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IMPACT OF RFID-TTI TECHNOLOGIES ON THE EFFICIENCY OF PERISHABLE PRODUCTS LOGISTICS

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ABSTRACT

The paper concerns the logistics activities related to perishable products. Perishable products are delivered from the production site to a warehouse by refrigerated truck. Perishable products are accepted or not at the warehouse entrance, according to their detected quality levels; if accepted, they are stored in the warehouse in suitable environmental conditions. Finally, they are delivered by refrigerated truck to the destination. Human errors affect these activities. Perishable products have to be delivered in a suitable quality level to the destination. Because of human errors, sometime products arrive in an unsuitable quality level and therefore, there is a loss for the company.

RFID technologies, integrated with time temperature indicators (TTI), allow a prompt detection of abnormal quality loss and the prompt actuation of mitigation actions.

In order to evaluate the benefits of different RFID-TTI implementation set-ups, the study defines a methodology that measures the risk of monetary losses. The method is applied to a case study and the results are presented.

Keywords: perishable products, RFID-TTI implementation set-ups, logistics, transport.

1. INTRODUCTION

1.1. Perishable products

Most perishable products are temperature sensitive and their quality level is therefore a function of product characteristics, conditions under which the product is maintained, and time (Sahin et al. 2007).

Sloof et al. (1996) introduced four mathematical descriptions to express the decrease in value of perishable products in a fixed environment. These four models are listed below:

- Zero order reactions having linear kinetics.
- Michaelis Menten kinetics.
- First order reactions having exponential kinetics.
- Autocatalytic reactions with logistic kinetics (Tijskens and Polderdijk, 1996).

A relationship between time and quality of perishable products can be built based on these models (Wang et al. 2010). For the same value of the initial quality and the same value of the quality limit, Figure 1 gives a summary of the change of quality attributes based on these four kinetic mechanisms. The functions of the linear kinetics model and the Michaelis Menten model are nearly the same in the initial period, so, most part of the two curves are overlapping in the figure.

In the figure, KQ indicates the “keeping quality”: the time that elapses between the production and the instant in which the quality deteriorates beyond an acceptance level.

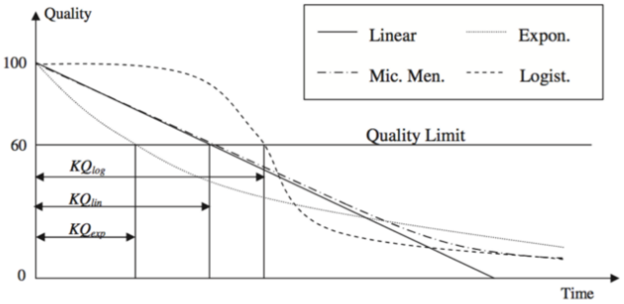

Figure 1: Decrease in quality for four types of mechanisms (Tijskens and Evelo, 1994)

1.2. RFID-TTI technology

Advanced product identification and sensory technologies, such as radio frequency identification technology (RFID) and time temperature indicator (TTI), enable to record transit times and time-temperature data that determine the actual perishable product quality. Therefore, these technologies allow a prompt detection of abnormal quality loss and therefore a prompt actuation of mitigation actions is possible.

As it concerns the reading (of the RFID-TTI sensor tag) and the transmission (to the information system), two possibilities can be considered: the reader and middleware read and transmit (1) only the latest sensor data or (2) all sensor data in a tag user memory. The first approach can be applied to systems that can send sensor data to information systems anywhere and in real-time through wireless communication devices. The second approach can be used when wireless communication is not available (Kang et al., 2012). According to these reading/transmission options and according to the locations where the reading/transmission takes place, different RFID-TTI implementations scenarios can be defined.

