Argumentative Support for Structured HACCP Plans

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***Abstract*—This research presents an argumentation based decision support system for implementing the Hazard Analysis at Critical Control Points (HACCP) standard in food industry. Our analysis starts by identifying the adequate technical instrumentation needed for supporting different aspects of the HAACP system. An integrated architectural solution is presented. The framework is built around concept maps and it exploits the integration of ontologies with argumentation theory by using the Argument Interchange Format ontology.**

***Index Terms*—decision support systems, food industry, description logic, argumentation, supply chains**

I. Motivation

Consumers nowadays manifest a lot of interest sorrounding the quality of food. At the same time, they spend a lot of energy to be informed with respect to the food they consume. However, we are facing food and food ingredients which come from different sources, which decrease the transparency of food supply chains. Food regulations, such as HACCP, Good Manufacturing Practice (GMP), or Good Hygiene Practice (GHP), aim to guarantee a certain level of quality [2].

From the current practice, even a large food company might face significant difficulties when developing an HACCP system [8]. Small and medium-sized enterprises have more hardships to implement regulatory norms. Among the identified factors are i) the focus on immediate profit rather than potential benefits from long term strategies and ii) time needed to identify and implement regulations for its specific activity domain [6].

From the technical perspective, artificial intelligence has now the chance to enter and help industry at a large-scale level. The agents from supply chains, in which technologies for improving efficiency have been deployed, prefer simple, mechanisms with understandable results, while they incline to reject complicated frameworks [10]. The current trend of researchers toward extending explanation capabilities and cognitive support is a natural and positive reaction to meet the current industry needs. The "artificial" component is about to be hidden by more and more cognitive-based emerging approaches in artificial intelligence.

The paper is organised as follows: In the next section the main steps of the HACCP plans are briefly presented. Section III introduces the technical instrumentation used in our framework, which is comprised by the AIF ontology and argumentation schemes. Section IV analyses the requirments of the HAACP system and matches them against the available technologies, whilst section V illustrates these concepts in a running scenario. Section VI browses related work and finally, conclusions are drawn.

II. HACCP Principles

ISO 22000 is a recent standard designed to guarantee safe food supply chains. Its main component is the HACCP system, which aims to identify all the possible safety hazards at which the consumer might be exposed, and also to provide clear justifications for the decisions taken to control these hazards. HACCP is based on the following principles [9]:

Hazard analysis. The business entities within the supply chain identify the food safety hazards and determine the preventive measures for controlling them.

Identify critical control points. A critical control point (CCP) is a point step in a food process at which a specific action can be applied in order to prevent or reduce a safety hazard to an acceptable level.

Establish critical limits. A critical limit is a criterion which separates acceptability from unacceptability. Criteria often used include measurements of time, temperature, moisture level, pH, Aw, available chlorine, and sensory parameters such as visual appearance and texture. Critical limits must be specified for each CCP.

Establish a system to monitor control of the CCP. Monitoring is the scheduled measurements for each critical limit. The monitoring plan must be able to detect loss of control at the CCP.

Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control. In order to handle deviations from the norma processing flow, corrective actions should be attached to each CCP in the HACCP system.

Establish procedures for verification to confirm that the HACCP system is working effectively. Internal auditing methods and verification procedures such as random sampling, can be used to determine if the HACCP system is working correctly.

Establish documentation concerning all procedures and records appropriate to these principles and their application. Record examples includes CCP monitoring activities and deviations, plus associated corrective actions.

The main goal of the standard is to build confidence between suppliers and their customers. It requires that business entities follow well-documented procedures, in which the quality of the items should be demonstrated by different types of justifications, and not only by attaching a quality label to the product.

Digital Object Identifier 10.4316/AECE.2010.02020

III. Enacting AIF Ontology As Concept Maps

Argument Interchange Format (AIF) Ontology. At the moment, the current standard of interchanging arguments between software agents is given by the AIF ontology [13].

Definition 1. The extended-AIF ontology has three disjoint sets of nodes:

- *An information node I-node∈N_I represents passive information of an argument such as: claim, premise, data, locution, etc.*

– A scheme node S−node∈N_S captures active information or domain independent patterns of reasoning. The schemes are split in three disjoint sets, whose elements are: rule of inference schemes (RA−node), conflict application node (CA − node), preference application node (PA − node).

