# Developing Hazard Ontology for Supporting HACCP Systems in Food Supply Chains

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***Abstract*—This paper proposes an agent-based solution to support small and medium companies willing to implement a Hazard Analysis Critical Control Point system in food supply chains. The difference is made between private knowledge of the agents and public knowledge by exploiting the capabilities of distributed description logic. To support hazard based reasoning, two ontologies were created: the *Hazard Ontology*, encapsulating the possible hazards in a specific business domain and the *HACCP ontology*, defining the basic concepts of the HACCP standard. The framework is exemplified on a shrimp supply chain scenario.**

## I. Introduction

The optimisation of supply chains has acquired great importance in the path towards recovery from the current economic crisis [1]. On the one hand, high prices put pressure on household income, particularly now at a time when an increase in consumption is needed. On the other hand, there is an escalate of the consumers awareness and interest with respect to the quality of the food they achieve. Complementarily, governments issue more constraining norms and policy initiatives aiming to improve practices in food supply chain regulations and to increase visibility, such as i) better awareness of contractual rights, ii) stronger actions against unfair practices iii) recommended standards contracts, or iv) quality standards to maintain a high level of food safety. Food regulations, as HACCP (Hazard Analysis Critical Control Points), Good Manufacturing Practice, or Good Hygiene Practice, are targeted to guarantee a certain level of quality [2].

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 six principles [3]: 1) *Hazard analysis*. The business entities within the supply chain identify the food safety hazards and determine the preventive measures for controlling them; 2) *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; 3) *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; 4) *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 normal processing flow, corrective actions should be attached to each CCP; 5) *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; 6) *Establish documentation* concerning all procedures and records appropriate to these principles and their application. Record examples include CCP monitoring activities and deviations, plus the associated corrective actions.

From the current practice, even a large food company might face significant difficulties when developing an HACCP system [4]. 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 the specific activity domain [5]. To handle this problem, this paper proposes an agent-based solution to support small and medium companies willing to implement an HACCP system. The difference is made between private knowledge of the agents and public knowledge represented by two ontologies: *Hazard Ontology*, encapsulating the possible hazards in a specific business domain and the *HACCP ontology*, defining the basic concepts of the HACCP standard.

## II. Distributed Description Logics

Distributed description logics (DDL) enables reasoning on multiple ontologies interconnected by directional semantic mapping, called *bridge rules* [6]. A bridge rule has the role to map concepts of the source ontology into concepts of the target ontology. This is particularly useful for the agents in the supply chain, which need to import and reuse concepts between several heterogeneous ontologies of their business partners, under the assumption that no central ontology exists.

**Definition.** A DL knowledge base consists of i) a terminological knowledge TBox encapsulating definitions of concepts and their relations (i.e., subsumption axioms) and ii) an assertional box ABox containing knowledge about individuals, their relations, and their membership in concepts..

We note by $\mathcal{T}_i$ the terminological knowledge, respectively by $\mathcal{A}_i$ the assertional knowledge of the agent $i$.

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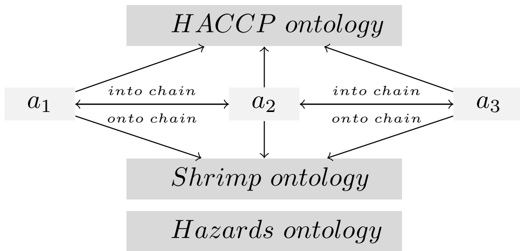


Fig. 1. Public and private knowledge in supply chains.

1. $Hazard \equiv (Biological \sqcup Chemical \sqcup Physical) \sqcap$
   $(\exists causeIllness.Consumer \sqcup \exists causeInjury.Consumer)$
2. $Biological \equiv Bacteria \sqcup Viruses \sqcup Parasites$
3 . $BacterialContamination \sqsubseteq Bacteria$
   $BacterialGrowt \sqsubseteq Bacteria$
4. $Physical \equiv ForeignMaterial \sqcup (NaturrallyOccuringObject \sqcup$
   $\exists hasThreat.Consumer)$
5. $fishBones : NaturralyOccuringObject$
6. $ForeignMaterial \equiv Glass \sqcup Metal \sqcup Plastic \sqcup Stone \sqcup Wood$
7. $Glass \equiv LightBulb \sqcup GlassContainers$

Fig. 2. Top level of the hazards ontology.

