Warehouse resilience framework for the Covid-19 disruption

Margherita Bernabei[a], Silvia Colabianchi[a], Francesco Costantino[a], Andrea Falegnami[a]

Department of Mechanical and Aerospace Engineering, Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy,
margherita.bernabei@uniroma1.it, silvia.colabianchi@uniroma1.it, francesco.costantino@uniroma1.it, andrea.falegnami@uniroma1.it

Abstract

The COVID 19 pandemic consistently impacted Supply Chains (SCs), involving the agri-food sector. Compared to other SCs, agri-food SCs have not suffered complete interruptions, but the effect of various exogenous and endogenous phenomena has impacted all the actors in the chains. Within the agri-food SC, wholesalers play a strategic role influencing the performance and service level of a large number of players. Despite their importance, there has been no in-depth analysis of the effect of the pandemic on wholesalers. The paper fills this gap by proposing a framework to guide wholesaler during a severe disruption event. The MARLIN framework (fraMework wArehouse ResiLience dIstruptioN) starts from a collection of the principal warehouse KPIs and from the identification through a literature analysis of the most significant factors and indicators on the pandemic disruption. The proposed framework supports wholesalers in identifying the most critical warehouse areas and defining interventions to mitigate the effects of future phases of the disruption. The framework has been tested on a case study involving an Italian wholesaler's warehouse located in central Italy. The results obtained have demonstrated the effectiveness of the framework by highlighting aspects that are difficult to identify in an emergency situation.

KEYWORDS

Coronavirus, distribution center, risk, lesson learned, decision making

1. Introduction

The COVID 19 pandemic consistently impacted multiple economic sectors, involving the agri-food sector. Agri-food supply chain is considered prime goods provider and, for this reason, during the pandemic the Institutions tried to guarantee its normal course. Despite the restrictions, most of the companies operating in these sectors were able to continue to operate. However, endogenous, and exogenous factors still generated negative effects, such as interruptions and slowdowns.

Globally, in the wholesale distribution stages, 75% of companies reported SC disruptions due to restrictions imposed in transportation (Grida et al., 2020; Tanaka & Guo, 2020; Telukdarie et al., 2020), including border closures and other restrictive measures. The wholesale distribution sector has four major sub-segments: healthcare, industrial, high technology, and food services. The pandemic has affected all sub-segments, some more than others and each slightly differently (Aday & Aday, 2020; Mahajan & Tomar, 2021) due to disruptions in transportation networks, wholesale market closures, financial constraints, market uncertainty, unavailability of personnel, closure of distributor retail space, shortages of heavy vehicles, and manpower required to load and unload goods from the warehouse to the wholesale market and subsequent points of sale (Altig et al., 2020; Khan et al., 2021; Ramasamy, 2020). Distribution represents a critical link in the food industry, depending heavily on obtaining raw materials from suppliers and ensuring the continuity of the flow of food from producers to end users. This sector relies heavily on the sales force and transportation services. Both have been severely affected by the stringent measures imposed by governments (Goddard, 2020). Moreover, the retail market closures have further challenged the final node of the SC. Social distancing and blocking measures have affected many retailers with physical stores, leading to a decrease in total sales worldwide, although the share of e-commerce retail sales has increased (Khan et al., 2021). Changes in consumption have also impacted the normal functioning of the SC, including marketing and distribution sectors. Gupta et al. (2021) highlight the critical role of order timing and pricing strategies for wholesale suppliers in a disorderly condition related to supply disruptions. A relationship between the quantity of orders, related to the disrupted supplier, and price leadership, emerged. Namely, this quantity tends to increase when the non-disrupted supplier is the leader. Moreover, the non-disrupted supplier can always charge the higher wholesale price if a disruption occurs before orders are received. Such insights can help operations managers to properly design ordering and risk mitigation strategies and redesign supply contracts in the event of supply disruptions. The pandemic consequences proved to be quite critical also because of the interrelationships among different members of the SC. Based on the definitions reported in the literature by Shu et al. (2014), pandemic has the potential of highly disruptive events, reflecting the improvisation, destruction, urgency, complexity, and diffusivity characteristics, resulting in the so-called ripple effect consequences (Price et al., 2017). Therefore, because such events are difficult to effectively predict and prevent, it is critical to know how to respond in a focused and rapid manner, due to the short-time response required for the above-mentioned reasons. In the current pandemic case, response to the event and consequent performances are key factors to ensure an adequate industry reaction and to mitigate a disruption phenomenon.

To date, there are no in-depth studies that address the issue of pandemic-related effects in wholesale warehouses. The following paper present a new framework to measure these effects, identify problem areas and where to intervene to mitigate future disruption effects starting from changes and effects on agri-food supply chain related to the pandemic. Especially, investigates the pandemic effects of an Italian wholesaler warehouse located in the central Italy. The research paper presents a new framework with a twofold objective reflecting the following Research Questions (RQ): i) how the effects of the pandemic can be measured in a wholesale warehouse? ii) How can problem areas be identified for action to mitigate the effects of future disruption?

Therefore, the framework and its application to a real case is presented in the following sections.

