# Redesign resilient production and distribution networks in the food catering industry

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**Abstract**: The catering industry is responsible for producing and distributing meals in schools, hospitals, and companies' cafeterias. Dietary pattern changes and smart working caused by the Covid pandemic highly affect the food catering industry. The demand contraction put in crisis the typical distributed productive structure of such a sector. A 30% revenue reduction from 2019 to 2020 called for the widespread network of production plants to cut corners. Production centralization leads to economies of scale but increases the logistics costs of distribution. We present a real case study of production network downsizing in the catering industry, focusing on optimizing logistics and fixed capacity costs. Meals distribution has tight time constraints due to the consumers-imposed time windows and the microbiological safety rules-imposed time windows. The proposed methodology integrates the vehicle routing problem developed by the company into a network costs optimizations problem. This optimization model exploits the pre-optimized routes defined by the company, chooses which plants to open, and performs the customer-route pairing for each picked production site. Different allocation scenarios of the same demand distribution are defined and analyzed in the case study, allowing a quantitative comparison between different redesign strategies. Results show how the mileage varies among the centralized scenarios, with a cost differential from +61% to + 29% compared to the distributed scenario. The comparison of pre and post covid demand scenarios shows how the model cushions the logistics costs: the optimal choices of the routes allows a 22% traveling reduction in the 38% post-pandemic demand reduction of the same service area. The model supports the decision-making process in the network redesign of the food catering industry by analyzing how alternative location-allocation scenarios deal with different demand patterns.

**Keywords**: Production Network Resilience; Food Distribution; Catering Logistics; Food Supply Chain Redesign

## I. INTRODUCTION

In recent decades, the consumption of away-from-home meals increased due to work, study, or tourist interest reasons [1]. Every day, in the Western countries, for necessity or choice, more than 50% of the food budget is spent on away-from-home meals [2]. Such expansion allowed the development of collective restoration services. Among the possible production and distribution system of foodservice industry, the deferred service is usually intended for institutional customers, such as schools and hospitals. In such a system, preparation and consumption are carried out at different times and places. Food preparation and cooking occur in large production plants called Centralized Kitchens (CeKis), then meals are delivered to the customers with insulated or refrigerated trucks. Depending on the service provided, minutes, hours, days, or months may elapse between preparation and consumption. Meals production, packaging, and delivery are phases of a very complex process that involve labor intensive activities, negotiations with the institutions, and precise logistics management [3]. The foodservice industry aids food security and provides a significant contribution to the employment state of the western world but challenges and complexities of catering production and distribution networks render the sector susceptible to economic instability and market changes.

A major challenge in the catering production and distribution activities is the compliance with the hygienic safety regulations [4]. Such rules dictate food must never be kept at room temperature after cooking. Indeed, the temperature interval between +15°C and +45°C represents the critical spot for bacteriological proliferation in the humid kitchen environment. CeKis require complex organizational systems together with insulated transport equipment to reach the clients with well-preserved meals.

Time constraints imposed by legislation are added to those imposed by customers. Service times can hardly be freely chosen since they depend on the institutional activities the catering company is called to serve (school, hospital, retirement home, penitentiary institution, etc.). The delivery time windows imposed by clients usually last a few dozens of minutes. Some institutions also impose menu constraints, which impact the production activities. Municipality often define schools' menus and their expected raw materials quality. Therefore, precise dietary tables must be drawn up according to the dietary needs of the different age groups. Additional restrictions are enforced to demand allocation and, indirectly, to kitchens location. CeKis' geographic coverage can be set by agreements with municipality or district offices which define the maximum distance allowed between the kitchen and the institutional delivery points.

If unfavorable lead times disrupt the subtle balance among consumer interests, legislation constraints and the intrinsic low marginality of the sector, decision-makers need supporting tools to deal with the collective restoration complexity [5]. In order to adapt to adverse events, the logistic distribution system must exhibit a resilient behavior. The COVID-19 outbreak stressed the sector and revealed critical issues to address [6]. While demand from schools and companies decreased and became discontinuous, hospitals urged a larger scale meals production [7]. A resilient FSC focuses on the capacity to adapt to demand or supply uncertainty rather than trying to minimize the risk in a known environment [8]. Demand and supply risks are magnified in decentralized catering networks. Small production capacities are not optimized for non-standard meals preparation: deliveries could delay, and bacterial hazards could occur. In larger plants, the local demand discrepancies balance, and the overall demand stays more homogeneous. In urban distribution systems, consolidation and coordination practices of larger plants can improve the logistic performance [9].

