The impact of Industry 4.0 to the environment in the cement industry supply chain

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Abstract:

The arrival of Industry 4.0, the growing concerns with environmental sustainability and the increase of competitiveness in the global market have forced the Cement Industry to focus its attention on the supply chain management activities' optimization. Activities such as the planning and scheduling operations and distribution of goods, are challenges to address to ensure work efficiency. The aim of this study is to draw attention to new researchers to the lack of supply chain management in this industry and its consequences. To work around these problems, the total integration of the supply chain, suggested by the Industry 4.0, should be something to focus on to improve operations and to decrease the environmental impact.

Keywords:

Industry 4.0, environment, supply chain management, cement, logistics, optimization.

1. Introduction

Cement, the glue of concrete, is the largest manufactured product by human society and the basic ingredient for the construction industry [1]. It is the second most consumed substance in the world after water and an irreplaceable ingredient in a vast majority of the applications needed in a daily life basis [2]. In the last 100 years, the world population has grown from 1.5 to 7 billion and nearly 3 billion people now live in or around the cities, and the population and urbanization ratio keep increasing in the recently years especially in the developing countries.

As urbanization changes the global landscape, demand to expand the built environment is growing. This demand reflects both a need to repair infrastructure (e.g., roads, buildings) in countries where old systems have lost functionality and a need to build new infrastructure in countries that are expanding current systems [3]. Consequently, the cement production keeps increasing abruptly, especially in China, India and other developing nations with high urbanization rate and economic increase [1,2]. This upturn in materials production is a cause for concern regarding environmental impact [3].

Being the cement industry an energy intensive industry, it is one of the major contributors for greenhouse gases (GHG) emissions [4–6], specifically CO2 emission, and it is one of the main emitters of particles, NOx and SOx. The cement industry is responsible for nearly 6–8% of total carbon emission, and the cement subsector consumes approximately 12–15% of the total industrial energy [1,7], so in some extent, the sustainable development of cement industry reflects and effects the sustainability of society development [1].

Sustainable manufacturing defined as the creation of manufactured products that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound [5,7], nowadays, has become a very important issue amongst industries around the world [7]. As it was mentioned, given the fact that the cement production is both energy and emission intensive [1,8] and given the need to reduce GHG emissions, especially of CO2, meeting the increasing demands for cement while also responding to the intense pressure to reduce the environmental impacts of their products and operations [9], sustainable growth will be an important challenge to the cement industry worldwide [1,10–12].

Also concerning this subject, some authors argue that increasing energy efficiency is the most direct method for reducing GHG emissions [13,14].

In addition to the fact that the concentration of greenhouse gases (GHG) from manufacturing factory activities and vehicle emissions has increased significantly over the years [13], according to some authors [2,15], it seems that cement industry lacks of Supply Chain Management (SCM).

This new fact adds serious problems to the cement industry sector mainly because the lack of SCM can add unnecessary costs to companies and aggravate the negative impact on the environment. So, according to this it is relevant to start this study with a clarification of what is the cement supply chain and what is the role of the SCM on it. Also, after this first analyse, a relationship between the SCM and Industry 4.0 is going to be proposed, always having in mind that the main goal of this study is to call attention to the actual state of the cement industry and what can be done to make it better, with more efficient processes and less pollutants.

1.1 Cement SCM

Companies seeking to reduce their GHG emissions often find that their direct emissions are dwarfed by the emissions in their supply chains [16], so first of all let us start with the definition of supply chain. Supply chain can be defined as the group of processes that start with the demand for raw materials and end in the relationship with the final client. Between these processes two different flows occur, the material flow and information flow and these two should be synchronized to have an "healthy" supply chain and an efficient SCM. So, SCM has the task to control and connect all the supply chain. A simplification of the cement supply chain is shown in Figure 1. Although supply chain management is a hot topic, still there are not many articles on supply chain in cement industry [2].

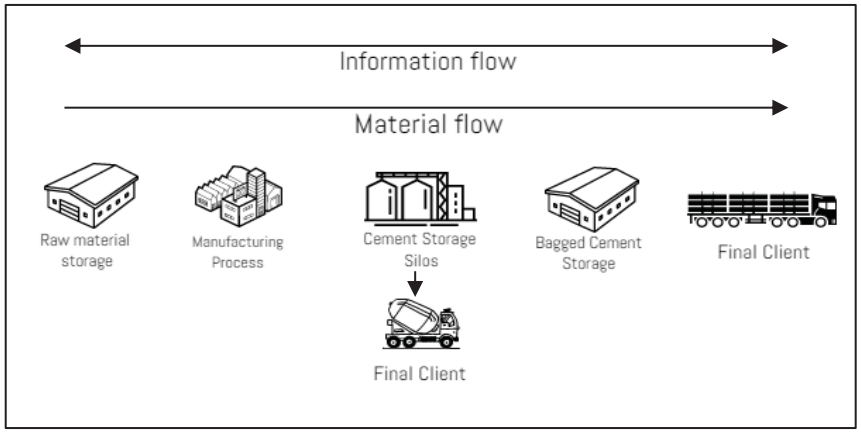

Figure 1. Simplification of the cement supply chain.