2. Effects on agri-food supply chain

In all the production, processing and marketing phases, shortages in the labor force were found, due to absenteeism of seasonal foreign labor in the countryside and in industry, especially in highly human concentrated ones, e.g. meat industries (Petetin, 2020; Priyadarshini & Abhilash, 2021; Tougeron & Hance, 2021). This situation resulted in a lack of products availability - ranging from raw materials to final goods - hindered all the more by constraints imposed on the international trade of goods both in import and export (Palouj et al., 2021; Priyadarshini & Abhilash, 2021). Pandemic also generated a widespread reduction in production levels, sometimes forcibly suspended or temporarily halted in many production facilities (Lacombe et al., 2021; Rozaki, 2020; Sharma et al., 2020). Pandemic also impacts on maritime, rail, and land transport networks related to food distribution (Loske, 2020). On the other hand, an input shortage, either in labor or transportation, generates negative knock-on effects, since an input in the SC production process constitutes an output of the previous process (Khan et al., 2021). As well, general government-imposed lockdowns have disrupted the employment of many citizens and consequently led to a general decrease in consumer income (Kumar et al., 2021; Kumaran et al., 2021). Furthermore, the security risk associated with theft and crime posed a serious threat to retailers (Felson et al., 2020). On the consumption side, a clearly visible shock was generated by changes in food behaviors and purchases (Abiral & Atalan-Helicke, 2020; Attwood & Hajat, 2020). Points of sale also experienced a decrease in end-product availability (Min et al., 2020; Pu & Zhong, 2020). End-consumer demand has grown in points of sale other than restaurants due to the interruption of HoReCa (Hotellerie Restaurant Café) channels. Also a growing trend in the demand for preservable products and the penalization of highly perishable products emerged (Tougeron & Hance, 2021; Wang et al., 2020; A. Weersink et al., 2021), such as consumption frequency change (Tougeron & Hance, 2021; Wang et al., 2020). So, the food insecurity phenomenon increased in two main perspectives: on one hand, the perceived lack of basic necessities, for the wealthier countries, which resulted in an irrational and immoderate purchase (Deaton & Deaton, 2020); on the other hand, a real food shortage in countries where already before the pandemic the nutritional level of the population was not fair and adequate (Akseer et al., 2020; Khan et al., 2021; Laborde et al., 2021). The persistence of the pandemic may have more permanent consequences on consumer purchasing channels and, consequently, retailers must adapt to this mutation, for example by favouring a multi-channel, physical and online marketing distribution strategy (Goddard, 2020). Afterall, the pandemic phenomenon has significantly impacted all production, processing, retail, distribution, and consumption activities.

3. MARLIN framework (fraMework wArehouse ResiLience dIstruptioN)

A literature analysis shows that the topic of the negative effects experienced during the pandemic in the food SC is widely discussed among scholars. All levels and sectors of the SC have been affected by this disruptive event, generating secondary chain effects on the entire system. Despite this, to date there is no in-depth research focused on the wholesale warehouse sector.

Therefore, a new framework was developed for the representation and analysis of a disruption in a warehouse. MARLIN framework aims to support SC stakeholders in: identifying areas in which more significant concerns were encountered and defining interventions to mitigate the effects of future pandemic disruption or future phases of the current pandemic. MARLIN integrates different theories and pandemic related research providing to warehouse stakeholders with a deeper understanding of the strengths and weaknesses of their system. The research process – sketched in Figure 1 – began with an analysis of the major impact areas within a large retail warehouse (Phase one). In the following phase two, the emergency areas were identified by selecting through a literature review both the most significant factors and indicators of a disruption and the obligations and limitations that impacted the management of the warehouses during the pandemic. In phase three, to quantitatively assess the state of the system, all key performance indicators related to warehouse management were collected. Finally, during phase 4 the authors conceptualized the iterative steps to be followed in order to apply consistently the MARLIN framework to any food warehouse, as indeed was done for validation purposes.

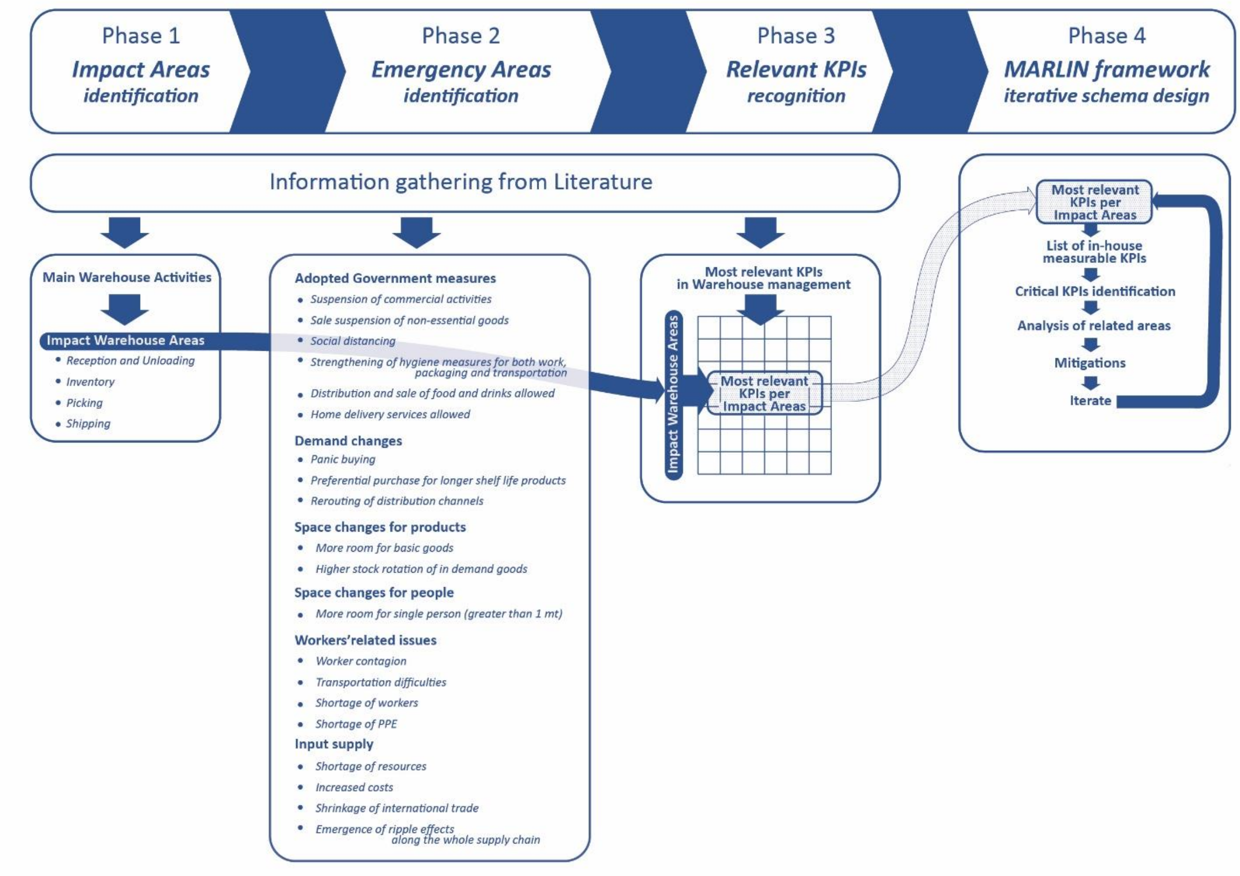

Figure 1. The research process put in place to build the fraMework wArehouse ResiLience dIstruptioN, a.k.a. MARLIN; The final iterative schema to be used is depicted in Figure 2.