This paper focuses on the interrelated optimization problems raised by distribution network complexities at the end of the catering value chain. The objective is to develop and apply a decision support tool to identify how many facilities to open, what demand to meet, and the vehicle paths to reach customers. The problem under consideration can be framed in the Location-Routing Problems (LRP) category. These problems combine two basic planning activities in logistics: decisions on the facility location (e.g., plants, warehouses, cross-docks) are made jointly with decisions on vehicle routing. If these two issues are addressed independently, planning results are sub-optimal, even in long-term location decisions scenarios. In order to get as close as possible to the optimal solution, the presented work follows a two-step hybrid approach. The first step optimizes the vehicle paths to meet all the perishability and consumers' needs constraints. The second step consists of constructing and implementing an ad hoc model that can be traced back to Set Covering problems. To simultaneously respond to the plant location decisions and the vehicle paths choice, the first step results feed the model in the second step. Such an approach allows flexibility and reduction of calculation time. Moreover, the location-allocation strategic decision can be driven by actual operational obstacles and constraints embedded into the routes of the first step, such as maximum allowed distance for specific customers or strict time windows constraints.

The article is structured in four sections. Section 2 defines the catering network, the entities, the flows, the characteristics of the meal, and the time constraints involved. An optimization model for the plant location is then proposed and described. Section 3 provides an overview of the AS-IS network management and introduces three TO-BE scenarios. The model is applied to the AS-IS and TO-BE scenarios, and comparisons are drawn. A Post-pandemic scenario is also studied to minimize the revenue loss caused by logistic operations. In Section 4 conclusions are drawn.

## II. METHOD AND MODEL

In this section, the formulation of an optimization strategy for meals delivery in a catering network of geographically distributed customers is presented. To address such a complex issue, the problem is separated into two parts. The first concerns the construction and optimization of delivery routes (i.e., a vehicle-routing problem), while the second part features an optimization model aiming at jointly deciding which centers to open (or to keep open) and which routes to activate to minimize costs, travel kilometers and travel times. (i.e., location-routing problem).

*First step: vehicle-routing problem*

Routes are built respecting the constraints imposed by the customers and the production and distribution activities. Specifically, each customer defines a precise time slot (even a few minutes) for the delivery, and the preparation procedure chosen imposes the maximum time window from meal packaging and meal consumption. The preparation procedure and the topographic features of the delivery point impose the truck characteristics (e.g., a delivery point located on a narrow road requires a small vehicle). All these constraints, together with the prohibition of splitting a delivery point's demand, determine the number of delivery points in a route (i.e., all the meals requested from a client must be supplied from one CeKi able to produce the meal with the preparation procedure and the packaging chosen by the client). The degrees of freedom of the demand allocation step depend on how many times a delivery point appears in the routes set. If agreements with municipalities dictate a delivery point must be served by a specific CeKi, such delivery point will appear only in the routes of such CeKi.

*Second step: location-routing problem*

In the optimization model, routes represent model parameters previously optimized using CeKi-imposed criteria. The complexity of this location-routing problem lies in the computational solvency rather than the theoretical formulation. The model aims to optimize the customer-CeKi pairing and assess the investment of opening or closing CeKis to reach maximum economic and service efficiency.

The vehicle-routing problem is a central issue in the catering industry and is supposedly already optimized through companies' decision-supporting tools. In applying the proposed framework, the already optimized company's routes represent the input of the location-routing problem. Since the first step represents a problem tied to the peculiarities of the specific business reality and local context under observation, this section focuses on the generalized formulation of the location-routing problem.