**Definition.** A DDL knowledge base $\mathcal{T}$ is a pair $\langle \mathcal{T}_i, \mathcal{B} \rangle$, consisting of a set of local TBoxes $\mathcal{T}_i$, each having its own DL language and a set of bridge rules $\mathcal{B}$ that provides mappings between these local TBoxes.

Every TBox is a set of subsumption axioms called general concept inclusions (GCI), each of the form $i : C \sqsubseteq D$, where $C$ and $D$ are concepts. The set of bridge rules $\mathcal{B}$ divides into sets of bridge rules $\bigcup_{i,j \in I, i \neq j} = \mathcal{B}_{ij}$. Each $\mathcal{B}_{ij}$ is a collection of bridge rules from $\mathcal{T}_i$ to $\mathcal{T}_j$ which are of two forms, *into-bridge rules* ($i : A \overset{\sqsubseteq}{\rightarrow} j : G$) and *onto-bridge rules* ($i : B \overset{\sqsupseteq}{\rightarrow} j : H$). Informally, into-bridge rules cause the mapped image of the source concept to always stay inside the target concept, whilst onto-bridge rules determine that the target concept is always inside the mapped image of the source concept [6]. Let $\mathcal{T}$ be distributed TBox over the set of agents $I$.

**Definition.** (Into-chain) An into chain of bridge rules is a directed path of into-bridge rules $\langle 1 : C_1 \overset{\sqsubseteq}{\rightarrow} 2 : D_2, 2 : C_2 \overset{\sqsubseteq}{\rightarrow} 3 : D_3, ..., n-1 : C_{n-1} \overset{\sqsubseteq}{\rightarrow} n : D_n \rangle$ of length $n > 0$ as that for each $1 < i < n$, $\mathcal{T} \models_\epsilon i : D_i \sqsubseteq C_i$.

**Definition.** (Onto-chain) An onto chain of bridge rules is a directed path of onto-bridge rules $\langle 1 : C_1 \overset{\sqsupseteq}{\rightarrow} 2 : D_2, 2 : C_2 \overset{\sqsupseteq}{\rightarrow} 3 : D_3, ..., n-1 : C_{n-1} \overset{\sqsupseteq}{\rightarrow} n : D_n \rangle$ of length $n > 0$ as that for each $1 < i < n$ $\mathcal{T} \models_\epsilon i : C_i \sqsubseteq D_i$.

Intuitively, subsumption propagates from one private ontology where it follows from the local knowledge of the agent to another agent ontology that is connected by bridge rules. For more specific information please refer to [6].

## III. Hazards-Based Reasoning

The knowledge is distributed both in public and private ontologies (see figure 1). This section formalises the public knowledge by defining i) the top level of hazards ontology,

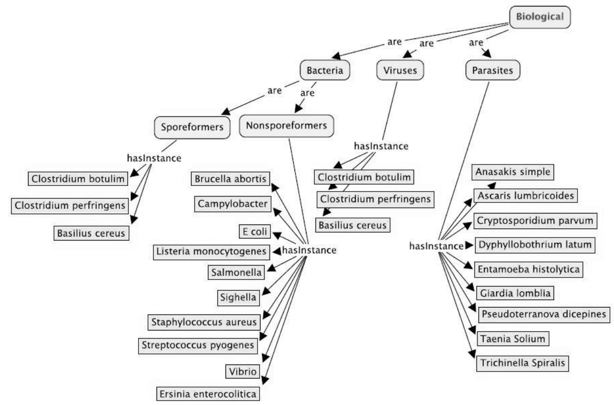


Fig. 3. Biological agents within hazards ontology.