This section firstly presents the generic building steps of the conceptual framework, then it shows the specific framework items, providing an in-depth description of their inter-relationships. The account of a real case application has been provided later in the article.

3.1. Impact areas

In defining the main activities and areas of a distribution center (DC) for the development of the framework, the classification of activities proposed by (Frazelle, 2001) and the description of a basic layout of a warehouse by (Staudt et al., 2014) were taken into consideration. Receiving, put away, storage, picking, and shipping are all examples of warehouse activities (Frazelle, 2001) which can be linked to specific warehouse areas (Kusrini et al., 2018). Receiving is a process that entails assigning vehicles to docks, as well as the planning and execution of unloading activities.

These activities are carried out on the warehouse reception and unloading area. Put away is the process of storing a purchased commodity or material in a warehouse. These activities refer to the operations that operators perform to store products unloaded from supplier trucks in the appropriate warehouse locations. This activity entails material handling and quality assurance. Order picking is the process of preparing an order. It is considered as warehouses' primary and labor-intensive activity and it is carried out in the picking area. Finally, shipping is the process of scheduling and allocating trucks to order docks, packaging after picking, and truck loading.

3.2. Emergency areas

Governmental obligations e limitations represent factors that directly or indirectly affected the warehouse management.

The main policy decisions pursued by most of the countries affected by the pandemic were the suspension of certain commercial activities in international and national areas, tourist activities, religious rituals, internal transport services and high-speed rail, maritime traffic, the closure of shopping centers, stores, bars and discos, the postponement of studies in schools and universities, the reduction of the employment rate in some government determined jobs and the conversion of the work system to home-based remote work (Grida et al., 2020). At the national level, the most significant restrictions introduced with respect to the case study can be summarized in the following (Governo Italiano Presidenza del Consiglio dei Ministri, 2021):

- Suspension of commercial activities, including establishments for the purchase of essential goods;
- Suspension of the retail activities, apart from the alimentary kinds and of first necessity, both in the commercial exercises of neighborhood and in the medium and large distribution;
- Suspension of catering services (including bars, pubs, restaurants, ice cream parlors, pastry shops), except for canteens and continuous catering on a contractual basis, which guarantee the interpersonal one-meter safety distance.
- License to operate for home delivery services in compliance with health and hygiene regulations for both packaging and transport.
- License to operate for food and beverage businesses located in the service and refueling areas along the road and freeway network and inside railway, airport, lake, and hospital stations guaranteeing a one-meter interpersonal safety distance.

Considering together these governmental restrictions and the main effects on agri-food supply chain emerged in literature, warehouse management must ensure an effective response, acting on some levers of intervention depending on the case study in analysis.

Demand

Pandemic changed the end customers demand in terms of volumes, since the uncontrolled purchases for certain product categories, a phenomenon known as *panic buying* emerged (Coluccia et al., 2021; Deaton & Deaton, 2020; Hobbs, 2020). Demand changes in terms of types of products, as a growing trend in the demand for preservable products and the penalization of highly perishable products, replacing them with those with longer shelf life arises (Coluccia et al., 2021; A. Weersink et al., 2021; White et al., 2021). Moreover, the closure of commercial activities, e.g., bars and restaurants, switched the final demand destined to HoReCa channels to other sales and distribution channels, including supermarkets, home delivery and online channels (Love et al., 2021). Within a few days, the most of total food expenses, previously spread across multiple distribution channels, shifted entirely to retail, resulting in significant consequences for all retailers (Končar et al., 2021; Skawińska & Zalewski, 2021). As a result, the demand at the wholesale warehouses changed.

Space

- *Required space for products*

Wholesale warehouses quickly had to address the pandemic to ensure faster pickup of goods subject to frequent demand and more space for goods subject to higher demand in terms of quantity. Pandemic effects show a consumption frequency changes because of demand for exported products decrease, growing trend in the demand for local ones (Bucak & Yiğit, 2021; Coluccia et al., 2021; Janssen et al., 2021). Furthermore, preservable products and highly perishable products were mainly replaced with those with longer shelf life (Coluccia et al., 2021; Tougeron & Hance, 2021; Alfons Weersink et al., 2021). Also uncontrolled purchases for certain product categories, as basic food products, emerged (Tougeron & Hance, 2021; A. Weersink et al., 2021). This required a warehouse's re-organization of goods in terms of spatial arrangement and space reserved for individual goods.

- *Required space for people*

Work activities not suspended needed to ensure social distancing, as also clear in the governmental restrictions (Governo Italiano Presidenza del Consiglio dei Ministri, 2021). Social distancing and blocking measures have affected many retailers with physical stores, including wholesalers, leading to a decrease in total number of workers (Khan et al., 2021).

Number of people

- *Number of available workers (unskilled and skilled jobs)*

Absenteeism of labor in industry and in skilled labor (e.g., in transportation activities requiring skilled driving, in port and international trade activities, in supporting production activities such as quality inspections, veterinary services, livestock feed supply and equipment maintenance services), emerged (Nakat & Bou-Mitri, 2021; Thilmany et al., 2021; Tougeron & Hance, 2021). This phenomenon can be traced back both to illness and to difficulty in reaching the workplace because of transportation restrictions imposed, including border closures and other restrictive measures (Governo Italiano Presidenza del Consiglio dei Ministri, 2021; Grida et al., 2020; Tanaka & Guo, 2020; Telukdarie et al., 2020) which led to labor issues for wholesalers.

- *Number of PPEs available for workers*

Work activities not suspended needed to ensure the presence of PPE such as masks and gloves

(Governo Italiano Presidenza del Consiglio dei Ministri, 2021). If not present, companies, including wholesalers, were forced to limit the number of workers to the one protected.

Input supply

A limited availability of resources and inputs both in terms of physical production inputs and human resources emerged (Nordhagen et al., 2021; Thapa Magar et al., 2021). This caused increased costs for producers, e.g., increases in transportation costs and input prices (Nchanji & Lutomia, 2021; Reardon et al., 2020; Van Hoyweghen et al., 2021) and resulted in a lack of products availability - ranging from raw materials to final goods - hindered all the more by constraints imposed on the international trade of goods both in import and export (Siche, 2020; Surni et al., 2020; Wannaprasert & Choenkwan, 2021). The inputs availability was also related do the widespread reduction of production levels, sometimes forcibly suspended or temporarily halted in many production facilities (Lacombe et al., 2021; Sharma et al., 2020).
On the other hand, an input shortage, either in labor or transportation, generates negative knock-on effects, since an input in the SC production process constitutes an output of the previous process (Khan et al., 2021). Therefore, wholesalers experienced, as an example, both the absence of sale products and packaging materials.

