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**Article**

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## OPERATIONS, INFORMATION & TECHNOLOGY | RESEARCH ARTICLE

# Controlling risks in sea transportation of cocoa beans

Yilmaz Uygun<sup>1\*</sup> and Syed Asad Imam Jafri<sup>1</sup>

**Abstract:** Due to the importance of cocoa in the food industry, there is a greater need to transport this commodity with fewer rejections and damage to quality. Growing in the tropical areas of the world, cocoa beans travel a considerable distance to their main importing destinations located in North America and Europe, most of which is covered by sea transport. Although an increasing amount of organizations is being involved in enhancing sustainable methods of farming practices to combat cocoa bean losses, this paper focuses on the loss identification incurred during sea transportation. The factors which adversely affect the quality of cocoa beans have been identified through literature and expert interviews and simulated using a System Dynamics modelling software. The main focus of this paper is whether the oft-cited ventilated-container mode of shipment is indeed the recommended solution to all the major risk factors affecting the quality of cocoa beans. In an attempt to mirror the real-time effects experienced by the beans



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### PUBLIC INTEREST STATEMENT

Growing in the tropical areas of the world, cocoa beans travel a considerable distance to their main importing destinations located in North America and Europe. Most of the travel is covered by sea transport during which the cocoa beans suffer from several external influences, such as mold, insects and contamination with heavy metals, etc., that have significant effects on the quality of the beans. The main focus of this paper is whether the oft-cited ventilated-container mode of shipment is indeed the recommended solution to all the major risk factors affecting the quality of cocoa beans. Our research shows that a certain countermeasure may be extremely beneficial under one scenario but detrimental under others. Here, especially ventilation proves advantageous only at higher temperatures but disadvantageous at lower temperatures.

during the sea journey, through the results of these simulations, we get an overview of how each risk factor is triggered and contributes to the degradation in the quality of the cocoa beans with and without the presence of countermeasures, like ventilated container, etc. These results also help us to ascertain the impact of countermeasures in different points in time of the journey, which leads to the conclusion of how a certain countermeasure may be extremely beneficial under one scenario but detrimental under others. Ventilation, as this research suggests, proves advantageous only at higher temperatures but disadvantageous at lower temperatures.

**Subjects: Freight Management; Supply Chain Management; Sustainable Engineering & Manufacturing**

**Keywords: cocoa beans; supply chain; container; risk factors; quality**

### 1. Introduction

Also termed as the “*Food of the Gods*,” cocoa beans are a globally consumed commodity, grown in areas north and south of the equatorial belt (Beg et al., 2017). They occur in cucumber-like fruits with each fruit consisting of up to 50 beans (GDV, 2018).

Western Africa is the international hub of cocoa production. The top producers are Ivory Coast, Ghana, Indonesia, Ecuador, Cameroon, Nigeria, Brazil and Papua New Guinea. Ivory coast accounts for 37% of global production and Ghana is responsible for 20% (Saltini et al., 2013). The demand for and thus the production of cocoa has constantly risen from 2012/2013 onwards (WCF, 2014).

Cocoa beans grown on Theobroma Cacao trees are the important seeds which are processed to extract chocolate liquor, cocoa powder and cocoa butter, which then become primary elements in the production of chocolates, chocolate beverages, cocoa powder and an array of cocoa-related products (Barry Callebaut, 2018). They grow in extreme hot and humid environments particularly in countries near the equatorial region, stretching from Mexico in the West all the way to Papua New Guinea in the East. The cocoa year runs from October to September, and the busiest shipping months from a shipping company’s perspective are October to March.

Cocoa beans are a sensitive product which have special preparing, warehousing and transportation requirements. The beans are accepted from traders and agents after certain quality standards are checked which include (CargoHandbook, 2013):

- Humidity
- Condensation
- Water content
- Post-fermentation/combustion
- Infestation

These are some of the factors that exporters face which leads to loss of cocoa bean quality. During sea transportation, these core factors along with varying temperature levels become a source of problems which lead to damage and/or loss of precious cargo. Although being checked and approved at the port of loading, cocoa beans travel a long distance to reach their final port of unloading, often taking up to 20 days or more. As a result, a significant fraction of the cocoa unloaded at the port of destination is often damaged both physically and chemically (GDV, 2018). Those are either scrapped or undergo some extra heat treatment by specialized service providers to be sold as lower quality beans.

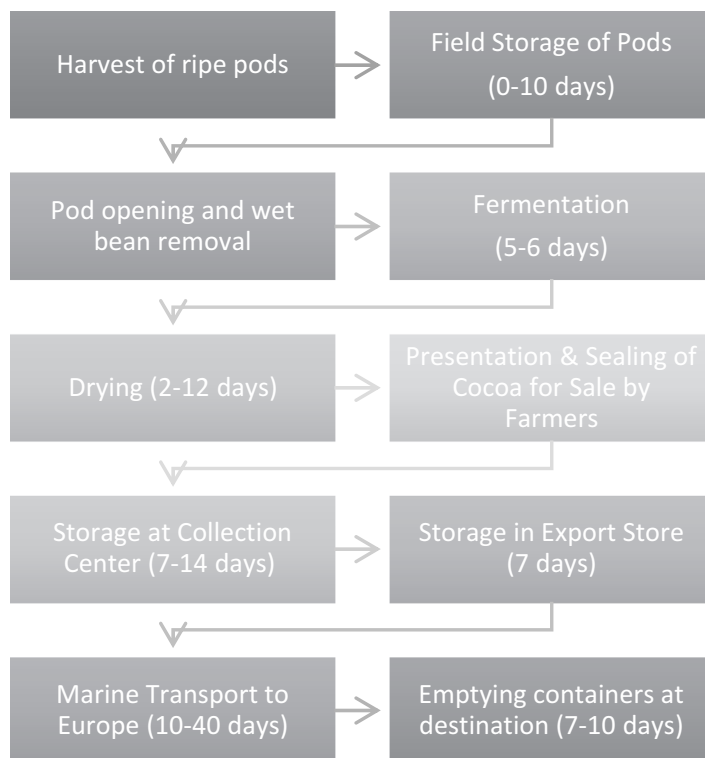
Although the issues in the transportation of cocoa, from farmers to authorized collection or take-over centers, have been discussed in some papers, such as Vigneri and Santos (2007), this paper is based on the research gap which exists in finding plausible or recommended solutions to the issues faced during the sea voyage of cocoa beans after leaving the port of origin, till reaching the port of destination. We are especially interested in the effects of problems related to sea transportation of cocoa beans. Our research is based on determining the standards upon which cocoa shipments should be carried out and compiling the risk factors that arise during the sea journey in a system dynamics model. The model will aim to recognize the impact of each selected risk factor on the damage and/or rejection of beans upon their final offloading.

