the type of the Source, for example “FloorLampInterface” and “FloorLampInterfaces”.

Table II shows suitable comparison conditions for each type of Target and Source.

2) **Addition rules:** Identify BDRs which can exist between two UML model elements satisfying the comparison rules. We classify UML model elements into new categories which we call Generation Model Elements (See Table III). We also define types of BDR which can be set between two Generation Model Elements (See Fig. 6). Based on these instructions, we can find BDR candidates between any two UML model elements by mapping them to Generation Model Elements.

3) **Selection rules:** Decide on the BDR candidates obtained after applying the addition rules to two UML model elements satisfying the comparison rules. In Table IV we describe how to choose BDR by using information of names, types, diagram

![Diagram of UML Diagrams](image)

![Diagram of Generation Model Elements](image)

**Fig. 6. Addition rules**

**Fig. 6. Addition rules**

**TABLE II**
COMPARISON CONDITIONS

| Target | Source | Comparison Condition |
|--------|--------|----------------------|
| Use case diagram | Actor | Include |
| Use case diagram | Use case | Include |
| Use case | Class diagram | Contained |
| Use case | State chart diagram | Contained |
| Use case | Collaboration diagram | Contained |
| Use case | Sequence diagram | Contained |
| Use case | Use case | Similar |
| Actor | Actor | Similar |
| Actor | Class | Similar |
| Actor | Object | SimType |
| Class diagram | Class | Include |
| Class diagram | Package | Include |
| Package | Class | Include |
| Package | Package | Similar |
| Class | Package | Similar |
| Class | Object | SimType, Contained |
| Class | State chart diagram | Contained |
| Class | Activity diagram | Contained |
| Class | Class | Similar, Include |
| Object diagram | Object | Include |
| Object | Class | SimType |
| Object | State chart diagram | SimType |
| Object | Activity diagram | SimType |
| Object | Object | Similar, Include |
| Component diagram | Component | Include |
| Component | Component | Similar |
| Deployment diagram | Node | Include |
| Node | Node | Similar |
| State chart diagram | State | Include |
| State | State | Similar, Include |
| Activity diagram | Action State | Include |
| Action State | Action State | Similar, Include |
| Collaboration diagram | Object | Include |
| Sequence diagram | Object | Include |

**TABLE III**
GENERATION MODEL ELEMENTS

| Generation Model Element | UML Model Element |
|--------------------------|-------------------|
| Classifier Element       | Actor, Use case, Class, Package, Node, Component, Object (Object diagram) |
| Relationship Element     | Relation, Aggregation, Dependency, Generalization, Link |
| State Element            | State, Action State |
| Transition Element       | Transition, Event, Action |
| Instance Element         | Object (Collaboration diagram, Sequence diagram) |
| Message Element          | Message |
| Relationship Diagram     | Use case diagram, Class diagram |
| Behavior Diagram         | State chart diagram, Activity diagram |
| Interaction Diagram      | Sequence diagram, Collaboration diagram |
TABLE IV
SELECTION RULES

| UML Element’s Type | Phase | Same | Adjoining | Separate |
|--------------------|-------|------|-----------|----------|
| Same               | Copy  | Exist Together | Information Sharing | - | Same Name |
| Different          | Concept | - | - | Same Different |

Fig. 7. Example of BDR generation

and phases of UML elements.

- **Information Sharing**: Two UML elements are in the same phase but in different diagrams, and are of different types.
- **Copy**: Two UML elements are in the same phase but in different diagrams. They have the same name and are the same type.
- **Concept**: Two UML elements are in adjoining phases.
- **Exist Together**: Two UML elements are in the same diagram, and certainly in the same phase.

C. Automatic BDR Generation

BDR generation includes five steps:

1) **Extraction of potential UML elements**: Search pairs of UML model elements satisfying conditions of the comparison rules.
2) **Retrieval of Generation Model Elements**: Find Generation Model Elements corresponding to these UML elements.
3) **BDR Candidate Identification**: List all BDR candidates between pairs of UML elements based on addition rules.
4) **BDR Selection**: Choose a suitable BDR for each pair of UML elements based on selection rules.
5) **BDR Addition**: Add the selected BDRs to the corresponding pairs.