10. $PotentialHazard \equiv Hazard \sqcap \exists identifiedIn.ProcessingStep$
    $\sqcap \exists has.ControlMeasure$
11. $SignificantHazard \equiv Hazard \sqcap \exists has.Justification$
    $\sqcap \exists has.ControlMeasure$
12. $NonSignificantHazard \equiv \neg SignificantHazard$
    $\sqcap has.Justification$
13. $SignificantPotentialHazard \equiv PotentialHazard \sqcap$
    $SignificantHazard$
14. $CCP \equiv ProcessingStep \sqcap \exists has.ControlMeasure$
15. $Justification \equiv \exists isConluclusionOf.ArgumentationScheme$
16. $ExpertOpinion \equiv (PresumptiveArgument \sqcap$
    $\exists hasConclusion.KnowledgePosition \sqcap$
    $\exists hasPremise.FieldExpertise \sqcap$
    $\exists hasPremise.KnowledgeAssertion)$
17. $AppToExpertOpinion \sqsubseteq \exists hasException.LackOfReliability$
18. $AppToExpertOpinion \sqsubseteq \exists hasException.Inconsistency$
19. $AppToExpertOpinion \sqsubseteq \exists hasException.LackOfReliability$
20. $PresumptiveArgument \sqsubseteq ArgumentationScheme$
21. $isConclusionOf^{-1} \equiv hasConclusion$

Fig. 4. Part of the HACCP ontology.

ii) the HACCP ontology, and iii) a specific extension of the hazard ontology, needed by the members of the supply chain to identify possible risk contamination in their particular production flow. Reasoning on private knowledge based on DDL is analysed in section IV.

### A. Hazard Ontology

Hazards are defined as biological, chemical, or physical agents that are likely to cause illnesses or injuries to the consumer (line 1 in figure 2). The definition is refined in line 2, where biological hazards include harmful bacteria, viruses, or parasites. This branch of the ontology is detailed in figure 3, where specific instances of bacteria are depicted. Chemical agents include compounds that can cause illnesses or injuries due to immediate or long-term exposure. Physical hazards (line 4) are either foreign materials unintentionally introduced in food products (ex: metal fragments in minced meat) or naturally occurring objects (ex: bones in fish, represented as assertional box in line 5) that are a threat to the consumer [7]. Common sources found in food processing facilities are light bulbs or glass containers (line 7).

### B. HACCP Ontology

The analysis starts by identifying potential hazards in each steppoint in the processing flow (line 10 in figure 4). During the hazard analysis the significance of each hazard is assessed, based on likelihood of occurrence and severity. The decision is taken from experience, epidemiological data and possible consequences of each hazard. Difference of opinions, even among experts, may occur regarding the significance of a hazard, but each decision should have a clear justification as part of an HACCP plan (given by $\exists has.Justification$ in line 11). In an HACCP implementation, any hazard that was declared significant should have at least one control measure to keep it within the critical limits (given by $\exists has.ControlMeasure$ in line 11). The disjoint category of hazards, denoted by the concept $NonSignificantHazards$ in line 12, should also be supported by a justification in the HACCP documentation. Note that, there is no need to define control measures for non significant hazards. Furthermore, a critical control point is defined as a processing step in which specific control measures should be applied to prevent the occurrence of a potential significant hazard (line 14).

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. The justifications are needed at several steps when defining the HACCP system: i) justifying hazards - arguments pro and against should be provided to justify the decision to classify a hazard as significant or not; ii) justifying control measures - the advantages and disadvantages of each control option are presented as supported arguments, respectively counter arguments; and iii) justifying associated critical limits: the recommended sources of information for justifying the chosen values for critical limits are scientific publications, norms, experts, or experimental studies [3]. A set of *Argumentation Schemes* is provided to record the justifications, which are formalised based on the Argument Interchange Format (AIF) ontology [8]. Line 16 exemplifies the formalisation of the $ArgumentFromExpertOpinion$ by stating the conclusion, the premises, and the set of critical questions or possible exceptions (lines 17, 18, and 19) that can be used to block the derivation of the consequent. Note that, the above *presumptive argument* is a subclass of argumentation scheme (line 20). The roles $isConclusionOf$ and $hasConclusion$ are inverse relations (line 21).

