Thirteenth Int. Conf. on IFSs, Sofia, 9-10 May 2009
NIFS Vol. 15 (2009) 2, 10-17

Fault Tree Analysis in an Intuitionistic Fuzzy Configuration Management Database

Boyan Kolev[1], Ivaylo Ivanov[2]

[1] – CLBME – Bulgarian Academy of Sciences, Bl. 105, Sofia-1113, Bulgaria
E-mail: bik@clbme.bas.bg

[2] – SoftConsultGroup Ltd – Dedeagach Str, Bl. 60A, c-x Strelbishte, Sofia-1408, Bulgaria
E-mail: ivaylo.ivanov@softconsultgroup.com

1. Introduction

Information Technology Infrastructure Library (ITIL®) is the de facto standard in Service Management. ITIL is a process oriented; quality focused; public domain; best practices framework. It was developed in late 1980's as a guide to the UK government and since then, the framework is used worldwide. ITIL principles are the basis for BS15000 and the currently developed ISO 20000.

Configuration management is an integral part of all other ITIL processes. According to [1] configuration management aims to assist with managing the economic value of the IT services by maintaining a logical model of the IT infrastructure and IT services, and providing information about them to other business processes. Configuration Management implements this by identifying, monitoring, controlling and providing information about Configuration Items and their versions.

In the terminology of Configuration Management, IT components and the services provided with them are known as Configuration Items (CIs). Each IT component is considered a CI.

As shown in Fig1, CIs can include hardware, software, active and passive network components, servers, documentation, services and all other IT components.

The scope of Configuration Management can be extended to include Information Systems rather than only Information Technology and in this case IT users, IT staff and business units can be considered CIs as well.

All CIs are included in the Configuration Management Database (CMDB). The CMDB keeps track of all IT components and the relationships between them. In its most basic form, a CMDB could consist of paper forms or a set of spreadsheets.

The relationships between CIs are useful for diagnosing errors and predicting the availability of services. Many different logical and physical relationships can be recorded.

Physical relationships:

- Forms part of: this is the parent/child relationship of the CI, e.g. a floppy disk drive forms part of a PC, and a software module forms part of a program.
- Is connected to: e.g. a PC connected to a LAN segment.
- Is needed for: e.g. hardware needed to run an application.

Logical relationships:

- Is a copy of: copy of a standard model, baseline or program.
- Relates to: a procedure, manuals and documentation, a SLA, or customer area.
- Is used by: e.g. a CI needed for providing a service, or a software module which is called by a number of programs.