Fig. 7 shows an example of automatic BDRs generation. Assume that we have some UML artifacts including the class “ElevatorControl” and the object “:ElevatorControl” which are in the same phase. Based on the comparison rules, these two UML elements satisfy the SimType condition. Therefore, we perform the second step, mapping these artifacts to Generation Model Elements. Using Table III, Generation Model Elements of the class “ElevatorControl” and the object “:ElevatorControl” are Classifier element and Instance element, respectively. Next, the addition rules are applied. The diagram in Fig. 6 shows that there are two candidates for the BDR between the class “ElevatorControl” and the object “:ElevatorControl”:

Information Sharing and Concept. Because both artifacts are in the same phase, we decide on Information Sharing for the BDR between these artifacts. Finally, information about a BDR, Information Sharing, with the class “ElevatorControl” at the Target and the object “:ElevatorControl” at the Source is added to the system.

D. Impact Analysis Tool

We have developed an impact analysis tool that implements dependency generator component and performs impact analysis process starting from a change root. This tool is developed as a plugin of Eclipse with three-layer framework (See Fig. 8). We have performed two case studies to evaluate our method. The precision of the generated BDRs is from 92.3% to 93.3%, and the recall is from 83.7% to 87.7% [23].

Fig. 9 shows a screen shot of the tool when we find impact elements of a change request by choosing the change root. Different colors mean different dependency chains.

Fig. 8. Framework of the Impact Analysis Tool

IV. CHANGE SUPPORT WORKFLOW GENERATION

In this section, we will present the way to generate CSWs based on dependency relationships among artifacts.

A. CSW Definition

As a workflow, a CSW must contain basic information such as change activities, software artifacts accessed by change activities, and change orders. In addition, to support inconsistency detection, we need to store active intervals of activities in a CSW. Regarding access control, information of the change worker associated with an activity will be recorded. Below is a formal definition of CSW.

**Definition 1**: A Change Support Workflow is a tuple $w = <id, A, D, T, W, GD, GW>$ where:
• \( id \) is the workflow identifier.
• \( A \) is a set of activities.
• \( F \subseteq (A \times A) \) is a set of arcs (flow relation) that represent the orders of change activities.
• \( D \) is a set of software artifacts accessed by activities of CSW.
• \( T = \{ r, w \} \) is a set of tasks on software artifacts \((r: read, w: write). read\) means that this artifact is used to implement a change on another artifact. \( write\) means that this artifact will be changed.
• \( W \) is a set of workers who execute activities of CSW.
• \( GD: A \times T \to 2^D \) is a function that returns a set of artifacts associated with an activity and a task.
• \( GW: A \to 2^D \) is a function that returns the workers associated with an activity of CSW.
• \( GT: A \to ((R^+ \cup \infty) \times (R^+ \cup \infty)) \) is a time interval function that returns the start time and the finish time of an activity. \( R^+ \) is the set of all positive real numbers. \( \infty \) denotes an undecided start time or finish time.

### B. CSW Generation

When a worker makes a change to an artifact, change root, this change may affect artifacts that have BDRs with the change root, and require extra modifications. By following BDRs among artifacts, we can find all potentially impacted elements.

Here is a general algorithm for identifying dependency graph starting from a root artifact. Dependency graph is a directed graph where vertexes are potentially impacted artifacts, and edges are BDRs among the potentially impacted artifacts. An edge \( e = (x; y) \) is considered to be directed from node \( x \) to node \( y \) if there is a BDR with the Target \( y \) and the Source \( x \).

1) The initial set of vertexes is the root artifact itself.
2) For each artifact in the vertex set, if there is a BDR having this artifact as the Target, add the Source element to the set if it is not already in the set, and add an edge directed from the Source to the Target.
3) Repeat Step 2 until all vertexes are examined and no new artifact appears.