### A. *Sets and parameters*

Sets:

$\boldsymbol{i} \in \boldsymbol{CK}$: Set of CeKis
$\boldsymbol{s} \in \boldsymbol{S}$: Set of CeKis' sizes
$\boldsymbol{j} \in \boldsymbol{C}$: Set of customers
$\boldsymbol{t} \in \boldsymbol{T}$: Set of meal types
$\boldsymbol{r} \in \boldsymbol{R}$: Set of routes

| | |
|---|---|
| $\boldsymbol{ckSize}\ (\boldsymbol{i},\boldsymbol{s}) \subset \boldsymbol{CK} \times \boldsymbol{S}$: | Subset of possible sizes t for CeKi i |
| $\boldsymbol{mixM}\ (\boldsymbol{i},\boldsymbol{s},\boldsymbol{t}) \subset \mathbf{CK} \times \mathbf{S} \times \mathbf{T}$: | Subset of possible sizes s of meal t in CeKi i |
| $\boldsymbol{mixD}\ (\boldsymbol{j},\boldsymbol{t}) \subset \mathbf{C} \times \mathbf{T}$: | Subset of meal typology t demanded by customer j |
| $\boldsymbol{routeCK}\ (\boldsymbol{r},\boldsymbol{i}) \subset \mathbf{R} \times \mathbf{CK}$ | Subset of routes r assigned to CeKi i |

Parameters:

| | |
|---|---|
| $\boldsymbol{CostOpen_{ist}}$ | Investment cost for opening CeKi i in the size s for the meal t [€]; (i,s,t) ∈ mixM |
| $\boldsymbol{CostClose_{ist}}$ | Investment cost closing CeKi i in the size s for the meal t [€]; (i,s,t) ∈ mixM |
| $\boldsymbol{CostDepr_{ist}}$ | Depreciation cost [€] for (i,s,t) ∈ mixM |
| $\boldsymbol{CostFix_{ist}}$ | Fixed capacity cost [€] for (i,s,t) ∈ mixM |
| $\boldsymbol{CostLabor_{ist}}$ | Labor cost [€] for (i,s,t) ∈ mixM |
| $\boldsymbol{CostOper_{ist}}$ | Operating cost [€] for (i,s,t) ∈ mixM |
| $\boldsymbol{ProdCap_{ist}}$ | Production Capacity [meals/year] for (i,s,t) ∈ mixM |
| $\boldsymbol{M}$ | Maximum number of meal typologies a CeKi can produce |
| $\boldsymbol{Time_t}$ | Maximum period of time between meal t packing and meal t delivery [min] |
| $\boldsymbol{CostTrFix_r}$ | Fix transportation cost for route r [€] |
| $\boldsymbol{CostTrVar_r}$ | Variable transportation cost for route r [€/km] |
| $\boldsymbol{TimeTr_r}$ | Transportation time for route r [min] |
| $\boldsymbol{DistTr_r}$ | Traveled distance for route r [km] |
| $\boldsymbol{FreqTr_r}$ | Frequency of route r [days/year] |
| $\boldsymbol{Demand_{ct}}$ | Demand of meal type t from customer c [meals]; (c,t) ∈ MixD |
| $\beta_{cr}$ | 1 if route r serves customer c, 0 otherwise |

Cost parameters are extrapolated from the CeKis' balance sheets. The five macro-cost items are the depreciation costs, the fix capacity costs (rentals, condominium expenses, insurance, garbage taxes), the operating costs (water, gas, electricity, fuels, maintenance, stock), the labor cost, and the logistic costs (transport, truck rentals, and maintenance).

The parameters $\beta_{c,r}$ constitutes the incidence matrix between eligible routes and customer served by such routes. The distribution-related parameters are the variable $CostTrVar_r$ and fixed $CostTrFix_r$ transportation costs, the route distance $DistTr_r$, and the route frequency $FreqTr_r$. Their values come from the first modeling phase through vehicle routing.