## 2. Transport processes of cocoa beans

The supply chain of cocoa from the farmland to the end product is quite extensive and comprises numerous components. For the focus of this research, it is important that attention is given to those areas of the chain from which data can be extracted and used to implement in the methodology to obtain the results required.

From the time they are sown, the fruit pods take roughly 5 months to ripen before they are ready for harvesting (Figure 1). During this time, they are exposed to insect infestation and despite improving farming practices, farmers have to fight against pests and diseases. After being harvested, the pods are collected in an open field and are left in that state for up to 10 days. Farmers claim this to be a prerequisite to enhance bean flavor. The pods are then opened commonly using knives and machetes, and wet beans are separated and laid out to form a heap on plantain leaves for fermentation. This is an essential step for flavor formation and enhancement which takes around 5 to 6 days. Fermentation is immediately followed by the drying process, to rid the beans of its high water content. Traditionally and still in most parts of Ghana, drying takes place on mats made from bamboo plants, raised at a certain height above ground. Although heating devices have been introduced to artificially boost the process, it is preferred to carry out this process under sun where natural heat, combined with wind, gradually decreases the water content inside-out. Quick-drying methods might dry out the exterior

**Figure 1. Process of cocoa transport [6].**



layer of the bean, but the core would still remain wet and affect the bean later making it moldy. This is also why this process can take up to 12 days. As the drying phases complete, beans should possess the desired and recommended 7% to 8% moisture content (FCC, 2005).

After drying the beans to the recommended level, the batch of beans is sealed and brought to collection/buying centers. Ghana, for example, has an abundance of buying centers. This country inaugurated the Ghana Cocoa Board (COCOBOD) to form a concrete structure for its entire internal cocoa value chain to ensure producer quality by providing infrastructure, collaborating with privately owned Licensed Buying Companies (LBCs) and maintaining the price system through its Quality Control Division (QCD) to facilitate internal buying and transport of cocoa (Asante, 2014). At those centers, farmers bring their produce which is weighed on certified weighing machines and keenly checked for moisture and quality levels, after which the farmers are paid instantaneously in cash and the bags are sealed by the QCD. Only when the buying sheds have collected enough bags, which could take up to 2 weeks, and a transport vehicle is arranged, the buyers transport the bags to the “take-over centers” of the COCOBOD where the government buys the bags from the LBCs at a pre-ascertained price. Once the purchase is made, the bags are transported to the port and stored at the exporter’s warehouse, which is a well-aerated stocking area according to COCOBOD’s regulation (FCC, 2005). The floor of the warehouse is supposed to be constructed with cement, possess fire-retardant characteristics and be slightly higher as compared to the outside ground to be safe from any form of flooding (ICCO, 2015). This is also where fumigation takes place to rid the beans of bugs and diseases. While waiting for sea vessel to arrive, containers get stuffed, and beans could have to wait another week after being loaded. Once the containers are on the vessel and documentation is complete, the sea journey begins which could vary between 10 and 40 days depending on several factors including distance and transshipment (FCC, 2005).

African countries involved in the production of cocoa have gone through major changes in infrastructure to facilitate and improve the transportation of cocoa. Railroads were the primary mode of internal transportation of cocoa in Ghana till 1974 where they accounted for 70% of cocoa moved, which dropped drastically to 5% by the year 2000 (Jedwab & Moradi, 2016). The road system was initially used as a feeder system to the railroads, which then converted into the most preferred way for the movement of cocoa. This was also credited to the fact that as farming areas increased, and new ones discovered, not all of the lands were accessible to the existing rail tracks. Also, recent governments had spent extensively in the construction of new roads after understanding the scope of their high-selling commodity, to the extent that roads became three times cheaper to build (Jedwab & Moradi, 2016). Hence, the disruptions in the internal carriage of cocoa were identified and dealt with to smoothen the flow of cocoa beans within the country.

### 3. Literature review

In general terms, controlling risks in sea transportation of cocoa beans relates to food safety. In recent years many papers were written that address weaknesses in the food supply chain. Triggered by scandals, such as food poisoning, the safety of food along the supply chain has been brought to the attention of researchers, especially in China. Lam et al. (2013) found that illegal food additives and contamination with environmental hazards are growing problems in the food supply chain in China. Bai et al. (2007) analyze two different safety assurance systems applied in China. Wu and Zu (2014) even compiled a book to look at this problem from different perspectives, such as the safety of import and export food, food safety risk assessment, food safety evaluation, the development of the Chinese legal system on food safety, the reform of the Chinese food management system, food safety standard system, information disclosure. They also give an outlook on possible future research topics. These publications show the importance of controlling the risks along the supply chain to avoid calamities, e.g., as seen during the melamine milk contamination in China in 2008.