The most straightforward way to generate a CSW from a dependency graph is to use the same structure as in the dependency graph. Each artifact is mapped to a new activity, and each BDR between two artifacts becomes an arc connecting two corresponding activities. However this method is just suitable for a very sparse dependency graph whereas a dependency graph is a dense graph in reality (See an example of a dependency graph at the bottom left corner of Fig. 10). Therefore, the structure of a CSW generated by this method is not a good formulation for change support, because several artifacts should be examined together. So we use a grouping technique to identify groups of strongly related artifacts and map each group to an activity in a CSW. A group contains artifacts connected together by Copy or Information Sharing relationships.

- Put artifacts connected by Copy or Information Sharing relationships into a group.

- Find the group containing the root artifact. Assign the root artifact to the write data set of the first activity in the CSW, and the remaining artifacts to the write data set of the second activity of the CSW.
- For the remaining groups, create the same number of new activities so that each new activity will receive each corresponding group as its write data set.
- If there is at least one Concept relationship between two artifacts in two different activities, create an arc from the activity containing the Target to the activity containing the Source.
- If the write data set of an activity contains an artifact, i.e. a diagram, that is the Target element of at least one Exist Together, this activity will be classified as a composite activity. A composite activity can include many CSWs whose root artifacts are the Source elements of these Exist Together relationships.

Based on Definition 1, the generated CSW will include information about elements \( A, F, D, T, \) and \( GD \) of a CSW. Elements related to workers, \( W \) and \( GW \), are decided by designers or project managers. The time interval, \( GT \), will be collected during workflow execution.

Fig. [10] describes an excerpt of a non-distributed Elevator Control System [22] with some important diagrams in the requirement definition phase (D1), analysis phase (D2, D3, D4 and D5) and subsystem design phase (D7 and D8). We assume that there is a change request on Select Destination use case, Artifact 1.1. For simplicity, we just show important diagrams for this change and the orders of change activities.

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### Notes
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three CSWs are also considered as three branches originating from the composite Activity 2.

C. CSW Execution Control

A CSW can be in one of three states: planning, executing, and finished. A CSW is in the planning state when it is generated automatically by the CSW Generator component at build time (CSW Generation Section). When a change worker starts the planning workflow, this workflow will move to the executing state. When the change worker finishes the last activity of the executing workflow, the CSW will be in the finished state, a finished workflow.

When a CSW moves from the planning state to the executing state, some values of the workflow may be modified by workers, such as worker assignment. Also, the start time and finish time of each activity can also be identified.

However, the most important thing that happens at runtime is the spread of dynamic change. Artifacts in these CSWs are not isolated, but are connected with artifacts in the same diagram by intra-dependency relationships. Because of these relationships, when these CSWs are executed, changes on artifacts being modified by activities in these CSWs will spread to the intra-dependency related artifacts. In the example described in Fig. 10, the artifacts which may be affected when CSWs W.2.1, W.2.2, and W.3.3 start executing are marked with thick red borders. Therefore, we need to dynamically generate new CSWs to meet the arising changes by using the same process described in the previous section. We call the original CSWs main CSWs, and the newly arising CSWs sub-CSWs.

To manage CSWs of a change request easily, we classify these CSWs into different grades, starting from 1st grade. 1st Grade CSWs are the main CSWs. CSWs from 2nd grade and higher are sub-CSWs. 2nd Grade CSWs are built based on 1st Grade CSWs. A 2nd Grade CSW is a CSW of which the root artifact has intra-dependencies with artifacts in the 1st Grade CSW, and has not yet appeared in any existing CSWs. After identifying the root artifact, we can find the elements of a new CSW by tracing BDRs starting from this root artifact. In general, n + 1th Grade CSWs will be built based on nth Grade CSWs in the same way (Fig. 11).