2. SYSTEM MODEL DEVELOPMENT

2.1. The logistic processes

The logistic processes taken into account are the ones that take place from the instant in which perishable products arrive at the warehouse to the instant they arrive at the destination. Goods arrive at the warehouse usually by refrigerated truck. Perishable freight units are managed as bulk goods in the warehouse. In the proposed study, each freight unit is subject to the following logistic activities (Figure 2):

- Check-in at the warehouse entrance: according to documentation check and visual checks on package status, goods are accepted or rejected at the receiving dock. In this phase, conservation instructions, shipping and priorities information are acquired. Freight units are tagged with labels reporting this information and then moved inside the warehouse.
- Refrigerating room: once the check-in procedure is concluded, freight units are stored inside the correct refrigerating room, based on conservation instructions.
- Truck consolidation: once the truck is available at the leaving dock, freight units are moved from the refrigerating room to the loading dock. Here, the truck is consolidated for last mile freight distribution (Cepolina, 2016; Cepolina and Farina, 2015). According to the data from the case study, the truck capacity is equal to 13 units.
- Freight transport to destination by refrigerating truck. From here, freight units will be delivered to urban areas possibly by multi modal systems (Molfino et al. 2015).

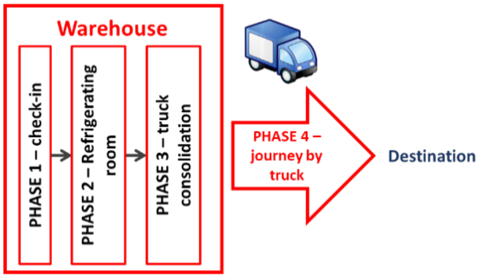

Figure 2: The simulated logistic processes.

Referring to Figure 3, in the paper Initial Quality Limit (IQL) is meant as the minimum acceptable quality level of the product at the check in (phase 1): the product should arrive at the warehouse entrance at a quality level > IQL. Final Quality Limit (FQL) is meant as the minimum acceptable product quality level at the destination: the perishable product should be delivered at the destination at a quality level > FQL. KQ is meant as the length of time from the product acceptance at the warehouse entrance to the time in which the quality deteriorates beyond FQL. Therefore, KQ is the maximum time interval at disposal for transferring freight from the warehouse to the destination in specific ideal conditions.

2.2. Human preservation errors

In the four phases previously described, **human errors** can occur.

Only errors those consequences could be reduced by RFID-TTI implementations will be considered. Thus, the human error typologies taken into account are:

- *Previous preservation error* (**type pp**): products arrive at the warehouse entrance with a quality level < IQL because of errors previously occurred.
- *Conservation error* (**type c**): units are put in the refrigerating room with delay.
- *Setting error* (**type s**): units are placed in the wrong refrigerating room (i.e. wrong temperature set-up)

Errors of **type pp** definitely compromise the products that in fact cannot be anymore delivered to the destination in a quality level >FQL.

The last two error types are preservation errors that occur in the warehouse and that cause an abnormal freight unit quality loss, specifically:

- Errors of **type c** lead to <u>a significant quality degradation</u>
- Errors of **type s** lead to a <u>slight quality degradation</u>

In both cases, products can be delivered, or not, to the destination in a quality level >FQL. When actual conditions (indicated in the following with the symbol *) deviate from specified ideal conditions because of conservation/setting error occurrence, the quality decrease will be faster and the linear function describing the kinetic mechanisms will be steeper than that referring to ideal conditions; FQL will be sooner reached and therefore, KQ* will be shorter than KQ (Figure 4) and KQ**< KQ* <KQ (Figure 5 and 6).

The quality loss entity depends not only on the error type but also on the amplitude of the interval of time that elapses between the moment in which an error occurs and the instant in which mitigation actions are implemented.

Without any RFID-TTI implementation, the quality level of each freight unit is monitored through temperature sensors placed by the producer within the pack and checked only at destination, once the package is opened.

Therefore, only at destination the temperature sensors are read and, if an error occurred, there is no way to mitigate it.

The introduction of RFID-TTI technology with different implementation set-ups impacts on: preservation error detection, actuation time of possible mitigation actions and thus, error consequence entity.

2.3. Scenario definition

Two scenarios are taken into account:

* Scenario NO RFID. It represents the current situation without any RFID-TTI implementation. Human errors of type~~s~~ *pp*), *c*) and *s*) can take place and are detected at destination. Therefore, no mitigation actions are possible.

