Tracking in real time the blood products transportations to make good decisions

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ABSTRACT

The French Blood Establishment (EFS) is the only one in France allowed dealing with the blood supply chain. The EFS centers are scattered in France and blood products are transported over hundreds of kilometers, from collection sites to hubs and from the hubs to distribution sites. The strong constraints on lifetime and storage conditions imply a traceability of transportation steps very accurate, which is necessary in case of unexpected and unwanted events. To make "good" decisions, we propose in this research work to use the Physical Internet philosophy. Thanks to sensors in containers and Complex Event Processing modules to aggregate and filter the data collected, we would be able to create a real time "field model". In case of crisis this model would be helpful and perfectly adapted to help the crisis unit to make "good" decisions and maybe propose solutions based on the past events.

Keywords

Blood, Physical Internet, Complex Event Processing, Process Mining

INTRODUCTION

The French Blood Organization (EFS) is the only one in France allowed dealing with blood supply chain from the donor to the receiver. In order to respond to the hospitals and patients' needs (more than 1 million people treated with blood products each year) the EFS has to collect blood (or directly one of its components) from around 10 000 people every day. This whole blood is split in 3 components (platelets, red blood cells, plasma) and samples are tested to validate the innocuousness before distribution to patients. We won't describe in this paper the plasma and platelets donations processes. In fact, the transportation processes are almost identical to the whole blood ones. Moreover, the whole blood represents the highest number of donations.

Different blood types exist and they are often not compatible one to another. Hence, this organization has to take from donors, among the 10 000 daily donations, the most important diversity of whole blood everywhere in France. Knowing that between two donations of "whole blood" donors have to wait 8 weeks at least 560 000 regular donors would be required (8 weeks * 7 days * 10 000 donations per day). However, on the ground, donors do not come back every 8 weeks precisely to give their blood and their donation may be refused (medical issues, illness). As a result, 40 000 day collections are necessary everywhere in the country each year, changing the collection sites in order to attract the broadest part of people with enough blood diversity (groups and phenotypes). Each year, the EFS collects around 2.98 million pouches and samples from 1.65 million donors. For this reason, this establishment is scattered among French regions in 132 EFS centers to collect and distribute the validated blood products to any hospital. These "blood products supermarket" (called distribution centers) have to store enough blood products with a high diversity, ready to be delivered because we do not know a priori the blood characteristics of the receivers, except for planned surgery or treatments.

Because of strict storage conditions (different temperatures according to the products, from -25°C for plasma, to +22°C for platelets), some short lifetimes (5 days for the platelets) and traceability requirements, it is necessary to follow precisely each pouch during its lifecycle. In fact, a blood product may cross hundreds of kilometers between the donor and the receiver. Knowing the temperature and time constraints, the transportation requires location and temperature tracking of each product in real time in order to optimize the transportation and detect unsafe products before distributing them.

The EFS centers are scattered in France and the blood products are vital for thousands of people. As a consequence, any attack or massive accident and any climate incident (storm, flood, etc.) or traffic jam may affect the blood supply chain. Therefore a crisis situation has two effects on the transport of blood supply chain: (i) an unpredictable request of blood products is made in the area of the crisis situation, which could imply a break down of specific blood product and (ii) the roads used by the supply chain as to be modified in order to take into account the effects of the crisis (e.g. road closure, traffic jam, etc.).

Therefore the work presented in this paper aims to modify the supply chain in efficient way based on the information gather from the crisis situation. For this, the main contribution of this paper is the description of a case study and the description of our approach to achieve this objective. Thus this paper is divided in three parts. In a first part, we explain several concept and research works that could be used to improve the blood products traceability during transportation steps and the process robustness to incidents. In a second part we develop the EFS organization and transportation process. In a third part we discuss the advantages of such approach to in a crisis management.

SCIENTIFIC CONTRIBUTION

Due to the consequences on ill or injured patients, the EFS must be able to react quickly and efficiently to any crisis due to an unforeseen event that affects the blood product supply chain. Therefore our objective is to transform the supply chain into an agile supply chain able to react at least to these 3 kinds of requests:

1. Blood product instant rise in a hospital or an area (attack, massive accident)
2. Site closure or break down of specific blood devices (testing laboratory, blood irradiating device)
3. Modify the supply chain based on information of the crisis situation (road(s) closure, traffic jam, forest fire, flood)

As described below, the transportation is one of the most sensitive steps of the blood supply chain during which currently we are almost blind. However, in case of an unforeseen event, which launches a crisis, we have to react quickly and efficiently with enough reliable information to make a "good" decision.