3.3. *Assessment factors*

The strategic role that a DC plays along the SC and the progressive increase in the complexity of the logistics network have made the analysis and monitoring of warehouse performance increasingly important, with the aim of both supporting the decisions of the management areas and developing a benchmarking process within the reference sector.
In order to develop a company's strategy and assess its management effectiveness, it is necessary to introduce and define a set of KPIs (Key Performance Indicators) that measure the progress and performance levels for the achievement of corporate objectives. Since deployment is a process that requires a large number of participants and activities, it is necessary to control and manage the totality of the planned activities, as well as all factors that directly or indirectly affect the plant's performance levels. These factors can be internal, depending on the equipment, layout or personnel involved, or external, depending on the actors in the SC (Tompkins & Smith, 1998). In order to monitor their own performance, but also to achieve cost savings and increase DC efficiency, companies define, measure and monitor KPIs (Singh et al., 2020).
Several scholars have looked into warehouse performance evaluation in various methods (Voronova & Berezhnaya, 2020). Each study focuses on a particular set of goals, metrics, and warehousing systems. For this framework the authors through an analysis of the literature have identified the most relevant indicators for assessing the impact of a pandemic disruption and indicating a potential intervention area. The identified KPIs were then classified by adapting Frazelle's model (Frazelle, 2001) that associates KPIs with warehouse activities. Identified warehouse KPIs collected are shown in Figure 1.

Warehouse KPIs		
Reception and Unloading Area	*Waiting Time*	$Waiting\ Time = Start\ of\ Unloading\ Activities - Arrival\ Time$
	Discharge Time	$Discharge\ Time = Departure\ Time - Start\ of\ Unloading\ Activities$
	Receiving Cycle Time	$Receiving\ Cycle\ Time = \frac{Receiving\ Time}{Number\ of\ discharged\ vehicles} = \frac{Waiting\ Time + Discharge\ Time}{Number\ of\ discharged\ vehicles}$
	Unloading speed	$Unloading\ Speed = \frac{Number\ of\ packages\ delivered}{Discharge\ Time}$
	Compliant orders rate	$Compliant\ orders\ rate = \frac{Compliant\ deliveries}{Total\ deliveries}$
Inventory Area	*Accuracy rating*	$Accuracy\ Rate = \frac{Total\ packages\ correctly\ stored}{Total\ packages\ stored}\%$
	Put Away Cycle Time	$Put\ Away\ Cycle\ Time = \frac{Total\ storage\ activity\ time}{Total\ packages\ stored}$
	Inventory accuracy	$Inventory\ Accuracy = \frac{Actual\ quantity\ in\ stock}{Quantity\ reported\ on\ WMS}$
	Average stock	$\underline{G_i} = \frac{\sum_{t=1}^{N} G_{it}}{N}$ $where\ \ G\_it = Stock\ level\ of\ product\ i\ in\ period\ t$
	Average stock value	$Average\ Stock\ Value = Average\ Stock * Unit\ Value$ $\underline{GV_i} = \underline{G_i} * V_i$
	Turnover rate	$Turnover\ Rate = \frac{Items\ sold}{Average\ Stock}$ $TR_i = \frac{Q_i}{\underline{G_i}}$
	Coverage ratio	$Coverage\ Ratio = \frac{1}{Turnover\ Rate}$
	Stock to sales ratio	$Stock\ to\ sales\ ratio = \frac{Average\ Stock}{Items\ sold} = \frac{1}{Turnover\ Rate}$
	Stock-out index	$Stock\ Out\ Index = 1 - \frac{Time\ in\ stock}{Total\ Time}$
	Receptivity index	$Receptivity\ Index = Number\ of\ storable\ load\ units$
	Receptivity saturation coefficient	$\lambda = \frac{N_{average}(\Delta T)}{Receptivity}\%$

	Selectivity index	$Selectivity\ Index = \frac{Load\ units\ directly\ accessible}{Receptivity\ Index}\%$
	Handling index	$Handling\ Index = Load\ units_{IN} + Load\ units_{OUT}$
	Surface utilization coefficient	$Surface\ utilization\ coefficient = \frac{Surface\ occupied\ by\ load\ units}{Total\ surface}\%$
	Volumetric utilization coefficient	$Volumetric\ utilization\ coefficient = \frac{Volume\ occupied\ by\ load\ units}{Total\ Volume}\%$
Picking Area	*Distribution centre uptime*	$Distribution\ center\ uptime = Max(End\ time\ preparation) - min(Start\ time\ preparation)$
	Pick List Preparation Time	$Pick\ list\ preparation\ time_j = End\ time\ preparation_j - Start\ time\ preparation_j$
	Picker Activity Time	$Picker_i\ activity\ time = \sum_{j \in PL_i} Pick\ list\ preparation\ time_j$
	Global Pick Rate (Distribution center pick rate)	$Global\ Pick\ Rate_{packages} = \frac{Number\ of\ Packages\ picked}{Distribution\ center\ uptime}$
	Pick rate per operator	$Pick\ Rate\ per\ operator_{i,packages} = \frac{Number\ of\ Packages\ picked_i}{Picker_i\ Activity\ Time}$
	Perfect Order Rate	$Perfect\ Order\ Rate = \frac{Pick\ Lists\ completed\ without\ delays}{Number\ of\ Pick\ Lists}$
Shipping Area	*Average Load Time*	$Average\ Load\ Time = LT_{Load\ Unit} * \#Load\ Units$ $LT_{Load\ Units} = Average\ loading\ time\ of\ a\ load\ unit$ $\#Load\ Units = number\ of\ load\ units\ that\ make\ up\ the\ vehicle$
	Order Fulfillment rate	$Order\ Fulfillment\ Rate = \frac{Fulfilled\ orders}{Scheduled\ Orders}\%$
	On-Time Delivery	$On\ Time\ Delivery = \frac{Orders\ delivered\ on\ time}{Total\ number\ of\ orders\ delivered}$
	Rate of Return	$Rate\ of\ Return = \frac{Numbers\ of\ units\ returned}{Total\ shipped\ units}$
	Order Accuracy	$Order\ Accuracy = \frac{Orders\ delivered\ correctly}{Total\ delivered\ orders}$
	Carrier Saturation	$Carrier\ Saturation = \frac{Load\ Volume}{Vehicle\ Volume}$

Table 1: Warehouse KPIs.