Variables:

| | |
|---|---|
| $y_{ist}$ | Equal to 1 if the CeKi *i* of size *s* is open for meal-type *t*. 0 otherwise. |
| $\alpha_{isr}$ | Equal to 1 if the route *r* with the starting point at CeKi *i of* size *s* is triggered. 0 otherwise. |

### B. Objective Function

Objective function

$$\begin{aligned} &\sum_{(i,s,t)\in MixM} (CostOpen_{ist} + CostDepr_{ist} + CostFix) \\ &\quad \cdot y_{ist} + CostClose_{ist} \cdot (1 - y_{ist}) \\ &\quad + \\ &\sum_{(i,s,t)\in MixM} (CostLabor_{ist} + CostOper_{ist}) \cdot y_{ist} \\ &\quad \cdot \sum_{(j,t)\in MixT} \sum_{r\in R} \alpha_{isr} \cdot \beta_{cr} \\ &\quad \cdot Demand_{ct} + \\ &\sum_{(r,i)\in routeCK} \alpha_{isr} \cdot FreqTr_r \cdot (CostTrFix_r \\ &\quad + CostTrVar_r \cdot DistTr_r) \end{aligned} \tag{1}$$

The linear objective function (1) is the sum of three macro-components: (i) fixed costs related to the capacity location decisions, (ii) variable costs which depend on the number of delivered meals, (iii) routing costs that are partially related to the means of transport (fixed costs) and partially linked to the length of the route (variable costs).

### C. Constraint formulation

Constraint

$$\sum_{s\in S} y_{ist} \le 1\ \forall i \in CK, t \in T \tag{2}$$

$$\sum_{t\in T} y_{ist} \le M\ \forall (i,s) \in ckSize \tag{3}$$

$$\sum_{(r,i)\in routeCK}\ \sum_{(i,s)\in Size} \alpha_{isr} \cdot \beta_{cr} = 1\ \forall j \in C \tag{4}$$

$$\sum_{r\in R} \sum_{j\in C} \alpha_{isr} \cdot \beta_{cr} \cdot DistTr_r \le ProdCap_{ist} \cdot y_{ist}\ \forall (i,s,t) \in MixM \tag{5}$$

$$TimeTr_r \cdot \alpha_{isr} \le Time_t \cdot y_{ist}\ \forall (r,i) \in routeCK, t \in T \tag{6}$$

$$y_{ist}, \alpha_{isr} \in \{0,1\} \tag{7}$$

Constraints (2) are used to ensure that at most one size can be opened for each CeKi. Due to organizational and technological reasons, the number of meal typologies activated for each CeKi could be limited. This is enforced by constraints (3). Constraints (4) associate each client with a specific CeKi, while the capacity constraints (5) set an upper bound on the demand that each CeKi can cope with. Finally, we use constraints (6) to guarantee a maximum delivery time for each meal typology.

## III. CASE STUDY

The proposed model is applied in an Italian retailing company's production and distribution network. Collective catering is the company's core business. 75% of its revenue is divided into school canteens (35%), corporate canteens (20%), and health services (15%). Every company's CeKi can produce and deliver from 2,000 to 7,000 meals per day. The territory of the study includes four CeKis, and the customers are distributed in an area of about 5,000 square kilometers around the production plants. The company's interest in the model application comes from the need for operations efficiency and resilience-building. Notwithstanding the generality of the model, the real-world application required a mediation with the company to meet business constraints. Previous agreements made with institutions, such as the need to serve certain areas from a specific CeKi, must be respected. In addition to contractual constraints, some limitations also emerge from the streamlining techniques of the production and distribution process leading the company to define hypothetical scenarios of CeKis location. What lies between two scenarios might not be feasible due to technical and policy reasons that cannot be mathematically modeled. From these considerations arises the need to force some scenarios within the optimization model through the definition of input parameters.

### *A. Network topology*

Since the meal production activities (from row ingredients procurement to meal delivery) are triggered by the clients' Request for Transports (RfTs), the meals flow is customer-pulled. The client also imposes a delivery time window for the daily meals distribution. Although very CeKi must respect the organizational standards dictated by regulations and preparation procedures, the plants are managed independently. Every plant exploits a proprietary software tool to optimize the delivery routes according to the constraints imposed, but then the routing decisions are periodically endorsed or modified by the CeKi management. On the one hand, this allows the CeKis to meet the needs of their specific clients and customize the offer; on the other hand, it produces inefficiencies, especially if the performance analysis is carried out on the overall network.