Another related area of research is the analysis and optimization of transportation in the food supply chain. Papers, like Wu et al. (2012), test and compare different algorithms to come up with a route of supplying fresh food with the least costs, especially transportation costs. Although

transportation costs, especially for commodities such as cocoa beans, are very important, the only focus on costs yields problems related to using improper and cheap transportation means which cause quality issues as discussed in this paper.

Some papers also look at transportation safety in the food supply chain and try to come up with a ranking of risks and associated control measures. Ackerley et al. (2010) conducted an empirical study among practitioners and experts in the food industry and found out that five food safety hazards pose the highest threats across all modes of transport. These are lack of security, improper holding practices for food products awaiting shipment or inspection, improper temperature control, cross-contamination, and improper loading practices, conditions, or equipment. This study also identifies preventive control measures to eliminate or mitigate the risks to food during transport and storage. These are employee awareness and training, management review of records, and good communication between shipper, transporter and receiver. This paper gives a good but general overview of risks and control measures across all food industries. Risk factors identified in this paper are also taken into account in our study.

On the level of cocoa beans, fermentation has a significant impact on the quality of the beans throughout the sea transportation. According to Moreno-Zambrano et al. (2018), cocoa bean fermentation is one of the least controlled processes in the food industry. Thus, they developed a quantitative model of cocoa bean fermentation based on available microbiological and biochemical knowledge that can quantitatively describe existing fermentation time series and that the estimated parameters can be used to extract and interpret differences in environmental conditions. Improper fermentation, either too much or too less, leads to issues during sea transportation that will be addressed in the following sections.

On the process level, cocoa, as a fragile commodity, can be affected by several risk factors. Even within the transportation part of the chain, there are different segments of transportation which play their part in effecting the cocoa beans. A commodity whose cost and quality are inversely proportionate to time, inefficiencies in handling of cocoa beans during its movement also account for rejections in the product. There are mainly two papers that address such issues.

Asante (2014) conducted a study among 150 candidates from three districts of Ghana. It was seen that in one-third of cases the length of time taken to evacuate cocoa from depots after they were sealed and graded takes longer than 1 week. The longer beans stay at the depots, the more aggravated their quality can become due to higher levels of fermentation, or due to the sacks being more easily attacked by foreign matter. Regarding the rejection of sealed and graded bags reaching the Takoradi port (Ghana) for the crop season October 2012 through May 2013 for one of the mentioned three regions, up to almost 10% of around 216,000 bags were rejected. Rejections occur due to a number of reasons, some of them directly related to mismanagement during transportation. The sealed and graded bags which were rejected were those which had been cleared by the LBCs in the region. Not only does it question the transparency of the LBC but also the procedures set in place to maintain a certain quality level. This study does however prove that internal transportation issues play a key role in defining the quality of cocoa before it leaves the country of origin.

In an attempt to understand and challenge the conventional containers used to transport coffee across the sea, Palacios-Cabrera et al. (2007) analyzed the effects of temperature and relative humidity on coffee beans during their journey from Brazil to Italy including rail transport within Italy. Coffee beans are a product similar in nature to cocoa and require protocols almost the same as those for cocoa. Both are fragile goods which can experience a change in their characteristics when exposed to changing temperature and humidity levels. This more than a month-long experiment revealed that containers stored at the deck of the ship experienced evident changes in moisture, which was recorded through instruments placed inside at the top, middle and bottom of a container. The bags on the top had the most increase in contamination-related values at the



end of the journey which were attributed to two factors, reduction in humidity due to fall in external temperature and/or occurrence of condensation due to external temperature falling below the dew point. Upon the unloading of bags, wetness was also noted on their surface which strengthens the notion of condensation and container rain. Along with other important findings of the case, one important factor was the change in moisture and temperature levels throughout the journey. The month-long journey over the sea created a number of factors which affected the quality of the coffee beans. Therefore, even if the beans were loaded onto the vessel in adherence to international standards, the factors en route play a significant impact on the quality level received at the port of destination.