* Scenario D - RFID-TTI implementation. The scenario refers to a RFID-TTI set-up where: RFID-TTI tags are applied by the producer to each freight unit and fixed RFID readers (portals) are located: at the warehouse entrance (reading point E); at the entrance (reading point I) and at the exit (reading point U) of the refrigerating room. Errors are detected only when the RFID reading happens: reading point E allows to detect *type pp* errors; reading point I allows to detect *type c* errors; reading point U allows to detect *type s errors*.

2.4. Mitigation actions

Once an error has been detected, the following **mitigation actions** are possible:

1. ***Product rejection*** - in case of detection of a *type pp error*, the product is rejected: this mitigation action is always successful.
2. ***Express delivery*** - in case of detection of a *type c error*: a truck with the compromised unit leaves the warehouse as soon as possible without waiting for other units. Therefore, the load factor (given by the rate between the number of units on the truck and the truck capacity) is lower than 1 and an additional truck will be required for delivering the remaining units that have been left in the warehouse for time saving. This mitigation action can be successful or not.
3. ***Accelerated delivery*** - in case of detection of a *type s error*: the truck reaches the destination in the minimum time, thanks to an increase in the commercial speed (for instance trough a reduction of the stop lengths, increase in the actual speed, re-routing). In this case the truck leaves the warehouse only when it has been consolidated with all the units, therefore, its load factor is equal to 1 and no additional trucks are required. This mitigation action can be successful or not, as described in section 2.5.
4. ***Travel cancellation*** - in case of *type c error* or *type s error* occurrences. If the previous mitigation actions are ineffective, there is no way for the company to deliver the compromised unit to the destination with a suitable quality level. In this case the subsequent transport phases are cancelled and, although the unit is lost, additional and useless travel costs can be saved.

2.5. Assessment of mitigation action's success

The following figures show Quality-Space-Time diagrams for a perishable product. The quality level is assumed to decrease linearly with time in specific ideal conditions. Q1 is the initial quality level of the freight unit at the warehouse entrance, while QD is the quality level at destination. FQL is the minimum quality level accepted at destination. t_1 is the unit entrance time in the warehouse. t_2 is the unit exit time from the warehouse. t_2-t_1 is the permanence duration of the unit in the warehouse. t_D is the time the unit is delivered to the destination. t_D-t_2 is the travel time from the warehouse to the destination. t_L is the time the unit reaches FQL. t_L-t_1 = KQ referred to specific ideal conditions.

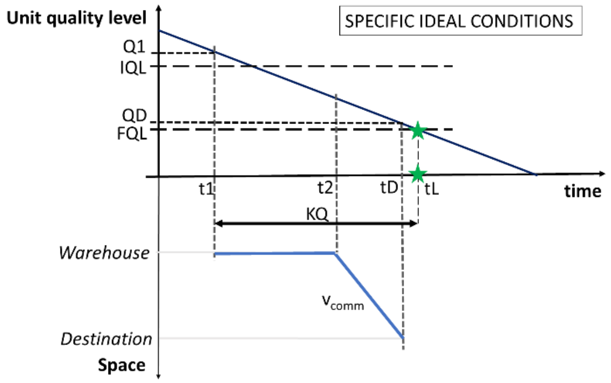

Figure 3: quality degradation with time in specific ideal conditions.

Figure 3 shows that in specific ideal conditions, (t_D - t_1) < KQ. v_{comm} is the normal truck commercial speed from the warehouse to the destination. The unit arrives at destination with a quality level >FQL (QD > FQL).

Figure 4 shows an example of *type s* error occurrence and the consequent adoption of the accelerated mitigation action. The error produces an increase of the perishable product degradation speed and as a consequence KQ* < KQ. An accelerated mitigation action has been adopted and the transport from the warehouse to the destination is performed at v_{comMAX} (>v_{comm}), which is the maximum commercial speed. The mitigation action results successful since (t_D - t_1) < KQ* and therefore QD > FQL.