### *B. AS-IS - Cost items analysis*

The AS-IS cost items analysis is carried out from the balance sheets each CeKi draws up. All the cost parameters defined in the proposed optimization model are evaluated from such analysis. Depreciation costs and fixed capacity costs remain stable throughout the year. Among variable costs, operating costs tend to be more stable, while personnel and logistics costs vary more depending on seasonality. €/meal is also influenced by seasonality, with a pick in the summer months when the demand drops.

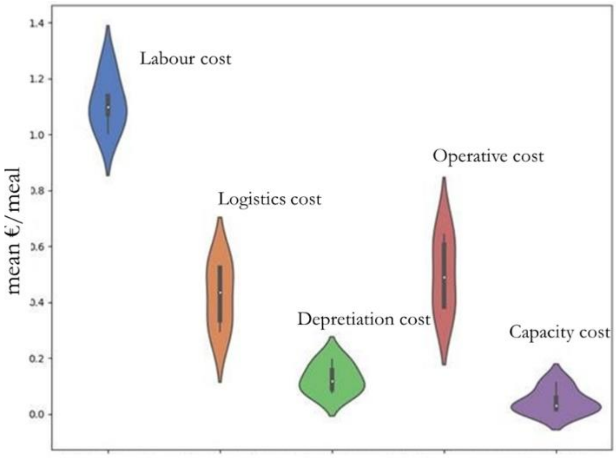

Fig. 1 Violin plot of cost items variability in the network

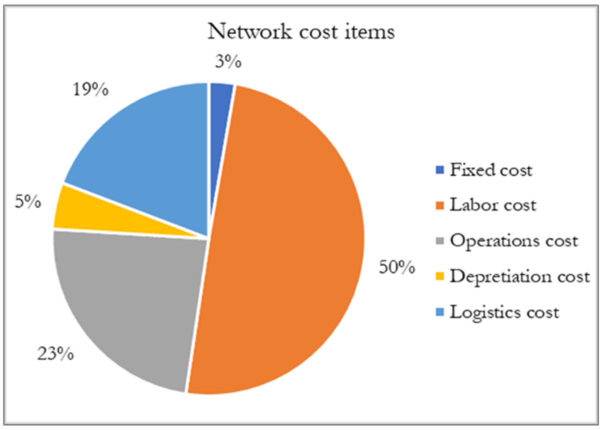

Fig. 2 Impact of cost items on full meal cost

*Fig.* 1 shows a box plot on the variability of €/meal per each cost item among the four CeKis analyzed throughout the year 2019, while *Fig.* 2 shows how much each cost item impacts the full meal cost (mean value of the four-CeKis network). Personnel, logistics, and operations costs are the more variable ones. Personnel costs are clearly the most critical macro-item on annual budgetary costs. In fact, labor is an essential factor in product preparation and handling. Ultimately, personnel and logistics costs can be pointed to as the most significant and variable macro-items However, while the formers are hardly impacted by strategic planning, the latter can be optimized through mathematical modeling.

### *C. TO-BE - Hypothesis and Scenarios*

The redesign of the CeKis network studied aims at streamlining operations through the comparative analysis of three alternative scenarios. The four existing CeKi will be called *CeKi1*, *CeKi2*, *CeKi3*, and *CeKi4*. The overall network capacity must reach 2.9 million meals per year to meet the regional demand.

*Scenario 1 – One new CeKi* - In this scenario, a new CeKi is opened (*CeKi5*). Since *CeKi5* would serve the overall regional demand (2.9 million meals per year), an optimal location analysis has been conducted to identify the best location while respecting the contractual obligations on delivery distances.

*Scenario 2 – One new CeKi and one optimized CeKi* - In this scenario, the efficiency of one of the existing CeKi is optimized (0.9 million meals per year in *CeKi2*), and the residual demand is allocated to a new CeKi (2 million meals per year in *CeKi5*).

*Scenario 3 – One enlarged CeKi and one optimized CeKi* - In this scenario, *CeKi2*'s production and distribution activities are optimized (0.9 million meals per year), and *CeKi4* is expanded to address the remaining demand (2 million meals per year).