3.4. Framework and method development

The framework shown in Figure 2 – MARLINFigure 2 is applied in 6 steps: 1) Selection of measurable KPIs; 2) Critical KPIs identification; 3) Analysis of relationships between critical KPIs and emergency areas; 4) Intervention measures identification; 5) Qualitative evaluation of relationships between measures and other KPIs; 6) Update time frame of analysis. We describe each step briefly and then present an application example in the next section.

Step 1: Selection of measurable KPIs. In this step the team will have to consider the list of KPIs available for warehouse management and evaluate which ones can be measured. In this phase it is necessary to understand which data are available and usable for the purposes of the analysis.

Step 2: Critical KPIs identification. In this step, the team identifies critical KPIs and compare them to the organization's target values.

Step 3: Analysis of relationships between critical KPIs and emergency areas. To mitigate disruption effects, it is valuable to identify any correlations between critical kpi and emergency areas. For each of the correlations identified, it is suggested to specify their nature: how are the two dimensions related? Is the correlation positive or negative?

Step 4: Intervention measures identification and qualitative evaluation of relationships between intervention measures and other KPIs. In this step, the team identifies the intervention measures to be implemented to mitigate disruption effects. In this step, it is also required to verify whether a chosen intervention could negatively affect other KPIs.

Step 5: Update time frame of analysis. Once the interventions are defined, a subsequent time frame is identified in which the analysis can be repeated and the KPIs monitored against the interventions.

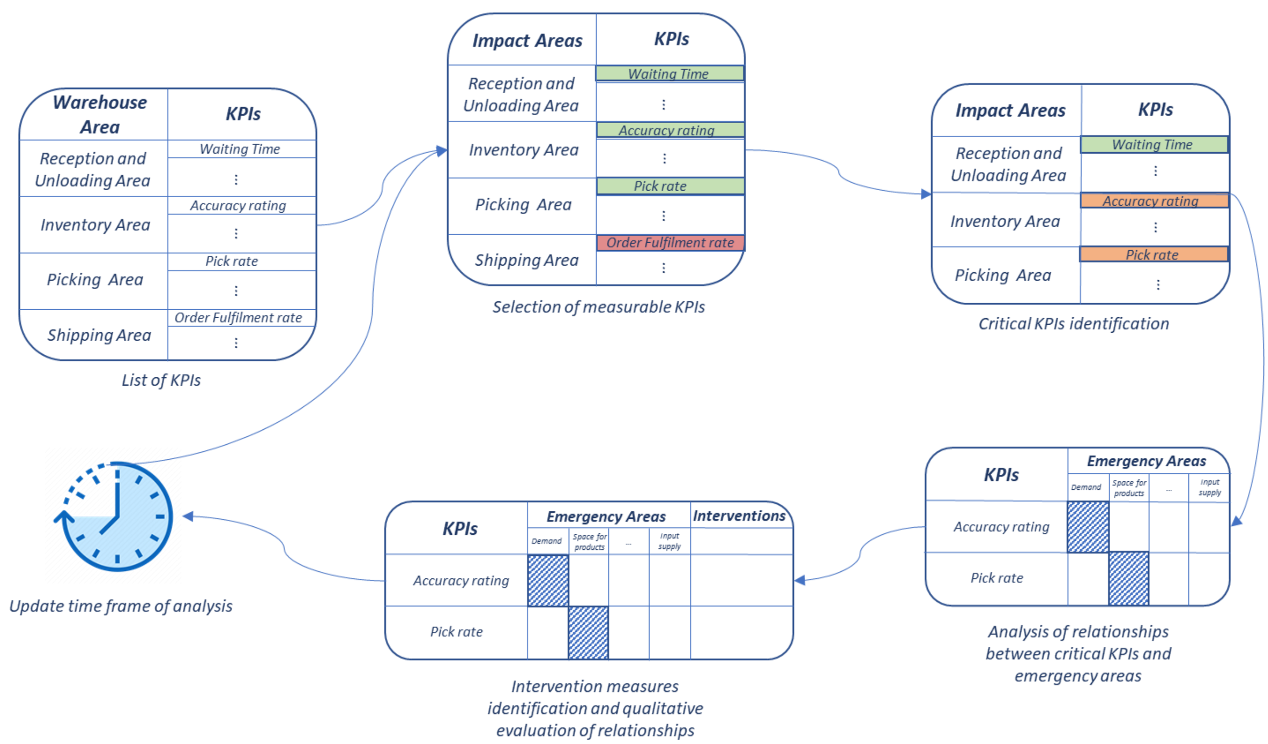

Figure 2 – MARLIN

4. Framework application

Case study data were collected in a DC located in central Italy and owned by one of the main companies in the sector. The DC manages the logistic flows of over 800 suppliers, 500 customers and the goods taken into analysis are 17000. The area occupied by the warehouse can be divided into three distinct zones: 1) Reception and Unloading Area; 2) Inventory & Picking Area; 3) Order preparation and Shipping Area. While the framework can result in extensive analyses, an abridged example is summarized in this paragraphs following the aforementioned steps of analysis.

Step 1: Among the 32 KPIs listed in the framework in this DC, it was possible to monitor 17 of them.

Step 2: KPIs were calculated for the first time frame. The time frame of analysis considers data from one month of disruption: a snapshot of the warehouse at the end of the first month of national lockdown (March 9 - April 9, 2020). Seventeen KPIs were calculated and compared to threshold values given by the organization. The following indicators were found to be critical: waiting time; stock-out index; handling index; pick rate per operator.

Step 3: For the purposes of this example, we report the analysis performed on the critical KPI: operator pick rate. During the first month of lockdown, the number of operators was reduced (due to quarantines and limitations on the number of people per m^2) and product demand increased, worsening pick rate values. We have therefore identified three correlated factors for this KPI: demand, people and space.

Step 4: In discussion with the warehouse logistics team, levers were identified to act on pick rate value. In particular, the choice was made to increase the total number of operators and to increase the working hours of the DC. This allowed operators to be spread out over multiple shifts and reduce the number of people per m^2. The step was concluded by verifying with the team if the chosen interventions could have negatively affected other KPIs.