Agility

In order to meet the needs implied by a crisis, any system has to be agile and adapt the response to the field. According to (Bénaben et al. 2015), agility can be considered as the ability to perform detection and adaptation to events (in a rapid and efficient manner). Agility may be considered as a way to adapt the dynamic of the situation and can be defined as follow (Barthe-Delanoë et al. 2013):

Agility = (Detection + Adaptation) * Reactivity

1. The detection is the finding of a situation gap that makes the ongoing business processes not relevant to the running situation,
2. The adaptation is executed, when a gap occurs, to change the current business processes to make them better relevant to the context,
3. The reactivity is a property that must ensure that detection and adaptation are done in a real-time (as fast as possible).

As a result, agility would permit to detect if the current transportation processes meet the requirements of the existing situation, which changes and evolves, and modify these processes if they are not yet relevant. The detection appears here as a key point to be able to adapt our way of doing in a crisis situation. During the blood product transportation processes we have to retrieve data from the field to have a real time model of the existing situation.

Physical Internet

Knowing this need of reliable information in real time, a Physical Internet (PI) approach could be helpful to reach this goal. As explained by (Crainic and Montreuil, 2016), the PI initiative is developing concrete means able to transform the fragmented freight transportation, logistics and distribution industries into an industry based on hyperconnected logistics. Goods will be encapsulated in designed-for-logistics standard, modular, smart and reusable PI-containers, from the size of small cases up to that of cargo containers (Crainic and Montreuil, 2016). These PI-containers should be routed across open logistics centers by exploiting real-time and worldwide identification and tracking systems. These containers can carry a number of data or information needed during the various operations related to transportation and handling (Charpentier et al. 2015).

Actually, a lot of existing research works focus on the supply chain improvements of such an approach. We think that these concepts could be used in order to improve the blood product supply chain and manage crisis more efficiently thanks to the amount of data collected from these containers. In fact, regarding to the number of blood products containers transported every day in France (several thousands) at any hour between dozens of EFS sites, the PI approach just for this organization would generate a huge quantity of data. These data concerning different events the PI-containers pass through, after being treated automatically would allow us to know the processes states with a high reliability and make a "good" decision.

Conceptually, the PI-containers can hold any product, like a traditional box but are active because they possess a component that owns several data linked with the shipment. (Sallez et al. 2015) distinguishes 3 types of PI-container:

- The T-container, like the actual one, it is directly transported by trucks, trains, boats, etc. In our case, the trolleys loaded in trucks are T-containers.
- The H-container, dedicated to be handled. It measures one of the several standard sizes, like the containers used currently at the EFS for fresh blood pouches or samples for instance.
- The P-container, it constitutes the packaging of each product, in our case this is the pouch.

The P-container sizes are adapted to the H-container dimensions, and that the same between H and T containers. These different sizes appear essential and well adapted to our need. In fact, if something unexpected happen which could have an impact on our products we need to know their location and storage conditions. If we track the H-containers (or T-containers), and know the list of the P-container they contain, knowing the location and storage condition of the H-container, we know location and storage condition of the P-containers and thus of our products. Thus, we would be able to follow each pouch in real time and warned in case of problem.

Complex Event Processing

The encapsulated containers' sensors collect a huge amount of data (several thousands of container, data collected every X minutes) that has to be treated to model and describe the process state (see figure 1). For instance, Physical Internet containers will send data like "I am here, my speed is X and the temperature Y". Each data alone does not enable to deduce anything and we do not know if this container is endangered. Similarly to (Villari et al., 2014), we would like to use lambda architecture to exploit PI approach for two purposes: a real time and a reactive analysis. First, thanks to a Transport Management System software we plan the trucks rounds, and every containers route.

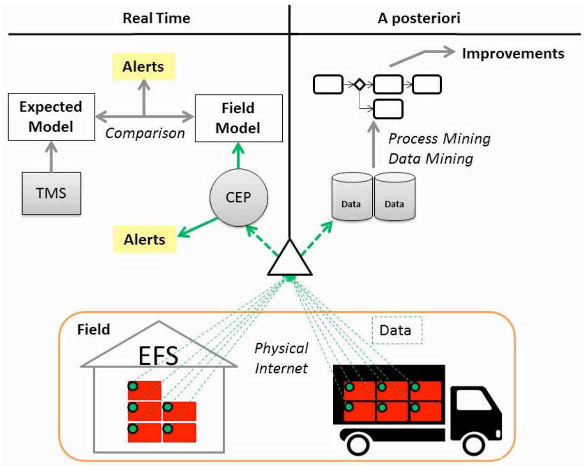

Figure 1. Lambda architecture for surveillance module

On the one hand, next to that, a complex event processing module aggregate, reduce and filter in real time all the data collected and sent by the sensors. We would be able to create alerts, based on specific and simple rules ("the temperature is lower than X"). At the same time we feed the "Field model". This model is compared with the expected one (provided by the TMS) and complex alerts are produced in case of divergence. This system would have two advantages:

1. Detect a crisis situation based on reliable information built with simple and complex rules
2. React properly in real time to a crisis situation, knowing a "Field model" fed in real time with data

In any case, it would be easier to make accurate and adapted decisions thanks to real facts measurements.