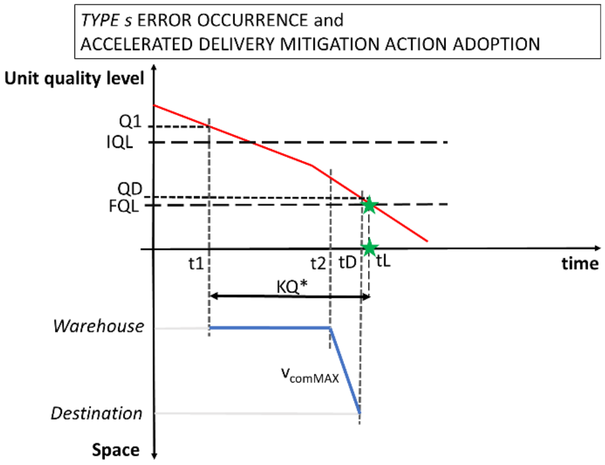

Figure 4: an example of *type s* error occurrence and the consequent adoption of the "*accelerated mitigation action*". The mitigation action results successful.

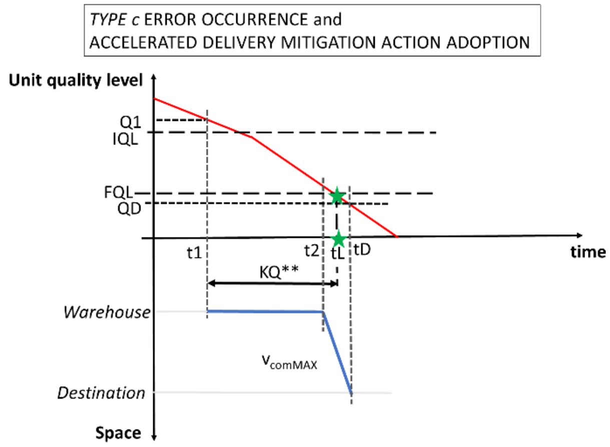

Figure 5: an example of *type c* error occurrence and adoption of the "*accelerated mitigation action*". The mitigation action results unsuccessful.

Figure 5 refers to a *type c* error occurrence and the adoption of the accelerated mitigation action. The error produces a strong increase of the perishable product degradation speed and, as a consequence, KQ** << KQ. An accelerated mitigation action has been adopted and the transport from the warehouse to the destination is performed at v_{comMAX} ($>v_{comm}$), which is the maximum commercial speed. The mitigation action results unsuccessful since (t_D - t_1) > KQ** and therefore QD < FQL.

Figure 6 refers to a *type c* error occurrence and express mitigation action adoption. The error produces a strong increase of the perishable product degradation speed and as a consequence KQ**<<KQ. An express mitigation action has been adopted therefore the compromised product stays for a shorter time in the warehouse (t_2- t_1 in Figure 6 << t_2- t_1 in Figure 5): as soon as the error is detected, freight leaves the warehouse. The transport from the warehouse to the destination is performed at v_{comm}. The mitigation action results successful since (t_D - t_1) < KQ** and therefore QD > FQL.

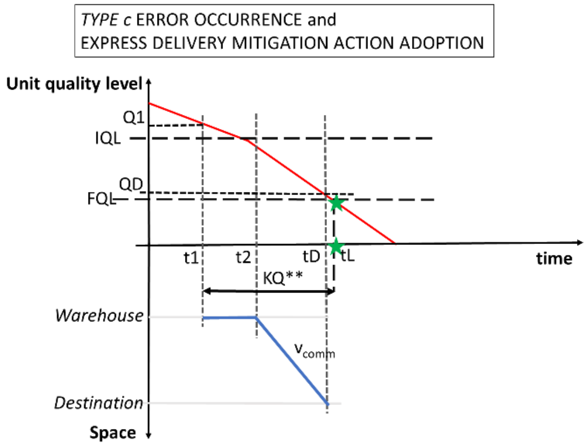

Figure 6: an example of *type c* error occurrence and adoption of the "*express mitigation action*". The mitigation action results successful.

3. METHODOLOGY

3.1. Goal and scope definition

A simulative analysis is aimed at assessing benefits of the previously described scenarios.

For each scenario, benefits are assessed in terms of **reduced risk of monetary loss** (Cepolina et al. 2018, Cepolina et al. 2019a). A low value of risk means a high-performance scenario.