– Forms of arguments F−node∈ N_F model argumentation schemes,by defining premises and conclusion descriptors, presumptions, and exceptions.

RA−nodes are used to represent logical rules of inference such as modus ponens, defeasible modus ponens, modus tollens. Specific pragmatic inference schemes such as: entailment, implicature, presupposition, deixis can be encapsulated within these nodes. Because of the separation of the argument structure, modeled with *I-nodes* and *Scheme-nodes*, from contexts, more power to re-use arguments, and flexibility in representation and acceptance is provided. *CA − nodes* represent declarative specifications of possible conflicts (such as *negation*). *PA−nodes* allow to declaratively specify preferences among evaluated nodes (such as *legis posterior*, *legis superior*, or *legis specialis*). Allowing the application of *CA−nodes* or *PA−nodes* over *RA−nodes* results in a very expressive formalism to model different types of arguments (meta-argumentation for instance). *F − nodes* focuses on the form aspect of arguments by allowing introduction of Argumentation Schemes (ASs) in the AIF ontology. The next section addresses ASs related issues.

Argumentation Schemes. From the practical viewpoint of enacting argumentation based applications, there is a gap between logic-based agents and human reasoning. The model of argumentation schemes aims to fill this gap by providing schemes capturing stereotypical patterns of human reasoning.

One example is the pattern *Argument from expert opinion* [14], depicted in figure 1. Formally, an argumentation scheme is composed of a set of premises A_i , a conclusion *C*, and a set of critical questions CQ_i , aimed to defeat the derivation of the consequent. One desiderata of the argumentation schemes is to simplify the argumentation process. This is done by hiding secondary premises and encapsulating them as critical questions. Based on the main premises A_1 and A_2, the consequent is defeasibly inferred. During the process of gradually revealing information when an hazard is analysed, when a counterargument arises, the conclusion might be defeated. Each argumentation line sustaining a claim provides the correspondent critical questions that the other members of the HACCP team use to challenge the pleading. When a critical question is conveyed, the conclusion of the argumentation scheme to which the respective *CQ* belongs is suspended, until the subject of the dispute is clarified.

Argument from expert opinion + AS EO

A_1 : *E asserts that A is known to be true.*
A_2 : *E is an expert in domain D.*
C : *A may (plausibly) be taken to be true.*

CQ_1 : *Is A within D*?
CQ_2 : *Is E a genuine expert in D*?
CQ_3 : *Is A relevant to domain D*?
CQ_4 : *Is A consistent with what other experts in D say*?
CQ_5 : *Has the expert E a good reputation*?

Figure 1. Critical questions block the derivation of the conclusion.

IV. MAPPING HACCP REQUIRMENTS TO THE AVAILABLE TECHNOLOGIES

The following analysis aims to identify the adequate technologies for each component of an HAACP system. The framework is built around concept maps and it exploits the integration of ontologies with argumentation theory.

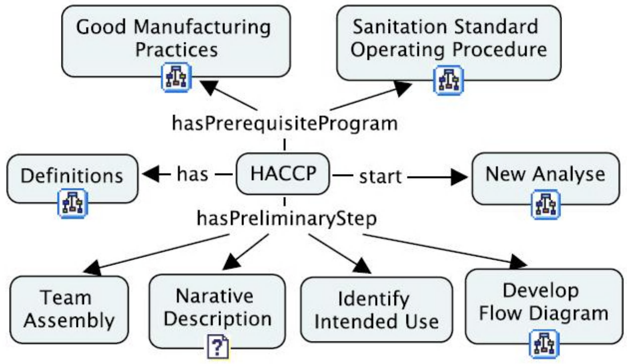

Figure 2. Starting a HACCP analyse.

Concept maps. Concept maps are provided[1] as templates for conducted structural HACCP analysis, such as:

Prerequisite programs: are needed before starting a new HACCP analysis. They are divided into two categories: i) operational conditions such as Good Manufacturing Practice and Sanitation Standard Operating Procedure, and ii) preliminary steps such as: team assembly, narrative description, or develop flow diagram. The top view of the supporting systems has links towards terms definitions or to the templates needed to conduct a new hazard analysis (figure 2).