The cost analysis for the newly built *CeKi5* was conducted based on benchmarks. CeKis capable of delivering a similar amount of meal/year expected in the scenarios TO-BE are sought among the existing facilities. The average operating costs of such CeKis are considered *CeKi5*'s benchmarks. The optimal location of *CeKi5* has been identified near the *CeKi4* one. *CeKi1*'s optimization, envisaged in scenarios 2 and 3, implies a production reorganization to allow a reduction in personnel costs per €/meal of about 10%. *CeKi2*'s expansion implies as well as a production operations redesign resulting in personnel costs reduction of €/meal of about 20%. The technical office estimated the approximate investment costs: 6 million € for scenario 1, 4 million € for scenario 2, and 2 million € for scenario 3. Based on these costs, the depreciation fees were also calculated. Error! Reference source not found. shows the known unit costs for the different scenarios.

TABLE 1
TO-BE SCENARIOS COST ITEM €/MEAL

| **Scenario** | **Personnel Cost** | **Logistics Costs** | **Operations Costs** | **Depreciation Costs** | **Capacity Costs** |
|---|---|---|---|---|---|
| *1* | 0.70 | ? | 0.31 | 0.21 | 0.04 |
| *2* | 0.79 | ? | 0.33 | 0.16 | 0.04 |
| *3* | 0.99 | ? | 0.52 | 0.09 | 0.02 |

The model application focuses on the impact of logistics on the appraisal of the costs. Difficulties in logistics costs estimation derive from the strong dependence on traveled kilometers and the frequent externalization of the meal distribution activity. For these reasons, the To-Be logistic cost assessment is based on the mileage burden associated to the scenarios.

### *D. Vehicle-routing problem*

A company's proprietary optimization software is exploited to define the set of routes. It is a vehicle routing solver with time windows able to minimize the total delivery mileage. The application requires data on suppliers, modes of transportation, CeKis, and customers to create the routes. Since the temperature must be maintained as long as possible, meals are kept in insulating polystyrene boxes during transportation. For this reason, every customer's RfT is converted into a Number of Boxes (NoB). Therefore, the truck's capacity and saturation are expressed in NoB. Each box can hold up to thirty single-produced trays. Each meal consists of 3 servings on average (namely three trays) and hot portions must be separated from cold ones (then a minimum of two boxes is needed). The resulting NoB for each RfT is estimated as:

$$NoB = \left(\frac{Meals * 3}{30}\right) * 2$$

A representative sample of customers served was selected to estimate the mileage burden for each scenario. In particular, we refer to the number of customers served and the respective average daily volumes of October, a typical peak month. The selected customers have a minimum weekly delivery frequency of 3 RoTs, and their As-Is allocation follows Error! Reference source not found.

TABLE 2
AS-IS SELECTED CUSTOMERS FOR MODEL APPLICATION

| **CeKi** | **Meals /Day** | **% Meals /CeKi** | **Customers** |
|---|---|---|---|
| *CeKi1* | 3,922 | 42 | 235 |
| *CeKi2* | 1,430 | 15 | 107 |
| *CeKi3* | 1,205 | 13 | 49 |
| *CeKi4* | 2,761 | 30 | 133 |
| *Total* | 9,318 | 100 | 524 |

The output of the vehicle routing step is the construction of the delivery routes for all the analyzed networks from every possible plant location. In this phase, the first optimization is carried out through the company's vehicle routing application. The result is a collection of optimal delivery routes in terms of mileage savings and response to delivery time constraints for each expected location. Each tour is a container of delivery points with defined characteristics, such as traveled km and delivery times. Error! Reference source not found. shows the vehicle routing parameters and the resulting routes.