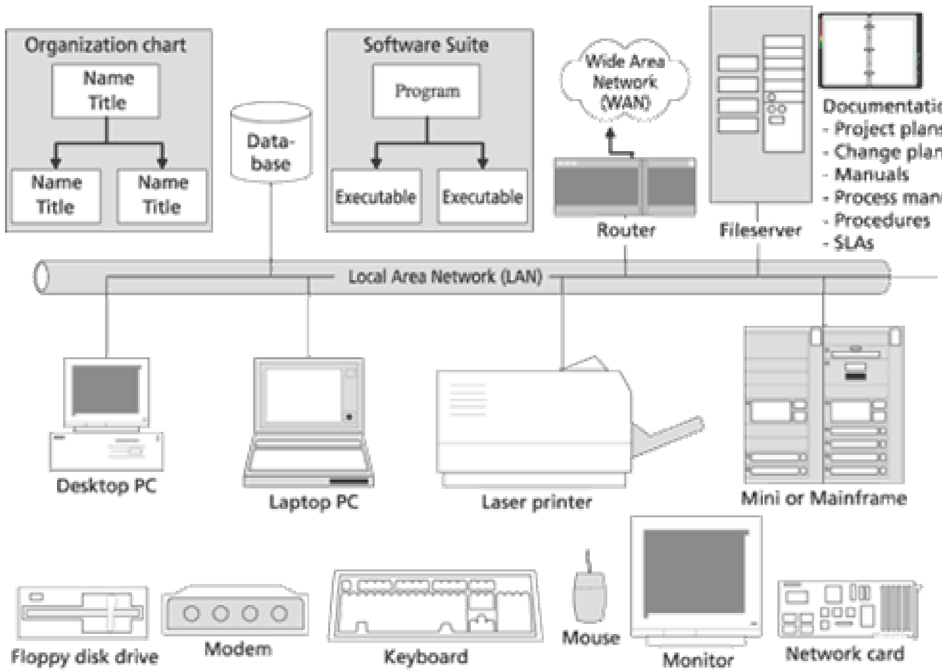

Fig. 1. Configuration Items

There can be many other types of relationships that help in different ITIL processes and activities. In this paper we focus on two of the most important ones: impact analysis and troubleshooting.

In our previous work [4] we introduced a new type of relationship between the CIs that describes the impact that one CI has on another. The meaning of the relationship is "In case of CI_1 failure what is the probability of CI_2 failure". Considering this, we introduced the notion of partial impact between components, expressed by means of intuitionistic fuzzy values carrying probabilistic information.

This new type of relationship should be stored in the CMDB and that is why we propose a new Intuitionistic Fuzzy CMDB (IFCMDB) model. It extends the usual CMDB model by adding intuitionistic fuzzy relationships between the CIs. This model allows us to approach impact analysis and troubleshooting in a different way.

In this paper we will present a methodology for discovering the root cause of a failure, i.e. "If a particular CI fails, what could be the root cause". The result will be a possibilistic distribution of all CIs which have direct or indirect impact over the failed CI, represented as an intuitionistic fuzzy set.

The theory of intuitionistic fuzzy sets (IFS) is proposed by K. Atanassov in [3] as an extension of the classical fuzzy sets theory. Each element of an intuitionistic fuzzy set has degrees of membership (μ) and non-membership (ν), which don't sum up to 1 thus leaving a degree of indefiniteness ($\pi = 1 - \mu - \nu$). A classical fuzzy set is a particular case of an IFS, where $\pi = 0$.

$$0 \le \mu \le 1;$$
$$0 \le \nu \le 1;$$
$$0 \le \mu + \nu \le 1.$$

Let *a* and *b* be intuitionistic fuzzy logical statements with estimations respectively $<\mu_a, \nu_a>$ and $<\mu_b, \nu_b>$, where μ_a is the degree of truth and ν_a is the degree of falsity of statement *a*. The logical operations conjunction (&), disjunction (∨) and negation (¬) are defined in two variants (classical and probabilistic) as follows:

Operation	*classical*	*probabilistic*
a & b	$< \min(\mu_a, \mu_b), \max(\nu_a, \nu_b) >$	$< \mu_a.\mu_b, \nu_a + \nu_b - \nu_a.\nu_b >$
a ∨ b	$< \max(\mu_a, \mu_b), \min(\nu_a, \nu_b) >$	$< \mu_a + \mu_b - \mu_a.\mu_b, \nu_a.\nu_b >$
¬ a	$< \nu_a, \mu_a >$	

2. The Intuitionistic Fuzzy Configuration Management Database Model

The information in an IFCMDB is organized in the form of an intuitionistic fuzzy oriented graph, where vertexes correspond to configuration items (components of the service infrastructure), while the presence of an intuitionistic fuzzy arc expresses the impact between two components along with its degree of certainty.

2.1.Definition of IFCMDB

IFCMDB = (C, D),

where C is a set of configuration items (components) and D is the intuitionistic fuzzy set of relationships between components:

$D = \{<a, b, \mu_D(a, b), \nu_D(a, b)> / a \in C, b \in C\},$

where the functions $\mu_D: C \times C \to [0, 1]$ and $\nu_D: C \times C \to [0, 1]$ define the probabilistic degrees of truth and falsity of the existence of a dependency between the components *a* and *b*.