Step 5: Once the analysis was completed, the organization implemented intervention measures and defined another time frame in which to repeat the evaluation.

Interestingly, the organization repeated the analysis one month after the end of the first lockdown (June 11 - July 11, 2020) reporting an improvement in the operator pick rate. It was noted that the longer hours and less clutter in the aisles by operators, made the conduct of operations smoother and improved the pick rate.

5. Conclusion and future research

The developed framework allows a systematic assessment of the impacts of the covid-19 pandemic in a warehouse offering organizations a tool to measure the effects of disruption and identify areas of intervention. It is theoretically grounded on three key concepts: impact areas, emergency areas, warehouse management KPIs.

The way the framework is designed, especially concerning the contents of the emergency areas, makes it ready-to-use only for assessing issues related to the current pandemic. The contents emerge directly from contextual events and cannot be generalized. However, excluding the emergency area components, the structure of the framework and the other areas components can be easily adapted to other emergency scenarios.

Overall, the framework is intended to help managers in guiding the decision-making process during an emergency; make logistics team meetings more agile; and optimize resources by quickly identifying critical system indicators.
In addition, the study investigates an under-explored aspect of the literature by bringing together specific studies on multiple pandemic effects. Finally, the framework provides researchers with an approach that can be readdressed, through further study, to other SC echelons or disruptions.

Acknowledgements

The authors thank Fabio Zaccagnini for his assistance in data cleaning and in the first part of analysis.

References

Abiral, B., & Atalan-Helicke, N. (2020). Trusting food supply chains during the pandemic: reflections from Turkey and the U.S. *Food and Foodways*, 226–236. https://doi.org/10.1080/07409710.2020.1790147

Aday, S., & Aday, M. S. (2020). Impact of COVID-19 on the food supply chain. *Food Quality and Safety*, *4*(4), 167–180. https://doi.org/10.1093/fqsafe/fyaa024

Akseer, N., Kandru, G., Keats, E. C., & Bhutta, Z. A. (2020). COVID-19 pandemic and mitigation strategies: Implications for maternal and child health and nutrition. *American Journal of Clinical Nutrition*, *112*(2), 251–256. https://doi.org/10.1093/ajcn/nqaa171

Altig, D., Baker, S., Barrero, J. M., Bloom, N., Bunn, P., Chen, S., Davis, S. J., Leather, J., Meyer, B., Mihaylov, E., Mizen, P., Parker, N., Renault, T., Smietanka, P., & Thwaites, G. (2020). Economic uncertainty before and during the COVID-19 pandemic. *Journal of Public Economics*, *191*, 104274. https://doi.org/10.1016/J.JPUBECO.2020.104274

Attwood, S., & Hajat, C. (2020). How will the COVID-19 pandemic shape the future of meat consumption? *Public Health Nutrition*, *23*(17), 3116–3120. https://doi.org/10.1017/S136898002000316X

Bucak, T., & Yiğit, S. (2021). The future of the chef occupation and the food and beverage sector after the COVID-19 outbreak: Opinions of Turkish chefs. *International Journal of Hospitality Management*, *92*(October 2020). https://doi.org/10.1016/j.ijhm.2020.102682

Coluccia, B., Agnusdei, G. P., Miglietta, P. P., & De Leo, F. (2021). Effects of COVID-19 on the Italian agri-food supply and value chains. *Food Control*, *123*. https://doi.org/10.1016/j.foodcont.2020.107839

Deaton, B. J., & Deaton, B. J. (2020). Food security and Canada's agricultural system challenged by COVID-19. *Canadian Journal of Agricultural Economics*, *68*(2), 143–149. https://doi.org/10.1111/cjag.12227

Felson, M., Jiang, S., & Xu, Y. (2020). Routine activity effects of the Covid-19 pandemic on burglary in Detroit, March, 2020. *Crime Science*, *9*(1), 1–7. https://doi.org/10.1186/S40163-020-00120-X/TABLES/3

Frazelle, E. (2001). World-Class Warehousing and Material Handling. *Undefined*.

Goddard, E. (2020). The impact of COVID-19 on food retail and food service in Canada: Preliminary assessment. *Canadian Journal of Agricultural Economics*, *68*(2), 157–161. https://doi.org/10.1111/cjag.12243

Governo Italiano Presidenza del Consiglio dei Ministri. (2021). *Coronavirus - Le misure attuate*