The lack of SCM in the cement industry brings many risks both to the environment and companies. To the environment, an inefficient SCM can contribute with unnecessary energy costs and gas emissions and, to companies it can bring logistical costs or even a decrease of service levels by not being able to satisfy the costumer's demand.

It is here where the Industry 4.0 concepts can represent an issue of study. Companies need the concepts of Industry 4.0 to connect all the information needed to have their supply chain updated, optimized and automatized [17,18]. There is a study [19] that explains how small fluctuations in consumer demand translate into increasingly large fluctuations in demand for upstream manufacturers. This amplification of variability in demand throughout a supply chain, known as the "bullwhip effect" can lead to excessive GHG emissions, particularly in basic material manufacturing [16]. The bullwhip effect also exacerbates emissions from freight transport [16]. This problem is just an example among others that are a consequence of the lack of connectivity in the supply chain and, this connectivity is a key word for the Industry 4.0 [20].

1.2 Industry 4.0 and Cement Supply Chain

During the last decade, the use and evolution of information and communication technologies in industry have become unavoidable, mainly by being vital for increasing the organizational efficiency and its level of competitivity, causing the fourth revolution, the Industry 4.0. This new era has promoted the adoption of information and communication technologies in most of the industry activities, but especially in logistics and production operations [18,21].

As the collaboration between suppliers, manufacturers and customers is crucial to increase the transparency of all the steps from when the order is dispatched until the end of the life cycle of the product, it is therefore necessary to analyse the impact of Industry 4.0 on the supply chain as a whole [22].

With the Internet transformation of the digital industry being an ongoing process, consequence of the Industry 4.0, the artificial intelligence, big data, and connectivity indicate the certainty of a new round of digital revolution [20]. In addition to it, concepts like Internet of Things and Big Data are starting to appear in industry mainly with the purpose of gathering information for decision making [23].

So, it is obvious now that the Industry 4.0 is going to take control of which companies are going to stay on market and which are not. With this control over the supply chain that Industry 4.0 promises to achieve, through the integration and connection of the processes, it will be possible for companies to have real time information to help make better decisions.

This real time information mentioned above is specifically profitable to cement companies. Knowing what clients are going to arrive and at what time of the day and knowing how much to produce and when to produce can really help companies improve both the environmental impact and energy costs. If they know exactly what to produce and when, there is not going to be overproduction, that could bring to the environment more pollution than what is necessary. If they know how many clients are in the plant, at any time of the day, and what clients are about to come, using scheduling procedures, they will avoid congestion inside the plants that will directly reduce the time of transportation of the products to the clients, reducing the GHG emissions from trucks.

With the real time information also comes along the concept of optimization. No process is perfect, there is always something to improve in order to reduce costs, to improve service levels or even to reduce the environmental impact. The logistics optimization can bring many benefits to companies, considering what has already been said. With models capable of forecast, plan or even schedule, the SCM becomes an easier task to do and with Industry 4.0 and its technology world the SCM also becomes more digital and precise.

So, to conclude this section and having in consideration how this study started, with the aim to achieve a sustainable growth for the cement industry sector, it is now evident that this will only be possible through the Industry 4.0 point of view. That is, with the use of technology and processes optimization in the supply chain it will be possible for the cement industry to keep growing in a sustainable way.

In the following sections two main areas of study, the planning and scheduling models and the routing and distributing models, are going to be analysed for this case study. The goal is to draw attention for what is possible to do in these two areas applied to the cement industry case study. No model was evolved; however, this research aims to captivate some authors to focus their attention in these areas and their potential.

2. Planning and Scheduling

Historically, the different stages of the supply chain have been managed independently, buffered by large inventories. Industry 4.0 wants to eradicate such philosophies and keep linked all entities and processes. Due to increasing competitive pressures, and market globalization, firms were forced to

develop supply chains that can quickly respond to customer needs. To remain competitive, these firms had to reduce operating costs while continuously improving customer service. Thus, planning and scheduling became some of the most important logistics functions in a supply chain system [24]. Now, reducing costs and increasing profitability are not the only objectives for industries, and environmental concerns are rising. There is the need of making logistics sustainable, while maintaining the development of the company. Therefore, these two fields, logistics and environment, must be deeply connected [5].

Planning determines what and how much to manufacture and to purchase to satisfy future demand for end products. Scheduling takes place at the execution level and is responsible for specifications of time at which every activity should start and end as well as the sequencing of jobs [25]. These activities are very complex and must take place within the enterprise and across the entire supply chain [26]. Industry 4.0 will help, coordinating assets to optimize the delivery of goods, services and information from supplier to customer, balancing supply and demand.