Brainstorming session: One difficulty comes from the fact that the hazard assessment follows the classical methodology based on a simple analysis of risks, rather than the approach based on a brainstorming session, as recommended by the NACMF [4]. A shared cognitive map is provided, so that the experts from the HACCP team can remotely introduce opinions in the soup of hazard-related concepts. The difficulty to gather experts from different fields (food, hygiene, technical devices), in the same time is ameliorated.

Monitoring activities: The agents involved in the monitoring process have different roles (supervisor, quality supervisor, cooker) and associated tasks, which can be easily modelled and presented as concept maps.

[1] Concept maps are used to provide intuitive visualizations of the justifications required by the HACCP process. CMap tool is used (http://cmap.ihmc.us/).

Ontological knowledge. When implementing the HACCP plan, the human experts need ontological knowledge during the following steps:

Hazard identification: The user can query hazards ontologies and their possible connections with ingredients and processing steps. Also, food and pathogens ontologies may be used to compare different risks which may stem from production system.

Automatic verification of the safety conditions: Having formal descriptions about what a safety device, process, or service represent (encapsulated as TBoxes) and by having the current situation (encapsulated as ABoxes) the system can automatically point out possible contradictions with the norms in use.

Interdisciplinary knowledge: The HACCP involves resoning within different domains: *medical* (health status, possible illness, possible causes, possible symptoms, alergies); *legal* (the current regulations, the responsabilities, safety norms, legal consequences); *food* (specific knowledge about the subject of activity for each business entity); *engineering (*functional parameters of devices, safety).

Interdisciplinary problems often involve a number of new concepts. The system offers the possibility to present graphically different ontologies in the same conceptual map.

Structured Diagramming Argumentation. The technical support for argumentation is needed during the HACCP development for:

Justifying hazards: Arguments pro and against should be provided in order to justify the decision to classify hazards as critical or not critical.

$Hazard \equiv \exists hasJustification.ArgumentationScheme$

A set of *Argumentation Schemes* are provided to record the justifications: *argument from expert opinion*, *argument from established practice*, *argument from former case* [14]. Based on the above definition, the reasoner can check that a justification is attached to both significant or not significant hazard. The argumentation schemes are presented as concept maps to be easily used by the human agents. At the same time, their formalisation is based on the AIF ontology, so that justifications for a specific decision can be automatically queried. The use of an ontology-based solution assures compatibility with the other modules of the system.

Justifying control options: For each hazard which is considered significant, a control measure should be defined.

$SignificantHazard = Hazard \cup \exists hasControlMeasure.$

The absence of the control measure is signaled as an inconsistency by the reasoner. The adavantages and disadvantages of each option are presented as supporting arguments, respectivly counter-arguments.

Justifying associated critical limits: The recommended sources of information for justifying critical limits are examples, scientific publications, norms, experts, or experimental studies. The rationale and the reference material should become part of the HAACP plan [9].

Fuzzy reasoning. It is used as a tool for qualitatively assessing the failure process. The fuzzy approach is adequate for the following activities:

Assessment of critical control points. For each step of the production process, one should decide whether that stage will be a CCP, depending on the hazard possibility of occurence (*rarely*, *often, sometimes*, *always*) and on its severity (*low*, *medium*, *high*).

Supply chain integration:.

– *Suppliers:* An important source of hazards appears when receiving the input items. Depending on the potential risk, the company should decide to rely on the information from the product label or to conduct its own measurements of the product characteristics. This qualitative decision is based on fuzzy assesments.

– *Buyers:* The feedback received from the buyers, representing their preferences and perceptions is fuzzy. Their subjective evaluation can refer to attributes such as: colour, smell, taste. An answer "very tasty" is more probable than a "preference of 85%" for a specific food product. The characteristic of fuzzy logic to reason with linguistic variables is exploited here.

– *Outsourcing:* The company decides if it is able to deal itself with all the identified hazards or to outsource this task. For instance, the presence of rodents, insects, or other pests is unacceptable. The hazards are related both to the direct effects of these pests, but to the risks coming from the substances used to eliminate them. A good option is to contract a specialised company to handle these hasards. The decision is based on a fuzzy assesment of the risk involved.