### C. Extending the top level ontology

The top level hazard ontology introduced in section III-A is extended for a particular business activity, namely shrimp processing. The well-known methodology of [9] is followed:

*1) Domain:* The domain of the ontology is hazard identification for shrimp processing. The ontology is used: i) to check if an HACCP implementation is correct and follows the standard specification and ii) by software agents to automatically design an HACCP plan based on two inputs - the production flow and the quality constraints specified by the business entity. The possible competence questions are: "Which are the possible control measures for a significant hazard?", "Which are the advantages of a specific control measure?", "Which is the control limit for a particular control measure?", "Which are the justifications for that value?", "What types of sensors can be used to monitor a control limit?", "What monitoring frequency is appropriate?", "Which are the critical control points?", "What should be recorded and how often?", "Which are the corrective actions in case of failing to avoid hazards?".

31. $MantisShrimp \sqsubseteq Shrimp, MysidShrimp \sqsubseteq Shrimp$
32. $Sulfites \sqsubseteq Chemical,$
 $BreathingDifficulty \sqsubseteq AllergicReaction$
33. $BreathingDifficulty \sqsubseteq \forall isCausedBy(... \sqcup Sulfites \sqcup ...)$
34. $isCausedBy^{-1} \equiv canCause$
35. $Sulfites \sqsubseteq \forall canCause.(BreathingDifficulty \sqcup Migraines \sqcup$
 $SkinRash \sqcup Itching \sqcup Flushing \sqcup Tingling \sqcup Swelling) \sqcap$
 $\forall hasRiskFor(Asthmatics \sqcup SalicylateSensitivityPersons)$
36. $ContactIce \equiv \exists contact.Food \sqcap \forall madeFrom.PotableWater$
37. $ContactSteam \sqsubseteq \forall contains.\neg Hazard$
38. $ArgumentFromPosCorrelation \equiv (PresumptiveArgument \sqcap$
 $\exists hasConclusion.PresumtiveStatement \sqcap$
 $\exists hasPremise.PositiveCorrelation \sqcap$
39. $AppToPossitiveCorrelation \sqsubseteq \exists hasException.FewInstances$
40. $AppToPossitiveCorrelation \sqsubseteq \exists hasException.ThirdFactor$
41. $a_1 : ArgumentFromPosCorrelation,$
 $p : PositiveCorrelation$
42. $c : PresumtiveStatement,$
 $e_1 : FewInstances, e_2 : ThirdFactor$
43. $hasPremise(a_1, p), hasConclusion(a_1, c)$

Fig. 5. Reusing knowledge to develop the shrimp hazard ontology.

*2) Consider Reusing.:* To our knowledge there is no available ontology developed for hazard identification in shrimp processing. However, there are some models that can be imported or adapted for our goal, split in the following categories:

*Shrimp related*: The agents should have strong knowledge about the own business domain, like shrimps classification, ingredients and additives effects or processing steps. Ontologies that can be reused are: Agrovoc thesaurus[1] with 2000 fishery related descriptors, FIGIS database containing aquatic species and fishing technologies[2], Fish Technology Knowledge Base containing 30000 bibliographic references about shellfish growing waters, food products safety or technology transfer[3]. A short example of knowledge reused from these sources is illustrated in figure 5, line 31.