2.1 Cement Production, Storage and Delivery

Warehouses and storage silos play a vital role in the cement industry supply chain, and can benefit as well from planning and scheduling. Silos are huge structures, responsible for holding thousands of tons of finished cement in inventory, until required for packaging or bulk shipping, and cement warehouses, on the other hand, hold bagged cement. Since they are both related to inventory and to the clients' supply, it is important to manage these resources with high efficiency [15].

Overproduction and high inventories can lead to unnecessary costs, both to the company and to the environment. Cement production releases large amounts of harmful substances and, in some countries, is the prime contributor of CO2 emissions from industrial sources [27]. Also, being cement a perishable product, it is likely to decay, if not sold quickly, leading to waste of goods and high costs for the company [15]. Warehousing and goods handling is also a problem and likely to contribute around 2–3 per cent of energy-related CO2 emissions worldwide [5]. Also, high inventory in the warehouses would only contribute to an entropy increase in that area, leading to an increase in human flaws and disorganization of processes. That way, knowing what to produce and when, can be of great use, in such large industry, and bring advantages to the environment too. There is a study [28] that suggests the elimination or reduction of such waste, through Internet of Things and Data analytics. In fact, with these areas, forecasting could be improved and production more automatized.

On the other hand, this industry is living in fierce competition and it is not acceptable for a client to see its demand unfulfilled because of stock break. Also, there is a lot of products a cement plant can offer, and customers always want their orders on-time. Since they go directly to both cement silos and warehouses to meet their demands, it is likely that, at peak times, some traffic jam delays the delivery. Allowing more clients inside the premises than the company can handle, at that time, not only can damage the relations with some customers but also the rest of the operations. Also, traffic congestion has an adverse effect on fuel consumption and the emissions of CO2 and other noxious gases, since when the traffic speed drops below 20 km/h, fuel consumption and CO2 emitted per vehicle-km rise steeply [5]. It has also been estimated that, for a 40-tonne articulated truck, making two stops per kilometre leads to an increase of fuel consumption by roughly a factor of 3 [5]. Therefore, it is imperative the existence of an agenda, that schedules the delivery of orders, so that every customer can see their demand fulfilled in a correct way, avoiding waiting times and congestion. Through optimization models, real time information and data integration between entities, manufacturer and customer, such agenda can be built. This agenda must be favourable to the company and to its respective clients and would not only contribute to a higher service level, but also improve the operations inside the cement plant.

2.2 Loading the Ship

Cement has a low price to weight ratio, making transportation costs higher than other variable costs in this industry. This means that transportation has a large impact on cement companies and should be an area to focus on, to increase profits [29]. In fact, according to [30], because of the weight of cement, it is not profitable to move it in by truck over distances longer than a few hundred kilometres. Maritime transportation enabled the expansion of plants coverage by reducing the transportation cost per ton and it is now cheaper to cross the Atlantic Ocean with 35 000 tonnes of cargo than to truck it for 300 km. In maritime transportation, large quantities are usually loaded at each call to a port and there are a lot of constraints and costs regarding its loading operation [29]. That way, it is imperative an efficient loading plan for the ship, to take the most advantages out of this type of transportation. Two situations arise from this problem, the one where the cement is near the port and the one where it is not. Both situations bring different challenges, to the company itself, and to the environment.

When the cement plant is near the port, the products are normally distributed in a storage yard near the ship. Then, forklifts take care of the transportation between this area and the cranes, which are responsible for loading the ship. In [31], the authors tried to improve the method by which the forklifts move cement and it was proven that a more organized and efficient transport of goods is possible, through optimization models. In fact, there was a reduction of at least 24 operation hours by the forklifts, resulting in an improvement of about 17%. A better utilization of these vehicles would benefit not only the company, but also the environment. A reduction in operating hours could mean less time for the ship at the port, less energy spent from the forklifts and a reduction of harmful emissions. Although it could seem a slight difference, considering the amount of orders of each cement plant, and the number of cement plants around the world, it can have an enormous impact.

On the other hand, when the cement plant is far from the port, cement needs to be transported by a fleet of trucks up close to the ship. Here, the challenge is to know the number of trucks to be utilized, so the loading is done promptly, and they are used efficiently. Although there is not much work in this industry, regarding this problem, in [32] the authors addressed the problem of deciding the size of a truck fleet and the routes taken by them. Optimization models were used to get the maximum savings and promising results arisen from them. Also, it is known that loading trucks have an high cost of air pollution to the public health, as it is demonstrated in [33]. In fact, it is estimated that freight transport accounts for roughly 8 per cent of energy-related CO2 emissions worldwide [34].