On the other hand, we will be able to rebuild our crisis management processes. Indeed, these data may be stored in databases. Data Mining and Process Mining on these huge log files, processed after the crisis, should be able to model the processes and find ways of improvement if any similar case occurs in the future. The Process Mining approach we use here is described by (Van der Aalst, 2011). Combining data and defining rules "If the container was here at this temperature this event occurred" we define the state of each container all along the time and the process step they went through. These analyses after crisis would be helpful to react faster and better if the same root events occur. Alerts on these particular events could be generated and allow the EFS to be aware that an unwanted situation is about to happen with a high probability.

BLOOD PRODUCTS AND SUPPLY CHAIN DESCRIPTION

The Blood supply chain

The EFS is split in 15 "regions" in France. Each of them owns its regional departments (collection, preparation, distribution, technic, logistic, communication, etc.). These departments apply in their perimeter the national strategic decisions and participate to national projects about their field.

We count 132 sites in France. In general, a region is made up of three types of sites:

- A hub composed by the preparation and usually the administrative and support departments.
- Several sites located throughout this region (from 5 to 15 approximately). In the majority of these sites a collection and a distribution centre are located. From these sites "one day collection teams" may leave to collect blood in near towns, universities, etc.
- In 4 regions, there is a laboratory, named QBD, in which we test the samples of every blood donations. Anywhere a person gives his blood the samples linked to the pouch will be treated in one of the 4 QBD.

Figure 2 represents those sites in a region and the main labile blood products flows between them.

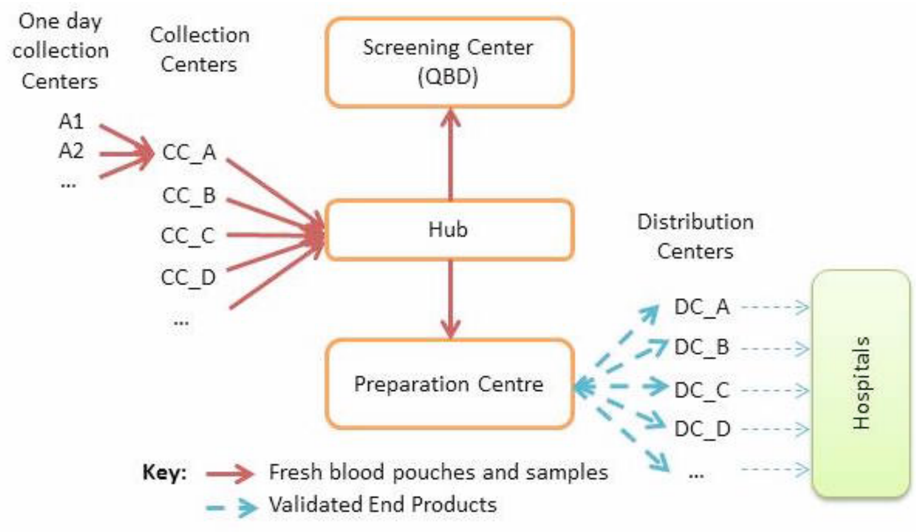

Figure 2. Labile blood products flow between collection and distribution centers

The supplying blood products

In order to meet the labile blood products' needs, the EFS follows an accurate process between the donors and the receivers (cf. figure 1):

1. A donor gives his whole blood in a collection centre. This collection centre may be in an EFS site or in a one day collection site (truck and/or tents, spaces lent by firms, universities…) that comes back to the nearest EFS permanent centre at the end of the day. A 500ml pouch and 6 blood tubes are collected from each donor.
2. All the donations (pouch and sample tubes) of the day are gathered in the EFS site and put in transportation container. A carrier, on a planned round, comes at one specific moment of the day and carries these boxes to the preparation platform, usually located in the regional hub.
3. In this site, each pouch will be treated and its components separated in three end products: plasma, platelets, and red blood cells. The day after at about midday these products are ready to be delivered if the samples do not reveal an illness. In some occasions, the product has to be irradiated before being distributed to a fragile patient. This need usually implies an extra transportation step to reach the irradiating device (quite rare and expensive) the closest.
4. In the meantime the sample tubes of all the collection centres of the region are gathered in this hub and carried to the QBD which is usually located in another site and another region (4 QBD in France vs 15 regions). In this lab, the samples are tested to confirm that the labile blood products are healthy and we are allowed to deliver them to patients.
5. If the results of its samples are correct, each labile blood product (plasma, platelets, red blood cells) must be stored in a central warehouse or in one of the regional offset stock (distribution sites). When a hospital needs a product, as a matter of urgency or for a scheduled surgery, a nurse calls the blood distribution site the nearest, asks for a product and call a carrier to pick it up. If this EFS centre owns this blood product it delivers it. However, if this EFS centre does not own it, we ask for an urgent transport between this centre and the closest one which owns it.