TABLE 3
VEHICLE ROUTING PARAMETERS AND ROUTES NUMBER

| **Location** | **Meals** | **NoB** | **Customers** | **Routes** |
|---|---|---|---|---|
| *CeKi1* | 9,318 | 2,304 | 524 | 44 |
| *CeKi2* | | | | 42 |
| *CeKi3* | | | | 43 |
| *CeKi4/ CeKi5* | | | | 41 |

The mileage quantification of the As-Is scenario was conducted by optimizing the delivery routes for each CeKi on the customers served in October 2019. In the mileage quantification of Scenario 1, all customers served in October 2019 are assigned to the new *CeKi5*. The increase in total km is +43% compared to the AS-IS Scenario. Since *CeKi4* and *CeKi5* are located in the same position, the logistics impact of Scenarios 2 and 3 coincide. On the other hand, customer allocation to the 2 CeKis of these scenarios highly affects the logistics costs. Therefore, two alternatives allocation rules were considered. The first one is a *geography-driven allocation*, in which customer allocation is dictated by proximity. The second alternative is a *mix-driven allocation*, in which the meal typology is taken into account, and every CeKi is specialized only to produce some kinds of meals. According to this rule, schools and corporate meals go to *CeKi5*/*CeKi4*, while hospital meals go to *CeKi2*. This configuration is logistically unfavorable but can create production efficiency in the plants and reduce operations costs.

TABLE 4
COMPARISON OF SCENARIOS MILEAGE

| | **CeKi** | **NoB** | **Routes** | **Km** |
|---|---|---|---|---|
| As-Is | *CeKi1* | 991 | 20 | 1,179 |
| | *CeKi2* | 374 | 9 | 600 |
| | *CeKi3* | 277 | 8 | 365 |
| | *CeKi4* | 662 | 10 | 657 |
| To-Be 1 | *CeKi5* | 2,304 | 43 | 4,014 |
| To-Be 2-3 Geo | *CeKi4/CeKi5* | 1,755 | 33 | 2,921 |
| | *CeKi2* | 549 | 12 | 706 |
| To-Be 2-3 Mix | *CeKi4/CeKi5* | 1,463 | 25 | 2,207 |
| | *CeKi2* | 374 | 20 | 2,309 |

The impossibility of a logistics cost assessment through logistics provider' bills makes cost evaluation of the

To-be scenarios a challenge. Therefore, the estimated mileage difference among the scenarios is used to obtain logistics cost items and complete Error! Reference source not found.. In order to come to a logistics cost parameter in €/km, every scenario's possible routes are analyzed. In Error! Reference source not found., for each scenario, the NoB to deliver is displayed, according to the production capacity available for every meal typology and the distance constraints imposed. From such hypothesis, the necessary number of routes and the total mileage associated with the routes are calculated. Since *CeKi4* and *CeKi5* locations are close, the resulting routes are the same when the clients assigned are the same. For this reason, for the same clients' allocation strategy, scenario 2 and scenario 3 have the same values. Compared to the As-Is scenario, scenario 1 mileage increases +43%, scenarios 2 and 3 with geography-driven allocation increase the mileage by +29.5%, and scenarios 2 and 3 with mix-driven allocation increase the mileage by +61.2%. In the mix-driven assignment, *CeKi2* serves distant customers. This entails a greater increase in traveled km but also a low trucks saturation due to delivery time constraints. **Error! Reference source not found.** outlines the complete cost items valorization.

TABLE 5
COST ITEMS PER MEAL FOR THE DIFFERENT SCENARIOS

| **Scenario** | **Labor cost** | **Logistics cost** | **Operations cost** | **Depreciation cost** | **Capacity cost** | **Full Meal Cost** |
|---|---|---|---|---|---|---|
| *AS-IS* | 1.111 | 0.423 | 0.501 | 0.101 | 0.057 | 2.19 |
| *TO-BE 1* | 0.705 | 0.607 | 0.31 | 0.21 | 0.037 | 1.87 |
| *TO-BE 2 Mix* | 0.794 | 0.683 | 0.333 | 0.161 | 0.041 | 2.01 |
| *TO-BE 2 Geo* | 0.794 | 0.548 | 0.333 | 0.161 | 0.041 | 1.88 |
| *TO-BE 3 Mix* | 0.991 | 0.683 | 0.517 | 0.091 | 0.017 | 2.3 |
| *TO-BE 3 Geo* | 0.991 | 0.548 | 0.517 | 0.091 | 0.017 | 2.16 |

### *E. location-routing problem*

For the model application, all the sets and parameters described in section 2 must be valued. The three alternative scenarios evaluation is based on the cost items defined in **Error! Reference source not found.**. The technical and political limitations enforcement is ensured by the maximum allowed productive capacities and the set of available routes. The definition of the available sizes through the subset mixM of possible sizes *s* of meals *t* in CeKi *i* require the model to choose only among the possible network configurations. The set of customers *C* consists of the 524 delivery points of the network. The demand parameters refer to the number of average daily meals requested by a customer over a year (2019). The route set R is the result of the routing optimization step. Travelled km and delivery times, derived from the routes set analysis, populate the parameters *DistrTr* and *TimeTr*. The logistic cost parameters are derived from the scenarios analysis carried out in the subsection 3.D.