To ensure that changes are executed in an exact and effective manner, we schedule CSWs of a change request in a pipeline mode. If two artifacts in two adjoining grade CSWs have an intra-dependency relationship, the activity in the higher grade CSW should be executed after the activity in the lower grade CSW (See Fig. 11p). CSM supports the change workers who execute CSWs of the same change request, by notifying them of common points, and forcing them to follow the execution order constraints, the intra-dependency relationships, between their own CSWs and others.

V. INCONSISTENCY AWARENESS

Most previous works in inconsistency awareness concentrated on code conflict, a kind of inconsistency caused by concurrent changes on shared artifacts. In [6], the authors classified conflicts into two types: direct conflict and indirect conflict. Direct conflicts are caused by concurrent changes to the same artifact. Indirect conflicts are caused by changes in one artifact affecting concurrent changes in another artifact. In general, indirect conflicts are more dangerous because they are detected late. CSM will consider both types of conflicts. We also pay attention to other types of inconsistencies occurring when activities in concurrent CSWs modify artifacts connected by some dependency relationships.

Like most other systems, CSM uses Version Control Systems (VCSs) to manage artifacts, and to support collaboration and parallel work. VCSs can detect direct conflicts by comparing check-in versions. However, VCSs cannot help in the case of indirect conflicts, because changes are implemented on different artifacts. Even if in the case of direct conflicts, VCSs detect them at check-in time when all changes have finished. This is a waste of time and effort. These inconsistencies should be detected as soon as possible. Our method is to detect (potential) inconsistencies at both build time and runtime.

Fig. 12 shows our approach to handling inconsistency using client-server architecture. Change workers use Change Support Clients to interact with their CSWs. A Change Support Server monitors CSWs at clients through Change Support Clients, analyzes collected information, and notifies change workers of (potential) inconsistencies. Change workers will need to negotiate to find resolutions for the inconsistencies.

A. Inconsistency Detection

Potential inconsistencies at build time are detected by checking the existence of shared artifacts among planning workflows, or among a planning workflow and executing workflows. Right after generating a new planning workflow, the system will check potential inconsistencies between the new workflow and other planning workflows or executing workflows. If there are shared artifacts between two planning...
workflows, there is a chance for the related workers to cooperate to reconsider their change requests and CSWs. If shared artifacts are detected between the new workflow and an executing workflow, new workflow should be delayed until the executing workflow has finished. Another candidate method is to use negotiation, as in the previous case.

To detect inconsistencies at runtime, we identify patterns of (potential) inconsistencies among executing workflows. These patterns are special cases of Unintentional Change in In-use Data (UCID) patterns that we have presented in [4], [8]. We assume that a worker will check out the latest versions of all necessary artifacts at the beginning of an activity, and check in modified artifacts at the end of each activity for all activities in his CSW.

The following notations are used in the definitions of inconsistency patterns:

- \( CO_A(d) \): Activity A checks out the latest version of artifact d.
- \( T − CO_A(d) \): Point in time when activity A checks out artifact d.
- \( V − CO_A(d) \): Version of d when it is checked out by activity A.
- \( CI_A(d) \): Activity A checks in artifact d.
- \( T − CI_A(d) \): Point in time when activity A checks in artifact d.
- \( V − CI_A(d) \): Version of d when it is checked in by activity A.
- \([T − CO_A, T − CI_A] \): Active Interval of activity A.

**Pattern 1: WW Direct Conflict** occurs when two activities in different CSWs concurrently modify (write) the same version of an artifact, and create two new conflicting versions.

- A and B have overlapping Active Intervals: \( [T − CO_A(d), T − CI_A(d)] ∩ [T − CO_B(d), T − CI_B(d)] ≠ ∅ \)
- Versions of the shared artifact between A and B at check-out time are the same: \( V − CO_A(d) = V − CO_B(d) \)
- Versions of the shared artifact between A and B at check-in time are different: \( V − CI_A(d) ≠ V − CI_B(d) \)

Based on Fig. 13h, we can detect the possibility of a WW Direct Conflict at the start time of activity B, instead of at the finish time of B, when change worker checks in the shared artifact.