#### 4. Risk factors

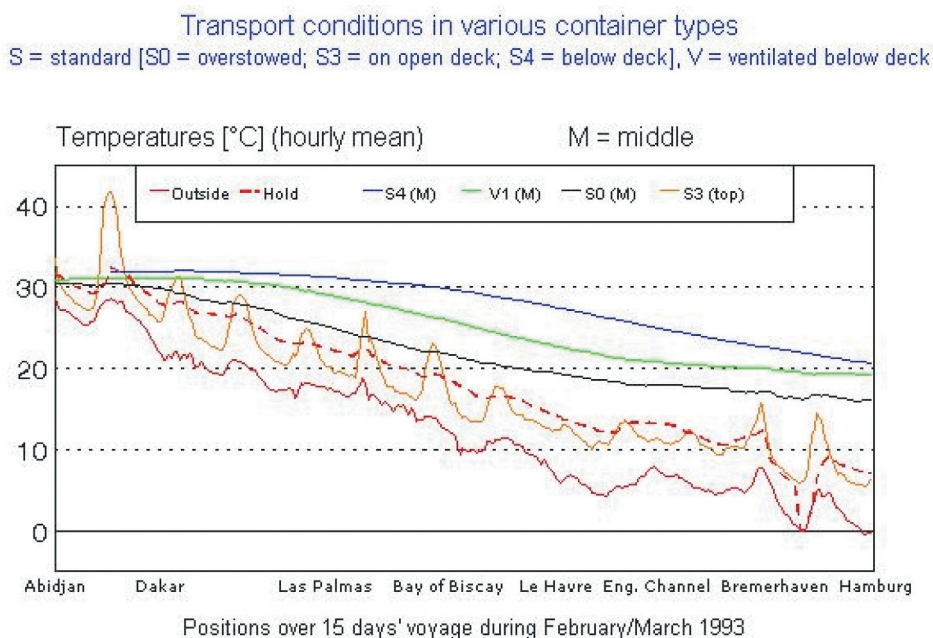
Against the backdrop of these studies, five risk factors are taken into consideration. These are factors which affect the quality of cocoa in the duration of its sea voyage. Each of these risk factors is triggered by temperature. The ideal outside temperature range for transportation should be between 15°C and 25°C (GDV, 2018). Rapid cooling and temperature-drops below the lower limit cause condensation and sweat damage, whereas increased temperature may lead to fermentation and the cargo catching fire. During transportation from western African countries, temperature variations occur at a vast scale. Figure 2 shows temperature differences between outside and cargo hold, and among several storage conditions within a ship.

The primary risk factors taken into consideration in this paper are humidity, water content, condensation, post-fermentation, insect infestation, and mold.

The ideal humidity to transport cocoa is between 70% and 75% (GDV, 2018). Due to temperature changes throughout the journey, humidity levels change as well, which drastically effects the impact of vapor damage on the beans in the form of mold formation (Figure 3). When temperature goes down, the air becomes more humid. High levels of vapor presence clog up the beans which then become part of lower graded beans.

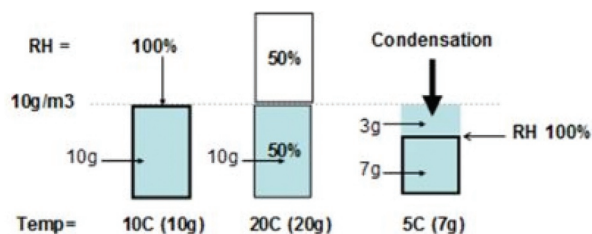
As to water content, cocoa beans are known to be highly hygroscopic and to release large amounts of water vapor during transport. Water content has accordingly been observed to fall by 1–3% during extended voyages. Improperly fermented and dried cocoa beans have a greater

**Figure 2. Temperature change during sea voyage (GDV, 2018).**





**Figure 3. Interplay of outside air temperature and inside humidity (Absortech, 2014).**



tendency to release water vapor. If the water content is below 6%, cocoa beans become brittle, while at a water content of more than 8%, there is a risk of vapor and mold damage which cause depreciation which may go as far as total loss due to rot.

As to condensation, sweat (or mold) damage is recognizable by spots on the bag fabric caused by drops of dirty water. Under these spots, there are clusters of cocoa beans covered with white mold and stuck together. In serious cases, the mold penetrates the kernel of individual beans. As a result, these then smell and taste musty. Such losses are usually limited to only a few bags in a consignment and are caused by the formation of ship sweat below deck, especially at night when the surrounding atmosphere and thus the outer walls of the hold cool down. If the upper layer of bags in the hold is inadequately covered, the dripping cargo sweat cannot be absorbed, penetrates into the bags containing the cocoa beans and causes the damage.

Under suitable ambient conditions (temperatures higher than 25°C, high relative humidity, and lack of oxygen supply) and due to their high oil content, cocoa beans have a tendency to self-heat and post-ferment. A factor to be noted is that cocoa beans have an oil content between 39% and 60%.

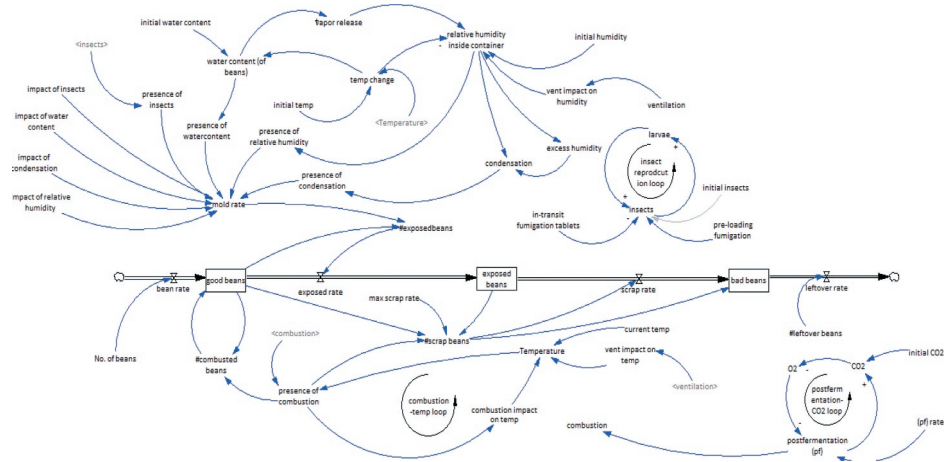
Insect infestation is another risk. Typical pests are the cocoa and meal moth, together with ants and cockroaches, which may cause severe losses by eating and contaminating the cargo. Infested cargo is usually fumigated to eliminate the living insects. Onboard pest control using fumigation tablets may result in dust deposits on the bags. Insect infestation usually originates in the country of production when the raw cocoa has been stored for an extended period, but infestation may also occur on long voyages.