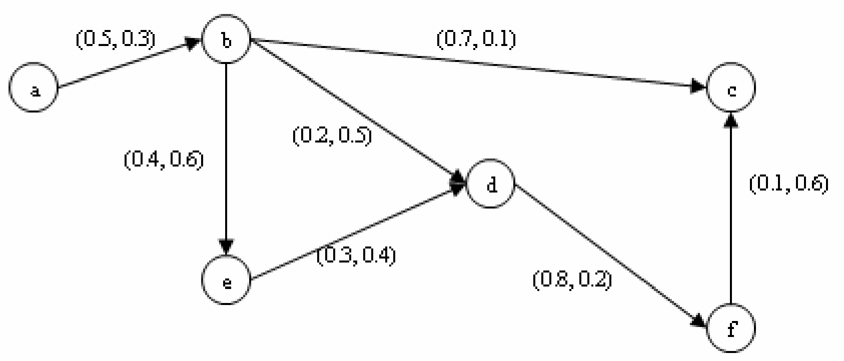

Fig.2. Example of IFCMDB graph

2.2. Direct Impact

The IFCMDB graph represents the direct impact relations (dependencies) between components as arcs. For the example on *Fig.2* if component *a* crashes and we define the direct impact of item *a* to item *b* as intuitionistic fuzzy probability that component b is still usable.

Determining the intuitionistic fuzzy probabilistic direct impact between CIs is out of the scope of this paper. It can be determined using statistical information, expert knowledge or some other means.

We assume that direct impact relationships between CIs are predefined.

2.3. Indirect Impact

Indirect impact is calculated instead of entered/maintained by the operator. The indirect impact between CIs has to be calculated considering the probabilities for direct impact. For the example on *Fig.2* if component *a* crashes and we need to know the probability that component *c* is still usable or not, we have to calculate the impact of *a* to *c*. We will propose a method for calculating indirect impact, using the intuitionistic fuzzy logical operations *conjunction* and *disjunction*:

Let *ddep(x, y)* denotes the direct impact (dependency) of component *y* from component *x*:

$$V(ddep(x, y)) = \begin{cases} \langle \mu_D(x, y), \nu_D(x, y) \rangle, & \text{if } \langle x, y \rangle \in D \\ \langle 0, 1 \rangle, & \text{if } \langle x, y \rangle \notin D \end{cases}$$

Let *idep(x, y)* denotes the indirect impact of component *y* from component *x*:

$$V(idep(x, y)) = \begin{cases} \bigvee_{(i,y)\in D} idep(x,i) \,\&\, ddep(i,y), & \text{if } x \neq y \\ \langle 1, 0 \rangle, & \text{if } x = y \end{cases}$$

2.4. Optimistic or pessimistic impact analysis

Different types of impact analysis involve the usage of classical or probabilistic variants of the logical operations *conjunction* and *disjunction* in calculation of indirect impacts. Depending on which combination of operations will be used, the indirect impacts may be greater or smaller. Three basic types of impact analysis are introduced: worst case (pessimistic), best case (optimistic) and moderate impact analyses.

2.4.1. Semantics of dependencies and relationships between components

The intuitionistic fuzzy dependencies between components may have different kinds of semantics depending on the type of information they represent.

- A probabilistic dependency between *b* and *d* means "the probability that *d* is out of order in case *b* is out of order";

- An ordinary fuzzy dependency between *b* and *d* means that "if *b* is out of order, then *d* is partially out of order".

The relationships between components may also have different kinds of semantics for components, which depend on multiple other components. In our example, the two incoming arcs for node *d* may mean different things:

- "*d* depends on the proper working of both *b* and *e*".
- "*d* is properly working if either *b* or *e* is properly working". This case is not yet investigated, anyway an operation different from *disjunction* must be used for the calculation of indirect impact for components with multiple incoming arcs.

2.4.2. <u>Worst case impact analysis</u>

The worst case impact analysis involves the usage of classical conjunction and probabilistic disjunction in calculation of indirect impacts. Thus a greater value for the degree of truth of indirect impacts is achieved:

$$V(p \,\&\, q) = \langle \min(\mu(p), \mu(q)), \max(\nu(p), \nu(q)) \rangle$$
$$V(a \vee b) = \langle \mu(a) + \mu(b) - \mu(a).\mu(b), \nu(a).\nu(b) \rangle$$

where *V* is the evaluating function of an intuitionistic fuzzy statement.