**Pattern 2: Potential Indirect Conflict** occurs when two activities in different CSWs concurrently modify two different artifacts that are connected by dependency relationships (BDRs or intra-dependency relationships).

- A and B have overlapping Active Intervals: \( [T − CO_A(d_2), T − CI_A(d_2)] ∩ [T − CO_B(d_1), T − CI_B(d_1)] ≠ ∅ \)
- \( d_2 \) can be reached from \( d_1 \) by dependency relationships

Based on Fig. 13h, we can detect this risk at the start time of activity B when change workers check out the artifact \( d_1 \) that depends on the artifact \( d_2 \) being modified by the concurrent activity A.

We call this pattern potential indirect conflict because conflict just happens between two artifacts if modification of an artifact is based on the content of the other artifact. This special situation is called **RW Direct Conflict**.

**RW Direct Conflict** occurs when an activity A uses (read) a version of an artifact d to modify (write) another artifact, and an activity B in a different CSW concurrently modifies (writes) the same version of d with A.

**Pattern 3: WWW Potential Indirect Inconsistency** occurs between two artifacts that are connected to the same artifact by dependency relationships (BDRs or intra-dependency relationships) and are modified (written) by two activities in the same CSW, because an activity in a different CSW (wrote) to this shared artifact sometimes during the interval between these two activities.

Fig. 13d describes a WWW Potential Indirect Inconsistency between three activities A, B, and P in which A and B are in the same CSW, and P is in a different CSW:

- P happens sometimes during the interval between A and B: \( [T − CO_P(d_2), T − CI_P(d_3)] ⊂ [T − CI_A(d_2), T −
$CO_B(d_7)$

- $d_2$ can be reached from $d_6$ and $d_7$ by dependency relationships

Based on Fig. 13, we can detect this potential inconsistency at the start time of activity B or activity P.

We name this pattern potential indirect inconsistency because inconsistency just happens between two artifacts in the same workflow if modifications of both artifacts are based on the content of the same artifact. This special situation is also called RWR Direct Inconsistency.

**RWR Direct Inconsistency** occurs when two activities in the same CSW use (read) different versions of an artifact to modify (write) other artifacts, which are different from the initial plan of their CSW, because an activity in a different CSW (wrote) to this shared artifact sometimes during the interval between these two activities.

Fig. 13 describes a RWR Direct Inconsistency between three activities A, B, and P in which A and B are in the same CSW, and P is in a different CSW. A and B will modify (write) $d_1$ and $d_2$, respectively based on d.

- P happens sometimes during the interval between A and B: $[T - CO_P(d), T - CI_P(d)] \subseteq [T - CI_A(d_1), T - CO_B(d_1)]$
- Version of the shared artifact at check-in time of A is the input of P: $V - CI_A(d_1) = V - CO_P(d)$
- Version of the shared artifact at check-in time of P is the input of B: $V - CI_P(d) = V - CO_B(d)$

**Pattern 4: W2W Potential Indirect Inconsistency** occurs when two activities in the same CSW modify (write) two artifacts, of which the artifact modified by the later activity is connected to the previous artifact by dependency relationships (BDRs or intra-dependency relationships), and another activity, in a different CSW (wrote) to the previous artifact sometimes during the interval between these two activities.

Fig. 13 describes a W2W Potential Indirect Inconsistency between three activities A, B, and P in which A and B are in the same CSW, and P is in a different CSW.

- P happens sometimes during the interval between A and B: $[T - CO_P(d_2), T - CI_P(d_2)] \subseteq [T - CI_A(d_2), T - CO_B(d_2)]$
- $d_2$ can be reached from $d_7$ by dependency relationships

Based on Fig. 13, we can detect this type of potential inconsistency at the start time of activity B or activity P.

We name this pattern potential indirect inconsistency because inconsistency just happens between two artifacts in the same workflow if modifications of both artifacts are based on the content of the same artifact. This special situation is also called WWR Direct Inconsistency.