Mold growth may considerably reduce the quality of cocoa beans. There are eight mold species which produce foul-smelling substances and also cause the tissue of the beans to decompose. Some species participate in self-heating of the cargo, while others may form strong toxins (Stancev, 1976). If the molds find favorable living conditions, i.e. when the critical water content of 8.5% is exceeded at an equilibrium moisture content of approx. 88%, the molds rapidly develop within 3–4 days, at the end of which period thousands of spores have formed on the surface of the cocoa beans. The number of mold spores may also be used to assess the quality of the cargo.

## 5. Model

To understand the dynamics between the various risk factors affecting the quality of cocoa beans during their transportation time on sea, some of the risk factors were modeled to understand the relationship. The model was mainly used to study the impact of each individual factor on the total shipment of the beans, however, it shows a lot more. Not only are the individual factors inter-related but some factors have a different impact when acting alone and an increased individual impact when acting with others. For the purpose of this research, Vensim® by Ventana Systems has been used as the software for modeling and simulation of the cocoa transportation. Figure 4 depicts the risk factors and their influence on beans as a System Dynamics specific causal loop diagram with stocks and flows. For better readability, only the major arrows are shown.

**Figure 4. Stock & flow diagram: dynamics of “good” cocoa beans converting into “bad” beans (created in vensim).**



Four risk factors attack the beans though a common fungus called mold. Post-fermentation leads to combustion and self-ignition due to high temperatures and lack of oxygen, which makes the beans non-consumable. All of these factors have separate ranges of parameters, out of which they lead to detrimental effects on the cocoa beans. The purpose of the model was to monitor the behavior of these factors during sea voyage and how they have an impact on the cargo, i.e. the beans. Since only sea voyage is considered, the time duration for the model was set to be 1 month or 30 days. This has been considered a constant and instead of showing its relationship to each individual risk factor, the relationship with the impacting factors shows its overall effect on the outcome. This causal loop diagram has been created outside-in: through literature and expert interviews we pinpoint the reasons for beans getting damaged during transportation and map our way into why the beans are turning into “scrap beans.” Each of the factors are affected by a different set of variables which have either a direct (positive) or an indirect (negative) relation to each variable. For example, “humidity” is positively affected by “water content” of the beans since if the water content of the beans rises beyond the maximum limit they can hold, they convert into vapor and contribute to the existing humidity inside the container. On the other hand, “temperature” has a negative relation as literature suggests that when the temperature rises, the air inside the container can hold more moisture hence relative humidity decreases (see also Figure 3). The variables of each factor determine the impact intensity of each risk factor, and all intensities have a combined effect on the level of damage being inflicted on the beans.

There are several reinforcing loops in this casual flow diagram; the main ones being between larvae and insects (i.e. vermin) and also for post-fermentation, denoted by a black arrow turning counter-clockwise. As the term suggests, the variables reinforce their values on each other showing a constant flow of activity. Reinforcing loops often have one variable with an initial value which gives a starting point for the chain of events. The initial value can be toggled to observe varied results, which does occur in practicality as different lot sizes may have different initial values for certain variables.

The stock & flow defines the process in which a stock or a pool of “good” beans transform into a stock of defected or “bad” beans. The pool consisting of good beans is considered the starting point, from where the beans change their state to being “exposed” and eventually being converted into bad. The reason for adding the exposed level is derived from literature; not all beans which undergo chemical and physical change are classified as worthless. Beans received at the port of destination are sampled and categorized based on the number of moldy beans in that sample size. The suitability of use becomes uncertain when there are more than 25,000 spores per gram (see Table 1) when analyzed during sampling (GDV, 2018). Therefore, exposed beans may also be considered suitable for use.

Table 1. Number of mold spores and their impact on quality (GDV, 2018)				
Category	Number of spores/gram	Macroscopic examination of samples	Suitability for use	Quality
1	100–1.000	No traces of mold growth	Yes	High
2	1000–10,000	Slight development of molds on individual beans	Yes	Low
3	25,000–100,000	Slight to considerable mold growth on all beans	Uncertain	Low
4	> 100,000	Severe mold growth over entire sample	Zero	Poor

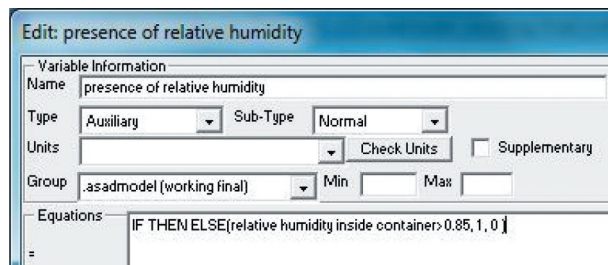
The initial value for “good beans” is assumed as the total weight of the consignment in kilograms, which is defined by the bean rate and for this simulation it is assumed to be 25,000 kg. This is the weight of one container containing bags of cocoa. The “exposed rate” is the number of beans being exposed per day due to all the variable risk factors associated with having a negative impact on the state of “good beans”, through “impact rates” of each of the risk factors. With the exception of the variable “insects,” all risk factors in this model are triggered by “temp change” variable, which is the difference between the existing outside temperature at a point in time and the initial outside temperature when the sea journey began. When conditions are suitable for a risk factor to be triggered, the “presence” of that risk factors becomes 1, indicating the risk factor to be active. For example, “relative humidity inside the container” is positively affected by vapor release, reduction in external temperature brought in by “temp change” and “initial humidity”, while being negatively affected by “ventilation” and a positive change in “temp change.” The polarity of relationships within variables is also shown through a “+” or “-” sign in the causal loop diagram (Figure 4). For the “presence of relative humidity” to become active, the precondition has been set in the variable’s formula. Only when the relative humidity inside the container is greater than 85%, the risk factor becomes active and has its impact on the beans (Figure 5). Similarly, all risk factors have been programmed to become active only under suitable conditions.