Once more, it is proven that, tools derived from industry 4.0 such as optimization models can have a huge impact in savings, not only for the company, but also to the environment.

3. Routing and Distribution

The increasing number of infrastructures in the world lead to a consequent increasing in the sector of transportation, particularly road transportation. Transportation is linked to producer, consumer and production costs. In many developed countries, transportation accounts between 6% and 12% of the Gross Domestic Product (GDP). Looking at a more comprehensive level to include logistics costs, such costs can account between 6% and 25% of the GDP [35].

A great part of this transportation has to do with the industry of the country. For all stated so far, cement industry has a big impact in terms of transportation as well. With vehicle motors relying heavily on the combustion of hydrocarbons, notably with the internal combustion engine, the environmental impact of cement industry, among others has increased with motorization [36]. In the cement industry, the most used vehicles are trucks. Trucking represents impacts on the environment in two different types of pollution: air and noise. In terms of noise, trucks may be a more significant source of noise than other modes of freight transport. A more detailed analysis in the impact of noise and air pollution by trucking can be seen in [37].

On the other hand, a study of the European Environment Agency (EEA) [2] shows the impact of the process of loading trucks to the environment. The study estimates the costs of air pollution, for different categories of Heavy Goods Vehicles (HGVs), to the public health. For example, diesel, used by most HGVs, causes more air pollution per kilometre than other fuels, and the HGVs are responsible for 40-50% of the nitrogen oxide (NOx) pollution from road transport in countries covered by the EEA, which shows the motivation and importance of this study [33]. As [33] reports, for each country, the cost per kilometre that each one of the studied vehicles has, in terms of air pollution. This work took place in Europe and tested sixty-six loading trucks in most of the great cities in the continent. It is important to notice that most of the studied vehicles, are the same trucks moving every day, inside the cement plants all over the world.

It is also important to refer some relevant aspects from this part of the study. For example, the average health cost of pollution from a 12-14 tonne Euroclass III lorry (typical loading tuck) is highest in Switzerland, at almost 0.12 € per kilometre. For the same truck, costs are also high in Germany, Romania, and Italy, for example [33]. The costs become lower in Malta and Finland, where the same lorry causes damage of around 0.005 € [33]. Inside of the same country the cost may differ between regions, like Zurich in Switzerland and Milan in Italy that have some of the highest costs when compared to other large urban zones. Also, the highest costs took place in cities with high population densities or in mountainous areas. In the other hand, lower costs were observed in places with lower population density or in countries where some maritime dilution can take place [33]. In most of the countries in [33], there are at least one cement plant. As stated before, there are serious environmental impacts by trucking but in what concerns to the cement industry, with an efficient utilization of industry 4.0 in a strategic phase of the supply chain, the environmental footprint will decrease considerably.

One of the possible problems has to do with the congestion inside of the plant. A big cement plant receives many trucks daily. Thus, whenever a truck enters on a facility, it must visit one, or more, places inside the plant. If the driver does not know the plant, which could happen due to the complexity and size of the plant, he will probably get lost. On the other hand, even if the driver knows the plant, the route he chooses to reach the destination could not be the best one (minimum distance or minimum time).

Not only in the cement industry, but also in other related factories, a routing solution could bring a big impact and benefits to favour the logistics' management inside the plant. If each vehicle has a route associated to it, the congestion inside the plant decreases [5], the queues in each area also decreases and the number of kilometres travelled by each vehicle is, in the worst case, equal to the situation where the driver chooses the best route, but in most cases, also decreases, directly decreasing the time the vehicle must remain inside de facility. A routing problem can have a huge impact in savings to a company.

This type of solution can be of easy modulation and implementation, and still bring many cost savings, like for example in [38]. It can decrease the number of trucks inside of the plant which cause a lot of air pollution, both because of the trucks but also for the powder ambient that already exists [5]. Thus, the number of kilometres that each truck makes without being necessary will only increase the already existent and inevitable impact of this industry [5,33].

4. Conclusion

In this paper it was shown the environmental impact of cement industry and how the lack of SCM is responsible for this matter. Also, ways of improving this aspect through optimization, were presented.

The cement industry finds itself in a period of fierce competition, due to the introduction of more and more restrict environmental regulations. Normally, managers of these huge companies are a bit reluctant to adjustments in their business because, although they bring improvements for the

environment, highly costs are associated with these changes. That way, finding approaches that can benefit both the company and the environment, can be of great importance for this industry.

Some processes were studied regarding the scheduling and planning of supply chain operations in the cement industry as well as routing/distributing of the goods. The critical aspects of these problems were highlighted, aiming to reduce both costs to the company and the negative impact to the environment.

Finally, with this research, it is our purpose to alert and influence other authors to this kind of problems. Linking both logistics optimization and environmental regulations, may be a way to take cement industry to another level.

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