*Health domain*: Agents should have knowledge related to possible food-generated diseases, pathogens taxonomies, possible causes, possible symptoms, allergies, or side-effects. Examples of health-related ontologies are: Unified Medical Language System[4] and Food Safety Ontology[5]. The knowledge extracted from these sources is generally oriented towards symptoms or disease definitions. In order to provide answers to the competency questions defined above, one option would be to reuse these definitions exactly, but to add some links to the current ontology. For instance, one should specifies that the role $isCausedBy$ is the inverse relation of $canCause$ (lines 33 and 34). The second option would be to reformulate the definition centered on hazard terms (i.e. sulfites, a chemical

[1] http://aims.fao.org/website/AGROVOC-Thesaurus
[2] http://fao.org/figis
[3] http://www.onefish.org/global/fishtechnology.jsp
[4] http://www.nlm.nih.gov/research/umls
[5] http://www.ipfsaph.org/En/default.jsp

hazard, can cause breathing difficulty, migraines, etc. and population with increased risk like asthmatics and salicylate sensitivity persons, as formalised in line 35.

*Legal domain*: The business entities should obey the current regulations and be aware of the legal consequences of their actions. Food safety norms have been extracted from the EU directive about fishery, Regulation no 852/2004 of the European Parliament, Regulation no 178/2002 about traceability, Fish and Fisheries Products Hazards and Controls Guidance. Two examples of such norms are formalised in figure 5: "Ice which comes into contact with food or which may contaminate food is to be made from potable water" (line 36), and "Steam used directly in contact with food is not to contain any substance that presents a hazard to health or is likely to contaminate the food" (line 37).

*Engineering*: functional parameters of devices (i.e. "the bulb should be cleaned every 6 weeks"), safety operation norms (i.e. "the turbidity of the water should not exceed 20 NTU".)

*Providing Justifications*: The decision taken in HACCP systems are justified based on the state of the art models for representing semantic arguments: the Argument Interchange Format ontology enriched with Walton, Pollock and Katzav-Reed argumentation schemes[6]. The *argument from positive correlation* is exemplified in lines 38-42. Its premise $p$ states "There is positive correlation between sulfits and allergic reaction (AR) to salicylate sensitivity persons (SSP)", whilst the conclusion $c$ defeasibly follows: "Sulfits may cause AR to SSP". In the AIF model, the derivation of the consequent can be blocked by instantiating a critical question or exception, such as: "Is there significant number of instances of positive correlation between AR and SSP?" ($e_1$) or "Can it be ruled out that the correlation between AR and SSP is accounted for by some third factor (a common cause) that causes both AR and SSP?" ($e_2$).

*3) Enumerate Terms:* Processing step, bacterial contamination, pathogen growth, critical limit, frequency, corrective action, hasControlLimit, hasFrequency, hasResponsable, etc.

*4) Defining Classes:* The hazard taxonomy should be extended with specific biological hazards: $BactContamin \sqsubseteq Bio$, $Sulfites \sqsubseteq Chemical$, $BactGrowth \sqsubseteq Bio$, $PathogenContamin \sqsubseteq Bio$, $PathogenGrowth \sqsubseteq Bio$. Technical parameters specifying the conditions for that hazard to occur are formalised: $SalmonellaGrowth \equiv hasAw. > 0.94 \sqcap hasPh.[3.7, 9.5] \sqcap hasSalt. < 8\% \sqcap hasTemperature.[5.2, 46.2]$.

*5) Defining Properties:* The definition of a control measure includes several roles: $44.ControlMeasure \sqsubseteq \exists hasCriticalLimit.Value \sqcap \exists hasFrequency.Time \sqcap \exists\exists hasMethod.\top \exists hasResponsable(Person \sqcup Sensor) \sqcap \exists hasVerification.Time \sqcap \exists hasRecord.Document \sqcap \exists hasCorrective.Action$

*6) Defining Constraints:* Short examples of constraints are: for each CCP exactly one agent is attached ($CCP \sqsubseteq = 1 has.Agent$) or $hasTemperature$ is a functional role.

[6]http://araucaria.computing.dundee.ac.uk/

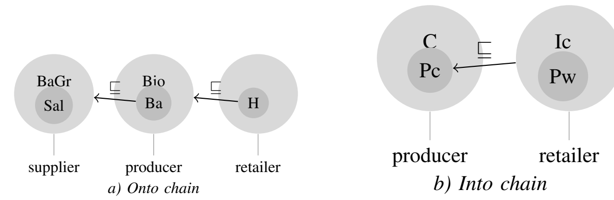


Fig. 6. Subsumption propagation.