### *F. Optimization results and post-pandemic scenario analysis*

For the first step, the computation time to obtain all the possible routes satisfying the imposed constraints is around 10 minutes. In the second step, the optimization model finds the solution in less than 15 seconds. Despite the large dataset, the total computation time of the two steps is reasonable.

With the 2.9 million meals demand, the optimal configuration is scenario 1. Although logistics costs increase, in a centralized CeKi operations are more efficient, the configuration is cost-effective, and the 6-million investment in the new CeKi is justified. Since the objective of the case study is to observe how the optimal configuration varies in stressed scenarios, the model has been tested with reduced demand. The demand may undergo sharp daily changes in an under-pressure configuration, such as the one encountered during the covid pandemic. In the first months after the pandemic, the catering company studied lost 17% of its clients and 30% of served meals. The logistics objective in such a context is to satisfy the demand while minimizing the waste of time and traveled km. Routes must be reformulated to adapt to the new thinned-out client network and the reduced demand to guarantee logistics efficacy and efficiency. The re-optimization of the delivery routes in the vehicle-routing problem allows a mileage saving of 22%. In the location-routing model, the network must still guarantee the same production capacity for the fully operational days but may face days almost without demand due to the forced closure of schools and companies. To represent this scenario, the daily demand has been left unchanged while the yearly delivery days have been reduced by 30%. In this recession scenario, the optimal network configuration is a hybrid between the As-Is and the third scenarios. Specifically, the model keeps open *CeKi3,* and *CeKi4* is expanded to serve 2 million meals per year with a 2-million investment. This analysis shows that logistics costs can be reduced to obtain a lower impact on economic losses due to sharp declines in demand, such as in 2020. Moreover, the redesign of the logistic network must consider stressed demand scenarios to understand which is the most flexible and resilient solution.

## IV. CONCLUSION

Optimization models have proven effective tools for studying SC under uncertainty, building resilient network solutions, and finding the best operations management practices [10], [11]. Uncertainty and network stresses can be introduced through demand and production data variation [12], allowing the study of the system flexibility and the network adapting capacity. The logistic leverage can aid Supply Chain (SC) redesign to optimize food distribution or nodes' location [13]. In the proposed two steps methodology, the logistics operations and the strategic redesign of a local catering network are jointly optimized. The methodology was applied to both pre- and post-pandemic data to support the company with resilient solutions. As the results suggest, an efficient food distribution system aids the catering network reaction to sudden and unexpected market shifts [14]. Uncertainty can significantly change the optimal network configuration, highlighting how strategic decision-making can hardly be performed without decision-supporting tools. The possibility of testing different configurations of geographical distribution and volume of demand allows great reliability of the results and less risky decision-making activity.

Future improvements of the proposed framework involve (1) the scaling-up of the model to assess the performance of the entire national network and (2) a more detailed analysis of cost parameters related to the types of meals and customers. (1) Applying the model to the complete national network allows to evaluate all the possible interregional logistics interactions. Whether regional networks are joined to constitute a unique system, kitchens from different regions can create synergies and be able to serve customers more efficiently. (2) The second point relates to the idea of leveraging machine learning techniques to improve the optimization model generalizability. Instead of considering costs as parameters known a priori, they would be defined as functions of the CeKi’s size or the meal typology. To this end, a comprehensive dataset containing all the CeKi's balance sheets data (tuples of CeKi size, meal typology, and contextual variables) and relative cost values can be used to fit a predictive model which is later embedded into the optimization model. As a result, the optimization model will no longer depend on predefined scenarios but will find and propose the best scenario.

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