In a given scenario *S*, R^S is assessed by summing for each damage class, the product between the average of the total damage levels belonging to the class, AD_{dc}, and the occurrence probability, H_{dc}, related to the respective class:

$$R^S = \sum_{dc} AD_{dc} * H_{D_{dc}} \qquad (1)$$

The **classes of damage** are 5: Negligible (if total damage level < 500 euro), Minor (if 501 euro < total damage level < 1000 euro), Moderate (if 1001 euro < total damage level < 3000 euro), Significant (if 3001 euro < total damage level < 5000 euro), Severe (if 5001 euro < total damage level).

The steps for calculating AD_{dc} are:

- assessing the damage level d_i experienced by each freight unit *i* in the scenario S, in the reference time period. This is done performing a run (n^{th} run) of a discrete event simulation
- in the n^{th} run, assessing the total damage level as: $D_n = \sum_{i=1}^{FUN} d_i$, extended to the overall number *FUN* of freight units handled in the reference time period. The resulting total

damage level D_n is reported to the related class D_{dc}.

- For each class D_{dc}: $AD_{dc} = \frac{\sum_{ndc} D_{ndc}}{N_{D_{dc}}}$ where D_{ndc} are the values D_n that fall within the D_{dc} class and $N_{D_{dc}}$ is the total number of D_{ndc}
- H_{dc} is the probability that, in the reference time period, the scenario is affected by the total damage level that belongs to class *dc*. This probability is assessed by Monte Carlo technique according to the procedure illustrated in Cepolina et al. (2019b). The following likelihood classes are considered: very unlikely (0-0,2), unlikely (0,21-0,4), possible (0,41-0,6), likely (0,61-0,8) and very likely (0,81-1).

3.2. Assessment of the damage level d_i - Discrete event simulation

During the n^{th} run of the discrete event simulation, the freight units are processed through the four logistic phases in Figure 2, human errors are generated, and eventual mitigation actions are applied.
For each freight unit *i*, damage level d_i is assessed by:

$$d_i = V_i * E_i + K_1 * travel\ cost_i^{extra} + K_2 * travel\ cost_{truck} - K_3 * travel\ cost_i^{normal\ speed} \qquad (2)$$

where:
Exposition E_i is the monetary value of freight unit *i* that includes the cost of moving a unit from the warehouse to the destination by a full load refrigerated truck (load factor = 1) with the normal commercial speed.

Vulnerability, V_i is a Boolean variable: V_i =1 when: -) a *type pp* error occurs but it is not detected at the check in and therefore *product rejection* mitigation action is not adopted; -) a *type s* error or a *type c* error occurs but it is not detected; -) a *type s* error or a *type c* error occurs and it is detected in the warehouse but the adopted *express delivery* or *accelerated delivery* mitigation actions do not result effective (QD < FQL). In all the other cases V_i = 0. In case V_i =1, the damage is equal to the costs related to the complete compensation of compromised units to the customer. If the unit quality level, detected in the warehouse, results < FQL, the damage value can be reduced by canceling the unnecessary transport of the compromised unit.

$travel\ cost_i^{normal\ speed}$ is the cost of moving a unit from the warehouse to the destination by a full load refrigerated truck with the normal commercial speed.

$travel\ cost_i^{extra}$ is the difference between:

- the cost of moving a unit from the warehouse to the destination by a full load refrigerated truck with the maximum commercial speed (through increased speed, rerouting and stop length reduction).
- $travel\ cost_i^{normal\ speed}$

$travel\ cost_{truck}$ is the cost of an additional refrigerated truck for moving freight from the warehouse to the destination

K_1 is a Boolean variable: K_1 =1 when an *accelerated delivery* mitigation action takes place; K_1 = 0 otherwise.

K_2 is a Boolean variable: K_2 = 1 when an *express delivery* mitigation action takes place and the additional truck travels with load factors <1; K_2 = 0 otherwise.

K_3 is a variable: K_3 = 1 when a *travel cancellation* mitigation action takes place; K_3 = 0 otherwise.