These regional and inter-regional transports are most of the time regular. Trucks rounds are planned to pick up blood donations and distribute end products to each collection/distribution site every day.

Lifetime and Storage conditions of blood products

The blood supply chain is very sensitive to any unwanted event because of:

- Product diversity: There are several dozens of blood products types (groups and phenotypes), which are often not compatible one to another. Consequently, it is necessary to take blood from different donors and store the most important diversity of blood products the closest to the future needs. To achieve this need, the EFS must be located in many decentralized centers in France which means to may be concerned by any traffic or weather issue in France.

- Compatibility: An inappropriate product may be lethal to a patient. Thus, it is essential to own and find in the blood products stock the appropriate one. Thus, each pouch can be asked anywhere. In case of accident or attack, we might have to find and transport as a matter of urgency over hundreds kilometers the only pouches compatible with a patient injured.
- Storage conditions: The blood products, as described below, must be stored in appropriate temperature environments and some of their lifespan are short between the donation and the transfusion (5 days for the platelets). Blood products are critical and have to be treated carefully all their "life" along, either in a site or a vehicle.

We can consider that each site in a region is 50-100km distant from the others. We distinguish 3 main transports. It is important to understand that in a same vehicle containers of each step may be gathered:

1. From the collection centres to the hub (raw materials: whole blood pouches)
2. From the hub to the QBD (samples of the raw materials)
3. From the hub to the distribution centres (blood products validated: platelets, plasma, red blood cells)

We focus here on the storage conditions. The table 1 sums up the constraints:

Table 1. Labile blood products storage conditions

Products	Lifetime	Temperature
Whole blood	Less than 48h	20°C or 4°C
Blood samples	Less than 48h	4°C
Platelets	5 days	22°C shaken
Red blood cells	42 days	4°C
Plasma	1 year	-25°C

Considering the very short platelets lifetime, the gap between storage temperatures and their level which have to be respected during the transport, this process appears as one of the critical step of the supplying labile blood products. Moreover, if we need to deflect a vehicle to supply as a matter of urgency a site with blood products for instance, it may impact fresh blood pouches in this vehicle which need to be treated quickly. Thus, making a decision without knowing in real time, anywhere at any time, the cargo and the state of any vehicle which transport blood products appears difficult.

Traceability and problematic

Currently, paper documents insure the containers (and product they contain) traceability. When a laboratory worker stores in a shipment area 3 containers, he fills in a paper form with different information: his identity, the recipient identity, the current site and the destination site, the containers quantity and their storage temperatures, the date and time. When he takes in charge these boxes, the carrier fills in the same document with his identity, the date and time, and the consistency check of the packages he takes. He leaves a copy of this document on the sender site which notifies his act and shows the evolution in the transportation process of this container. Thanks to temperature sensors in the refrigerated enclosures in the vehicles or into the isotherm containers, we have data about the temperature all along the transport. These data are usually visible in real time by the carrier on his dashboard and by the users (sender or recipient) when all the containers are unloaded.

In case of emergency, this system is not efficient and do not allow to make a "good" decision with enough reliable information. In fact, unless we look at every paper form on each site of the region to know which are the products in the containers in the vehicle we do not have a reliable visibility on what each vehicle transport, either in quantity or quality. In our Warehouse Management System a product may have one of these two states: "In site A stock" or "Sent from site A to site B" but nothing more. As a consequence, the traceability is insured but on different media (papers on sites, temperature in the truck or on a web application, planned round, product in our WMS, etc.) and different places. The sources of exploitable data are numerous, a lot of them are not computerized and there is a lack of some data.

In case of crisis (unexpected demand of a hospital, round vehicle incident (traffic, bad weather conditions, issue with the temperature of an enclosure, etc.), truck overloaded, etc.) we do not have enough information to make a good, or the less worst, decision. The monitoring and the tracking of these sensitive product are not effective and neither efficient.