With the expose rate being an inflow, the number of “exposed beans” is determined which acts as another stock. After considering the “maximum scrap rate” function, the exposed beans not suitable for use are converted to scrap beans, which determines the number of scrap beans per day or the “scrap rate.” The stocks and flows also show the risk factor “presence of combustion” attached to “#scrap beans.” Beans which undergo combustion are directly converted to scrap as they do not enter the exposed phase since combusted beans are not consumable once affected. This rate then fills up the stock of “bad beans” or the beans not suitable for consumption. The time length of this simulation has been ascertained as 30 days; the average time taken for a ship-bearing cargo departing from Ghana to reach the port at Hamburg (Germany).

### 6. Simulation results

The primary conditions are given in Table 2. These are the primary conditions in which the vessel leaves the port loaded with containers filled with bags of cocoa beans. During the month

**Figure 5. Condition for relative humidity to become active (created in vensim).**



**Table 2. Primary condition for simulation runs. Ideal conditions as per GDV (2018)**

Primary conditions	
Current temperature	0.28
Relative humidity	0.75
Water content	0.06
Insects	0.3
Ventilation	0/1

We defined four scenarios based on significant changes in temperature. In the first one, the temperature is set to the highest realistically possible value that triggers the combustion of the beans. In the second scenario, we set the temperature to the lowest realistically possible value that increases the relative humidity. In the third and fourth scenarios, we add ventilation.

**Table 3. Variables and values for the three different scenarios**

Variable	Values			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Current temperature	0.42	0.05	0.31	0.05
Relative humidity	0.525	2.65	0.325	2.65
Water content	0.05	0.109	0.05	0.109
Presence of water content	-	1	-	1
Impact of water content	-	0.06	-	0.06
Presence of insects	1	1	1	1
Impact of insects	0.05	0.007	0.05	0.007
Fumigation tablets	0.175	-	0.175	-
Presence of Condensation	-	1	-	1
Impact of condensation	-	0.008	-	0.008
Presence of relative humidity	-	1	-	1
Impact of relative humidity	-	0.007	-	0.007
Combustion	1	0	0	0
Ventilation	0	0	1	1

of October, the average temperature in Ghana is 28°C and relative humidity there is 75%. When “ventilation” is set to 0, we assume that the container is not ventilated and at 1, ventilation exists.

In scenario 1, we set the “current temperature” setting in the model to 0.42 (=42°C) to reflect the maximum temperature recorded during the sea voyage from Ghana to Hamburg (see Table 3). At this temperature, combustion comes into effect. It is also important to note that combustion according to current settings, comes into effect at values greater than 0.31 (=31°C). Ventilation is set at 0 indicating that the container is not ventilated. Under current settings the other factor which effects the beans is insects.

**Figure 6. Change of the number of good, exposed, and bad beans over time in the first scenario.**

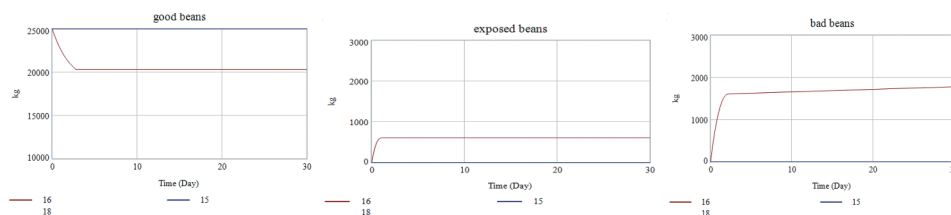


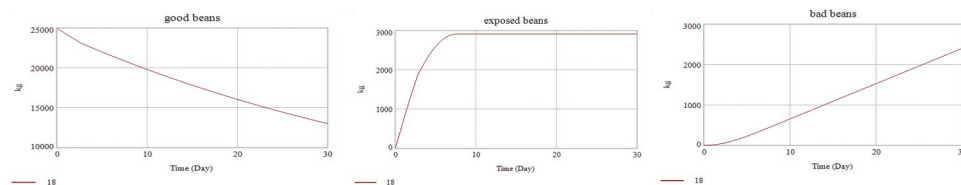
Figure 6 shows the results of the stocks in the model. There is an exponential increase in the number of bad beans to 1,780.25 kg and an increase in “exposed beans” by 606.26 kg by the end of the simulation. The decrease showed in good beans is an accumulation of both exposed and bad ones. There is also a decrease in the level of bean water content due to the increase in temperature. Other risk factors remain unchanged as they are not affected by an increase in temperature.

In the second scenario, the temperature is set at 0.05 (=5°C) to signify the lowest temperature achieved during the journey. In this simulation, the effects experienced at 0.05 already begin at 0.18; therefore, the effects on beans at lower temperatures exist for all temperatures <0.19 (relative humidity threshold). With the temperature falling well below optimum travel conditions, relative humidity increases beyond 100%. As the literature suggests, when relative humidity surpasses 100%, condensation forms on the inside of the containers due to excessive moisture which leads to sweat damage. Combustion is inactive while all remaining risk factors are active, contributing to a higher mold rate. This results into higher exposed beans, increased levels of bad beans and hence lower levels of good beans (Figure 7). This shows us that extremely low temperatures have a more severe impact on the beans than extremely high temperatures.