Process adjustment. Actions need to be taken to bring the CCP under control before the critical limit is exceeded. The point where the operators take such action is called the *operating limit*. The process should be adjusted when the operating limit is reached to avoid violating critical limit. A fuzzy controller is the right tool to avoid loss of control by taking corrective actions.

Modelling fuzzy critical limits. Consider some microrbiological data. One rule can say: r_1:*"The product is safe if it is kept no longer than 48 hours at a temperature below* 10^oC*"*. What happens if the product is kept 47 hours at the temperature of 9^oC. Is it safer comparing with the situation in which it is kept for 1 hour at a temperature of 12^oC? According to the rule r_1, the second item is not considered safe. The alteration of product features is not done in step-like functions. Rather, the degradation is gradually, fuzzy membership functions being able to model better these cases.

Reports. Fuzzy logic is suitable to generate easy to understand reports to the decision makers.

Rules. Different rules types appear within an HACCP plan:

Corrective actions: *"If temperature not in the control limit → stop the line ∧(destroy the product ∨ record it)"* or *If ¬label → label it*. Such rules are used in the 6^{th} step of the HAACP plan.

Safety norms: Example follow:*"Sliced ready-to-eat meat products may not include red designs"*.

Periodic verifications: *"The workers should wash their hands every four hours"*.

RUNNING SCENARIO

We illustrate the support for building an HAACP plan for a cooked shrimp company (the scenario is adapted from [3]). The first action would be to complete the template provided for the preliminary steps. The template is represented as a nested concept consisting of i) team assembly, ii) narative description, iii) identify intended use, and iv) develop flow diagram (recall figure 2).

Narrative and flow diagram. *Incoming materials.* Frozen raw shrimp is received shell-on from international and domestic sources. After the acceptance an individual storage lot number is assigned and the shrimps are placed in frozen units. Buying requirement specifies that the shrimp must not contain any sulfite residual and a certification attesting the absence of sulfites should accompanied the items. Fresh, shrimps are acquired directly from local fishermen. The shrimps are often treated with sulfiting agents such as sodium bisulfite or sodium metabisulfite to prevent black spot formation. Shrimp are mixed with ice into recipients containing potable water. The materials used for packing are delivered in clean and covered vehicles. After lot numbers are assigned, the shrimp are placed into dry storage warehouses [3].

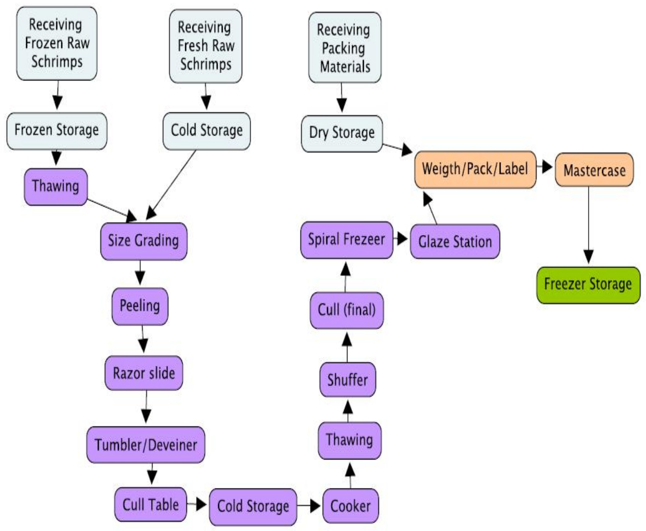

Figure 3. Cooking shrimp production flow with concept maps.

Processing. The thawing for the frozen shrimp uses potable water maintained at 18^o*C* to 33^o*C* and circulated with aeration. During the rotation through the recipients, workers remove any foreign objects. The unfrozen shrimp are conveyed to a *size grader* for sizing the shrimp. As the shrimps go through the rollers, various sides are placed in separate totes for icing and they are cascaded to the peeling room. During *the peeling procedure* the shell of the shrimp is cracked by a several inclined spinning roles. *A deveining process* follows in which a razor slide cuts the shrimp and exposes the vein. *The tumbler* rolls the product and pulls the exposed vein. The deveined shrimps are conveyed to a culling table. Workers on the both sides of the *cull table* will remove broken shrimps, pieces, unpeeled, or undeveined, crushed or blackspot items. The remaining shrimps are frozen and returned to *cold storage*. Before *cooking*, the defrozen is achieved by passing the product through a steam injector. In order to cool the shrimps, they are exposed to a *cold-water spray*. On the final *cull table*, workers remove any other broken items. In the *spiral freezer* the product is exposed to air cooled by standard ammonia refrigeration. The *glazing operation* follows, in which an adjustable water spray is used to confer uniform glaze.