dal Governo.
Grida, M., Mohamed, R., & Zaied, A. N. H. (2020). Evaluate the impact of COVID-19 prevention policies on supply chain aspects under uncertainty. *Transportation Research Interdisciplinary Perspectives*, *8*, 100240. https://doi.org/10.1016/J.TRIP.2020.100240
Gupta, V., Ivanov, D., & Choi, T.-M. (2021). Competitive pricing of substitute products under supply disruption. *Omega (United Kingdom)*, *101*. https://doi.org/10.1016/j.omega.2020.102279
Hobbs, J. E. (2020). Food supply chains during the COVID-19 pandemic. *Canadian Journal of Agricultural Economics*, *68*(2), 171–176. https://doi.org/10.1111/cjag.12237
Janssen, M., Chang, B. P. I., Hristov, H., Pravst, I., Profeta, A., & Millard, J. (2021). Changes in Food Consumption During the COVID-19 Pandemic: Analysis of Consumer Survey Data From the First Lockdown Period in Denmark, Germany, and Slovenia. *Frontiers in Nutrition*, *8*. https://doi.org/10.3389/fnut.2021.635859
Khan, S. A. R., Razzaq, A., Yu, Z., Shah, A., Sharif, A., & Janjua, L. (2021). Disruption in food supply chain and undernourishment challenges: An empirical study in the context of Asian countries. *Socio-Economic Planning Sciences*, 101033. https://doi.org/10.1016/J.SEPS.2021.101033
Končar, J., Marić, R., Vukmirović, G., & Vučenović, S. (2021). Sustainability of food placement in retailing during the covid-19 pandemic. *Sustainability (Switzerland)*, *13*(11). https://doi.org/10.3390/su13115956
Kumar, P., Singh, S. S., Pandey, A. K., Singh, R. K., Srivastava, P. K., Kumar, M., Dubey, S. K., Sah, U., Nandan, R., Singh, S. K., Biswas, J. K., & Drews, M. (2021). Multi-level impacts of the COVID-19 lockdown on agricultural systems in India: The case of Uttar Pradesh. *Agricultural Systems*, *187*. https://doi.org/10.1016/j.agsy.2020.103027
Kumaran, M., Geetha, R., Antony, J., Vasagam, K. P. K., Anand, P. R., Ravisankar, T., Angel, J. R. J., De, D., Muralidhar, M., Patil, P. K., & Vijayan, K. K. (2021). Prospective impact of Corona virus disease (COVID-19) related lockdown on shrimp aquaculture sector in India – a sectoral assessment. *Aquaculture*, *531*, 735922. https://doi.org/10.1016/J.AQUACULTURE.2020.735922
Kusrini, E., Novendri, F., & Helia, V. N. (2018). Determining key performance indicators for warehouse performance measurement - A case study in construction materials warehouse. *MATEC Web of Conferences*, *154*. https://doi.org/10.1051/matecconf/201815401058
Laborde, D., Martin, W., & Vos, R. (2021). Impacts of COVID-19 on global poverty, food security, and diets: Insights from global model scenario analysis. *Agricultural Economics*, *52*(3), 375–390. https://doi.org/10.1111/AGEC.12624
Lacombe, A., Quintela, I., Liao, Y.-T., & Wu, V. C. H. (2021). Food safety lessons learned from the COVID-19 pandemic. *Journal of Food Safety*, *41*(2). https://doi.org/10.1111/jfs.12878
Loske, D. (2020). The impact of COVID-19 on transport volume and freight capacity dynamics: An empirical analysis in German food retail logistics. *Transportation Research Interdisciplinary Perspectives*, *6*. https://doi.org/10.1016/j.trip.2020.100165
Love, D. C., Allison, E. H., Asche, F., Belton, B., Cottrell, R. S., Froehlich, H. E., Gephart, J. A., Hicks, C. C., Little, D. C., Nussbaumer, E. M., Troell, M., & Zhang, W. (2021). Emerging COVID-19 impacts, responses, and lessons for building resilience in the seafood system. *Global Food Security*, *28*. https://doi.org/10.1016/j.gfs.2021.100494
Mahajan, K., & Tomar, S. (2021). COVID-19 and Supply Chain Disruption: Evidence from Food Markets in India†. *American Journal of Agricultural Economics*, *103*(1), 35–52.

https://doi.org/10.1111/AJAE.12158
Min, S., Zhang, X., & Li, G. (2020). A snapshot of food supply chain in Wuhan under the COVID-19 pandemic. *China Agricultural Economic Review*, *12*(4), 689–704. https://doi.org/10.1108/CAER-04-2020-0056/FULL/PDF
Nakat, Z., & Bou-Mitri, C. (2021). COVID-19 and the food industry: Readiness assessment. *Food Control*, *121*(June 2020), 107661. https://doi.org/10.1016/j.foodcont.2020.107661
Nchanji, E. B., & Lutomia, C. K. (2021). Regional impact of COVID-19 on the production and food security of common bean smallholder farmers in Sub-Saharan Africa: Implication for SDG's. *Global Food Security*, *29*. https://doi.org/10.1016/j.gfs.2021.100524
Nordhagen, S., Igbeka, U., Rowlands, H., Shine, R. S., Heneghan, E., & Tench, J. (2021). COVID-19 and small enterprises in the food supply chain: Early impacts and implications for longer-term food system resilience in low- and middle-income countries. *World Development*, *141*. https://doi.org/10.1016/j.worlddev.2021.105405
Palouj, M., Lavaei Adaryani, R., Alambeigi, A., Movarej, M., & Safi Sis, Y. (2021). Surveying the impact of the coronavirus (COVID-19) on the poultry supply chain: A mixed methods study. *Food Control*, *126*. https://doi.org/10.1016/j.foodcont.2021.108084
Petetin, L. (2020). The COVID-19 Crisis: An Opportunity to Integrate Food Democracy into Post-Pandemic Food Systems. *European Journal of Risk Regulation*, *11*(2), 326–336. https://doi.org/10.1017/ERR.2020.40
Price, C. C., Zhu, J., & Hillier, F. S. (2017). Volume 245 Series Editor. *International Series in Operations Research & Management Science*. https://doi.org/10.1007/978-3-319-41613-7
Priyadarshini, P., & Abhilash, P. C. (2021). Agri-food systems in India: Concerns and policy recommendations for building resilience in post COVID-19 pandemic times. *Global Food Security*, *29*, 100537. https://doi.org/10.1016/J.GFS.2021.100537
Pu, M., & Zhong, Y. (2020). Rising concerns over agricultural production as COVID-19 spreads: Lessons from China. *Global Food Security*, *26*. https://doi.org/10.1016/j.gfs.2020.100409
Ramasamy, D. (2020). Impact Analysis in Banking, Insurance and Financial services industry due to COVID-19 Pandemic. *Pramana Research Journal*, *10*(8), 19–29.
Reardon, T., Mishra, A., Nuthalapati, C. S. R., Bellemare, M. F., & Zilberman, D. (2020). Covid-19's disruption of India's transformed food supply chains. *Economic and Political Weekly*, *55*(18), 18–22.
Rozaki, Z. (2020). COVID-19, Agriculture, and Food Security in Indonesia. *Reviews in Agricultural Science*, *8*, 243–260. https://doi.org/10.7831/RAS.8.0_243
Sharma, R., Shishodia, A., Kamble, S., Gunasekaran, A., & Belhadi, A. (2020). Agriculture supply chain risks and COVID-19: mitigation strategies and implications for the practitioners. *Https://Doi.Org/10.1080/13675567.2020.1830049*. https://doi.org/10.1080/13675567.2020.1830049
Shu, T., Chen, S., Lai, K. K., Zhang, X., & Wang, S. (2014). Managing risk of supply chain disruptions. *Managing Risk of Supply Chain Disruptions*, 1–199. https://doi.org/10.4324/9781315776910/MANAGING-RISK-SUPPLY-CHAIN-DISRUPTIONS-TONG-SHU-SHOU-CHEN-KIN-KEUNG-LAI-XIZHENG-ZHANG-SHOUYANG-WANG
Siche, R. (2020). What is the impact of COVID-19 disease on agriculture? *Scientia Agropecuaria*, *11*(1), 3–9. https://doi.org/10.17268/sci.agropecu.2020.01.00
Singh, P., Ghosh, S., Saraf, M., & Nayak, R. (2020). A Survey Paper on Identifying Key Performance Indicators for Optimizing Inventory Management System and Exploring