*7) Creating Instances:* Instances of biological hazards are graphicaly represented in figure 3.

*8) Checking for Anomalies:* The identified anomalies correspond to bugs in the HACCP plan. Common inconsistencies are: i) an identified hazard has no justification (violating axioms 11 and 12); ii) a significant hazard has no control measure defined (violating axiom 11); iii) the frequency of monitoring is not specified (violating axiom 44).

## IV. Distributed Reasoning

This section presents how DDL is used to reason on the private knowledge of the business entities. The bag of knowledge is not uniformly distributed among the agents in the supply chain: part of them has specific knowledge related to a domain and more general or fuzzy knowledge about other domains. For instance, the actors from the end of the chain (retailers, shipment agents) have refined knowledge about consumers and related services offered for them, but they have only a general view on the ingredients of the products they sell. Quite the opposite, the agents from the beginning of the chain have specific knowledge about processing food technologies or handling safety hazards, and limited or indirect knowledge with respect to the end user requirements or complaints.

*Example (Onto chain).* Consider the supply chain formed by three agents: the retailer $r$, the producer $p$, and the supplier $s$ (figure 4a). The agent $r$ does not accept any hazards ($H$) in its selling items. He knows that the producer $p$ can introduce only biological hazards ($Bio$). The agent $p$ has sanitized against viruses and parasites producing facilities, so in its viewpoint only bacterial hazards ($Ba$) can occur during an incorrect processing step. He knows that under improper storage conditions of its supplier the growth process of existing bacteria can occur. Finally, the supplier $s$ has identified salmonella ($Sal$) as a possible occurrence, taking safety measures to prevent it. The corresponding DDL is: $\langle\{\mathcal{T}_r = \{H\}, \mathcal{T}_p = \{Ba \sqsubseteq Bio\}, \mathcal{T}_s = \{Sal \sqsubseteq BaGr\}\}, \mathcal{B} = \{H \overset{\sqsubseteq}{\rightarrow} Bio, Ba \overset{\sqsubseteq}{\rightarrow} BaGr\}\rangle$. Based on the subsumption propagation property of onto-chains in DDL [6], one is able to infer that $Salmonella$ is a potential hazard for the retailer.

*Example (Into chain).* Consider the retailer $r$ which knows that among its intended consumers ($Ic$) are pregnant women ($Pw$) too (figure 4b). The set of intended costumers is subsumed by the larger set of potential consumers ($Pc$), as defined by the producer $p$ from which the retailer achieves the items. In his turn, the producer knows that the potential clients represent only a subset from the set all existing clients

| | | |
|---|---|---|
| $\mathcal{T}_s$ | 50. | $Mercury \sqsubseteq Chemical$ |
| | 51. | $Tuna = \exists contains.Mercury \sqcap$ ... |
| $\mathcal{T}_p$ | 52. | $Methymercury = \exists causeDamage.Fetus \sqcap$ |
| | 53. | $Fetus = \exists carried.PregnantWoman$ |
| $\mathcal{B}_{sp}$ | 54. | $Methymercury \sqsubseteq Mercur$ |

Fig. 7. Reasoning on distributed knowledge in the supply chain.

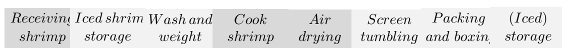


Fig. 8. Dried shrimp process flow chart.

| Agent | $H_2$ | $H_4$ | $H_5$ |
|---|---|---|---|
| Critical limits residuals | No detectable sulfits | 212F for 3 minutes | Water activity $\leq .85$ achieved in 8 hours |
| What | Presents of sulfits | Water temperature & cook time | Water activity & drying time |
| How | Rapid sulfit test | Sensor temperature and time | Water activity |
| Frequency | Every boat | Every batch | Every batch sensor and time |
| Who | RFID sensor | RFID sensor | Quality control agents |
| Corrective action | Reject | Hold and evaluate or recook | Continue drying until $\leq .85$ |
| Verification | Dayly record review, Seasonly lab reports | Daily record review, Validation study | Daily record review, Calibration of water activity meter |
| Record | Receiving record | Cooking log | Drying record |

TABLE II
MONITORING PLAN OF THE AGENTS PLACED IN CCPS.