Packaging and Storage. The finished product is conveyed to the *weigh, pack, and label station*, where automatic system weighs the shrimp and bags the correct quantity in prelabeled bagging material. Each container will be identified by the production date and lot number. The containers are than *mastercased* as specified by the customers. The product is placed into *frozen storage* without delay, and stored on a first-in, first-out strategy [3].

While narrative presentation encapsulates the above free description, the flow diagram concept has a reference toward the specific process flow of the business entity, represented as concept maps in figure 3.

Hazard analysis. During the hazard analysis step the significance of each hazard is assessed according to the likelihood of occurance and its severity. The decision is taken based on experience, epidemiolgical-data and significance of each hazard. Difference of opinions, even among experts, may occur regarding the importance of a hazard.

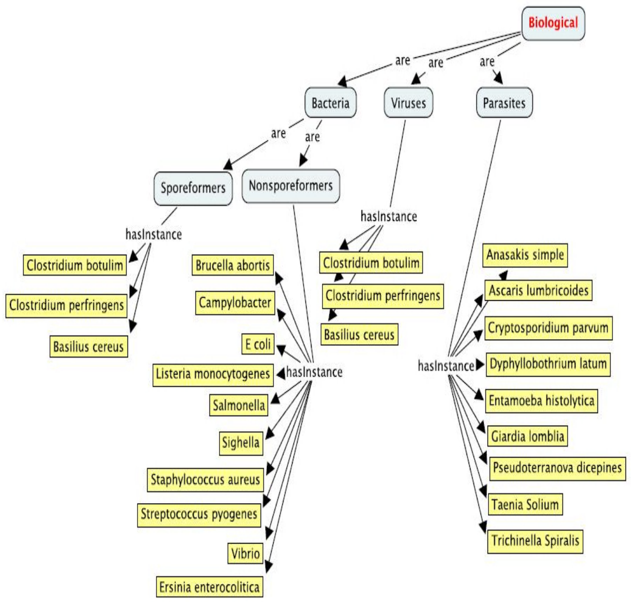

Figure 4. Biological agents within hazard ontology represented as concept maps.

Hazards ontology. Hazards are defined [3] as biological, chemical, or physical agents that are likely to cause illnesses or injuries in the absence of their control (line 1 in figure 5). Biological hazards include harmful bacteria, viruses, or parasites (line 2). The developed ontology is description-logic based and can be visualised as a concept map. Part of it, which includes biological hazards, is depicted in figure 4. Chemical agents include compounds that can cause illnesses or injuries due to immediate or long-term exposure.

1. *Hazard* = (*Biological* U *Chemical* U *Physical*) U □(*causeIllness t Injury*).*Consumer*
2. *Biological* = *Bacteria* U *Viruses* U *Parasites*
3. *Physical* = *ForeignMaterial* U (*NaturrallyOccuringObject* U □*hasThreat .Consumer*)
4. *FishBones* : *NaturralyOccuringObject*
5. *ForeignMaterial* = *Glass* U *Metal* U *Plastic* U *Stone* U *Wood*
6. *Glass* = *LightBulbt GlassContainers*
7. *Sulfits* □ *Chemical*
8. *Sulfits causeAllergicReaction PregnantWoman*
9. *causeAllergicReaction* □ *causeIllness*
10. *PregnantWoman* □ *Consumer*

Figure 5. Modelling hazard ontotology in description logic.

Argument from positive correlation + AS PC

A_1 : There is a positive correlation between sulfits and allergic reaction (AR) to pregnant women (PW).
C : Sulfits may cause AR to PW .

CQ_1 : Is there a positive correlation between AR and PW?
CQ_2 : Are there a significant number of instances of the positive correlation between AR and PW?
CQ_3 : Can it be ruled out that the correlation between AR and PW is accounted for by some third factor (a common cause) that causes both AR and PW?
CQ_4 : If there are intervening variables can it be shown that the causal relationship between AR and PW is indirect (mediated through other causes)?