2.4.3. <u>Best case impact analysis</u>

The best case impact analysis involves the usage of probabilistic conjunction and classical disjunction in calculation of indirect impacts. Thus a smaller value for the degree of truth of indirect impacts is achieved:

$$V(p \,\&\, q) = \langle \mu(p).\mu(q), \nu(p) + \nu(q) - \nu(p).\nu(q) \rangle$$
$$V(a \vee b) = \langle \max(\mu(a), \mu(b)), \min(\nu(a), \nu(b)) \rangle$$

where *V* is the evaluating function of an intuitionistic fuzzy statement.

2.4.4. <u>Moderate impact analysis</u>

The moderate impact analysis involves the usage of either probabilistic or classical logical operations in calculation of indirect impacts.

- Probabilistic operations are more applicable for IFCMDBs with probabilistic kind of component dependencies:

$$V(p \,\&\, q) = \langle \mu(p).\mu(q), \nu(p) + \nu(q) - \nu(p).\nu(q) \rangle$$
$$V(a \vee b) = \langle \mu(a) + \mu(b) - \mu(a).\mu(b), \nu(a).\nu(b) \rangle$$

- Classical intuitionistic fuzzy operations are more applicable for IFCMDBs with ordinary fuzzy kind of component dependencies:

$$V(p \,\&\, q) = \langle \min(\mu(p), \mu(q)), \max(\nu(p), \nu(q)) \rangle$$
$$V(a \vee b) = \langle \max(\mu(a), \mu(b)), \min(\nu(a), \nu(b)) \rangle$$

2.5. Example for impact analysis

For the example on *Fig. 2*, if *a* crashes and we need to determine the probabilities for any of the other components to be out of order, we have to calculate the indirect impact of other components from *a* using the probabilistic moderate impact analysis:

$$V(idep(a,b)) = V(idep(a,a) \,\&\, ddep(a,b)) = \langle 0.5, 0.3 \rangle$$
$$V(idep(a,e)) = V(idep(a,b) \,\&\, ddep(b,e)) = \langle 0.2, 0.72 \rangle$$

$$V(idep(a,d)) = V(idep(a,b)\ \&\ ddep(b,d) \vee idep(a,e)\ \&\ ddep(e,d)) = < 0.154, 0.5408 >$$
$$V(idep(a,f)) = V(idep(a,d)\ \&\ ddep(d,f)) = < 0.1232, 0.63264 >$$
$$V(idep(a,c)) = V(idep(a,b)\ \&\ ddep(b,c) \vee idep(a,f)\ \&\ ddep(f,c)) = < 0.358008, 0.31563072 >$$

3. Fault Tree Analysis and Reverse Impact Calculation

The purpose of a fault tree analysis is to determine the root cause of a failure, considering the fact that a particular item is out of order. The analysis procedure takes into account direct and indirect impacts of other components over the failed CI. The result of the analysis is an intuitionistic fuzzy distribution of CIs giving an ordered set of possible root causes.

Assuming that the CI y has failed, the intuitionistic fuzzy set, representing the root cause possibilistic distribution, is defined as follows:

$$R(y) = \{ < x, \mu_R(x, y), \nu_R(x, y) > \mid x \in CI \} ,$$

where:

$$\mu_R(x, y) = \mu(idep(x, y)),$$
$$\nu_R(x, y) = \nu(idep(x, y))$$

and *CI* is the set of all configuration items.

3.1. Calculation of indirect impact following the reverse dependency direction

The methodology for calculating indirect impact, introduced in 2.3, follows the forward dependency direction. Following it we can answer the question "Which are the indirect dependants of a particular CI *x*?", starting from the node *x* in the dependency graph (the IFCMDB) and traversing through its direct or indirect dependants. For clarity purposes we will refer to this methodology as *Forward Impact Calculation (FIC)*. However, the root cause analysis requires the reverse task to be solved, i.e. "Which CIs does the item *y* depend on?". There are two ways to have this question answered:

- to store the result from FIC in a relation in the database or
- to calculate the dependencies of *y* from other CIs starting from *y* and following the reverse dependency direction.