Different Visualization Tools. *Proceedings of the International Conference on Intelligent Computing and Control Systems, ICICCS 2020*, 627–632. https://doi.org/10.1109/ICICCS48265.2020.9121036

Skawińska, E., & Zalewski, R. I. (2021). Activities of food retail companies in poland during the COVID-19 pandemic in the context of food security. *Sustainability (Switzerland)*, *13*(13). https://doi.org/10.3390/su13137323

Staudt, F., Mascolo, M. Di, Alpan, G., Taboada Rodriguez, C. M., Taboada, C. M., Warehouse, R., Staudt, F. H., Mascolo, D. I., Alpan, M. ;, & Rodriguez, ; (2014). Warehouse performance measurement: classification and mathematical expressions of indicators. *Dinalog BETA TRAIL*, 1–9. https://hal.archives-ouvertes.fr/hal-01242034

Surni, Nendissa, D. R., Wahib, M. A., Astuti, M. H., Arimbawa, P., Miar, J. Kapa, M. M., & Elbaar, E. F. (2020). Socio-economic impact of the Covid-19 pandemic: Empirical study on the supply of chicken meat in Indonesia. *AIMS Agriculture and Food*, *6*(1), 65–81. https://doi.org/10.3934/agrfood.2021005

Tanaka, T., & Guo, J. (2020). How does the self-sufficiency rate affect international price volatility transmissions in the wheat sector? Evidence from wheat-exporting countries. *Humanities and Social Sciences Communications*, *7*(1). https://doi.org/10.1057/s41599-020-0510-8

Telukdarie, A., Munsamy, M., & Mohlala, P. (2020). Analysis of the impact of covid-19 on the food and beverages manufacturing sector. *Sustainability (Switzerland)*, *12*(22), 1–22. https://doi.org/10.3390/su12229331

Thapa Magar, D. B., Pun, S., Pandit, R., & Rola-Rubzen, M. F. (2021). Pathways for building resilience to COVID-19 pandemic and revitalizing the Nepalese agriculture sector. *Agricultural Systems*, *187*. https://doi.org/10.1016/j.agsy.2020.103022

Thilmany, D., Canales, E., Low, S. A., & Boys, K. (2021). Local Food Supply Chain Dynamics and Resilience during COVID-19. *Applied Economic Perspectives and Policy*, *43*(1), 86–104. https://doi.org/10.1002/aepp.13121

Tompkins, J. A., & Smith, J. D. (1998). *The warehouse management handbook* (2nd Ed.). Tomkins Press.

Tougeron, K., & Hance, T. (2021). Impact of the COVID-19 pandemic on apple orchards in Europe. *Agricultural Systems*, *190*, 103097. https://doi.org/10.1016/J.AGSY.2021.103097

Van Hoyweghen, K., Fabry, A., Feyaerts, H., Wade, I., & Maertens, M. (2021). Resilience of global and local value chains to the Covid-19 pandemic: Survey evidence from vegetable value chains in Senegal. *Agricultural Economics (United Kingdom)*, *52*(3), 423–440. https://doi.org/10.1111/agec.12627

Voronova, D., & Berezhnaya, L. (2020). Logistic approach to a company's performance assessment based on a KPI system. *IOP Conference Series: Materials Science and Engineering*, *817*(1). https://doi.org/10.1088/1757-899X/817/1/012037

Wang, E., An, N., Kiprop, E., & Geng, X. (2020). Consumer food stockpiling behavior and willingness to pay for food reserves in COVID-19. *Food Security*.

Wannaprasert, P., & Choenkwan, S. (2021). Impacts of the covid-19 pandemic on ginger production: Supply chains, labor, and food security in northeast thailand. *Forest and Society*, *5*(1), 120–135. https://doi.org/10.24259/fs.v5i1.11897

Weersink, A., von Massow, M., Bannon, N., Ifft, J., Maples, J., McEwan, K., McKendree, M. G. S., Nicholson, C., Novakovic, A., Rangarajan, A., Thompson, J., & Wood, K. (2021). COVID-19 and the agri-food system in the United States and Canada. *Agricultural Systems*,

188. https://doi.org/10.1016/j.agsy.2020.103039
Weersink, Alfons, von Massow, M., Bannon, N., Ifft, J., Maples, J., McEwan, K., McKendree, M. G. S., Nicholson, C., Novakovic, A., Rangarajan, A., Richards, T., Rickard, B., Rude, J., Schipanski, M., Schnitkey, G., Schulz, L., Schuurman, D., Schwartzkopf-Genswein, K., Stephenson, M., … Wood, K. (2021). COVID-19 and the agri-food system in the United States and Canada. *Agricultural Systems*, *188*, 103039. https://doi.org/10.1016/J.AGSY.2020.103039
White, E. R., Froehlich, H. E., Gephart, J. A., Cottrell, R. S., Branch, T. A., Agrawal Bejarano, R., & Baum, J. K. (2021). Early effects of COVID-19 on US fisheries and seafood consumption. *Fish and Fisheries*, *22*(1), 232–239. https://doi.org/10.1111/FAF.12525

Short Biography

Margherita Bernabei: MSc in Management Engineering, she is a PhD student in Industrial and Management Engineering at the University of Rome La Sapienza, Italy. Her research includes project management, industry 4.0 challenges and supply chain resilience.

Silvia Colabianchi: MSc in Management Engineering, she is a PhD student in Industrial and Management Engineering at the University of Rome La Sapienza, Italy. Her research includes industrial cyber resilience, manufacturing processes and product defect identification.

Francesco Costantino: MSc in Mechanical Engineering, Master Degree in Quality Management and Engineering and Ph.D. in Engineering of Industrial Production, he is an associate professor at the Department of Mechanical and Aerospace Engineering, "Sapienza" University of Rome, holder of the chair of Operations Management, and of the chair of Smart Factory. His research activity is focused on the analysis and design of industrial systems, with particular attention to risk management, environment and sustainability, supply chain management, smart manufacturing, and performance management.

Andrea Falegnami: MSc in Mechanical Engineering, Ph.D. in Industrial and Management Engineering, he is currently a post-doctoral researcher in Industrial and Management Engineering at the University of Rome La Sapienza, Italy. His research activities are mainly focused on digitalization, cyber-socio-technical systems behaviour, methodological aspects of resilience engineering and its applications to industrial systems.