Figure 6. The I-node "sulfits cause allergic reaction to pregnant women" is supported by the F-node "argument from positive correlation".

Physical hazards are either foreign materials unintentionally introduced in food products (ex: metal fragments in minced meat) or naturally occurring objects (ex: bones in fish) that are a threat to the consumer [3] (lines 3, 4, and 5). Common sources are light bulbs, glass containers and glass food containers (line 6). Given the information node that sulfiting agents, which are chemical compounds (line 7), may cause allergic reactions to sensitive persons such as pregnant women (line 8), and knowing that *AlergicReaction* is a subproperty of *Illness*, one can infer that sulfits are *Hazards*. The knowledge that *PregnantWoman* is considered potential *Consumer* (line 10) was used to support the above consequent. Technical knowledge from the ontology, encapsulated as I-nodes, is supported in our approach by argumentation schemes. Consider the information in line 8, which is backed by the instantiation of an *Argument from positive correlation* scheme (figure 6). The A_1 premise is supported by the *Argument from statistical evidence* scheme.

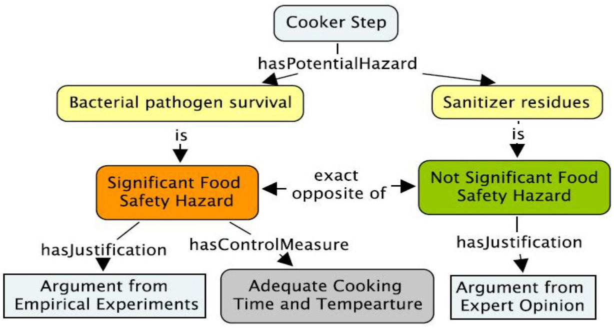

Figure 7. Significance of hazards are backed by argumentation schemes.

Justifying hazards. Each process step is analysed in order to identify potential hazards. Let's consider the *cooker step*, in which two potential hazards occur: a biological one (bacterial pathogen survival) and a chemical one (sanitizer residues). These hazards are clasified as significant or not by the HACCP team. Both positive and negative decisions should be justified in the HACCP process. A set of argumentation schemes is available, the HACCP team can instantiate the most adequate ones for the current case (see figure 7). Here, the pathogen survival hazard has been identified as significant. The above decision is justified by an *argument from empirical data scheme*, according to which without proper processing time and temperature, pathogens such as *Listeria monocytogenes*, *Salmonella*, and *Vibrio* may survive. The control measure applied to prevent this hazard is adequate cooking time and temperature. The sanitizer residues are not considered significant, and the decision is supported by an *argument from expert opinion scheme*. The expert of the company responsable for line sanitarization guarantees the insignifiance of potential residues, given the current context.

Justifying control measures. The control measure appearing in figure 7 has emmerged after an argumentation process depicted in figure 8. Thus, the first option for the control measure is to set a microbiological limit, under which the product is considered safe. This implies direct measurements of the pathogens within the item. The disadvantages of this solution are: i) difficulty to monitor, ii) measurements are necessary to determine critical limits derivations, iii) results are obtained in several days, and iv) samples need to be large enough to be meaningful. The second option is to set a minimum internal temperature at which the pathogens are destroyed. Of course, justification should be given for the chosen value. The method is practical and more sensitive. The third option is to control the factors that affect the internal temperature of the product such as oil, cooking time, or thickness of the pane. The method requires justifications between these limits and the internal temperature of food. It is very practical and it increases confidence in the measurements. A preference application node (*PA-CostSavings*) is applied on the identified options. In the AIF approach, the preference node can be itself the subject of debate, in which case it can be attacked or supported by different nodes.

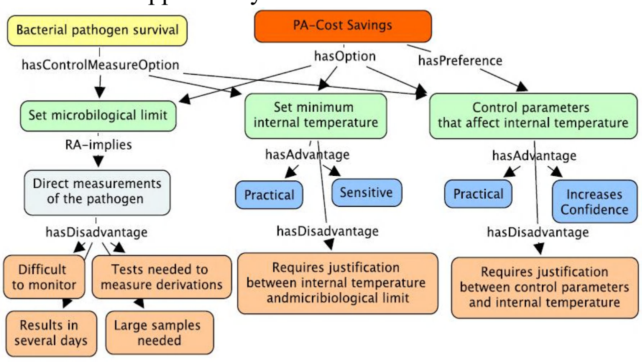

Figure 8. Deciding on the adequate control measure.