($C$). The resulting DDL is: $\langle\{\mathcal{T}_r = \{Pw \sqsubseteq Ic\}, \mathcal{T}_p = \{Ic \sqsubseteq Pc\}, \}, \mathcal{B} = \{Ic \overset{\sqsubseteq}{\rightarrow} Pc, \}\rangle$. Based on the subsumption propagation property of into-chains in DDL [6], the producer $p$ infers that $PregnantWoman \sqsubseteq Client$.

This information obtained from subsumption propagation from the retailer, combined with the information propagated from the supplier, can be used by the producer $p$ to identify potential hazards over the entire supply chain, not only to its private processing line.

*Example.* Several types of fish are not recommended to pregnant women because some of them contain high levels of mercury, which can cause damage to the developing nervous system of the fetus. Mercury is released into the air through industrial pollution and can accumulate in streams and oceans, where it turns into methylmercury. The methylmercury builds up in fish, especially those that eat other fish.

The above knowledge is usually distributed among the members of the supply chain. In figure 7 lines 50 and 51 represent the terminological knowledge of the supplier $s$, lines 52 and 53 the concepts of the producer $p$, whilst the bridge rule between the agents $s$ and $p$ appears in line 54. Combining this knowledge with the information deduced earlier, that pregnant women are potential customers of the retailer $r$, the producer is able to identify a hazard in the supply chain. The typical solution consists in labelling the product accordingly.

Currently, DDL does not allow to propagate subsumptions over roles. Consider the situation in which an ingredient may cause allergic reaction to sensible persons, and this information is stored by the agent $r$: $\mathcal{T}_r = \{Sulfits = \exists causeAllergicReaction.PregnantWomen\}$ and let the bridge rules $\mathcal{B}_{rp} = \{causeAllergicReaction \sqsubseteq causeIllness, Sulfits \sqsubseteq Chemical\}$. The producer $p$ also knows that chemical hazards cause illness to possible clients $\mathcal{T}_p = \{Chemical = \exists causeIllness.PotentialClient\}$. DDL cannot exploit the knowledge encapsulated in the first rule from the set $\mathcal{B}_{rp}$ of bridge rules between $r$ and $p$. Thus, the information that sulfits cause illness to pregnant women is not derived.

## V. AGENTS FOR MONITORING THE HACCP PLAN

This section details how the agents can be enacted in a shrimp processing supply chain scenario. The shrimp are delivered by suppliers on ice, head-on, small, and fresh and are kept on ice until processing. They are washed and weighed to remove ice and damaged shrimp. After that, each batch of shrimp is boiled in salt water. The amount of salt used determines the desired flavour of the end product. Additional salt is added to the cooking water to maintain a constant concentration. Shrimp are then placed in forced-air drying unit, usually for six to seven hours. The shells and heads are removed into a rotating screen drum. The shrimp may be stored under refrigeration, although this is not necessary [7]. The flow chart is depicted in figure 8, where the shaded steps represent CCPs.

Following the HACCP methodology, for each processing step, potential hazards are identified and categorized (column 3 in table I. Recall definitions 11 and 12 in figure 4 where each hazard, no matter if significant or not, should have a justification. Valid justifications can be selected from the hazards ontology, as column $Justification$ in table I bears out. According to definition 11 in figure 4, each significant hazard (denoted with $Sig$) has a control measure attached to it (column $Control\ Measures$). For each identified CCP, a hazard agent holds the responsibility to prevent it: $H_2$, $H_4$, and $H_5$. Table II details the monitoring tasks of these agents. Each agent is designed to monitor specific parameters, the method used for measurements and their frequency, and who is responsible for data acquisition (human agent or RFID sensor, as formalised by axiom 44.). The specification includes what automatic measures are taken in case of nonconformance and the amount of data that needs to be recorded.