**WWR Direct Inconsistency** occurs when an activity of a CSW uses (reads) a different version of an artifact, instead of the version created by another activity in the same CSW, to modify (write) another artifact, because an activity in a different CSW (wrote) to this shared artifact sometimes during the interval between these two activities.

Fig. 13 describes a WWR Direct Inconsistency between three activities A, B, and P in which A and B are in the same CSW, and P is in a different CSW. We will replace these inconsistency-related CSWs with the new CSWs that implement the new change request. This method can apply to potential inconsistencies between planning workflows.

**Inconsistency Resolution**

Resolving (potential) inconsistencies among CSWs is not simple because different workers design different CSWs for different change requests, and a designer may know nothing about the work of others. Therefore, the cooperation of change workers is the most important factor. When receiving a warning of inconsistencies or potential inconsistencies from CSM, the related workers will contact with each other to conduct a negotiation. Face to face discussion, email, phone, instant messenger, etc. can be their communication means. Below are some methods for fixing inconsistencies which change workers can consider in their negotiation:

- Use a fine-grain work approach. CSWs can still work concurrently if they modify different parts of inconsistency-related artifacts.
- Create a new change request that is a combination of change requests implemented by inconsistency-related CSWs. We will replace these inconsistency-related CSWs with the new CSWs that implement the new change request. This method can apply to potential inconsistencies between planning workflows.
- Merge inconsistency-related parts of CSWs to create a new workflow.

**VI. RELATED WORK**

In the change support field, much previous work focused on change impact analysis on source code [21]. By generating and managing CSWs, our CSM aims to support not only impact analysis, but also change planning and change execution.

Regarding collaborative inconsistency, most previous studies are about code conflicts caused by concurrent changes of different developers. Traditional approach uses a version control system such as CVS [13] or Subversion [14] in conjunction with the programming environment to address the problem of concurrent accesses. An issue with this approach is that conflicts are detected at check-in time after a user has finished his changes. To be able to catch conflicts while developers are implementing their tasks, workspace awareness techniques were proposed. Tools such as IBM’s Jazz.net platform [10] or Microsoft’s CollabVS system [11] augment the awareness of developers and propagate changes at file/class level immediately after they happen. Also, some researchers have investigated how to exploit the information produced by integrated development environments during development such as Mylyn [15], Sypware [16], and Syde [12]. Palantir [6] is the first awareness tool that tries to detect indirect
conflicts in addition to direct conflicts. A new approach to detect potential indirect conflicts was presented in CASI [17].

However, none of the previous works mentions conflicts among UML model elements. AMOR [18], SMoVer [19], and COMOVER [20] are model versioning systems that consider conflicts among model elements. Nevertheless, like other VCSs, conflicts in these systems are just detected at check-in time. Also, conflict caused by concurrent changes is just one source of inconsistency.

ADAMS [25] is an example of a different approach to support distributed collaborative work. It is a web-based system that integrates project management features and artifact management features.

VII. CONCLUSION

In this paper, we have presented a Change Support Model for distributed collaborative work. To help change workers implement change activity safety and efficiently, CSM generates Change Support Workflows based on dependency relationships among software artifacts. Towards CSW generation, we have proposed a model and a tool for automatic generation of Basic Dependency Relationships among UML model elements. In addition, CSM also considers inconsistency caused by concurrent CSWs that work on shared artifacts or dependent artifacts. To detect inconsistencies as soon as possible, our method detects potential inconsistencies at both build time and runtime. We have also identified inconsistency patterns to help detect inconsistencies at runtime more effectively. CSM will help collect and analyze information of local CSWs to notify change workers about risky points. Some inconsistency resolutions have been proposed too.

In future work, we will improve our method of inconsistency handling, especially inconsistency analysis and resolution. Next, we will work on generating dependency relationships connecting UML model elements to source code. Finally, we will develop a tool that implements CSW generation and inconsistency awareness support.

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