Justifying critical limits. When chosing the third option, a chain of justifications between *external factors - internal temperature – pathogens level* has been created and which the supervisor should be able to follow (see figure 9). The oil should have at least 378°*C*, cooking time more should be more than 1 minute, and thickness of the pan 1/4 inch. Tests are needed to validate that the above combination will always lead to an internal temperature of at least 180°. Based on these tests, an *Argument from Empirical Evaluation* scheme is instantiated to support the I-node *Internal temperature > 180*^{0}. This is used as a premise in an *Argument from Scientific Publication* scheme, used to back the fact that pathogen limit is satisfied.

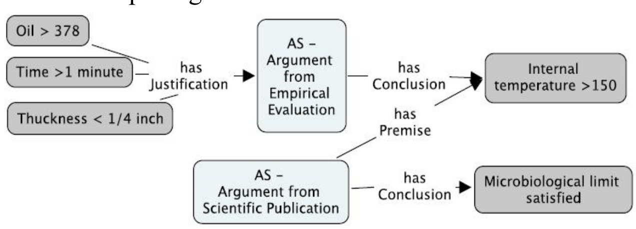

Figure 9. Establishing critical limits.

V. Related Work

The use of technology for improving food supply chains is investigated in [10]. A multi-agent system is designed and its business value is evaluated. The benefits were evaluated using agent-based simulation. Our approach does not focus on the replacement of humans by software agents, but to provide cognitive support to the team responsable for the food quality to identify and control the potential hazards. Our paper is in accordance with outcomes of the experiments in [7] stating that the level of sofistication is limited by user acceptance constraints, and not by the limitations of the available technologies.

Fault tree analysis, for the analytical decomposition of the relevant steps in the process flow of a food product, and fuzzy logic, for quantitative measures of occurance likelihood were proposed in [4]. The above reasearch focuses on the implementation of the first two principles of the HAACP. Similarly, we also advocate the use of fuzzy reasoning to enable automatic identification of critical control points. In our integrated architecture, which provides cognitive support for all steps of the HACCP development, additional tasks were identified for the the fuzzy module, such as: i) modelling fuzzy critical limits and ii) using fuzzy controllers to take corrective actions when the operating limit is reached.

To evaluate the effectiveness of the HACCP implementation in food industry, a quality cost model is proposed in [12]. The model assumes that quality costs can be computed from eleven different components affected by quality level, market, and production parameters. The model was validated with experimental data within the fish industry. The above research helps business entities to conduct the feasability study in order to decide on the costs and benefits of the HAACP. In the business workflow, our work can be seen as continuation by providing adequate technical instrumentation to firms which have decided to implement the HAACP system.

Many authors emphasize the use of fuzzy logic to model uncertainties in supply chains [1]. The safety of each operation in the process flow of the HACCP is evaluated based on a fuzzy model in [11]. Our analysis identified all the specific activities during HACCP development in which fuzzy logic can be proved useful. For instance, a fuzzy controller is proposed to avoid violating critical limits. The supply chain integration module based on fuzzy reasoning helps the system to adapt both internally and in conjunction with its suppliers to marketplace changes such as customer feedback or more constraining regulations, as advocated by [5]. Deeper investigation is needed to exploit the full potential of fuzzy techniques in the hazard analysis domain.

VI. Conclusion

This research presents a support decision system for implementing the HAACP system in the food industry. We identified the requirements for an HACCP framework, but we focused on represented arguments supporting the decisions that should be taken during the process.

One advantage of the approach relies on the fact that we managed to integrate the human oriented aspects needed in a support system (by using concept maps and argumentation schemes for presenting arguments) with the software agents oriented aspects (description logic for argument querying and the AIF ontology for supply chain integration).

ACKNOWLEDGMENTS

This work was supported by CNCSIS - UEFISCSU, project number PNII-IDEI code 170, 2009-2011, "Argnet-Support System for Structured Argumentation in the Web Context".

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