APPLICATION CASE

We described now 3 kind of crisis that can occur anytime in the EFS:

1. Blood product instant rise in a hospital or an area (attack, massive accident)
2. Traffic jam or bad weather conditions
3. Breaking down of an irradiating device.

In particular those last years and maybe future, France has to deal with terrorism threat. Charlie Hebdo attack, November 2015 Paris attacks, July 2016 Nice attack are one of the last and most deadly terrorist attacks in France. In this situation, or after a major accident (car crash, explosion, building collapse, etc.), the blood needs in the nearest hospital usually rise quickly because of all the people injured. A crisis unit is ready to be opened whenever and the transportation of blood must not be a problem.

If a rise of blood product needs appears in a medium size city, in which an EFS center named “A” is settled, the center will receive all the demands from the nearest hospitals. Usually, in this kind of situation, people are transported in different hospitals, sometimes in several cities in the region, which implies several blood products demands to several EFS centers. As a consequence, the EFS centers that have been asked for products will try to deliver them. In this region, like in every other, emergency transportation processes, containers, transport subcontractors and EFS carriers are defined and ready to be called at any time.

Because the demand is high and diverse, the EFS center “A” may not have all the blood products in its warehouse and even if this center is able to deliver them all, it has to resupply its warehouse as quick as possible. In this situation, the central warehouse in the regional hub site is usually asked to resupply the EFS center “A”. If some products are required as a matter of urgency to be delivered, the closest EFS center of the region, which owns them, must send some of them. In any case, resupplying or distinctive product need, the crisis unit may ask for help to other EFS region and transport blood product as a matter of urgency over hundreds of kilometers. It is not rare and implies a perfect coordination of all this flows between people who are often not located in the same places.

The numerous source of information are here inefficient. In fact, people who coordinate these actions do not know easily in real time where the vehicles they ask for are located neither if the storage temperature is respected and which the products in the vehicles are. Sometimes information from location and temperature sensors is available in real time but in different media that is complex in particular when several region have to provide site “A”. In some occasion, it could be faster to deflect a vehicle, which passes near from this site, but we do not know which the blood products it transports are. If a vehicle comes from another region, it will sometimes deliver the regional hub because of contract conditions. Then another vehicle will transport the blood products to site “A” in the region. In this situation, following and coordinating efficiently in real time the transportation with our current system is almost impossible. Finally, when the carrier arrives near the EFS site, he has to know if there is traffic jam, security perimeter and areas closed because of the attack, to adapt his way. Sometimes a police escorts may be necessary and have to be foreseen. Thanks to the approach we described before we could make decision thanks to a high number of reliable information about our container and adapt in real time vehicle ways to the needs.

The second example is about bad weather conditions and traffic jam. We described the EFS centers network above and noticed that any bad weather condition in France, which has an impact on traffic, may have an impact on the blood supply chain. A typical case is the wildfire or a flood, which create a road closure and traffic jam. Thanks to the real time system we described, it would be easy to know at any time if the products in the round vehicle are required as a matter of urgency on a site, if their storage conditions are threatened and make a decision: deflect the vehicle, make it wait on the departure site, ask for police escort, going back to the last EFS center, etc.

The third example shows how we could optimize easily the transportation in case of problem and save time. In fact, some products need to be treated in an irradiating device before being delivered to patients. This kind of device is very expensive and each region owns at least one, usually located close to the central warehouse. If an irradiating device breaks down, we need to organize transportations to the nearest one, sometimes in another region. Using existing rounds or deflecting a vehicle that contains the blood product we need to irradiate could permit not just to look for an available product in the warehouses of the EFS centers but anywhere around the closest irradiating device, including in the vehicles.

CONCLUSION

To conclude, we described the French Blood Establishment supply chain and the sensitiveness of the products transported. Currently, the traceability is insured but the meanings to achieve these goals are not effective and efficient enough to make good decision in case of crisis. Indeed, the numerous media on which data are registered, and for a large part not computerized, do not allow to the crisis unit or the transportation department director to have enough reliable, accurate and updated information. In order to collect and send data, the use of PI-containers appears adapted. Due to their sensitiveness and their vital impact, tracking (location and temperature) each pouch whatever are the conditions (rounds, emergency transportation) would be a real improvement. The lambda architecture, linked with Complex Invent Processing modules would generate with these data enough useful information to be alerted in case of problem, to make adapted decisions in real time and adjust after the crisis the response processes.

After some iterations, we expect to have enough data and relevant scenario to foreseen a crisis. Indeed, root events apparently not dangerous alone can have a very bad impact if they occur in a specific sequence. If we are able to spot these sequences it is possible to predict a crisis and propose solutions to avoid it or reduce its consequences.

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