4. DISCRETE EVENT SIMULATOR

4.1. Simulation data input

The simulation model has been implemented in Anylogic, a discrete event analysis has been adopted.
The system is defined by:

- the reference time period: a typical 8 hours working day has been considered.
- the freight demand, specified in terms of:
  - number of freight units that arrive at the warehouse within the reference time period: 364
  - freight arrival rate: it has been assumed uniform and arrivals have been assumed deterministic.
  - freight unit economic value: referring to perishable units, we assumed each freight unit has a value of 3349 euro. The value is obtained considering: 19 SDRs/kg (Special Drawing Rights) where 1 SDRs = 1.23 euro, unit's weight equal to140 kg, average transport cost equal to 77 euro for an average distance of 400 km.
- four process phases as described in Figure 2. Process times are assumed deterministic and are shown in Table 1.
- human preservation error probabilities: we assumed a Bernoulli distribution for human errors with mean values equal to 0.001430 for *type c* conservation errors, 0.002143 for *type s* setting errors and 0.000357 for *type pp* previous preservation errors.

Table 1: Process times.

		Process times
Phase 1 check in	Freight unit	17,5s
Phase 2 refrigerating room	Freight unit	25200s (7h)
Phase 3 truck consolidation	truck	900 s
Phase 4 journey by truck	truck	28800s (8h)

- mitigation action costs:
    - Product rejection: the unit is rejected without any other transport cost and any other administrative and legal cost requested in case of dispute
    - Express delivery, the cost ($travel\,cost_{truck}$) is related to the additional requested truck. Its total travel cost is assumed equal to 900 euro that is the total cost of a 400 km journey performed by a van with gross vehicle weight < 3,5t. It has been assessed with the data provided by the Italian Observatory on road freight transport activities (http://www.mit.gov.it/mit/mop_all.php?p_id=10640) and assuming that variable costs constitute about 44% of the total travel cost (Jacyna and Wasiak, 2015).
    - Accelerated delivery, the cost ($travel\,cost_i^{extra}$) is related to the requested increase of the commercial speed. Its cost is assumed equal to 75.5 euro/truck according to available commercial rates, considering an average distance of 400 Km between the warehouse and the destination.
    - Travel cancellation, it is a save of money related to the fact that if a unit cannot reach the destination in a quality level > QL, it is not worth to pay for the journey cost. The journey cost of a freight unit ($travel\,cost_i^{normal\,speed}$) is assumed equal to 77 euro/unit. We assumed that the total travel cost is equal to 1000 euro and that in the journey 13 freight units are transported. 1000 euro is the total travel cost of a 400 km journey performed by a truck with gross vehicle weight included in (11,5t - 26t). The total travel cost has been assessed with the data provided by the Italian Observatory on road freight transport activities (http://www.mit.gov.it/mit/mop_all.php?p_id=10640) and assuming that variable costs constitute about 44% of the total travel cost (Jacyna and Wasiak, 2015).

4.2. Simulation output

The performance of each scenario is evaluated in terms of the risk at which the company is exposed during the reference period, evaluating the R^S value and the risk matrix composed by H_{dc} and D_{dc} classes. A number of 1000 iterations have been carried out for both the scenarios, in order to satisfy the stopping criteria defined in Cepolina et al. (2019b).

4.2.1. Current scenario: NO RFID-TTI

The obtained risk value for the current scenario is:

$$R^S = 4735.5\ euro$$

The resulting risk matrix is displayed in Table 2. It is possible to observe that for the 41% of cases the class of damage is “Severe” corresponding to a total damage level higher than 5001 euro. In this scenario all the errors generated during simulation cannot be mitigated leading to the complete freight unit loss and the entire transport cost.

Table 2: Risk matrix for the current scenario (no RFID-TTI implementation)

		H_{dc}				
		Very Unlikely (0-0.2)	Unlikely (0.2-0.4)	Possible (0.4-0.6)	Likely (0.6-0.8)	Very likely (0.8-1)
D_{dc}	Negligible		0.25			
	Minor	0				
	Moderate	0				
	Significant		0.34			
	Severe			0.41		

4.2.2. Scenario D: RFID-TTI implementation

The obtained risk value for the scenario with RFID_TTI implementation is:

$$R^S = 2372.7\ euro$$

The resulting risk matrix is displayed in Table 3.