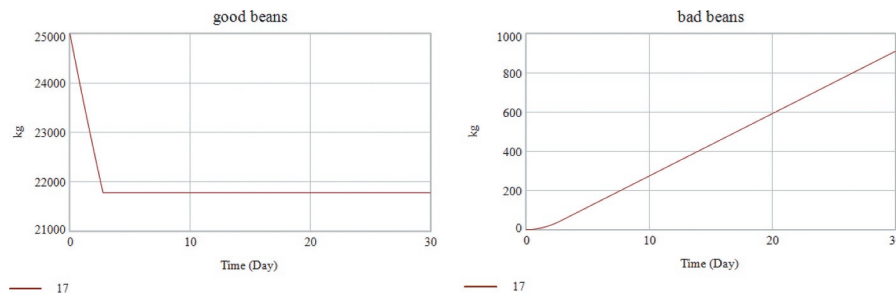
In the third scenario, ventilation was switched to 1 to observe the effects on beans when they are transported in a ventilated container. With the temperature set at 0.31 and with ventilation on, combustion has not come into effect because with ventilation on combustion will come into effect at 0.35 or higher. As a result, the number of good beans effected has decreased and which leads to lower number of aggregate bad beans to 910.89 kg (Figure 8). Even with combustion not contributing to bad beans, the presence of insects still has its impact on the state of beans.

In scenario IV, the variables are set at the same values as scenario II but with ventilation set at 1. As already established in Scenario II, the relative humidity threshold is 0.19. As ventilation decreases “current temperature” by a factor of 0.3, the threshold with ventilation active increases to 0.22, i.e. the effects in Scenario II start to come into effect at 0.21. The results achieved show the extent of bean damage at extreme low temperatures but with ventilation active as it effects not just temperature but also levels of relative humidity (Figure 9).

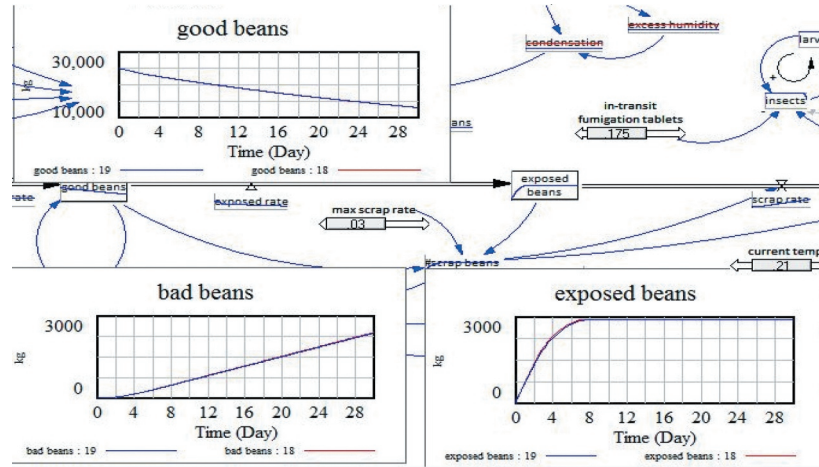
**Figure 7. Change of the number of good, exposed, and bad beans over time in the second scenario.**



**Figure 8. Change of the number of good, exposed, and bad beans over time in the third scenario.**



**Figure 9. Main results of scenario IV with ventilation.**



As Scenario I shows results for “current temperature” = 0.42, it is important to note that the results had already changed at “current temperature” = 0.31 due to combustion that starts coming into effect at this temperature. For result comparison, we compare results at values 0.31.

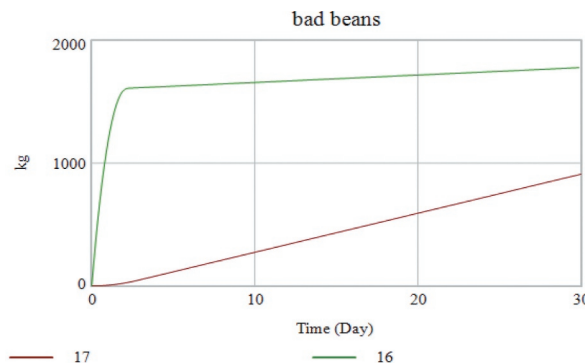
**7. Discussion**

In Figure 10, the green curve, run 16 (Scenario I), shows results at “current temperature” = 0.31 indicating higher values for “bad beans” as it incorporates scrap beans due to the presence of risk factors “insects” and “combustion.” Whereas the red curve, run 17, shows results at “current temperature” = 0.34—which is just below where combustion starts—indicating lower levels of “bad beans” since only “insects” influence the outcome in this state.

This analysis shows that active ventilation can delay the effect of combustion, which is beneficial as this is a risk factor that converts beans from their normal state to scrap, with no exposure phase in between. Therefore, any steps taken to delay the combustion process would prove extremely beneficial for the outcome of beans. One of the limitations of this model is that it does not calculate losses every increment of “current temperature” as the impact of risk factors has been preset at certain exact values of temperature. However, it helps understand the stages at which impact is maximum or most drastic and eventually how the state of beans changes overtime.