## VI. DISCUSSION AND RELATED WORK

Several projects within the agriculture domain[7], like *The Fishery Ontology Service*, has starting to exploit semantic interoperability in fishery information systems. The use of technology for improving food supply chains is investigated in [10]. A multi-agent system is designed and its business value is assessed. The benefits were evaluated using agent-based simulation. 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 occurrence likelihood were proposed in [11], by focusing on the implementation of the first two principles of the HACCP.

To evaluate the effectiveness of the HACCP implementation in food industry, a quality cost model is proposed in [12]. The approach assumes that quality costs can be calculated from eleven components affected by quality level, market,

[7] Agriculture Ontology Service at http://www.fao.org/agris/aos

| Step | Potential hazard | Sig | Justification | Control Measure | CCP | Agent |
|---|---|---|---|---|---|---|
| Receiving | $BactContamin$ | Yes | Shrimps are natural reservoirs of pathogens | Cooking | No | $H_1$ |
| | $Sulfits$ | Yes | Potential for allergic types reaction | Reject shrimps containing sulfits | Yes | $H_2$ |
| Iced storage | $BactGrowth$ | Yes | Pathogen growth if temperature abused | Cooking | No | $H_3$ |
| Cook | $BactGrowth$ | Yes | Improper cooking allows survival of pathogens | Control temperature during cooking | Yes | $H_4$ |
| Drying | $BactGrowth$ | Yes | Improperly dried shrimp have a wet spot, allowing pathogen growth | Reduce water activity to acceptable levels | Yes | $H_5$ |
| Tumbling | $PathogenContamin$ | No | Controlled by SSOP | | | $H_6$ |
| | $PathogenGrowth$ | No | Low water activity | | | |
| Packing | $PathogenContamin$ | No | Controlled by SSOP | | | $H_7$ |

TABLE I
ASSIGNING AGENTS FOR HAZARDS MONITORING.

and production parameters. The model was validated with experimental data within fish industry. Whilst, the above research helps business entities to conduct the feasibility study in order to decide on the costs and benefits of the HACCP, our work can be seen as continuation by providing adequate technical instrumentation to firms which have already decided to implement the standard.

One issue regards the ability of agents to obtain and monitor the business process. The data model in our approach is based on the *TraceCore XML* standard, whilst the data acquisition exploits the RFID technology. *TraceCore XML* is a standard of exchanging traceability information electronically in the food industry. Based on RFID the quality of products can be monitored not only at the internal level of production, but along the entire supply chain [13]. Business entities are already deploying RFID sensors in products that could be damaged due to the overcome of the critical limits of temperature. As an example consider the case of frozen chickens which have a high risk of salmonella contamination if the temperature becomes too high for too long. If the temperature exceeds the critical limit established within the HACCP plan, a permanent electrical change occurs in the RFID-based label of the item. When interrogated by a RFID reader, the product responds with the corresponding warning message [14].

The ideas presented here can be used as a starting point to develop early warning systems that will be able to alert the possibility of not meeting the current quality standard in food supply chains. Based on this alert, the chain should be able to adapt either the processing parameters of some business agents (time of storing, frozen temperature) to keep to promised quality, or to change the price or the envelope of the item accordingly. Such a monitoring system meets the following business needs of the supply chain: i) quality management according to the HACCP plan, ii) support withdrawal of non-conformant products, iii) legal compliance with food regulations, iv) brand protection at the supply chain level.

## VII. CONCLUSION

The main contribution of the paper consists of developing two ontologies for supporting hazard based reasoning in food supply chain. Providing the set of argumentation schemes our model is in line with the main requirement of the HACCP systems to record all the justifications on which a safety decision was taken. Consumers are seen as innovators from a service dominant knowledge perspective [15]: they have greater capabilities to design their own products, tailored for specific needs. In our approach, the customers are empowered with the capability to choose the exact product instance which best fits them from an existing set of items. Hence, they are offered a greater level of protection against hazards.

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