Table 3 Risk matrix for the scenario D (RFID_TTI implementation)

		H_{dc}				
		Very Unlikely (0-0.2)	Unlikely (0.2-0.4)	Possible (0.4-0.6)	Likely (0.6-0.8)	Very likely (0.8-1)
D_{dc}	Negligible		0.40			
	Minor	0.1				
	Moderate	0.02				
	Significant		0.34			
	Severe	0.14				

The frequency of the number of time that the total damage level falls within the class “severe” drops down to 14%. At the same time the frequency of “negligible” damages increases from 25% to 40%, while for the class "significant" the frequency remains the same and equal to 34%. The resulting risk reduction obtained with this RFID-TTI implementation is about 50%.

Figure 7 shows the error distribution in 1000 runs, while Figure 8 shows the number of times that the system has selected each kind of mitigation action.

When type pp error takes place (125 times) the possible mitigation action is "product rejection" and can be applied in all the cases (125 times).

In case of "type c" error, the "express delivery" mitigation action is successful in 237 cases of 485 (49%), in all the other cases "travel cancellation" is applied.

In case of "type s" error, "accelerated delivery" is successful 394 times of 801 (49.2%), otherwise, as for type c error, travel cancellation is applied.

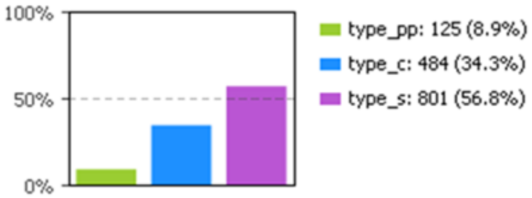

Figure 7: Scenario D, error occurrences in 1000 iterations

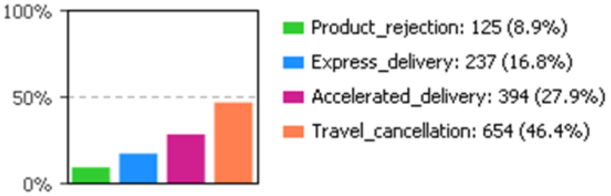

Figure 8: Scenario D: Mitigation action distribution (1000 iterations).

4.2.3. Scenario D: implementation costs

The costs can be divided in to two groups: warehouse implementation costs and tag's costs for each freight unit. The cost of each RFID reader is in the range 1200 euro (2 antennas) -1600 euro (4 antennas, if needed). Installation costs have to be added for each portal and can be between 300 and 600 euros. The cost of each RFID-TTI tag with temperature sensor is between 9 euro and 15 euro, depending on order quantities, much higher than the cost of a single RFID tag that is between 0.07-0.1 euro. It is possible to notice that tags with sensors are quite expensive, but it is important to underline that they can be reusable a very high number of times within the battery duration. Therefore, the average cost of initial hardware implementation for Scenario D can be considered equal to 5550 euro (3 portals). Whilst the average cost for 364 RFID-TTI tags is about 4368 euro. The cost of the middleware, needed to communicate tag data to the software, is included in previous costs, while the costs needed for the software are not displayed since can be much variable in relation with the amount of data managed, how data are stored and the integration with the company management software.

5. CONCLUSIONS

Traceability represents a major concern in supply chains of perishable products. Fresh goods contamination is a critical issue since the increasing complexity of supply chains makes these events more likely to happen (Bruzzone et al. 2014). Progress enables complex and integrated monitoring systems based on Internet of Things, continuous monitoring and real-time alerting. However, the adoption rate of these innovations is not fast enough due to the need of expensive equipment and a robust digital infrastructure (Gallo et al. 2018).

Montecarlo simulation is used to estimate the value of damage in presence of uncertainty. A similar approach in the food industry has been applied by Tufano et al. (2018).

The present study shows how the introduction of RFID-TTI technology allows a risk reduction of about 2363 euro (about 50% with respect to the current scenario) for the management of 364 freight units, having the possibility of mitigate human error consequences with "express or accelerate delivery" and travel cancellation if all possible mitigation actions don't allow to guarantee the suitable quality level during the logistic chain.

As far as implementation costs is concerned, the possibility of reusing RFID-TTI tags and who is in charge of applying tags to the units (producer, carrier…) become crucial aspects to discern how much the technology can be convenient for the carrier company.

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