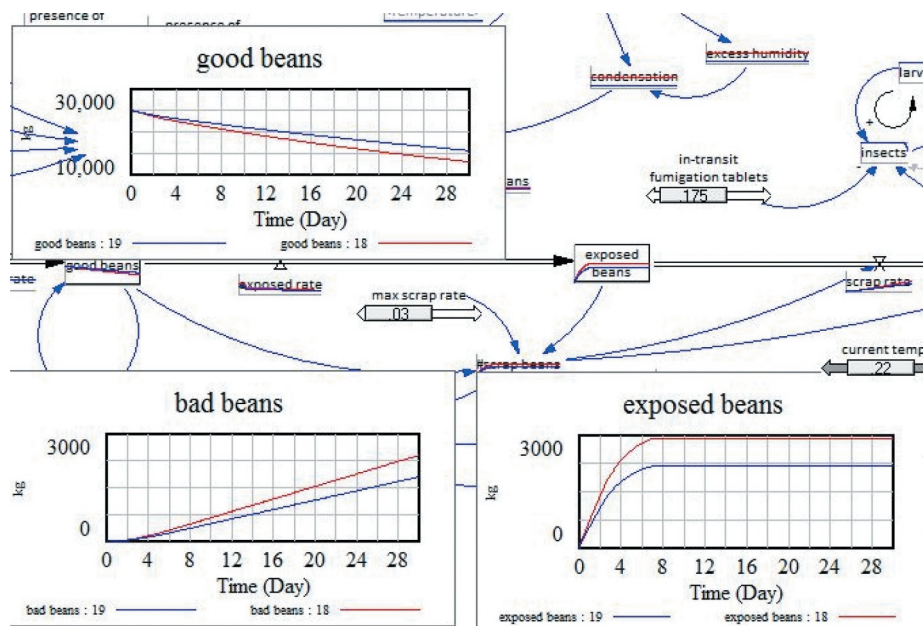
In Figure 11, we compare Scenario II and IV where ventilation plays the differential role again. However, the impact of ventilation, according to the model, at lower temperatures is more detrimental than valuable. Similar to the previous case and keeping the limitations in mind, we see all other risk factors having their influence on the condition of the beans well before they experience the lowest

**Figure 10. Comparison of scenario I & III: impact of ventilation of No. of bad beans.**





**Figure 11. Comparison of scenario II & IV: impact of ventilation of No. of bad beans.**



temperature conditions. Since ventilation has an indirect relation with temperature with a factor of 0.3, the value for “current temperature” will decrease at a faster rate when ventilation is active. Therefore, when “current temperature” = 0.22, risk factors will not start operating with ventilation ( $0.22 - 0.3 = 0.19$ ) as active as risk factors damage the beans only at “current temperature”  $\leq 0.18$ . The graph also shows the distinction between results when ventilation is active and inactive. It is important to note that ventilation when active has an indirect relation with “relative humidity” as well.

This analysis supports the claim made in one of our expert interviews that an increasing number of importers are using regular containers or mega-bulk method for the shipment of cocoa beans instead of the recommended ventilated containers. The claim was that the use of regular containers is to minimize transportation costs as the use of ventilated containers is costlier. However, with these simulations, we can also ascertain that although ventilation is a necessary measure to avoid risk factors such as combustion by reducing temperature and preventing excessive post-fermentation, it triggers or expedites other factors providing them a more favorable environment to exist and have their impact on the overall bean quality. Since the model also shows that the existence of four risk factors combined is greater than the elimination of one, it could be in favor of importers of cocoa to use regular containers even though that one factor, combustion, changes the state directly from “good” to “bad” which means the beans would not be consumable.

## 8. Conclusion and recommendations

With the use of ventilated containers, cocoa beans may be protected from the risk of combustion by delaying the initiation of the process. Therefore, ventilation proves to be a very beneficial countermeasure, keeping in perspective that combustion directly converts good beans into bad ones, skipping the exposed beans state entirely. However, at lower temperatures when other risk factors considered under this study become active, ventilation helps to expedite the process by making the good beans reach the exposed state quicker and eventually becoming part of bad beans. As ventilation plays the role of reducing the temperature within the container, this act proves advantageous at higher temperatures but disadvantageous at lower temperatures. Although ventilation has numerous benefits which include reducing the effects of certain risk factors such as condensation and relative humidity, the negating effects with temperature are much higher. As a result, the overall impact of adding this countermeasure proves to be counterproductive. Based on the results achieved through the modeling, we suggest adjusted ventilated containers triggered by changes in outside temperatures. As different risk factors are triggered over a range

of temperatures, the containers may be fitted with sensors which activate or deactivate ventilation upon temperature changes, to contribute towards maximum protection of cocoa beans from external risk factors.

The study was undertaken with some limitations and challenges did come up along the way. Keeping in mind the ever-changing nature of environment at sea, it might be difficult to simulate the conditions to be exactly accurate based on assumed values. As mentioned earlier in the study, although the variables were created based on information from literature, they were calculated based on assumptions due to the unavailability of actual data which is also why the existing model does not incorporate all of the risk factors discussed in the literature, as adding more variables with assumed values may alter the overarching behavior.

As this research paper is focused on the impact of external factors on cocoa beans during their transportation via sea, it could become a basis for multiple streams of future research. The basic principle of the model could be utilized to study the impact of factors using other modes of transportation, for instance, road or rail. The beans also spend a significant amount of time laying in warehouses at the port of origin, transfer and destination due to various factors, e.g., customs, quality checks, government approvals, strikes and more. In addition to this, the contribution of technological advances in Automated Guided Vehicles, e.g., as discussed in Güller et al. (2017), to handle the beans in the ports of destination with respect to managing the fumigation and cleansing process of beans. The System Dynamics approach could be used to analyze the changing nature of the beans when they are stored. The effects of prolonged waiting times at warehouses could trigger a chain of events which could lead to efforts being made to reduce the downtime in the supply chain. A similar study could be made for other perishable items transported over a long distance, which are susceptible to external natural factors like weather.

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