The first strategy requires maintaining an indirect impact relation in the database and keeping it consistent with the IFCMDB, i.e. recalculating the indirect dependencies on each modification in the IFCMDB graph. However, in a relatively large and dynamic database this would affect the performance of configuration management.

The second one implies the definition of methodology for calculating indirect impacts starting from the dependant and traversing through its input arcs in the reverse direction. We will refer to this method as *Reverse Impact Calculation (RIC)*. RIC uses the following formula to calculate indirect impact:

$$V(idep(x, y)) = \begin{cases} \bigvee_{(x,j)\in D} ddep(x, j)\ \&\ idep(j, y), & \text{if } x \neq y \\ < 1, 0 >, & \text{if } x = y \end{cases}$$

4. Comparison between indirect impact calculation methods

The indirect impact of *x* over *y* can be calculating using either FIC or RIC method. The choice of calculation method usually depends on the task to be solved – impact analysis or root cause analysis. However, in the general case, FIC and RIC indirect dependencies may differ. An example of such case is the calculation of *idep(b, f)* from the graph depicted in *Fig.2*:

- following FIC method:

$$idep(b, f) = (ddep(b, d) \vee (ddep(b, e) \& ddep(e, d))) \& ddep(d, f)$$

- following RIC method:

$$idep(b, f) = (ddep(d, f) \& ddep(e, d) \& ddep(b, e)) \vee (ddep(b, d) \& ddep(d, f))$$

One can easily see that the two indirect dependencies are equal only if the conjunction is distributive over the disjunction. However, the probabilistic types of logical operations don't have distributive property, so if the impact analysis fixes on probabilistic operations, different FIC and RIC indirect impacts may be obtained.

5. Conclusion

Implementing an IFCMDB helps ITIL based Service Management produce better Impact analysis. This area of techniques answer the questions: "If/when a CI fails what is the impact on the other CIs" and "If/when a CI fails what is the root cause for that failure?".

Depending on the coverage of the Configuration Management process the CIs can be hardware or software components, services exposed to the users/customers and even the business units of the company.

Several ITIL processes can use IFCMDB and the methods proposed. IT Service Continuity and Availability Management when performing risk analysis and component failure impact analysis. Change management needs to perform impact assessment in order to approve or reject a change.

IFCMDB – based methods have two basic advantages compared to other impact analysis methods used in ITIL (e.g. Component Failure Impact Analysis):

1. The IF component gives a model that is closer to reality
2. The Configuration Manager needs to define only "direct impact" relations and all the "indirect impact" relations are calculated.

These advantages significantly reduce the effort needed to perform impact analysis and produce results that are closer to reality.

6. Further work

More accurate root cause analysis can be made if more than one failure is considered, i.e. if several items show symptoms of failure and most probably there is a common root cause for all failures, this can be analysed by combining the root cause possibilistic distributions considering all of the symptomatic items. We will further investigate a methodology for combining root cause distributions in order to better analyse cases of more complex failures.

The impact analysis model can also be extended by involving a reliability measure of root items, i.e. considering the fact that a particular item is less probable to cause a failure than another. This will affect the root cause possibilistic distribution.

As subject to further work we will also investigate FIC and RIC methods in more details to analyse the conditions, under which the FIC and RIC indirect dependencies will or will not differ.

REFERENCES

[1] Office of Government Commerce (OGC), *Service Support Book*, The Stationery Office Publishing House, 2005

[2] Office of Government Commerce (OGC), *Service Delivery Book*, The Stationery Office Publishing House, 2005

[3] Atanassov K. *Intuitionistic Fuzzy Sets*, Springer-Verlag, Heidelberg, 1999

[4] Ivanov I., B. Kolev, *Intuitionistic Fuzzy Extensions to the Information Technology Infrastructure Library Configuration Management Database*, 2007, 6 pp.